Sleep, Mood, and Cognitive Vulnerability in Adolescents – A Naturalistic Study Over Restricted and Extended Sleep Opportunities

Bei Bei, BSc., MSc., DPsych(Clinical)

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Melbourne School of Psychological Sciences
University of Melbourne
Australia

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ABSTRACT

**Introduction.** It is well established that for adolescents, school days are associated with sleep restriction, and that insufficient sleep has been linked to mood disturbances. This longitudinal study assessed sleep, mood, and life stress over the school term and vacation periods with restricted and extended sleep opportunities. The relationships between objective and subjective sleep, as well as between sleep and mood were examined. A cognitive model was proposed and tested to assess whether sleep-specific (i.e., dysfunctional beliefs and attitudes about sleep) and global (i.e., dysfunctional attitudes) cognitive vulnerabilities played a role in these relationships.

**Methods.** One-hundred and forty-six adolescents (47.3% male) aged 16.2±1.0 years (M±SD) from the general community wore an actigraph continuously for four weeks: the last week of a school term (Time-E), the following two-week vacation (Time-V), and the first week of the next term (Time-S). Social demographic information, chronotype, and cognitive vulnerabilities were assessed at Time-E. Subjective sleep, symptoms of depression, anxiety, and life stress were repeatedly measured at Time-E, Time-V, Time-S, and the middle of the subsequent school term. Regression analyses were used to explore the relationship between sleep and mood, and structural equation modelling was used to examine changes of variables over time, as well as the moderating roles of cognitive vulnerabilities.

**Results.** Compared with school days, sleep during the vacation was characterized by later timing, longer duration, lower quality and greater variability. Daily changes in actigraphy-measured sleep over the vacation period showed linear delays in sleep timing throughout the vacation, while changes in time-in-bed were non-significant. The first vacation week was characterized by a linear decrease in total sleep time and sleep quality, and these changes stabilized during the second vacation week.

Compared to vacations, school terms were associated with higher symptoms of depression, anxiety, and life stress. Poorer sleep quality, particularly poorer subjective perception of sleep quality, was significantly associated with higher symptoms of depression and anxiety. Sleep-specific cognitive vulnerability moderated the relationship between objective and subjective sleep onset latency during extended but not restricted sleep opportunity. After controlling for life stress, global cognitive vulnerability played different moderating roles in the relationship between subjective sleep and mood over school term and vacation periods. Higher global cognitive vulnerability was associated with a stronger relationship between subjective sleep and symptoms of anxiety (but not depression) during the school term, as well as with a stronger relationship between subjective sleep and symptoms of depression (but not anxiety) during the vacation period.
Conclusion. Sleep, mood, and life stress changed markedly over the school term and vacation periods. Changes in sleep over the vacation suggested that the recovery from school-related sleep restriction was completed within two weeks’ extended sleep opportunity, and the average sleep duration over this period suggested that sleep requirements in adolescence may be less than conventionally described in the media and in the scientific literature. Cognitive vulnerabilities played important roles in the relationship between sleep and mood. Adolescents with higher cognitive vulnerability might be more emotionally vulnerable towards school-related sleep restriction. These findings have important implications for future studies, as well as practical implications for policies and interventions designed to improve adolescents’ wellbeing.
DECLARATION

This is to certify that:

a) this work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

b) this thesis is being submitted in total fulfilment of the requirements for the degree Doctor of Philosophy.

c) this thesis is the result of my own investigation, except where otherwise acknowledged.

d) this thesis is less than 100,000 words in length exclusive of tables, figures, references, and appendices.

Signed ……………………………………………. (BEI BEI)

Date .......................... 22/04/2014
Publications arising from this thesis have included:

**Peer-Reviewed Journal Article**


**Conference Proceedings**


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1 INTRODUCTION

Thesis Overview

This thesis reports findings from a longitudinal study that examined adolescents’ sleep and mood over school terms and vacation periods with restricted and extended sleep opportunities. A two-step cognitive vulnerability model was tested to explore the relationships between objectively/subjectively assessed sleep and mood.

The INTRODUCTION section begins with an overview of the sleep and the circadian system (1.1), followed by characteristics of sleep/wake patterns during adolescence and factors that contribute to them (1.2). The effects of sleep and circadian alteration on mood were reviewed with a focus on research conducted in adolescents (1.3). In 1.4, inadequacies and limitations of existing studies were described, and how the current study addressed these issues was discussed. This section ends with the four main aims of the study and their respective hypotheses.

The METHODS section describes details of study samples, procedures, measurements, and statistical methods used for testing of hypotheses.

Findings were reported in four separate sections, corresponding to each of the aims described in the INTRODUCTION. Within each of these sections, the analyses conducted were described and results were presented, followed by discussions of results specific to each aim.

The final GENERAL DISCUSSION section brings together the overall findings, discusses their theoretical and practical implications, strengths and limitations, and future directions.
1.1 Sleep and the Circadian Rhythm

1.1.1 Stages of Sleep

Polysomnography (PSG) is the gold-standard measurement of sleep and its stages. It collects electro-physiological information such as electroencephalography (EEG), electro-oculography, electromyography, and cardiac/respiratory function measurements, and plots them against time. Using PSG, sleep during a typical night is classically divided into cycles such that each cycle consists of a progression of three non-rapid eye movement (NREM) sleep states (i.e., Stage N1-N3), followed by a period of rapid eye movement (REM) sleep (Iber, Ancoli-Israel, Chesson, Quan, Medicine, 2007). Each cycle typically lasts approximately 90 minutes (including 20-30 minutes REM sleep) and repeats itself four to five times throughout the night, with the amount of REM sleep increasing in each successive cycle. Distinctive features of each sleep stage are summarized in Table 1.

Table 1

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Wakefulness</th>
<th>Stage N1</th>
<th>Stage N2</th>
<th>Stage N3</th>
<th>REM</th>
</tr>
</thead>
<tbody>
<tr>
<td>EEG</td>
<td>Alpha activity (8-12 Hz); Beta activity (13-30 Hz).</td>
<td>Theta activity (3.5-7.5 Hz).</td>
<td>Theta, spindles, and K-complexes</td>
<td>High voltage, low frequency delta activity (~2 Hz)</td>
<td>Desynchronized activity; theta and beta activity, slightly slower than wakefulness.</td>
</tr>
<tr>
<td>Eye movements</td>
<td>Rapid, blinking</td>
<td>Rolling</td>
<td>Still</td>
<td>Still</td>
<td>Rapid</td>
</tr>
<tr>
<td>Muscle tone</td>
<td>Highest</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
<td>Lowest, muscular paralysis</td>
</tr>
<tr>
<td>Length in sleep cycles</td>
<td>N/A</td>
<td>~10 minutes</td>
<td>~15 minutes</td>
<td>~45 minutes</td>
<td>20-30 minutes</td>
</tr>
<tr>
<td>Examples of other features</td>
<td>Transitional state; Subjective feeling of wakefulness</td>
<td>Growth hormone secreted; sleep walking upon arousal from N3</td>
<td>Dreaming</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. EEG=electroencephalography; N/A=not applicable; REM=rapid eye movement.

The relatively short Stage N1 sleep is typically thought of as a transition between wakefulness and sleep, and excessive Stage N1 sleep indicates poor sleep quality. Stage N2 sleep accounts for about half of total sleep and contains a characteristic electroencephalographic signature, the K-
complex (high-voltage negative and then positive discharge), often followed by a sleep spindle (high-frequency, low-voltage discharge of approximately 0.5 seconds). K-complexes occur randomly throughout stage 2 sleep, but may also occur in response to external stimuli. It has been suggested they reflect a sleep maintenance, rather than an arousal, response (Nicholas, Trinder, & Colrain, 2002). Stage N3 sleep, also known as slow wave sleep (SWS), usually starts after about 15 minutes, signalled by the occurrence of high-amplitude, low frequency delta activity. Stage N3 sleep is considered the deepest stage of sleep, and individuals tend to report feeling rested after having ample SWS (Heinzer et al., 2001). A sleep-deprived person typically enters Stage N3 readily when sleep opportunity arises (Dijk, Hayes, & Czeisler, 1993).

REM sleep is a distinct state classically associated with dreaming. It resembles wakefulness according to EEG and neurochemical criteria, but significant regional differences in brain function occur during this stage, such as marked increases in limbic activity (“the emotional brain”) and reductions in activity in the prefrontal cortex (“the rational brain”), which might account for some features of dreams (Braun et al., 1998). In comparison to previous sleep stages, breathing tends to be more irregular in REM sleep, and cardiac arrhythmias may be more common. Consequently, people often find it easier to wake out of REM sleep than other sleep states (Schenck & Mahowald, 2002).

1.1.2 The Circadian Rhythm

Endogenous biological processes that repeat themselves approximately every 24 hours are defined as “circadian” if they persist with a similar period in the absence of external time cues (i.e., zeitgebers). Many bodily rhythms are circadian, for example, core temperature (Refinetti & Menaker, 1992), digestion (Waterhouse, Minors, Atkinson, & Benton, 1997), and the regulation of sleep and wakefulness (Dijk & Schantz, 2005). The major circadian “clock” in humans and animals is located in the suprachiasmatic nucleus (SCN) in the hypothalamus, controlling the secretion of melatonin from the pineal gland that peaks at night and ebbs during the day (Ditty, Williams, & Golden, 2003). The SCN can function autonomously, but can also be entrained by zeitgebers. For example, the core of the SCN receives photic input from the retina that triggers a response within the SCN neurons, but it also receives non-photic input from different parts of the brain (Cermakian & Boivin, 2003). Therefore, the circadian rhythm is believed to be regulated by the SCN as it integrates both internal and external triggers (Grandin, Alloy, & Abramson, 2006), although it is unclear which source of cues, internal or external, has more predominant influence.

There is evidence that behavioural processes such as subjective alertness, cognitive performance, and short-term memory have an endogenous circadian component (Dijk, Duffy, &
Czeisler, 1992; Johnson et al., 1992). Studies that induced circadian phase shifts have found that the circadian patterns of subjective alertness and cognitive performance maintain similar temporal relations to other reliable circadian markers (Boivin, Duffy, Kronauer, & Czeisler, 1994; Czeisler et al., 1990). This suggests that the circadian clock that times the biological rhythm might also affect the observed daily variations in these variables. Further, a number of studies (Boivin et al., 1997; Monk, Buysse, Reynolds, Jarrett, & Kupfer, 1992; Wood & Magnello, 1992) have suggested that in healthy individuals, mood is also modulated by the same processes.

Measureable changes in endogenous rhythms can be used to infer circadian phase. The timing of distinctive increases in melatonin secretion in the evening during very low light conditions, for example, is considered a marker of circadian phase (Zeitzer, Dijk, Kronauer, Brown, & Czeisler, 2000). Circadian phase can also be estimated through self-report. The Morningness-Eveningness Questionnaire (Horne & Ostberg, 1976) for example, is well established to provide indication of circadian preference that correlates well with that assessed through physiological markers.

### 1.1.3 The Two Process-Model

Thirty years after its proposal, the classic “two-process model” (Borbély, 1982) continues to be the predominant theory on sleep and wake regulation. It describes the interaction of a homeostatic process S and a circadian process C. Process S represents sleep need, which increases exponentially with increasing duration of wakefulness, and decreases during NREM sleep. In the EEG, the level of S is reflected in the density and frequency of slow-wave activity (SWA). Sleep onset, sleep termination, and the occurrence of NREM sleep are determined by the level of S, a gating system under control of the circadian process C, and of course, a person’s conscious decision as to when to go to sleep (Daan, Beersma, & Borbély, 1984). The regulation of REM sleep is more complicated, involving a homeostatic component, an interaction between circadian and ultradian mechanisms, as well as reciprocal interaction between NREM and REM-sleep. The amplitude and phase characteristics of process C can be estimated from biological rhythms (e.g., core body temperature, melatonin) measured under a “constant routine”1 or “forced desynchrony”2 protocol, which allow the separation of the respective contribution of S and C to the regulation of sleep/wake cycles (Dijk et al., 1992; Hiddinga, Beersma, & Van den Hoofdakker, 1997). Studies that have employed this method suggest that interactions between the circadian system and the sleep/wake

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1 Subjects are kept in a low-light bedroom in supine position with regular small isocaloric snacks.
2 It was developed to avoid the sleep deprivation induced over time in the classic 40-hour constant routine. In this protocol, subjects are forced to sleep and wake for several days on an artificial day-length schedule that is outside the range of entrainment of the human circadian system (e.g., a 22-hour-day, or a 28-hour-day), while their circadian rhythms remain constant.
cycle determine the course of many variables, such as sleepiness, alertness, cognitive performance, and, last but not least, mood (Boivin et al., 1997; Dijk et al., 1992).
1.2 Sleep in Adolescents

1.2.1 Developmental Aspects of Normal Sleep

Identifiable sleep patterns emerge from as early as 28-30 weeks of gestation (Dickerson & McGurk, 1982; Graven, 2006), and evolve across the lifespan. With an average of 16 hours per day, newborns experience their lifetime maximal amount of sleep, over twice that of an average older adult. The highest percentage of REM sleep (~50% compared to ~20% in adults) occurs during the first six months of life, and much evidence supports the role for REM in initial neurosensory development and ongoing neural plasticity (Graven, 2006). Adult-like SWS first emerges at 2-3 months of age (Schechtman, Harper, & Harper, 1994), which coincides with the maturation of thalamocortical and intracortical connectivity in the brain as well as a period of prolific synaptogenesis, processes that promote and support high-voltage, synchronised slow wave activity (Heraghty, Hilliard, Henderson, & Fleming, 2008). By the age of two, NREM sleep fully matures, and between two and five, SWS becomes increasingly prominent (Carskadon & Dement, 2000; Dickerson & McGurk, 1982), and is associated with higher arousal thresholds than SWS in older children and adults (Busby, Mercier, & Pivik, 1994). A decline in SWS then occurs from late childhood through adulthood (Crabtree & Williams, 2009; Roffwarg, Muzio, & Dement, 1966), and is thought to relate to a parallel loss of cortical synaptic density as a result of normal cortical “pruning”, particularly during adolescence (Feinberg, 1982; Kurth et al., 2010). Figure 1 was adopted from an early review (Roffwarg et al., 1966) showing the changes in overall sleep as well as REM and NREM sleep across the lifespan.

The circadian rhythm emerges around 3-5 weeks and is firmly established by 6 months of age (Dickerson & McGurk, 1982). During the first year of life, sleep periods gradually consolidate into a main nocturnal sleep period with one or two daytime naps (Heraghty et al., 2008), and by the age of six, the majority of children will have ceased daytime naps while having a single nocturnal sleep period (M. Crabtree & Williams, 2009).

The significant changes in sleep patterns across the lifespan suggest an intimate relationship between the maturational processes and sleep/wake cycles. As illustrated in Figure 1, during adolescence, sleep patterns undergo a clear transition that marks the start of typical adult sleep patterns. The following sections review factors that affect adolescents’ sleep/wake behaviours during this transition, as well as typical adolescent sleep patterns.
Figure 1 Changes in sleep across the lifespan, adopted from Roffwarg, Muzio, & Dement (1966).

1.2.2 Factors Affecting Sleep in Adolescents

1.2.2.1 Neurobiological Factors

**Neurobiological maturation and reduced homeostatic sleep drive.** From early adolescence to young adulthood, healthy individuals undergo a decline in synaptic density (Segalowitz, Santesso, & Jetha, 2010). This is evident in magnetic resonance imaging studies that have shown declines in grey matter, and in blood glucose metabolism throughout adolescence (Pfefferbaum et al., 1994; Sowell, Trauner, Gamst, & Jernigan, 2002). These changes are also reflected in sleep EEG studies (I. G. Campbell, Higgins, Trinidad, Richardson, & Feinberg, 2007) that found a similar maturational decline in slow-wave activity (SWA, or delta power). As the EEG represents synchronized synaptic activity, the decline in power of its lower frequency has been hypothesised to reflect the process of synaptic pruning (Niedermeyer & da Silva, 2005). The reduction of synaptic density during adolescence is accompanied by a complementary increase in connectivity between neural regions. This is supported by EEG studies on hemispheric coherence that found more coordinated EEG activity during sleep as adolescents mature (Barry et al., 2004; Tarokh, Carskadon, & Achermann, 2010). The reduction in synaptic density and increase in neuronal connectivity reflect a reorganisation of the brain during adolescence, a process that directly affects sleep and wake behaviours. A core feature of these maturational processes is the reduction in homeostatic sleep drive, which has been thought to be indicated by a progressive reduction in SWS.
over the adolescent period (Carskadon et al., 1980). Changes in sleep architecture and homeostatic regulation of sleep are reviewed in the next section on sleep patterns during adolescence.

**Delayed circadian phase.** A delay in the circadian oscillator during adolescence is consistently reported by studies that measured circadian phase subjectively using questionnaires (Carskadon, 1990; Carskadon, Vieira, & Acebo, 1993), and objectively using saliva melatonin (Carskadon, Acebo, & Jenni, 2004; Carskadon, Acebo, Richardson, Tate, & Seifer, 1997). Mechanisms behind this delay, however, are not clear, with different hypotheses having been proposed and tested. The hypothesis that the delay was due to a lengthening of the typical ~24-hour circadian period was tested by a small \( n=10 \) study using a forced desynchrony protocol (Carskadon, Labyak, Acebo, & Seifer, 1999). In this study, circadian period was within the range reported for young and older adults recorded in a similar experimental protocol (Czeisler et al., 1999), although three adolescents had periods outside the range reported for adults. In addition, there was no correlation of period with pubertal status in this small sample. Therefore it cannot be concluded whether the phase shift in sleep timing was due to intrinsic circadian period becoming longer across development. The notion that increased light sensitivity in adolescents resulted in more pronounced shifts in melatonin secretion when exposed to evening light was not supported by the finding that early- and mid-post-pubertal adolescents do not differ significantly in the melatonin suppression response to light (Carskadon & Acebo, 2002).

1.2.2 Social Factors

**School schedules.** Early school start times (i.e., 8:30am at most Australian schools) often require sleep/wake timing that is earlier than what adolescents naturally prefer. When combined with the aforementioned delay in sleep timing and decrease in sleep propensity at night-time, early rise-time due to school schedules often creates an accumulated sleep debt throughout weekdays among adolescents. As a consequence, later sleep timing and longer sleep duration is one of the most robust findings in studies that compared adolescents’ sleep/wake patterns during weekends with that during school weekdays (Carskadon, 2002; Short, Gradisar, Lack, Wright, & Dohnt, 2013). Further, efforts to delay adolescents’ school start time by a modest 30 min have resulted in a substantial increase (45 min) in sleep duration, as well as significant improvements in mood and alertness (Owens, Belon, & Moss, 2010).

**Parental control over bedtime.** Adolescence is typically accompanied by increased autonomy and decreased in parental control over behaviours, including sleep/wake behaviours. It has been reported in a longitudinal study, that prevalence of parental control over bedtime was low, and decreased from 3% to less than 1% among Italian adolescents aged 15 to 18 (Giannotti, Cortesi, Sebastiani, & Vagnoni, 2005). This is consistent with cross-sectional studies that showed that only
5.1% of high school students (13-19 years) had parental input into bedtimes (Carskadon, 2002), and this rate was reported to be under 1% among senior high school students (Yang, Kim, Patel, & Lee, 2005). Further, recent evidence suggested that earlier parental set bedtimes are associated with less depressive symptoms and suicidal ideation, which the authors speculated to be facilitated by longer sleep times (Gangwisch et al., 2010).

**Social and cultural obligations and interests.** As parental control over bedtimes decreases with age, completions of social/cultural activities such as homework (13%), social activities (11%), television viewing (9%) were considered by adolescents as common cues for bedtimes (Carskadon & Acebo, 2002). Increases in school-related activities and demands have been linked to poor sleep in adolescents (Wolfson & Carskadon, 1998). On one hand, academic obligations were the most commonly cited reasons for late bedtimes in high school students (Gau & Soong, 1995; Yang et al., 2005), contributing to shorter time-in-bed; while on the other hand, a considerable proportion of adolescents engage in extra-curricular activities (Andrade et al., 1993) and part-time work (I. Campbell & Burgess, 2001), which not only compete for time with sleep (Bachman & Schulenberg, 1993), but might also contribute to life stress that might affect sleep quality (Wolfson & Carskadon, 1998). In addition, night time use of media and electronic devices has increasingly been linked to sleep problems in adolescents. Earlier studies reported that the presence of television or computers in the bedroom was associated with shorter sleep duration (van den Bulck, 2004), and that over half of adolescents with mobile phones reported being awakened by phones (van den Bulck, 2003). Recent integration of the internet into mobile devices further encouraged the use of these devices for interactive purposes (e.g. social media) at bedtime (Cain & Gradisar, 2010). It is worth noting that although there is a consistent relationship between greater bedtime media use and shorter sleep duration, the compromise in sleep duration was small (10-15 min; Cain & Gradisar, 2010). In addition to a reduction in sleep opportunity, the use of media devices at bedtime might lead to increased mental and physical pre-sleep arousals that might compromise sleep quality (Weaver, Gradisar, Dohnt, Lovato, & Douglas, 2010).

**1.2.2.3 Psychopathology**

In addition to the above factors that are relatively external to one’s psychological state, a smaller proportion of adolescents experience poor sleep as a symptom of psychiatric disorder that might or might not have reached diagnostic threshold. Of relevance to this thesis are depressive and anxiety disorders – two most commonly diagnosed psychiatric disorders during adolescence with point prevalence of 0.4-8.3% (Birmaher et al., 1996) and 5-10% (Spence et al., 2003) respectively. The comorbidity of the conditions is common (Essau, Conradt, & Petermann, 2000), although
anxiety disorders often precede the emergence of depressive disorders in vulnerable individuals (Beesdo et al., 2007).

In both adults (Mendelson, Gillin, & Wyatt, 1977) and adolescents (Alfano, Ginsburg, & Kingery, 2007; Ivanenko, Crabtree, & Gozal, 2005), the presence of depressive and anxiety disorders have been consistently associated with subjective sleep complaints such as longer SOL, poorer perceived sleep quality, and higher sleep-related daytime dysfunction. In adults, PSG studies comparing sleep in individuals with a Major Depressive Disorder (MDD) with that of healthy controls typically reported longer sleep onset latency (SOL), disturbances in sleep continuity, a reduction of the interval between sleep onset and the occurrence of the first REM period (i.e., REM latency) in those with MDD (Benca et al., 1992). Further, greater REM density has consistently been shown to be associated with higher vulnerability/risk of depression (Friess et al., 2008; Lauer, Schreiber, Holsboer, & Krieg, 1995; Modell, Ising, Holsboer, & Lauer, 2005). Differences in PSG sleep between adolescents with MDD and healthy controls are similar to those in adults, albeit the differences are less consistent in adolescents. A review of 10 earlier studies of sleep in MDD among adolescents (Rao et al., 2002) found that five studies reported disturbances in sleep continuity, six reported shortened REM latency, two found higher REM density, while no studies found differences in SWS. More recently in a larger sample of adolescents (97 MDD vs. 76 healthy controls), researchers (Robert et al., 2006) noted that compared to healthy controls, males but not females with MDD had greater sleep disturbance and lower SWS. This sex difference was supported by a recent study (Lopez, Hoffmann, Emslie, & Armitage, 2012) showing adolescent males but not females with MDD having less SWA early in the night compared to controls; this study also showed that compared to controls, male but not female adolescents with MDD had shorter REM latency and a higher percentage of REM sleep. Studies on the differences in objective sleep between adolescents with and without anxiety disorders are limited. Among the few existing PSG studies (Forbes et al., 2008; Rapoport et al., 1981), the most consistent findings have been that compared to healthy controls, adolescents with anxiety disorders tend to have longer SOL, more awakenings, and lower sleep efficiency (SE). Similar to individuals with MDD, shorter REM latency and less SWS in the early part of the night compared to healthy controls have also been noted in adolescents with anxiety disorders. These suggest that the presence of psychopathology, in particular high prevalence disorders such as anxiety and depressive disorders, might affect both subjectively and objectively measured sleep in affected adolescents.
1.2.3  Sleep Patterns during Adolescence

The interaction amongst the above-mentioned neurobiological and psychosocial factors creates unique characteristics in the sleep and wake patterns in adolescents. This section reviews changes in sleep architecture, sleep behaviours, as well as typical sleep features during the adolescence period.

1.2.3.1  Changes in Sleep Architecture and Homeostatic Sleep Regulation

Across adolescence, REM sleep deceases in its absolute duration, but not as a percentage of TST (Ohayon, Carskadon, Guilleminault, & Vitiello, 2004). In contrast, a marked reduction in SWS is seen as the key feature associated with sleep changes during adolescence, a process that has been considered to reflect a progressive reduction in homeostatic sleep drive (Carskadon et al., 1980). Early cross-sectional (Feinberg et al., 1990) and more recent longitudinal studies (I. G. Campbell et al., 2011) based on visual stage analysis has shown that SWS declines with age across adolescence. These findings are consistent with studies using spectral analysis of SWA, the reduction of which has been associated with a non-specific reduction in EEG power that was linked to the aforementioned synaptic pruning across adolescence. Cross-sectional studies have indicated that pre-pubertal children and younger adolescents (9.6-12.9 years) have higher EEG power than older adolescents (11.8-15.9 years) across both NREM and REM sleep (Jenni & Carskadon, 2004). Further, longitudinal data from childhood (mean age 10.13) to early adolescence (mean age 12.28), showed spectral power declined for both NREM and REM sleep, and particularly for lower frequency (<10 Hz) activity (Tarokh & Carskadon, 2010). This was shown to be followed by a further decline to NREM EEG power from mid- to late-adolescence (Tarokh, Van Reen, LeBourgeois, Seifer, & Carskadon, 2011).

Across a typical night, SWS declines exponentially during successive sleep cycles. In addition to the age-related decline in overall SWA, a longitudinal study of school night sleep from early to late adolescence, demonstrated that the spectral power in the first NREM period, first decreased significantly, then plateaued with age (I. G. Campbell et al., 2011). Although this finding was not supported by an earlier investigation that showed these changes to be non-significant (Carskadon et al., 2004), it raises the possibility that homeostatic sleep drive in the early part of the night is lower in older adolescents with potential implications for sleep-onset.

When studying homeostatic sleep drive in adolescents, it is important to consider the impact of school-related sleep restriction on the build-up of sleep debt across a school week, as well as the recovery of such sleep debt upon removal of school schedules during weekends and vacations. In a laboratory-based longitudinal study examining the dynamics of PSG-measured sleep during two
school nights and two extended sleep nights, Feinberg and Campbell (Feinberg, Davis, de Bie, Grimm, & Campbell, 2012) showed that across adolescence, TST decreased with age on school nights but increased on subsequent extended sleep nights; the decrease on school nights was related to decreases to NREM sleep, which was stable across adolescence on extended sleep nights. This suggests that homeostatic sleep drive across adolescence might be affected by a complex interaction between maturation-related reduction in SWA and sleep restriction/recovery related to externally enforced sleep/wake schedules.

1.2.3.2 Changes in Sleep Behaviours

When sleep opportunity was fixed at 10 hr in the laboratory, PSG-measured TST was shown to approximate 9 hr with little change between ages 10 to 17 (Carskadon et al., 1980; Carskadon & Acebo, 2002). However, survey studies from industrialized countries have consistently shown that not only is adolescents’ actual sleep duration substantially shorter than that observed in the laboratory, it also decreases with age. For example, cross-sectional data from the USA showed that from age 10 to 18, sleep decreased from almost 10 hr to a little over 7 hr (Carskadon, 1990), and between age 13 and 19, TST decreased on average 40 min on school nights, with similar decreases also occurring on non-school nights (Wolfson & Carskadon, 1998). Similarly, normative data from over 4000 Australian adolescents showed that sleep duration decreased by an average of 12 min per night between age 9 and 18 (Olds, Maher, Blunden, & Matricciani, 2010). A Canadian longitudinal study of over 1000 adolescents aged 10-13 found that sleep duration decreased by over one hour across the three year span (Laberge et al., 2001). It has been suggested that this commonly reported reduction in sleep duration was primarily due to delayed bed times across adolescence and inflexible school start times, as some have reported that bedtimes were 45 min later in older compared to younger adolescents with little differences in rise-times (Wolfson & Carskadon, 1998).

Longitudinal studies on the developmental trajectories of adolescents’ sleep/wake behaviours have rarely been studied in a relatively large community sample using objective measurements of sleep. One actigraphy study (Sadeh, Dahl, Shahar, & Rosenblat-Stein, 2009) followed up 94 children and adolescents aged 9.9-11.2 years annually for three years, and showed that TST decreased with age and was lower on school nights compared to non-school nights, whilst SOL increased with age on both school and non-school nights. In addition, both SOL and TST were associated with measures of pubertal status, suggesting a link between changes in adolescent sleep/wake behaviours and maturational development.
1.2.3.3 Restricted and Extended Sleep Opportunities

Perhaps the most robust finding in adolescent sleep literature is the discrepancy in sleep/wake behaviours between school (typically Sunday to Thursday nights during school terms) and non-school nights (typically Friday and Saturday nights during school terms, and vacations). Sleep timing on non-school nights being substantially later and sleep duration longer compared to school nights. This discrepancy reflects restricted sleep opportunities during school weekdays that are primarily caused by early school start times; upon the removal of school-related sleep restriction (i.e., during weekends and vacations), adolescents’ sleep/wake behaviours are considered to reflect the combination of largely developmentally normal sleep and the recovery from sleep restriction.

**Sleep timing.** Bedtimes and rise-times on non-school nights are significantly later than that of school nights, and this discrepancy increases with age. Normative data based on self-report (Olds et al., 2010) showed that at 16-17 years, bedtimes on non-school nights were about 30min, and rise-time 82min later than that of school nights. Between the age of 9 and 17, rise-time on school days was reasonably consistent at around 7:00am, but on non-school days, it delayed from 7:24am to 8:53am in males, and from 7:50am to 9:05am in females. This delay in sleep timing during non-school days with extended sleep opportunities is consistent with the aforementioned gradual delay in circadian phase preference with age.

**Sleep duration.** The later sleep timing on non-school days is accompanied by substantially longer sleep duration. Across a typical school week, time-in-bed was reported to stay relatively stable at 9.5 hr across school nights, whilst increases to over 10 hr on weekends (Olds et al., 2010). In younger adolescents, TST on non-school nights typically averages 30-60 min longer than that during school nights; both cross-sectional (Wolfson & Carskadon, 1998) and longitudinal (Laberge et al., 2001) studies showed that this discrepancy increases with age, and reaches over 2 hr in older adolescents. Studies have shown that TST on school and non-school nights both decline with age, with some studies showing similar rates of decline for both school and non-school nights (Wolfson & Carskadon, 1998), and others showing greater decline on school nights (12 min/year) compared to non-school nights (4 min/year) (Olds et al., 2010). This suggests that the increase in school vs. non-school night differences in sleep duration is likely resulted from a decrease in sleep duration on school nights rather than increases on non-school nights. As the differences in school and non-school night TST is often taken to indicate inadequate sleep time during school nights, the increase of such differences with age suggests potential increases in sleep debt across adolescence (Wolfson, 1996).
1.2.3.4 Sleepiness and Sleep Propensity

When tested in the laboratory with fixed TIB of 10 hrs, daytime sleepiness has been shown to be greater in more mature adolescents despite the lack of difference in TST between older versus younger adolescents (Carskadon et al., 1980). One interpretation is that sleep need remains stable across adolescence, and the increase in sleepiness is related to the progressive reduction in obtained sleep across adolescence. However, the increase in sleepiness in older adolescents persists when sleep duration is maintained at early adolescent levels (Carskadon et al., 1980). Another probability is that the increase in longitudinally measured daytime sleepiness is related to a maturational declines in SWA when controlling for sleep schedules and durations (I. G. Campbell et al., 2007). However, it is unclear why SWA would decline if sleep debt (sleepiness) were increasing. The third probability is that there is a maturational component of the increase in adolescent sleepiness with age that is independent of sleep itself. Finally, as mentioned earlier, sleep propensity is affected by an interaction between Processes S (i.e., homeostatic) and C (i.e., endogenous circadian), as well as actual sleep schedules. In the presence of maturational delays in the circadian oscillator and a decrease in homeostatic drive, early sleep timing as a result of school schedules, might lead to decreased sleep propensity in the evening and increased daytime sleepiness, particularly in the morning (Carskadon et al., 2004; Carskadon & Acebo, 2002).
1.2.4 Summary

Adolescence is accompanied by substantial changes in the child’s neurobiological, social, and psychological milieu, and influences from all these aspects play important roles in adolescents’ sleep/wake behaviours. On one hand, maturational processes cause a delay in the endogenous circadian oscillator and a reduction in homeostatic drive, reducing sleep propensity in the evening. On the other hand, parental control decreases and social/cultural interests and obligations increase, and when combined with maturation-related reduction in sleep propensity, become permissive of continued waking activities and delayed bedtimes. In addition, early school start times around the world further restrict adolescents’ sleep opportunities during school weekdays. Among adolescents experiencing psychopathology, such as anxiety and depressive disorders, sleep quality might be further compromised. As a consequence, typical sleep patterns during adolescence are characterized by restricted sleep opportunities during school days with earlier sleep timing and shorter sleep duration, and extended sleep opportunities during non-school days with later sleep timing and longer sleep duration. These discrepancies in sleep timing and duration increase with age across adolescence, and school days, particularly those during mid-late adolescence, are widely considered to be associated with significant sleep debts as well as an externally imposed sleep/wake schedule that is earlier than what adolescents internally prefer.
1.3 The Effects of Sleep and Circadian Alteration on Mood

The substantial discrepancy in sleep duration and timing on school and non-school nights raises concerns that during school terms, adolescents are chronically sleep-restricted, and that their sleep timing is displaced in relation to their preferred circadian phase (Dorofaeff & Denny, 2006; Loessl et al., 2008). These potentially common features of adolescent sleep, in particular, insufficient sleep, have been associated with a number of psychosocial and physical consequences, for example, impaired cognitive performance (Wolfson & Carskadon, 1998), compromises in school grades (Arne Eliasson, Eliasson, King, Gould, & Eliasson, 2002), increased risk for obesity (Spruyt, Molfese, & Gozal, 2011), and more pertinent to this thesis, increased symptoms of depression and anxiety (Moore et al., 2009).

As discussed earlier, the presence of anxiety and/or depressive disorders could contribute to poor sleep. On the other hand, disruptions to sleep and circadian functioning are well documented to affect mood and affect regulation in individuals with or without mood disorders. Over the years, there has been a shift away from considering sleep disturbance as simply epiphenomenal to the comorbid mood problems. Instead, the current view is that sleep disturbance is an important yet understudied mechanism, contributing to the cause and/or the maintenance of mood symptoms (Harvey, 2001; McCrae & Lichstein, 2001; Smith, Huang, & Manber, 2005).

In adolescents, sleep restriction and the displacement of sleep timing go hand-in-hand, thus in naturalistic settings, the impact of typical adolescent sleep patterns on mood come from the combined effects of both features. This section gives an overview on the respective effects of sleep restriction and displaced sleep timing on mood, followed by a review of studies that examined the effects of typical adolescent sleep patterns on emotional wellbeing.

1.3.1 Sleep and Circadian Alteration Affect Mood

1.3.1.1 Acute Sleep Deprivation

In healthy individuals, acute sleep deprivation is associated with increased sleepiness, fatigue, and as well as lapses in attention and other cognitive capacities (Bonnet & Arand, 2003). In addition, sleep loss can amplify negative emotion in response to unpleasant events, lessen positive responses to pleasant ones, and has a mood-worsening effect (Zohar, Tzischinsky, Epstein, & Lavie, 2005). In approximately half of depressed individuals, however, both total and late night acute sleep deprivation, have been associated with a rapid, robust, yet transient (i.e., not extending beyond the next sleep period) antidepressant effect (Gerner, Post, Gillin, & Bunney, 1979; Schilgen & Tölle, 1980; Wu & Bunney, 1990).
1.3.1.2 Chronic Sleep Restriction

The effects of long-term sleep restriction and disruption on mood are complex and variable, to a certain extent being based on the frequency and amount of sleep loss. The majority of studies investigating sleep restriction have dealt with performance and objective alertness effects. Seven consecutive nights with an average of five hours’ sleep per night unsurprisingly produced increased reaction time and decreased vigour and concentration in laboratory settings (Bonnet & Arand, 1995; Carskadon & Dement, 1981). Some authors have suggested that mood is influenced by sleep loss to a greater extent than cognitive or motor functioning (TurekZee, P. C., 1999). Due to methodological and ethical issues, there are relatively fewer controlled investigations into the effect of chronic sleep restriction on mood compared to that of acute sleep deprivation. However, some degree of chronic sleep loss is common in the real world. A study on interns in a medical resident program throughout an academic year (Rosen, Gimotty, Shea, & Bellini, 2006) reported a significant association between the increased prevalence of chronic sleep deprivation (from baseline 9% to year end 43%) and the increased prevalence of moderate depression (from 4.3% to 29.8%). In patients with severe insomnia, the likelihood of having depression has been shown to increase fourfold (Hohagen et al., 1993; Schramm, Hohagen, Käppler, Grasshoff, & Berger, 1995).

Theories that attempt to address the mechanisms underlying negative impact of chronic sleep restriction on mood have thus far been somewhat speculative. According to early behavioural theories (Seligman, 1975), being deprived of control over a lengthy period of time could lead to learned helplessness and depression (Seligman, 1975). This theory might apply when sleep is restricted by external factors (e.g., fixed schedules) over which a person does not have control. Another theory emphasized the effect of fatigue and daytime sleepiness produced by chronic sleep loss, as fatigue was believed to lead to irritability and depression (G. Parker, 2000). An alternative model (Patten, 1999) proposes the possibility of an adaptive biological response to sleep loss being converted to psychosocial stress because of an accumulation of stressful circumstances and experiences.

1.3.1.3 Displacement of Sleep Phase

The displacement of sleep phase is the misalignment of the sleep/wake cycle and the endogenous circadian oscillator. In the chronotherapy literature, a rapid antidepressant effect is typically reported when bright light is used to advance the circadian phase (Wirz-Justice, Benedetti, & Terman, 2009). It is, however, not clear whether this is primarily caused by the exposure to bright light, shift in circadian phase, or acute partial sleep deprivation during the morning hours.
In cases of chronic sleep phase displacement (e.g., with shift-workers), reports of anxiety and depressive symptoms are often reported (Cavallo, Jaskiewicz, & Ris, 2009; Gordon, Cleary, & Parker, 1986; E. Samaha, Lal, Samaha, & Wyndham, 2007). In community samples, winter circadian phase delay due to changes in daytime sunlight have been associated with lowered mood (Murray et al., 2003). However, controlled studies examining the impact of chronically displaced sleep phase on mood are rare. One such study induced desynchrony between circadian phase and the sleep/wake cycle in healthy young subjects, and reported a significant yet complex interaction of the circadian and wake-dependent fluctuation of mood (Boivin et al., 1997); when the analysis was conducted at specific circadian phases, mood improved, deteriorated, or remained stable, depending on the duration of prior wakefulness. This leads to the notion that the interaction of sleep deprivation/displacement and the diurnal variation of mood is complex, and should be interpreted as a function of the simultaneous changes in circadian phase and prior sleep-wake history and organization (Boivin et al., 1997; 2000). Despite the lack of understanding regarding more specific mechanisms, these studies support the presence of a mood-circadian interaction, and that displacement of sleep phase might have impact on mood, particularly when such displacement is chronic.

1.3.2 The Effects of Sleep on Mood in Adolescents

1.3.2.1 Observational Studies with Cross-Sectional Designs

Sleep measured subjectively. The vast majority of studies that have examined the consequence of typical adolescent sleep patterns on mood have taken a cross-sectional approach. Among them, subjective measurements such as self- or parental-report were the most frequently used methods to assess sleep duration or quality. There is overwhelming evidence that the report of insufficient sleep, and lower perceived sleep quality and quantity is associated with a range of consequence on mental health, such as lowered mood and daytime functioning (Short et al., 2013; Warner, Murray, & Meyer, 2008), depressed mood and suicidal ideation (Gangwisch et al., 2010), symptoms of anxiety (Bei et al., 2013), and increased risk-taking behaviours (Pasch, Laska, Lytle, & Moe, 2010).

Sleep measured objectively. Cross-sectional PSG studies that have examined the relationship between sleep and mood have mostly compared PSG differences between adolescents with and without depression and/or anxiety symptoms. As discussed earlier in 1.2.2.3, the presence of an anxiety or depressive disorder is associated with varying degrees of alterations in sleep structure. Actigraphy studies that assessed overall sleep/wake patterns among community samples are rare.
The only such existing study (Moore et al., 2009) found that amongst 247 adolescents, subjective sleepiness was related to higher anxiety/depressive symptoms as well as perceived health, but no significant associations between objective sleep duration or variability in sleep duration with psychological variables were found.

These studies are, however, correlational. Given the aforementioned bi-directional relationship between sleep alteration and mood, they do not help ascertain the specific impact of typical adolescent sleep patterns on mood and affect regulation.

1.3.2.2 Observational Studies with Longitudinal Designs

Sleep measured subjectively. Longitudinal studies with subjective measurements of sleep have linked disturbed subjective sleep to increased risk of mood problems during follow-up. A study that followed 490 children from the age of 4 to 15 with sleep assessed yearly through parental report found that sleep at 4 years predicted behavioural and emotional problems at 15, and that the correlation between sleep and anxiety/depressive symptoms increased with age (Gregory & O'Connor, 2002). Based on large sample archival data, it was reported that adolescents who reported symptoms of insomnia not only experienced higher levels of depressive symptoms at the time, but also at 6 to 7 years follow up, and had higher risk of developing a depressive disorder (Roane & Taylor, 2008). The first prospective study that examined the consequence of short sleep on a broad range of aspects of functioning found that in a community sample of over 4000 adolescents, those who reported short sleep had an increased risk of developing depressive disorder in a one year follow-up (R. E. Roberts, Roberts, & Duong, 2009). A more recent study of similar design (Glozier et al., 2010) found that the presence of baseline psychological distress had a differential effect on how sleep affects subsequent mood symptoms. Short sleep linearly increased the risk of psychological distress persisting at 12 and 18 months follow up, while for those without psychological distress at baseline, only very short (<5 hours) sleep was a risk factor.

Sleep measured objectively. Few studies have examined the relationship between objective sleep and mood with a longitudinal design. One such study (Goetz, Wolk, Coplan, Ryan, & Weissman, 2001) assessed sleep using PSG measures from 40 adolescents with major depression and 30 healthy controls aged 6 to 17 years (diagnoses confirmed by semi-structured clinical interview) and followed up with the same assessment in 10 to 15 years. They found that those who met the criteria for a major depressive episode at either time had significantly more SWS and TST than those who met the diagnostic criteria at neither. This finding was however contrary to studies that have linked short sleep duration with increased risk for depression. Also, longer SOL was a significant predictor of the presence of depression at follow-up, highlighting the importance of sleep onset abnormality among adolescents at risk for depression.
1.3.2.3 Experimental Studies

Causal relationships can be more readily inferred from experimental studies in which aspects of sleep are directly manipulated. To date, there have been two such studies that tested the causal impact of short sleep on adolescent mood and emotion regulation. One study by Harvey and Dahl’s group found that one night of 6.5 hrs’ TIB at home, followed by one night of 2 hrs’ sleep, reduced adolescents’ self-ratings of positive affect, changed their vocal patterns in a manner suggesting increased negative affect, and made them more vulnerable to negative moods in response to a challenge (Dagys et al., 2011; McGlinchey et al., 2011; Talbot, McGlinchey, Kaplan, Dahl, & Harvey, 2010). Despite the patterns of sleep restriction in this study being rather different from that experienced by adolescents in naturalistic settings, its rigorous experimental methods allowed for the clear interpretation that the sleep manipulation caused a change in mood and emotion regulation.

With the aim of better understanding the effects of chronic sleep restriction on adolescents’ mood, Baum and colleagues (2013) implemented a three-week sleep manipulation protocol on 50 healthy adolescents aged 14 to 17 with a randomized, counterbalanced, crossover experimental design. A baseline week was followed by five nights’ sleep restriction (6.5 hr TIB) and then five nights’ healthy sleep duration (10 hrs’ TIB). Results showed that compared with the longer sleep duration, adolescents reported being more tense/anxious, angry/hostile, confused, and fatigued, and as less vigorous when sleep was restricted.

These two studies provided methodologically strong evidence that several days’ of shortened sleep in adolescents might worsen mood and decrease ability to regulate negative emotions. Although it is worth noting that as sleep deprivation/restriction studies conducted in the laboratory were not, and cannot be, blinded to participants, and findings are subjected to participants’ expectations on the effects of sleep loss.

1.3.2.4 Intervention Studies

Given the probable impact of short and/or poor sleep on adolescents’ wellbeing, a few studies have made an effort to improve sleep with the intention to improve other aspects of functioning. Research in this area is limited but growing. One of the first intervention studies in adolescents targeted delayed circadian rhythm, but found no change in either sleep or mood with morning bright light therapy (Hansen, Janssen, Schiff, Zee, & Dubocovich, 2005). A school based sleep intervention focused on educating students about sleep hygiene and the practice of healthy life-style (Moseley & Gradisar, 2009). The study found that although students showed generally improved sleep knowledge and those who had delayed sleep phase reduced the difference between weekday
and weekend sleep schedules, there was no significant improvement in sleep quantity/quality or mood measures.

Two intervention studies that showed promising results combined cognitive behavioural therapy for insomnia and mindfulness meditation, and targeted groups of adolescents with existing psychopathology. In a group of adolescents with comorbid substance abuse and insomnia, a seven-week intervention significantly improved subjective sleep and produced an improving trend in actigraphy-assessed sleep. Other outcome measures such as daytime sleepiness, substance use, aggression, and trauma symptoms also showed significant improvement (Bootzin & Stevens, 2005; Haynes et al., 2006; Stevens, Haynes, Ruiz, & Bootzin, 2007). Interestingly, the frequency of mindfulness practice was positively correlated with the increase in sleep duration, as well as improvement in self-efficacy about substance use, highlighting therapeutic benefits of mindfulness in the treatment of comorbid insomnia among adolescents (Britton et al., 2010). A similar group intervention was piloted on adolescent girls with elevated symptoms of anxiety (Bei et al., 2013). Results showed significant improvement on actigraphy-assessed SOL, SE, and TST, earlier sleep timing, and more regular bedtimes. Participants also self-reported significant improvement in SOL, sleep quality, and sleep-related daytime dysfunction. Changes in symptoms of anxiety were present but small.

Similar to experimental studies, intervention studies aim to impose manipulations on sleep, and by assessing subsequent changes in other areas of wellbeing such as mood, a causal relationship between such changes might be inferred. Indeed, existing studies showed some benefits of sleep-promoting interventions in unselected adolescent populations. For adolescents with psychopathology, sleep interventions show promise in improving both sleep and mood. However, it is possible that more general aspects of these interventions (e.g., coping skills), rather than the improvements in sleep per se, might have directly contributed to the improvement in psychopathology.
1.3.3 Summary

Sleep and circadian alterations, particularly chronic sleep restriction and displacement of sleep phase, have negative impact on mood. Observational studies with subjective measurements of sleep suggest that typical adolescent sleep patterns characterized by sleep restriction and earlier than preferred sleep timing during school days have been consistently associated reports of poor mood cross-sectionally and increased risk for mood-related problems longitudinally. Findings have been less consistent when sleep was measured objectively, with some evidence that longer SOL is a risk factor for depression. Although more work is needed, the two existing studies that imposed experimental sleep restriction on adolescents have found that a few hours’ sleep restriction over a few days could increase negative mood and affect emotional regulation in adolescents, lending further support for a link between typical adolescent sleep patterns and mood disturbance. Outcomes from sleep intervention studies in adolescents have been mixed. The few existing clinical trials suggest that when intervention was applied with a group of adolescents with traits suggesting psychological vulnerability (e.g., history of substance use, comorbid anxiety symptoms), meaningful improvements in sleep were more consistently observed, and that such improvements could be accompanied by improvements in comorbid psychopathology.
1.4 Inadequacies in the Literature and thus the Current Study

There are a considerable number of studies that have examined adolescents’ sleep patterns in the context of school-related sleep restriction. However, a number of major gaps still exist in our understanding of adolescents’ sleep/wake behaviours, particularly with regards to their consequences for wellbeing. This section identifies two main areas in which more systematic research is needed. At the end of this section, how the current study will address specific issues in these areas will be discussed, followed by the rationale, design, aims, and hypotheses of this thesis.

1.4.1 Area 1: Sleep Patterns Over School Terms and Vacations

1.4.1.1 Empirical Gaps

Does sleep change over the school term? It is well established that adolescents’ sleep patterns differ significantly between school weekdays and weekends. Five days’ school-related sleep restriction, followed by two days’ weekend recovery sleep, comprise a typical seven-day cycle that is repeated across a school term. Studies that have examined adolescents’ sleep patterns over the school term have typically assessed sleep cross-sectionally, or compared sleep between weekdays and weekends, without taking into consideration the timing of sleep assessment in relation to a school term. No study has examined whether recovery sleep is completed over a typical school term weekend. If sleep debt from the prior school week were not sufficiently repaid, it would be reasonable to surmise that as a school term progresses, aspects of sleep, especially SOL, which reliably shortens as sleep drive increases, would change as unpaid sleep debts increased. To date, no study has examined sleep longitudinally to determine whether it changes over a school term.

Transitions between restricted and extended sleep opportunities. Despite the knowledge that sleep/wake patterns differ substantially between school weekdays and weekends, no study has documented patterns of sleep over the days of transitions between restricted and extended sleep opportunities. Existing studies typically averaged sleep measured across “weekdays” and compared that to “weekends”. However, the definition of a “weekday” is inconsistent, with some studies using Monday to Friday nights (Li et al., 2010), some using Sunday to Thursday nights (C.-W. Kim et al., 2012; Short et al., 2013), and others not reporting such information (Strauch & Meier, 1988) or using questionnaires that did not specify what “weekdays” and “weekends” were referring to (Y. J. Lee, Cho, Cho, & Kim, 2012). To better understand sleep/wake behaviours during the transitions between restricted and extended sleep opportunities, comparisons of sleep among school day nights (i.e. Monday to Thursday), non-school day nights (i.e. Saturday and vacation nights), and transition
nights (i.e. Friday and Sunday) are needed. Further, at the start of a school term, adolescents have typically had a vacation during which sleep opportunities were relatively unconstrained, whilst during later school weeks, a shorter two-day extended sleep opportunity would proceed school-related sleep restrictions. Little is known regarding how short versus long periods of extended sleep opportunities affect transitions into restricted sleep. This can be studied by examining the differences in aspects of sleep at the start versus at a later time of a school term.

**Extended sleep opportunity during the vacation period.** Current adolescent sleep research has focused on insufficient sleep, whilst unconstrained sleeping over an *extended* period of time has rarely been studied. The timing, duration, and quality of sleep adolescents obtain during such periods are poorly understood. Studies conducted over extended periods of unconstrained sleeping are important, as they may help answer questions regarding the length of time it takes adolescents to recover from school-related sleep restriction, and adolescents’ preferred sleep duration (Matricciani, Blunden, Rigney, Williams, & Olds, 2013). School vacations are ideal naturalistic extended periods during which adolescents experience relatively unconstrained sleeping. In addition, the absence of school-related sleep restriction during the vacation allows better examination of how factors such as age, sex, and morningness-eveningness affect adolescents’ sleep/wake behaviours. Three existing studies using subjective measurements of sleep found that average sleep duration was longer and sleep timing was later during vacations compared to school terms (Crowley, Acebo, Fallone, & Carskadon, 2006; Strauch & Meier, 1988; Warner et al., 2008). Crowley and colleagues (Crowley et al., 2006) also reported greater correlation between dim light melatonin onset (DLMO) phase and sleep timing during vacations than during school terms. In young adults, a higher association between DLMO phase and sleep/wake schedules was found in unconstrained compared to experimentally fixed schedules (H. J. Burgess & Eastman, 2005). In general, these studies suggest that school vacation periods might provide a naturalistic window through which relatively unconstrained sleep could be studied.

1.4.1.2 Methodological Issues

**Longitudinal design.** The vast majority of existing adolescent sleep studies are cross-sectional. Such design provides description of overall sleep/wake patterns and their association with outcomes in physical and mental health. To better understand how sleep/wake behaviours change over school terms and vacations, and explore the impact of such changes on adolescents’ wellbeing, longitudinal studies with repeated measurements on both sleep and wellbeing are needed.

**Analysis of day-to-day sleep variation.** Sleep studies that have used instruments such as sleep diaries and actigraphy often take measurements repeatedly over multiple days. However, data
collected across several days are typically reduced into an average, losing valuable information on how sleep changes from one day to another. Further, with missing data being a frequent part of longitudinal designs, traditional statistical methods such as repeated-measures analysis of variance have been increasingly challenged. Studies that utilized the richness of daily sleep data through sophisticated analyses are rare but are increasing, for example Mixed Effects Model (Åkerstedt, Axelsson, Lekander, Orsini, & Kecklund, 2013), Ecological Momentary Assessment (Miller, Kyle, Marshall, & Espie, 2013), and Latent Growth Model (Fredriksen, Rhodes, Reddy, & Way, 2004). These new methods not only assess dynamic changes of observations over multiple time points, but also allow examinations of individual differences in these changes.

**Objective measurements of sleep.** Despite relatively high correlations observed between objectively and subjectively measured sleep, these two constructs are increasingly recognized to be different. Significant differences between both measures are commonly reported by studies that used both, and their relationships with outcome variables, particularly those measured using self-report, also frequently differ (Baker et al., 2012; Bei, Milgrom, Ericksen, & Trinder, 2010).

Existing studies that used only subjective measurements of sleep are limited in understanding the causal relationship between objectively compromised sleep and psychological outcomes due to potential subjective biases in the measurements of both. Whilst PSG studies provide gold standard measurements of objective sleep, they are often challenged by limited sample sizes, difficulties in measuring sleep across multiple days, and an often-unnatural laboratory environment. The use of actigraphy has increased substantially over the past decade, but few of these studies have examined naturalistic sleep/wake behaviours in a relatively large sample of adolescents in the community.

### 1.4.2 Area 2: How Sleep Affects Mood, the Role of Cognitive Vulnerability

The existing literature focuses on whether there is relationship between sleep and mood, and provides compelling evidence that sleep disruption/restriction are associated with disturbances in mood and affect regulation, particularly when sleep was measured subjectively. However, few studies have explored the mechanisms underlying this relationship, and no clear conclusion regarding these has yet been drawn. Further, despite strong empirical evidence for the role of cognitive vulnerability in the development and maintenance of mood disorders (Lakdawalla, Hankin, & Mermelstein, 2007), no study has proposed a psychological pathway from objectively disrupted/restricted sleep to mood disturbances and examined it systematically. The following sections review the concept of cognitive vulnerability and discuss its potential roles in the sleep-mood relationship.
1.4.2.1 Cognitive Vulnerability

Cognitive vulnerability refers to pre-existing erroneous beliefs, cognitive bias, or pattern of thoughts that predispose an individual to higher likelihood of psychopathology when confronted with stressful experiences (Freeman & Felgoise, 2005). Theories have approached the origins of cognitive vulnerabilities from different perspectives such as attachment theory (Bowlby, 1977; Bretherton, 2010), schema models (Segal, 1988; Young, Klosko, & Weishaar, 2003), learned hopelessness (Seligman, 1975), and cognitive models (Beck, 1987). Among these, Beck’s cognitive model is one of the most studied, and it is widely applied in clinical settings for the treatment of depression, anxiety, and other psychopathology (Butler et al., 2006). The model proposes that early adverse events foster negative attitudes and biases about the self, the world, and the future (e.g., “If I fail at something, it means I’m a total failure.”), which are integrated into the cognitive organization in the form of schemas; the schemas become activated by later life stress impinging on the specific cognitive vulnerability and lead to the systematic negative bias at the core of depression (Beck, 2008). The original model (Beck, 1967) refers to usual precipitating life stress as severe life events (e.g., death of a loved one), but more recent research has suggested that milder stressful life events provide an alternate pathway to depression in vulnerable individuals (Kendler, Kuhn, Vittum, Prescott, & Riley, 2005; Ng et al., 2012).

The catalysing role of dysfunctional attitudes, a critical feature of cognitive vulnerability in Beck’s cognitive theory, in the development of mood problems following life stress is well supported in adult populations (Scher et al., 2005). For instance, young adults with greater cognitive vulnerability were shown to be more likely to experience depressive symptoms after negative outcomes on college applications (Abela & D’Alessandro, 2010). Fewer studies have examined dysfunctional attitudes reported in adolescents. Those that took a prospective approach have found that dysfunctional attitudes, either alone or in interaction with life stress, predicted depression (Abela & Sullivan, 2003; Lewinsohn, Clarke, Seeley, & Rohde, 1994; Lewinsohn, Joiner, & Rohde, 2001). For example, in the Oregon Adolescent Depression Project involving a representative sample of community adolescents (Lewinsohn et al., 1994; 2001), Beck’s cognitive theory was conservatively tested with some known risk factors for depression, such as current depression, the presence of current or past non-mood disorder, and family psychiatric history, controlled for as covariates. The analyses supported, on a trend level, Beck’s cognitive theory for the development of depression during a one-year follow-up.

Dysfunctional attitudes are often assessed using the Dysfunctional Attitudes Scale (Iber et al., 2007; A. N. Weissman, 1979; A. N. Weissman & Beck, 1978), which assesses cognitions individuals hold towards self and the world that are not specific to a certain domain. When thoughts and beliefs are related to sleep (e.g., “I cannot cope after a poor night’s sleep”), they are
sleep-specific. Sleep-specific cognitive vulnerability is most commonly assessed using the Dysfunctional Beliefs and Attitudes about Sleep (DBAS) Scale, which assesses the degree to which an individual endorses a series of cognition regarding sleep and its impact on daily life (Morin, 1994).

1.4.2.2 The Role of DBAS in Sleep Perception

Dysfunctional beliefs and attitudes about sleep are most commonly studied in relation to insomnia. Observational studies have consistently reported that individuals with insomnia have stronger endorsement of DBAS than healthy individuals (Morin et al., 1993). Intervention studies have also shown that changes in DBAS are correlated with improved sleep efficiency and better maintenance of improvements at follow-up (Morin et al., 2002). These suggest that dysfunctional beliefs are not simply a correlate of sleep complaints, but play a causal or maintaining role in sleep problems.

The contribution of DBAS to sleep complaints is elegantly illustrated in the cognitive model of insomnia proposed by Harvey (Harvey, 2002), which was heavily influenced by Beck’s cognitive model of depression and well supported by empirical evidence in the adult literature. It proposed that individuals with insomnia tend to be preoccupied by sleep and the daytime consequences of poor sleep. This excessive negatively toned cognitive activity activates both autonomic arousal and emotional distress, which then triggers selective attention and monitoring of internal and external sleep-related threat cues. These processes can lead to overestimation of perceived sleep deficit, and individuals with persistent difficulties with sleep could develop rigidly held dysfunctional beliefs about sleep.

The cognitive model of insomnia provides a rationale for understanding individual differences in perception of sleep and its daytime consequences from a cognitive vulnerability framework. As discussed earlier, adolescents regularly undergo sleep restriction, and sleep-related daytime dysfunction is widely reported. It would be of theoretical as well as clinical interest to assess whether sleep-specific cognitive vulnerability played a role in adolescents’ subjective perception of sleep restriction. To date, few studies have assessed DBAS among adolescents, and even fewer explored its role in relation to school-related sleep restriction. In one study of 45 younger adolescents aged 11-12, higher DBAS was associated with longer actigraphy SOL; in addition, there was some evidence that adolescents’ DBAS mediated the relationship between parental DBAS and adolescents’ sleep (Ng et al., 2012). In another study in older adolescents (mean age 17.7 years), those who habitually napped ≥2/week were compared to those who did not nap. The nappers reported significantly less night-time sleep and higher DBAS than non-nappers. In addition, among nappers, higher DBAS was associated with greater negative affect (Gradisar et al.,
As napping behaviours are intimately related to perceived sleep quality and its consequence on daytime functioning (Morin & Espie, 2003), these findings suggest that like in adults, sleep-specific cognitive vulnerability as measured by DBAS, might contribute to adolescents’ perception of sleep.

1.4.2.3 From Sleep Perception to Mood, the Role of Cognitive Vulnerability

Few studies have investigated potential psychological mechanism underlying the strong relationship between subjective sleep complaints and mood. A recent study of 218 community dwelling older adults showed that DBAS and hopelessness partially mediated the impact of insomnia on depressive symptoms (Sadler et al., 2013). This suggests that non-sleep specific cognitive vulnerability, such as hopelessness, might play a role in how perceived poor sleep affects mood.

Research has only recently begun to examine the interaction of cognitive vulnerability and sleep in youths, and the majority of such studies have focused on samples with elevated anxiety. Earlier work by Alfano and colleagues (2009) found that sleep problems were associated with higher anxiety and depressive symptoms, and in an adolescent sample (but not in children) it was also significantly associated with cognitive errors. They suggested that such cognitive processes could be involved in the association between sleep complaints and mood symptoms in youths. Gregory and colleagues (2009) studied sleep-related cognitions, and noted that children as early as 8 to 10 years old share similar cognitive distortions about sleep as adults. Further, about a quarter of an unselected sample catastrophized about sleep, and catastrophizing was linked to disturbed sleep.

The role of cognitive vulnerabilities in the relationship between sleep restriction and mood among healthy adolescents is currently unexplored territory. A recent study (Regestein et al., 2010) on female college students found that insufficient sleep specifically correlated with melancholic symptoms such as "I felt depressed" or "I thought my life had been a failure" (i.e., cognitive errors) rather than "poor concentration" or "difficulty to get going", suggesting a stronger cognitive component in the sleep-mood link than a somatic one. This also highlighted that underlying cognitive processes are not only critical in sleep-mood interaction among anxious youths, but that they could also play a role in the depressogenic effect of long-term sleep restriction in healthy population.
1.4.3 Current Study

1.4.3.1 Design and Rationale

In Australia, a school year commonly consists of four terms of ~10 weeks, with a typical two-week vacation between terms (with the exception of five-week summer vacations). This longitudinal study captured the naturalistic transitions between school terms and a two-week vacation with the assumptions that (a) sleep opportunity is restricted during school terms and that vacation restores sleep by providing relatively extended sleep opportunities for desired sleep durations at preferred circadian phases; (b) life stress varies across a school term as school-related demands wax and wane; because of the timing of examination periods more life stress are likely to be present at the end of the term than during the start of the term or during the vacation. Thus, the design allowed for naturalistic manipulation of both sleep and life stress via factors that are both common and relatively independent of adolescents’ psychological states.

This design is based on the methodological limitations identified in the current literature. In addition, a cognitive vulnerability model was proposed and tested to address the aforementioned conceptual gap from objective sleep to mood.

Methodological Rationale. First, the target population in this study is adolescents, as they are ideal candidates for studying the effects of sleep restriction on mood. As discussed earlier, the major contributing factors to their sleep restriction/disruption (e.g., maturational processes, early school times) are mostly independent of individuals’ psychological state, thus less likely to confound potential consequences of objectively restricted sleep on mood. In addition, school-attending adolescents systematically undergo similar school-vacation schedules. This provides a natural platform for studying how individual differences in certain characteristics, such as cognitive vulnerability, play a part in individuals’ responses to similar changes in sleep/wake patterns.

Second, in light of the aforementioned limitations in the existing literature, this study incorporated the following features: (a) a longitudinal design with sleep measured on a daily basis across school weeks, vacation, and transitional days between the two; (b) application of statistical modelling to better understand the dynamic changes in sleep and mood over repeated measurement occasions; (c) sleep measured objectively via actigraphy and subjectively via self-report; (d) a relatively large sample of community dwelling adolescents who were recruited and tested in their home and school environment to better understand their naturalistic sleep/wake patterns.

Conceptual Rationale. In order to explore the mechanisms underlying the sleep-mood relationship, a two-step cognitive vulnerability model on how sleep affects mood (see Figure 2) was tested in this thesis. It was proposed that from a psychological perspective, evaluations of “actual” sleep (objectively assessed sleep duration and quality) affect mood through subjective perception of
objective sleep, and thus the degree to which mood is affected, depends on the nature of these perceptions, that is, on cognitive vulnerabilities of the individual.

![Diagram](image)

*Figure 2* A cognitive vulnerability model for the impact of sleep on mood.

The first step deals with subjective perception of sleep. It was proposed that individual differences in sleep-specific cognitive vulnerability, such as beliefs and attitudes about sleep, moderates how objective sleep is perceived subjectively. This step applies the cognitive model of insomnia in restricted and extended sleep opportunities among adolescents, and highlights the subjective nature of sleep perception. The second step deals with the effects of sleep perception on mood, and is based on the cognitive model of depression. It was proposed that perceived poor sleep and its daytime consequences functions as a form of life stress, activates maladaptive schemas in vulnerable individuals, and further leads to worsening of mood. For example, individuals who hold the belief that “I cannot function after insufficient sleep the night before” would be more likely to perceive restricted sleep opportunity as a threat, thus self-report poorer sleep than those who do not hold this belief; perceived poor sleep and its daytime consequences might interact with global beliefs such as “people will probably think less of me if I make a mistake”, and lead to symptoms of depression and/or anxiety.

1.4.3.2  Aims and Hypotheses

Below are the four main aims of this study with the specific hypotheses tested within each aim. Aim 1 corresponds to Area 1 of the aforementioned inadequacies in the literature, and assessed longitudinal changes in adolescents’ sleep/wake behaviours over naturalistically restricted and extended sleep opportunities using objective and subjective measurements of sleep. Aim 2, 3, and 4 collectively assessed a cognitive model of the impact of objective sleep on mood, and addresses Area 2 of the inadequacies previously identified.

Aim 1.  To investigate sleep timing, duration, and quality in a community sample of adolescents during school terms and vacations with restricted and extended sleep opportunities using
objective and subjective measurements of sleep. The hypotheses were made based on the aforementioned studies that compared weekday and weekend sleep.

H 1.1. School weekdays will be associated with restricted sleep opportunity. More specifically, compared to vacations, (a) sleep duration will be shorter, and (b) sleep will be more consolidated (i.e., shorter SOL, higher SE, lower %WASO) during school weekdays on both objective and subjective measurements.

H 1.2. During the vacation period, evening preference and older age will be associated with later bedtimes and rise-times.

H 1.3. Significant differences found in sleep timing and duration between the school term and vacation periods will largely occur abruptly on the first night of the transitions. By contrast, there will be relatively little changes in sleep/wake behaviours over the two-week vacation period.

Aim 2. To investigate the similarities and differences between objective and subjective sleep, and explore the roles of sleep-specific cognitive vulnerability (i.e., DBAS) in determining the nature of poor subjective sleep in restricted and extended sleep opportunities.

H 2.1. There will be significant correlations between objectively and subjectively measured sleep variables.

H 2.2. There will also be significant differences between objectively and subjectively measured sleep variables, suggesting subjective biases in sleep perception.

H 2.3. The relationship between objective and subjective measures of TST and SOL will vary as a function of DBAS.

Aim 3. To investigate the relationship between objective and subjective sleep and symptoms of depression and anxiety across school terms and vacations.

H 3.1. During school term, later sleep timing, shorter sleep duration, and poorer sleep quality will be associated with symptoms of depression and anxiety. This relationship will be found for both objectively and subjectively measured sleep.

H 3.2. During the vacation when school-related sleep restriction is absent, poorer sleep quality will be associated with symptoms of depression and anxiety.

Aim 4. To investigate the role of global cognitive vulnerability to emotional disorder (i.e., dysfunctional attitudes) in determining the sleep-mood relationship during restricted and
extended sleep opportunity, while taken into consideration the levels of life stress. To test the overall hypothesis H 4.3, preliminary hypotheses H 4.1 and H4.2 were tested.

H 4.1. Symptoms of depression and anxiety will be lowest during the vacation, followed by the start and middle of a school term, and highest towards the end of a school term.

H 4.2. The intensity of life stress will be lowest during the vacation, followed by the start and middle of a school term, and highest towards the end of a school term.

H 4.3. The strength of the relationship between sleep and mood will be dependent upon the levels of cognitive vulnerability in both restricted and extended sleep opportunities. Specifically it is predicted that symptoms of depression and anxiety will be more associated with poor sleep in those with higher levels of cognitive vulnerability.
METHODS

2.1 Participants

2.1.1 School Context

Participants were from 68 Australian secondary colleges, 63 of which are located in metropolitan Victoria, one in regional Victoria (three participants), two in Queensland (three participants), one in New South Wales (one participant), and one in Australian Capital Territory (one participant). On average, there were 2.15 ± 2.45 (±SD) participants from each school (SD = 2.45), with a range of 1 to 15. The majority of participants reported that their school activities (including extra-curricular) started at 8:30 a.m. (47.26%) or 9:00 a.m. (36.99%), and finished at 3:00 p.m. (25.34%), 3:30 p.m. (43.15%), or 4:00 p.m. (14.38%).

2.1.1.2 Demographics

A total of 146 participants, 69 (47.26%) males, 77 (52.74%) females, were recruited. They had a mean age of 16.18 ± 1.00 (16.23 ± 1.09 for males and 16.13 ± 0.99 for females), and were enrolled in Year 12 (38.36%), Year 11 (32.88%), Year 10 (26.03%), and Year 9 (2.74%) of secondary schools. Independent-sample t-test and $\chi^2$ tests showed no significant difference in age and year level distribution between males and females. Participants were mostly of Australian (59.59%) or Asian (26.71%) background, with small proportions of European (5.48%), African (2.05%), Middle Eastern (2.05%), and other (4.11%) backgrounds.

2.1.1.3 Current Medical Conditions and Medications

One male participant who reported having jaw pain during participation, reported receiving a cancer diagnosis after completing the study. One female participant reported suffering from Coeliac Disease and another from anaemia. A small number of participants were on regular medication: three males and one female on antibiotics, one male on pain relief, one female on immunotherapy injection, two males on acne medications, three females on oral contraceptive pills, two males on methylphenidate, and four females on selective-serotonin re-uptake inhibitors. All remaining participants denied having current medical conditions or taking medications that would affect sleep.
2.1.1.4 **Psychiatric Disorders**

**Current.** Nine (6.16%) participants reported a current psychiatric diagnosis. Three females reported current diagnoses of a depressive disorder, all of whom endorsed a past diagnosis of a depressive disorder within the previous two years; two males and one female reported current diagnoses of an anxiety disorder, and one of the males also reported a past diagnosis of an anxiety disorder; two females endorsed current diagnoses of both a depressive and an anxiety disorder, both of whom reported past diagnoses of the same disorders, one since early childhood, the other within two years; one male reported both current and past diagnosis of attention deficit hyperactivity disorder.

**Past.** Ten (6.85%) participants reported having had past psychiatric diagnoses that were no longer current: three males and two females with a diagnosis of a depressive disorder, one male and three females with a diagnosis of an anxiety disorder, and one male with diagnoses of both a depressive and an anxiety disorders. All past psychiatric diagnoses (apart from one female whose depressive disorder was diagnosis within four years) were within the past two years.

2.1.1.5 **Sleep Disorders**

**Current.** Six (4.11%) participants, two males and four females, reported a current diagnosis of insomnia, and one of the males also reported suffering from insomnia and sleep apnoea in the past. One female reported having hypersomnia, and she also reported suffering from current depression and anxiety. Ten (6.85%) participants self-reported having current symptoms of various other sleep disorders with no apparent compromise in actigraphy assessed sleep: two males and four females with both current and past symptoms of bruxism, one female with parasomnia (sleep-walking), one female with periodic limb movement disorder (PLMD), one female with bruxism and restless legs syndrome (RLS), and one female with RLS and hypersomnia.

One female reported suffering from current insomnia, both current and past parasomnia and RLS, as well as past sleep apnoea and narcolepsy; actigraphy revealed significant impairment of night-time sleep as well as extensive daytime napping behaviours in this participant, and she was excluded from all analyses that involved actigraphy assessed sleep. This participant also reported both past and current diagnosis of a depressive and an anxiety disorder.

**Past.** Eight (5.48%) participants reported suffering from past symptoms of sleep disorders that were no longer current: one male and four females with past insomnia, one male with bruxism, one female with parasomnia (sleep-walking), and one female with both bruxism and parasomnia (sleep-walking).
Only participants with current medical, psychiatric, or sleep disorders that showed apparent compromise in actigraphy-assessed sleep as characterized in significant number of night-time awakenings and frequent daytime naps, were exclusion. Exclusion was not applied on other participants as medical, psychiatric, and sleep disorders normally occur within community samples and, as such, exclusion would reduce representativeness. Details on participant inclusion and exclusion are presented in 2.5.
2.2 Procedures

2.2.1.1 Recruitment

All procedures were approved by the Human Research Ethics Committee of the University of Melbourne. Participants were recruited via three methods. (a) Project flyers with contact details of the research team were displayed on bulletin boards of community centres such as local gyms and bookstores. Interested participants/parents/guardians who responded to the flyers were sent links to the project’s online plain language statements (PLS) and consent websites via email. (b) Emails containing the link to the project’s PLS for schools were sent to independent schools in Melbourne metropolitan areas, and interested schools were asked to forward PSL and consent website links to Year 10 to Year 12 students via email or newsletter; (c) project website links were also placed in online youth and parenting related forums such as Youth News and Raising Children Network, as well as included in Staff News of the University of Melbourne. Participants were not reimbursed for their time, but were given two movie vouchers as an appreciation of their participation.

Online PLS for schools as well as PLS and consent forms for parents and participants are displayed in Appendix A.

2.2.1.2 Informed Consent

After viewing the PLS online, interested adolescents and parents/guardians gave consent by filling in a brief form, in which they were also asked to enter their emails, phone numbers, as well as the adolescent’s initials and date of birth for identification purposes. Once consents from both the adolescent and his/her parental/guardian were received, a researcher telephoned both the adolescent and his/her parent/guardian to first, reiterate key information in the PLS and confirm their consent, and second, obtain further participant details such as full names, postal addresses, name of school, and term dates.

2.2.1.3 Experimental Procedures

Data were collected over five rounds during Terms 1, 2, 3 of 2011, and Terms 1 and 2 of 2012. The experimental protocol started during the second last week of a term and finished during the middle of the next term.

Questionnaires. Questionnaire data were collected online. At the beginning of each survey, the participant was asked to enter his/her email, initials, and date of birth, while other personal identification information was not requested during questionnaire completion. For each round, participants were sent the Starter Survey and the Repeated Survey at the start of the second last
week of a school term, and were asked to complete both within two weeks, by the end of the term. The Repeated Survey was again sent to all participants in the middle of the following school holiday, at the end of the first week of the next term, and in the middle of the next term. They were given one week to complete the three follow-up Repeated Surveys. See Table 2 on the timing of questionnaire administration, and Table 3 for the content of Starter and Repeated Surveys.

Table 2

Timing of Survey Administration

<table>
<thead>
<tr>
<th>Time-E</th>
<th>Time-V</th>
<th>Time-S</th>
<th>Time-M</th>
</tr>
</thead>
<tbody>
<tr>
<td>Last 2 weeks of a term</td>
<td>2nd week of the vacation</td>
<td>2nd week of the next term</td>
<td>Middle of the next term</td>
</tr>
<tr>
<td>Starter Survey</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Repeated Survey</td>
<td>Repeated Survey</td>
<td>Repeated Survey</td>
<td>Repeated Survey</td>
</tr>
</tbody>
</table>

Table 3

Content of the Starter Survey and the Repeated Survey

<table>
<thead>
<tr>
<th>Starter Survey</th>
<th>Repeated Survey</th>
</tr>
</thead>
<tbody>
<tr>
<td>Social Demographic Information (SDI)</td>
<td>Centre for Epidemiological Studies Depression Scale (CESD)</td>
</tr>
<tr>
<td>Morningness - Even eveningness Questionnaire (MEQ)</td>
<td>Spence Children’s Anxiety Scale (SCAS)</td>
</tr>
<tr>
<td>Dysfunctional Beliefs and Attitudes about Sleep Scale (DBAS)</td>
<td>Pittsburgh Sleep Quality Index (PSQI)</td>
</tr>
<tr>
<td>Dysfunctional Attitude Scale (DAS)</td>
<td>Inventory of High-School Students’ Recent Life Experiences (IHSSRLE)</td>
</tr>
</tbody>
</table>

**Actigraphy.** An actigraph was mailed to each participant with instructions, sample output report, and a prepaid self-addressed envelope for posting the actigraph back to the research laboratory. Participants were instructed to wear the actigraph on the non-dominant hand for both day and night from the start of the last term week throughout the school holidays until the end of the first week of the next term. They were also asked to press the “Event Marker” button when going to bed intending to sleep and when getting up, for both night-time sleep and daytime naps.
2.2.1.4 Feedback to Participants

Upon completion of the study protocol, all participants received two feedback reports on the information they provided during their participation: one on circadian preference based on responses on the Morningness - Eveningness Questionnaire (MEQ), the other on sleep quality and quantity based on actigraphy data with reference to means for the whole sample. Sample reports are displayed in Appendix C.

Participants who scored $\geq 22$ on the Centre for Epidemiological Studies Depression Scale on any of the time points were contacted by a Clinical Psychologist on the team. On all occasions there were no risk concerns, and these participants were encouraged to speak to their parents/guardian about how they were feeling if they had not already done so, and seek professional help if needed.
2.3 Measurements

2.3.1 Demographics and General Sleep and Health

The Social Demographic Information (SDI) questionnaire inquired about the following aspects of participants’ personal history, as well as sleep and general health: date of birth, sex, ethnicity, year level, school starting/finishing time, weight and height, presence of major medical conditions, current use of prescription (including sleep) medication, current/past diagnosis of psychiatric disorders, and current/past diagnosis of sleep disorders.

2.3.2 Sleep and Circadian Preferences

2.3.2.1 Actigraphy as a Measure of Objective Sleep

Devices. Objective sleep quality and quantity was measured using actigraphy, a movement-based wrist-watch like device that is widely used to study sleep/wake patterns and circadian rhythms (Sadeh, 2011). The actigraphs used in this study were the Actiwatch 2 and Actiwatch-64 manufactured by Mini Mitter in Oregon, USA (see Figure 3). Both devices are water-resistant, capable of continuous data collection for five weeks, and have an integrated Event Marker button for participants to enter time-stamped information (e.g., bedtime and rise-time). The manufacturer has reported equivalent sleep statistics on data collected on these two actigraph models (Respironics, Philips, 2008).

Figure 3 Mini Mitter Actiwatch 2 (left) and Actiwatch-64 (right).

Actigraphy use in adolescents. A recent review on the use of actigraphy in children and adolescents (L. Meltzer, Walsh, & Traylor, 2012a) reported that when sleep/wake measurements by actigraphy were compared against polysomnography in child and adolescent populations, high
sensitivity (i.e., true positive rate; 82.2-99.3) was consistently found across ages and settings. Specificity however, varied from study to study. The review pointed out that overall specificity was low, with 55% of studies reporting under 60.0, although it is worth noting that the majority of studies reviewed were conducted on infants, toddlers, and pre-schoolers; only one small study ($N=16$) focused on the adolescent population (Sadeh, Sharkey, & Carskadon, 1994), and reported both good sensitivity (95.0) and specificity (74.5). A more recent empirical study comparing two actigraphs and PSG in children and adolescents lends further support to the concern regarding epoch-by-epoch specificity (i.e., true negative rate), in particular for the periods after PSG sleep onset (L. Meltzer et al., 2012a). The comparisons of outcome sleep variables, however, told a different story. When analysed using standard settings, controlling for age and sleep disordered breathing status, the Mini Mitter actigraphs reported no significant difference in TST compared to that measured by the PSG. A statistically significant overestimation of WASO by 10 minutes and underestimation of SE by .4% were noted, but these differences were not clinically meaningful (L. Meltzer et al., 2012a; Sadeh, 2011). These results provide strong evidence for the accuracy of actigraphy in identifying sleep periods. Although the accuracy of actigraphy in identifying WASO in the paediatric population is limited, its capacity in measuring overall sleep quality and quantity appears not to be compromised.

**Raw data recording and processing.** The actigraph records epoch-by-epoch activity counts, and in the present study, a one-minute epoch length was used. The minute-by-minute activity counts were processed in Actiware 5 by Mini Mitter, giving two sets of binary data, wake versus sleep (i.e., sleep analysis), and mobile versus immobile (mobility analysis). Each given minute was assigned a wake/sleep score (1 for wake and 0 for sleep) and a mobility score (1 for mobile, 0 for immobile). All procedures discussed below are based on standard setting of the Actiware. The Actiware determined whether a given minute was scored as wake or sleep by comparing activity counts for the minute in question, and the two minutes immediately surrounding it on each side, to a threshold value, in this study 40 (Medium, also the default setting). If the number of counts exceeds this threshold, the epoch was scored as wake; if it falls below, or is equal to the threshold, the epoch was scored as sleep. The activity counts of surrounding minutes were given different weight according to their adjacency to the target minute. For example, the total activity value for the 12:00 epoch shown in Figure 4 would be $100 \times (1/25) + 42 \times (1/5) + 20 + 13 \times (1/5) + 67 \times (1/25) = 37.68$, and the target epoch would be scored as sleep. Whether a given minute was scored as mobile or immobile depends only on the presence of activity counts for this minute. If activity counts are present, the minute would be scored mobile, if not, immobile.
Methods

Sleep/wake scores and mobility scores were then analyzed for each 24-hour cycle (6:00 p.m. till next day 5:59 p.m.). The time between bedtime (BT) and rise-time (RT) was defined as the rest interval, or time-in-bed. Both BT and RT were determined primarily by Event Markers entered by participants. Event Marker information was available for an average of 82.67±15.99% of bedtimes and 78.89±20.71% of rise-times. In the absence of an Event Marker, bedtimes and rise-times were estimated from visual screening of actograms (i.e., a graphic view of rest/activity history, see Figure 5) around self-report bedtimes and rise-times. The time lapsed between sleep onset and sleep termination was defined as the sleep interval. After the start of each rest interval, the start of each sleep interval was automatically set by the Actiware to the first epoch of the first 10 consecutive epochs scored as immobile; prior to the end of each rest interval, the end of each sleep interval was automatically set to the last minute of the last 10 consecutive epochs scored as immobile.

Figure 4 The calculation rules of activity values for the target epoch 12:00.

Figure 5 Rest and sleep intervals in a 24-hour actogram.
A number of actigraphy sleep variables were derived for each 24-hour sleep cycle with their definition and calculation shown in Table 4. These were sleep timing variables bedtime (BT_{acti}) and rise-time (RT_{acti}), sleep duration variables time-in-bed (TIB_{acti}) and total sleep time (TST_{acti}), and sleep quality variables sleep onset latency (SOL_{acti}), sleep efficiency (SE_{acti}), and percentage of wake after sleep onset (%WASO). Daily variation in sleep variables was calculated as the absolute difference between the value of one day and the following day averaged over the days of the period in question. Daily variation variables use the suffix “vari”, e.g., BT_{vari} means daily variation of BT. Sleep and wake regularity for school terms and vacations was calculated as the standard deviations of the sleep variable in question over the eight school term weekdays and the 15 vacation days. Sleep regularity variables use the suffix “sd”, e.g., BT_{sd} means regularity of BT.

Table 4

<table>
<thead>
<tr>
<th>Variable</th>
<th>Definition and calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timing</td>
<td>The time participants went to bed intending to initiate sleep.</td>
</tr>
<tr>
<td>Bedtime (BT_{acti})</td>
<td>The time participants went to bed intending to initiate sleep.</td>
</tr>
<tr>
<td>Rise-time (RT_{acti})</td>
<td>The time participants got up intending to terminate sleep.</td>
</tr>
<tr>
<td>Duration</td>
<td>The time between BT and RT, also known as rest interval.</td>
</tr>
<tr>
<td>Time-in-bed (TIB_{acti})</td>
<td>The time between BT and RT, also known as rest interval.</td>
</tr>
<tr>
<td>Total sleep time (TST_{acti})</td>
<td>The time a participant spent sleeping during night-time sleep; calculated as the total number of minutes during a sleep interval that was scored as sleep.</td>
</tr>
<tr>
<td>Quality</td>
<td>Time required for sleep initiation; calculated as the difference in minutes between bedtime and the initiation of a sleep interval.</td>
</tr>
<tr>
<td>Sleep onset latency (SOL_{acti})</td>
<td>Overall quality of sleep for a given rest interval; calculated as the percentage of TST_{acti} in the corresponding TIB_{acti}.</td>
</tr>
<tr>
<td>Sleep efficiency (SE_{acti})</td>
<td>Overall quality of sleep for a given rest interval; calculated as the percentage of TST_{acti} in the corresponding TIB_{acti}.</td>
</tr>
<tr>
<td>Percentage wake after sleep onset (%WASO)</td>
<td>Sleep quality for a given sleep interval, after sleep onset; calculated as the percentage of minutes scored as wake in the corresponding sleep interval.</td>
</tr>
</tbody>
</table>

All 24-hour cycles of actigraphy recordings fell into one of the following categories:

a) School days that started on a school term weekday and ended on a school term weekday, typically from Mondays to Thursdays. School days at Time-E and Time-S were coded as E1-E4 and S1-S4 respectively;
b) A vacation that started on the first non-school after the school week (typically a Saturday) and ended on the second last day of the school vacation (typically a Saturday); these days are coded as V1-V15;

c) SatDay was the Saturday of Time-S, and the only non-school day during a school term in the study protocol;

d) FriDay started on a school day and ended on a non-school day; FriDay at Time-E and Time-S were coded as FriDay1 and FriDay2;

e) SunDay: started on a non-school day and ended on a school day; SunDay at the end of the vacation and Time-S were coded as SunDay1 and SunDay2.

2.3.2.2 Subjective Sleep

The Pittsburgh Sleep Quality Index (PSQI; Buysse, Reynolds, Monk, Berman, & Kupfer, 1989) was used to measure subjective perception of sleep. It is a widely-used and well-validated (Carpenter & Andrykowski, 1998) self-report questionnaire that covers both the physical and psychosocial domains of sleep dysfunctions.

The PSQI differentiates “poor” from “good” sleep by measuring the following seven areas: total sleep time ($TST_{psqi}$), sleep onset latency ($SOL_{psqi}$), sleep efficiency ($SE_{psqi}$), sleep disturbance ($SD_{psqi}$), subjective sleep quality ($SQ_{psqi}$), the use of sleeping medication, and sleep-related daytime dysfunction ($DD_{psqi}$, i.e., difficulties in keeping awake while performing everyday activities; difficulties in keeping up enthusiasm). A scaled global PSQI score is indicative of overall sleep quality, and in adults, a global score of greater than five indicates a “poor sleeper”. Although there is no existing cut-off score for adolescents, the PSQI has been successfully applied in the adolescent population to assess sleep problems with good reliability (Bei et al., 2013; Zhou et al., 2011).

When using the original PSQI, participants rate 15 items covering the above domains on a 0 (“less than once a month”) to 3 (“three or more times a week”) frequency scale according to their subjective perception over the month prior to assessment. In this study, the PSQI was used to measure sleep patterns over the course of a week, and therefore the frequency scale was revised into 0 (“not at all”), 1 (“once or twice a week”), and 2 (“three or more times a week”) to match the one-week assessment period. Subjective component scores were derived using PSQI raw values for: $TST_{psqi}$ (minutes), $SOL_{psqi}$ (minutes), $SE_{psqi}$ (%), $SD_{psqi}$ (sum of items 5b-5j), $SQ_{psqi}$ (item 9), and $DD_{psqi}$ (sum of items 7-8). When relating subjective sleep to mood, item 8 “during the past week, how much of a problem was it for you to keep up enthusiasm to get things done?” was removed from the $DD_{psqi}$ subscale to reduce multicollinearity.
2.3.2.3 **Circadian Preferences**

The Morningness – Evenness Questionnaire (MEQ) is a 19-item questionnaire that assess habitual rising and bed times, preferred times of physical and mental performance, and subjective alertness after rising and before going to bed (Horne & Ostberg, 1976). It is the gold standard instrument in assessing self-report circadian preference and has been validated for use in adolescents (Giannotti, Cortesi, Sebastiani, & Ottaviano, 2002). This questionnaire was scored using the standard method, producing a total MEQ score with higher values indicating more morning preference and lower values indicating more evening preference. In this study, Cronbach’s alpha for the MEQ was .80.

2.3.3 **Mood**

**Centre for Epidemiological Studies Depression Scale (CESD).** This widely used 20-item scale assesses symptoms of depression in the general population (Radloff, 1977), and has been successfully validated for use in adolescents (Radloff, 1991). Participants were required to rate the frequency with which they had felt or behaved in a particular way over the past week on a four-point Likert scale with 0 being “Rarely or none of the time”, and 3 being “most or all of the time”. The total scores range from 0-60 after reverse scoring four items, and higher scores indicate higher levels of depressive symptoms. In adolescents, scores ≥ 24 in females and ≥ 22 in males were considered indicative of depressed mood (Roberts, Lewinsohn, & Seeley, 1991). Given the anticipated differences in sleep between school terms and vacations, as well as to reduce colinearity when the relationship between sleep and mood were examined, scores on the item “my sleep was restless” was removed from the total score in all analyses. In this study, Cronbach’s alpha for the CESD at Time-E, Time-V, Time-S, and Time-M were .90, .90, .89, and .83 respectively.

**Spence Children’s Anxiety Scale (SCAS).** The SCAS is a well-validated 44-item self-report questionnaire for assessing various aspects of anxiety in children and adolescents (Spence, 1998). Participants were asked to rate each item based on their experience over the past week on a four-point Likert scale, from 0 being “never” to 3 being “always”. Six items on the scales were not related to anxiety and not scored. The total score on the 38 anxiety items (SCAS) indicates overall levels of anxiety whilst six subscales assess the following specific domains: generalized anxiety, panic/agoraphobia, social phobia, separation anxiety, obsessive-compulsive disorder, and fears of physical injury. Total scores of SCAS that were 32 or less for males and 38 or less for females were considered to be within the normal range. In this study, Cronbach’s alpha for the SCAS at Time-E, Time-V, Time-S, and Time-M were .92, .93, .93, and .94 respectively.
2.3.4 Life Stress

The Inventory of High-School Students’ Recent Life Experiences (IHSSRLE) is a 41-item self-report questionnaire measuring adolescents’ daily life stress and hassles (Kohn & Milrose, 1993). This scale was chosen, not only because it contains items that are closely related to everyday life experiences of the studied population (e.g., “lower grades than you hoped for”, “Disagreements with boyfriend/girlfriend”), but also because its relatively low contamination from psychological distress and high correlations with other measures of stress such as the Stress subscale of the Depression Anxiety Stress Scale (S. H. Lovibond & Lovibond, 1995). Participants were asked to rate from 1 (“not at all”) to 4 (“very much”) how each experience had been a part of his/her life over the past week. Higher total scores on the IHSSRLE (shortened as STRESSOR) reflect experience of greater recent hassles. In this study, Cronbach’s alpha for the IHSSRLE at Time-E, Time-V, Time-S, and Time-M were .94, .95, .94, and .94 respectively.

2.3.5 Beliefs and Attitudes

Dysfunctional Beliefs and Attitudes about Sleep Scale-16 (DBAS-16). The DBAS-16 is an abbreviated form of the DBAS that is well-validated and widely used in assessing sleep-related cognitions (Morin, 1994). The authors recently reported adequate psychometrics for the brief form (Morin, Vallières, & Ivers, 2007). Participants were asked to rate each item from 0 (“strongly disagree”) to 10 (“strongly agree”) based on how they personally agreed or believed in each statement, for example, “I avoid or cancel obligations (school, social, family) after a poor night's sleep”, “after a poor night's sleep, I know that it will interfere with my daily activities on the next day”. Minor modifications in phrasing were made in a few items for use in adolescent population in this study. Higher total scores on the DBAS-16 indicate higher endorsement of dysfunctional beliefs and attitudes about sleep. Cronbach’s alpha for DBAS-16 in this study was .86.

Dysfunctional Attitude Scale (DAS). The DAS is a 40-item self-report questionnaire that assesses assumptions and beliefs associated with the cognitive content of depression based on Beck’s cognitive theories (Weissman, 1979; Weissman & Beck, 1978). It is widely used in the adult population and has recently been validated for use in adolescents (Prenoveau et al., 2009). Participants were asked to rate each item from 1 (“totally agree”) to 7 (“totally disagree”), and sample items include “it is difficult to be happy unless one is good-looking, intelligent, rich, and creative”, “I am nothing if a person I love doesn't love me”. After reverse scoring 10 items, higher total scores (DAS) of all items are indicative of higher endorsement of dysfunctional attitudes. Cronbach’s alpha for DAS in this study was .92.
2.4 Data Analysis and Statistical Methods

This section starts with an introduction to structural equation modelling, a statistical framework that was central to the testing of multiple hypotheses in this thesis, followed by background on methods employed to handle missing data. The second half of this section describes methods used for preliminary data analysis, followed by an overview of the data structure, as well as statistical methods and packages used to test each hypothesis.

2.4.1 Structural Equation Modelling

2.4.1.1 Overview

Structural equation modelling (SEM) takes a confirmatory (i.e., hypothesis-testing) approach to the analysis of a structural theory. The term “structural equation” conveys that the causal processes being examined are represented by a series of structural (i.e., regression) equations, which can then be modelled to enable a clearer conceptualization of the theory under examination. The hypothesised model can be tested statistically in a simultaneous analysis to determine the extent to which it is consistent with the data. If goodness-of-fit is adequate, the model argues for the plausibility of the postulated relations among variables; if it is inadequate, the hypothesised relation is rejected. In addition to the confirmatory (as opposed to exploratory) approach to data analysis, SEM has several strengths compared to traditional multivariate procedures: (a) SEM assesses and corrects for measurement errors by providing explicit estimates of these error variance parameters; (b) SEM procedures can incorporate both observed and unobserved (i.e., latent) variables; and (c) it is the only widely and easily applied method for modelling multivariate relations and for estimating point and/or interval indirect effects (Byrne, 2011).

A typical SEM model includes a measurement model and a structural model. The measurement model defines relations between the observed variables and the underlying constructs they are designed to measure (i.e., unobserved or latent variables). It takes a confirmatory factor analysis approach, and specifies the pattern by which each observed variable loads on a particular factor. The structural model defines relations among the latent variables, as well as between latent variables and other observed variables.

Model-fitting. The primary task of SEM is to determine the goodness-of-fit between the hypothesised model and the sample data, with the intention of not rejecting the null hypothesis. A number of goodness-of-fit statistics have been developed and are reported in Mplus (L. K. Muthen & Muthen, 2012). The commonly reported likelihood-ratio \( \chi^2 \) (\( p > 0.05 \) indicating model fit) has a
number of limitations, such as being sensitive to sample size with the tendency to be substantial when the sample size is large even if the model does not hold, and to distort the statistical significance of the model test when sample size is small or non-normally distributed (Brown, 2006). Other model fit indices commonly used are the Comparative Fit Index (CFI), Tucker-Lewis Fit Index (TLI), Root Means Square Error of Approximation (RMSEA), and the Standardized Root Mean Square Residual (SRMR). Although some researchers (MacCallum & Austin, 2000) have advocated for the use of one index over others, it has been recommended that researchers should assess overall goodness-of-fit based on multiple fit statistics due to the strengths and limitations of each index (Byrne, 2011; L. K. Muthen & Muthen, 2012). Recommended cut-offs for good fit are: .95 for both CFI and TLI, less than or equal to .06 for RMSEA, and less than or equal to .08 for SRMR (Hu & Bentler, 1999).

**Comparisons of model fit.** Nested models refer to models that are substantially equivalent, except for a subset of parameters that are free in one model and constrained in the other. Model fit between two nested models can be compared using $\chi^2$ difference statistics, and the model that fits significantly better is considered to better represent the data. In this study, comparisons of model fit between nested models were used when variations of a hypothesis were tested and compared, and when modifications were required to improve goodness-of-fit. Although Mplus gives modification recommendations based on Modification Index (Sorbom, 1989), decisions on modification in this study were largely based on theoretical grounds with statistical indices as guide. Only modifications that made a significant improvement in fit were included.

**Significance testing.** Latent variables and their standard errors were estimated and the significance testing was achieved through dividing parameter estimates by their standard errors. This calculation operates as a $z$-statistics and tests whether the estimate is statistically different from zero. If the test statistic is $>1.96$, significant difference from zero on the .05 level is indicated. In addition, $R^2$ value and its standard error are also reported, representing the proportion of variance in each variable accounted for by its related factor.

**Standardization.** Parameter estimates can be standardized or unstandardized. Standardization helps comparisons of results across parameters and models, whilst unstandardized estimates are readily interpretable using the same units in which the variables were measured. In this study, unstandardized estimates were reported when direct interpretation of parameter estimations were needed, otherwise standardized estimates were reported. Standardization was based on background and outcome variables (i.e., STDYX in Mplus).
2.4.1.2 Latent Growth Curve Modelling

Traditional statistical strategies for longitudinal data such as repeated-measures analysis of variance are increasingly perceived as somewhat inadequate due to their inability to handle missing data, capturing individual differences in change over time, and giving insight to how individual differences affect change trajectories. A number of statistical methods have been developed to overcome these limitations, and most have fallen within frameworks of multilevel (or hierarchical linear) modelling (MLM; Bryk & Raudenbush, 1987; Hox, 2010; Raudenbush & Bryk, 2002), and structural equation modelling (SEM; T. E. Duncan, Duncan, & Strycker, 2006; McArdle & Epstein, 1987), the latter of which is known as latent growth curve (LGC) modelling. These two frameworks treat “time” differently: MLM requires nested data structures (e.g., students nested within classrooms) and time is treated as an independent variable at the lowest level, and the individual on the second level; LGC adopts a latent variable approach and incorporates time via factor loadings. This difference leads to different strengths of both frameworks when handling certain types of data. For example, in the MLM framework it is easy to add more levels (e.g., students nested in classrooms nested in schools). On the other hand it is possible to model measurement error in LGC, as well as embed it in a larger path model by combining several growth curves, or by using growth factors as predictors for outcome variables. However, recent developments have blurred differences between these frameworks, and they were termed by some researchers as the “unequal twin” (Schnabel, Little, & Baumert, 2000). Essentially, MLM is a univariate approach, with time points treated as observations of the same variable, whereas LGC a multivariate approach, with each time point treated as a separate variable (Stoel, Van den Wittenboer, & Hox, 2003). The mean and covariance structure of the latent variables in LGC correspond to the fixed and random effects in MLM, making it possible to specify the same model using either framework with identical results (Hox & Stoel, 2005).

Typically LGC models start from a basic model with two building blocks (Willett & Sayer, 1994): Level 1 “within-person” regression model that represents intra-individual change over time, and Level 2 “between-person” model that focuses on inter-individual differences in change. Covariates may be added to extend the basic model to answer additional research questions.

Intra-individual change. The first level in LGC models examines the within-person trajectory, which if hypothesised to be linear, will include two growth factors: an intercept parameter representing initial status of the outcome variable, and a slope parameter representing the rate of change over the time period of interest. In a linear model, time is coded in a way that expresses linear change. The origin (i.e. 0) of the time scale is placed at the time point that represents “initial status”, which could be, but is not necessarily, the first measured time point. Intercept factor loading is fixed at zero for all time points while loadings for the slope factor (also
known as time scores) for each time point increases in a linear fashion. In a linear model where measurements took place at equal intervals, time scores would be specified as 0, 1, 2, 3…, or 0, .1, .2, .3; if measurement intervals are not equal, time scores may be adjusted to reflect the time intervals (e.g., time scores for 1, 4, 8 months’ post-intervention follow-ups can be specified as 0, 1, 2.33). When change is not linear, the following strategies could be applied (T. E. Duncan et al., 2006): (a) allowing one or more time score parameters to be freely estimated, (b) adding additional growth factors (e.g., a quadratic factor), (c) fitting data to known trajectories using fixed time scores (e.g., LGC with a logarithmic trend), (d) modelling complex changes piece by piece (i.e., piecewise growth modelling).

Within the SEM framework, this step captures the measurement model that incorporates linkages between the observed variables and their underlying unobserved factors (i.e., latent factors, and in linear LGC the intercept and slope). It is essentially a factor analysis model with factor loadings fixed in such a way that allows the interpretation of the latent factors (Byrne, 2011).

**Inter-individual differences.** In this second level of LGC, it is hypothesised that trajectories of change will vary across individuals as a consequence of different intercepts and slopes. The LGC estimates the means and variances for both intercept and slope values: the means represent the average population values, and the variances represent deviations of the individual intercepts and slopes from their population means. A slope factor that is not statistically different from zero indicates a plateau effect, or little change with time. The intercept–slope covariance represents the population covariance between any deviations in initial status and rate of change. Within the framework of SEM, this portion of the model reflects the structural part that represents relations among latent factors, and in LGC, structure is limited to only the means and variances of the Intercept and Slope growth factors (Byrne, 2011).

**Covariates.** The above basic two-level LGC can be extended by adding covariates so additional questions can be explored, e.g., “do one or more predictors explain differences in trajectories of change?” can be explored. Covariates can be constant throughout all time points (i.e., time-invariant), or vary on each measurement occasion (i.e., time-varying). In this study, age, sex, and MEQ were examined as time-invariant covariates when day-to-day changes in sleep were examined for the vacation period. It was assumed that their effects were constant over time, and their impact on change trajectories were modeled by regressing growth factors on them. When exploring how sleep and life stress affect mood over the school term, subjective sleep and life stress were modeled as time-varying covariates. Time-varying covariates were modeled by regressing the dependent variable (i.e., mood) for each time point on the time-varying covariates (i.e., subjective sleep and life stress) for the corresponding time point. The effects of time-varying covariates can be hypothesised to vary across time but remain the same among individuals (in this study, life
stress), or vary across individuals but remain constant over time (in this study, subjective sleep). The latter of which is also known as random effects, and can be modeled in the form of random slopes, a latent variable that represents individual variation in the influence of the time-varying covariate on the dependent variable. By regressing random slopes on additional explanatory independent variable(s), it is possible to examine contributing factors to such individual variation. In this study, the random slopes of subjective sleep were regressed on DAS to examine whether dysfunctional attitudes played a role in how subjective sleep affected mood.

**Sample size.** The sample size required for LGC is not straightforward and there is no current guideline. Some researchers have advocated a minimum of 200 (Boomsma & Hoogland, 2001), a rule-of-thumb for SEM models involving latent variables. Others have suggested that due to repeated measurements, LGC is less demanding in sample size than conventional SEM models; sample size required decreases as the number of measurement occasions increases, and some have shown that a sample size as small as 20 could work well in a simple LGC (L. K. Muthen & Muthen, 2002).

**Statistical assumptions.** The LGM assumes certain characteristics of the latent variables. These include means of residuals and covariances among residuals being zero, not only on each occasion across individuals, but also on each individual across measuring occasions.

### 2.4.1.3 Multiple Group Analysis

Multiple group analyses are used when SEM procedures are applied on more than one sample, and typically the central concern is whether components of the measurement and/or the structural model are invariant (i.e., equivalent) across groups of interest. Testing for group invariance usually begins with the determination of a separate baseline model for each group that best fits the data, followed by testing for invariance. Parameters that are hypothesised to be invariant across groups are constrained to be equal while subsequent tests of the structural parameter (e.g., factor variances/covariances, regression paths, and latent means) are conducted. In this study, multiple-group SEM were used when moderation analyses were applied on three time points with groups being separate time points.

### 2.4.2 Handling of Missing Data

The management of missing data is an unavoidable component of conducting longitudinal research using a community sample. Standard analyses of incomplete data such as list-wise deletion, assume that the data are missing completely at random (MCAR), that is, missing values are a random sample of all data values, and the missing data do not depend on the values of
available data. The assumptions of MCAR, however, can be particularly questionable in longitudinal studies where missing data and attrition could be related to certain participant characteristics. A number of missing data procedures address missing patterns that are not MCAR. This study used multiple imputation (MI) and full information maximum likelihood (FIML), two common approaches to missing data that are based on strong statistical traditions and are widely considered as not only acceptable, but often the best available methods for dealing with missing data (Graham, 2009). Both methods assume that data are at least missing at random (MAR), a less restrictive missing pattern than MCAR. Under MAR, the probability that an observation is missing can depend on observed values, but does not depend on values that are missing, nor on unmeasured variables. The aforementioned MCAR is a special case of MAR where missing data are not related to either observed or missing values. Despite operation differences, MI and FIML generate comparable results when applied appropriately, and yield less biased and more efficient estimates than list-wise deletion (Enders & Bandalos, 2001; R. J. A. Little & Rubin, 1989).

2.4.2.1 Multiple Imputation (MI)

In MI (R. J. A. Little & Rubin, 1987), missing data are handled in a separate step before the main analysis. This study uses multiple imputation based on chained equations, which allow a separate regression equation for each variable to be imputed, and does not require the response variable to be normally distributed (e.g., responses could be continuous, ordinal, binary). Imputation using chained equations is an iterative procedure. Let X be an n x m data matrix with missing values, where i = 1, ..., n, and j = 1, ..., m. At each iteration imputation by chained equations fill in missing values in the jth column by prediction from the remaining. This is done until all m data columns in X have been imputed. In the second iteration, this process is repeated but now using the real and imputed values in the regressions used to impute missing values again. This process continues until the algorithm converges (i.e., when the change in the imputed values form an additional iteration is deemed trivial). From the converged estimates, multiple imputed values are drawn, and these are the imputed data used for the final analyses. In this study, MI was used when multiple regression analyses were conducted to examine the relationships between sleep and mood. Datasets with missing values were multiply imputed five times, which is generally considered to be sufficient (Rubin, 1987). Regression coefficients were combined based on Rubin’s Rules (Rubin, 1987), $R^2$ were combined by averaging $R$, and significance testing for $F$ and $R^2$ were conservatively based on the degrees of freedom for the list-wise deleted model.
2.4.2.2 *Full Information Maximum Likelihood (FIML)*

In FIML (or ML), missing data handling and parameter estimation are completed in a single step. The procedure calculates the log likelihood of the data for each observation, and has the strength of providing reasonable estimates of standard errors with missing data. In this study, FIML was applied when structural equation models (SEM) were estimated in Mplus using the MLR estimator, which provides the same estimates as ML while having standard errors and $\chi^2$ robust to non-normality of outcomes and non-dependence of observations (L. K. Muthen & Muthen, 2012). In addition to MAR, FIML also assumes that observed variables are derived from population distributions with roughly the same multivariate kurtosis as a multivariate normal distribution (Wichman, Preacher, Briggs, & MacCallum, 2008).

2.4.3 *Preliminary Analyses*

2.4.3.1 *Distributions and Outliers*

All variables were screened for distribution based on range, skewness, kurtosis, and frequency histograms. All continuous variables were considered reasonably normal in distribution, and no transformation was performed. To identify outliers in each variable, observations with values 3.29 standard deviations above or below the mean (i.e., likelihood of 0.1%, or <1 participants in this study were expected to fall outside of this range) were identified. For questionnaire variables, these observations were considered outliers. For objective sleep variables, all identified observations were screened case-by-case, and a set of cutoffs for determining outliers was based on both the identified extreme values and common sense (e.g., bedtimes after 6:00 a.m., TST >12 hours after total sleep deprivation the previous night). Analyses were performed twice, with and without outliers. A robust estimator with good performance for data drawn from a wide range of distributions as well as outliers was used when missing data were addressed using FIML. Key findings in this thesis did not differ when analyses were performed with or without outliers, and unless otherwise specified, results were based on analyses including outliers. In some instances, excluding outliers improved model fit (e.g., when daily objective sleep variables across the vacation period were examined using latent growth models), in which cases reported results were based on analyses without outliers.
2.4.3.2 Exploring Correlations and Changes Over Time

To explore the strength of relationships among variables, correlation and scatter plot matrices were examined in preparation of formal analyses. Correlations were based on Pearson correlation with missing data addressed using FIML. For variables that were measured longitudinally, individual growth curve trajectory plots were produced and examined, so the overall patterns of change in the sample, the degree of individual differences at each time point, as well as individual differences in change trajectories could be explored visually.

2.4.4 Analysis Overview

2.4.4.1 Data Structure

The design of this study resulted in a dataset that contained variables that were measured repeatedly (i.e., longitudinal), as well as variables that were measured on only one occasion (i.e., cross-sectional) and were assumed to undergo little change over the course of the study protocol. Table 5 shows all variables that were included for analysis and their availability at each time point.

Table 5
Overall Data Structure with Variables Measured Longitudinally and Cross-Sectionally

<table>
<thead>
<tr>
<th>Longitudinal variables</th>
<th>Time scale (weeks)</th>
<th>Cross-sectional variables</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time-V</td>
<td>Time-S</td>
</tr>
<tr>
<td>Objective sleep (actigraphy)</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>Subjective sleep (PSQI)</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>Mood (CESD and SCAS)</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>Life stress (IHSSRLE)</td>
<td>×</td>
<td>×</td>
</tr>
</tbody>
</table>

*Note.* The time scale was based on a typical 10-week school term; × data available.

Given school terms and vacations alternate in a cyclic pattern throughout a year, it was assumed that changes in repeatedly measured variables such as sleep, mood, and life stress, follow a similar pattern throughout each vacation-term cycle. Therefore, measurement time points were arranged based on their natural positions in each cycle, instead of the actual sequence data were
collected. This arrangement helps modelling and describing changes in these variables across a typical vacation-term cycle. Time-V was conceptualized as a condition with relatively extended sleep opportunity, whilst Time-S, Time-M, and Time-E were conceptualized as conditions with relatively restricted sleep opportunity.

2.4.4.2 Examining Longitudinal Changes

**Paired-samples t-test.** To examine the differences in sleep between extended and restricted sleep opportunities, as well as the differences between objectively and subjectively measured sleep, paired-samples t-tests were used. Significance testing for differences in means was accompanied by effect size analysis based on Cohen’s $d$, with values above 0.2, 0.5, and 0.8 suggesting small, moderate, and large effect sizes respectively (Cohen, 1988).

**Latent growth curve (LGC) modelling.** When changes in variables were examined across more than two time points, such as when changes in sleep, mood, and life stress were examined over school terms and vacations, LGC modelling within the framework of SEM were used (see details in the SEM section).

2.4.4.3 Examining Relationships between Constructs

**Multiple regression.** To examine whether objective/subjective sleep made a significant contribution to mood, multiple regression was applied cross-sectionally for each time point.

**Moderation analysis.** To examine whether the relationship between two constructs $X$ and $Y$ was dependent on a third construct $M$, moderation analyses were used. This involved including an interaction term between $X$ and $M$ by multiplying the two (i.e., $XM$), and including it in a multiple regression analysis along with $X$ and $M$ as independent variables and $Y$ as the dependent variable. Simple effects of $X$ and $M$ on $Y$ were established via significance-testing of their regression coefficients, whilst the moderating effect of $M$ was established when the regression coefficient of $XM$ was statistically significant. In this study, $X$ and $M$ were mean-centred before entering the moderated regression. This allowed the coefficients of $X$ and $M$ to be estimated when the other was at its mean, instead of being 0, assisting interpretation of their simple effects on $Y$. Significant moderating effect of $M$ was followed up by simple slope analysis, which examined the relationship between $X$ and $Y$ when $M$ was low (one $SD$ below the mean), median (at the mean), and high (one $SD$ above the mean). In this study, moderation analysis was applied when examining whether the relationship between objective and subjective sleep depended on DBAS, and whether the relationship between subjective sleep and mood depended on DAS.
2.4.4.4 Examining Relationships between Constructs Over Time

As sleep, mood, and life stress variables were measured repeatedly over time, statistical methods that allow integration of longitudinal data were used, so that the relationships amongst them could be examined with parameters over all time points in question estimated simultaneously. In this study, multiple groups SEM and LGC modelling with timing varying covariates (with/without random slopes) were applied. They are discussed in detail in the SEM section.

Table 6 summarizes the type of analysis, the number of time points included in each analysis, and the missing data method used in examining each hypothesis. The background on SEM methods used in this thesis is presented in greater detail in the following section. All significance testing was based on \( p \) value less than .05.

2.4.5 Statistical Packages

Data manipulation and analyses were conducted using R 3.0.0 (R Core Team, 2013), a free programming language and software environment for statistical computing and graphics. Standard functions in R are highly extendible through the use of additional packages contributed by the R community. Appendix C shows the list of R packages used in data processing and analysis. Preliminary analyses, mean comparisons, and regression analyses with multiple imputations were conducted in R. Structural equation models were estimated using Mplus 7 (L. K. Muthen & Muthen, 2012) through MplusAutomation (Hallquist & Wiley, 2013) in R, which automates the input of Mplus models, extracts model results, and compares nested models.
Table 6

Summary of Statistical Methods Used in Analyses

<table>
<thead>
<tr>
<th>Hypothesis</th>
<th>Analysis</th>
<th>Time points</th>
<th>Missing data method</th>
</tr>
</thead>
<tbody>
<tr>
<td>H 1.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Differences in objective and subjective sleep between school terms and vacations</td>
<td>Paired-samples t-tests</td>
<td>2</td>
<td>Pairwise deletion</td>
</tr>
<tr>
<td>Changes in subjective sleep over school terms</td>
<td>LGC modelling</td>
<td>3</td>
<td>FIML with MLR</td>
</tr>
<tr>
<td>H 1.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H 1.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day-to-day changes in objective sleep over the vacation and the roles of sex, gender, and circadian preference</td>
<td>LGC modelling with and without time-invariant covariates</td>
<td>15</td>
<td>FIML with MLR</td>
</tr>
<tr>
<td>H 2.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correlations between objective and subjective variables</td>
<td>Pearson correlations</td>
<td>1</td>
<td>Pairwise deletion</td>
</tr>
<tr>
<td>H 2.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Differences between objective and subjective variables</td>
<td>Paired-samples t-tests</td>
<td>1</td>
<td>Pairwise deletion</td>
</tr>
<tr>
<td>H 2.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DBAS moderates the relationship between objective and subjective sleep</td>
<td>Moderation analysis in Multiple Groups SEM</td>
<td>3</td>
<td>FIML with MLR</td>
</tr>
<tr>
<td>H 3.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Effects of objective/subjective sleep on mood</td>
<td>Multiple regression</td>
<td>1</td>
<td>Multiple Imputation</td>
</tr>
<tr>
<td>H 3.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H 4.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Changes in mood and life stress over school terms and vacations</td>
<td>LGC modelling</td>
<td>4</td>
<td>FIML with MLR</td>
</tr>
<tr>
<td>H 4.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H 4.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Role of DAS in subjective sleep and mood relationship over school terms</td>
<td>LGC Modelling with time-varying covariates and random slopes</td>
<td>3</td>
<td>FIML with MLR</td>
</tr>
<tr>
<td>Role of DAS in subjective sleep and mood relationship over the vacation</td>
<td>Moderation analysis</td>
<td>1</td>
<td>FIML with MLR</td>
</tr>
</tbody>
</table>

Note. LGC = Latent Growth Curve, FIML = Full Information Maximum Likelihood, MLR = Maximum Likelihood Robust estimator in Mplus, SEM = structural equation modelling; DBAS = Dysfunctional Beliefs and Attitudes about Sleep, DAS = Dysfunctional Attitude Scale.
2.5 Attrition and Missing Data

2.5.1 Actigraphy

As mentioned in Methods, two female participants were excluded from all objective sleep analyses, one due to multiple sleep disorders with apparent objective sleep disruption on actigraphy, the other lost the actigraph prior to commencing the study. One female was physically ill during Time-E and her data during that time was excluded from all analyses; in addition, she dropped out on the third day of the vacation and was excluded from overall comparisons of objective sleep.

Table 7 summarizes information on data completeness for overall objective sleep analyses where sleep variables were based on the daily average of available data across a given period. These values indicated that overall, the rate of missing values was low, which is consistent with the overall finding that among the 4004 (28 days x 143 participants) daily data, at least 3660 (91.40%) were present. Missing data analyses showed that other than a non-statistically significant \(p=0.08\) trend that females were more likely to have missed Time-S, missing data on all time points were not related to either age or sex.

Table 7
Data Completeness for Overall Objective Sleep Analyses

<table>
<thead>
<tr>
<th>N=146</th>
<th>Vacation (15 days)</th>
<th>Time-S school days (4 days)</th>
<th>Time-E school days (4 days)</th>
<th>School days (8 days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nothing missing</td>
<td>98 (67.12%)</td>
<td>121 (82.88%)</td>
<td>131 (89.73%)</td>
<td>120 (82.19%)</td>
</tr>
<tr>
<td>Partial missing</td>
<td>45 (30.82%) missing 3.38±3.32 days</td>
<td>15 (10.23%) missing 1.73±.70 days</td>
<td>10 (6.85%) missing 1.10±.30 days</td>
<td>22 (15.07%) missing 1.65±.78 days</td>
</tr>
<tr>
<td>Complete missing</td>
<td>0</td>
<td>2M5F</td>
<td>1M1F</td>
<td>1F</td>
</tr>
<tr>
<td>Excluded</td>
<td>3F</td>
<td>3F</td>
<td>3F</td>
<td>3F</td>
</tr>
</tbody>
</table>

Note. No missing=all data available; Partial missing=data were not available for all days and sleep variables were based on the average of available data; Complete missing=no data were available; Excluded=no data were included in overall analyses. M=male, F=female.
2.5.2 Questionnaires

One male was excluded for Time-V PSQI due to a relapse of delayed circadian phase disorder; one female’s subjective SOL from Time-S was 540 minutes and was removed as an outlier. Table 8 summarizes the percentages of observations that had 0, 1, 2, or 3 missing time points, as well as the rate of missing data for each of the four time points. Given the longitudinal nature of data collection, the rates of missing were low overall. The majority of participants (~85%) provided complete data for all four time points, or missed only one time point (~11%), and less than 5% of participants missed two or more time points. Not surprisingly, Time-M being the final data collection time point, had the highest percentage of missing data (~11%) compared to other school term time points (~4% for both Time-S and Time-E), whilst vacation time point Time-V had the lowest missing data rate (<1%). Missing data analyses showed a non-statistically significant ($p=.07$) trend for males to have more missing data at Time-S; other missing data were not related to either age or sex.

Table 8
Rate (Number of Observations) of Missing for Questionnaire Data

<table>
<thead>
<tr>
<th></th>
<th># of missing time point(s)</th>
<th>For each time point</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>CESD, SCAS, PSQI</td>
<td></td>
<td></td>
</tr>
<tr>
<td>($N=146$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>84.93%</td>
<td>11.64%</td>
</tr>
<tr>
<td>CESD, SCAS, PSQI</td>
<td>(54M70F)</td>
<td>(11M6F)</td>
</tr>
<tr>
<td>IHSSRLE</td>
<td>84.25%</td>
<td>10.96%</td>
</tr>
<tr>
<td>($N=146$)</td>
<td>(53M70F)</td>
<td>(11M5F)</td>
</tr>
<tr>
<td>MEQ, DBAS, DAS</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

Note. CESD=Centre for Epidemiological Studies Depression Scale, SCAS=Spence Children’s Anxiety Scale, PSQI=Pittsburgh Sleep Quality Index, IHSSRLE=Inventory of High-School Students’ Recent Life Experiences, MEQ=Morningness-Eveningness Questionnaire, DBAS=Dysfunctional Beliefs and Attitudes about Sleep Scale, DAS=Dysfunctional Attitude Scale. M=male, F=female.
The following four sections 3 to 6 details findings from analyses that were conducted to examine the aforementioned aims and hypotheses. In each section, a set of related hypotheses were tested. At the end of each section, findings are summarized and discussed with respect to the aim the section addresses. Background on statistical methods used in these sections was presented in the METHODS section. In addition, all sections start with an overview of the analyses and their specifications.

3.1 Objective Sleep

3.1.1 Overall Changes

To examine the differences in objective sleep between start versus end of the term school days, sleep variables for these periods were averaged and compared using paired sample $t$-tests. To examine overall differences in objective sleep between school days and the vacation, sleep variables for Time-E and Time-S school days were averaged and compared to that during the vacation.

3.1.1.1 End versus Start of the School Term

Sleep timing and daily variation were similar during Time-E and Time-S as indicated by non-significant differences in $BT_{acti}$, $RT_{acti}$, and most daily variation variables. However, Time-S had shorter sleep duration ($TST_{acti}$) and compromised sleep quality ($SOL_{acti}$) as participants transited from the vacation to school days. Variability of $SOL_{acti}$ was also greater during Time-S than Time-E. Table 9 shows descriptive statistics and results of paired-sample $t$-tests for Time-E versus Time-S.
Table 9
*Means (Standard Deviations) and Results of Paired-Samples t-Tests for Time-E versus Time-S*

<table>
<thead>
<tr>
<th></th>
<th>M(SD)</th>
<th>df</th>
<th>t</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time-E</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BT&lt;sub&gt;acti&lt;/sub&gt; (min) ‡</td>
<td>11:15 p. m. (61.80)</td>
<td>134</td>
<td>-1.34</td>
<td>-.17</td>
</tr>
<tr>
<td>RT&lt;sub&gt;acti&lt;/sub&gt; (min) ‡</td>
<td>7:20 a.m. (43.35)</td>
<td>134</td>
<td>-.48</td>
<td>-.06</td>
</tr>
<tr>
<td>TIB&lt;sub&gt;acti&lt;/sub&gt; (min)</td>
<td>484.96(50.57)</td>
<td>134</td>
<td>1.07</td>
<td>.13</td>
</tr>
<tr>
<td>TST&lt;sub&gt;acti&lt;/sub&gt; (min)</td>
<td>397.13(46.01)</td>
<td>134</td>
<td>1.98*</td>
<td>.24†</td>
</tr>
<tr>
<td>SOL&lt;sub&gt;acti&lt;/sub&gt; (min)</td>
<td>16.06(11.98)</td>
<td>134</td>
<td>-2.81**</td>
<td>-.35†</td>
</tr>
<tr>
<td>SE&lt;sub&gt;acti&lt;/sub&gt; (%)</td>
<td>81.92(5.16)</td>
<td>134</td>
<td>1.79</td>
<td>.22†</td>
</tr>
<tr>
<td>%WASO (%)</td>
<td>12.43(4.27)</td>
<td>134</td>
<td>.67</td>
<td>.08</td>
</tr>
<tr>
<td>BTvari (min)</td>
<td>44.24(31.02)</td>
<td>129</td>
<td>.16</td>
<td>.02</td>
</tr>
<tr>
<td>RTvari (min)</td>
<td>33.25(31.05)</td>
<td>129</td>
<td>1.84</td>
<td>.23†</td>
</tr>
<tr>
<td>TIBvari (min)</td>
<td>54.36(34.40)</td>
<td>129</td>
<td>-.06</td>
<td>-.01</td>
</tr>
<tr>
<td>TSTvari (min)</td>
<td>53.27(32.98)</td>
<td>129</td>
<td>.23</td>
<td>.03</td>
</tr>
<tr>
<td>SOLvari (min)</td>
<td>10.93(10.81)</td>
<td>129</td>
<td>-3.92**</td>
<td>-.50†</td>
</tr>
<tr>
<td>SEvari (%)</td>
<td>4.81(3.09)</td>
<td>129</td>
<td>-.95</td>
<td>-.12</td>
</tr>
<tr>
<td>%WASOvari (%)</td>
<td>2.68(1.44)</td>
<td>129</td>
<td>-1.46</td>
<td>-.18</td>
</tr>
</tbody>
</table>

*Note.* *p*<.05, **p**<.01; effect size being †small and ‡‡moderate; ‡ mean values presented as clock time.

3.1.1.2 School Days versus the Vacation Period

School vacation was significantly different from school days on all aspects of sleep measured. Compared to school days, participants had significantly later BT<sub>acti</sub> and RT<sub>acti</sub>, the latter of which contributed to the significantly longer TIB<sub>acti</sub> and TST<sub>acti</sub>. Sleep quality was worse during the vacation, as evidenced in the significantly longer SOL<sub>acti</sub>, lower SE<sub>acti</sub>, and higher %WASO during the vacation than during school days. Both daily variation and regularity of sleep were significantly more variable during the vacation, with sleep timing being the most variable aspect. Table 10 shows descriptive statistics and results of paired-sample *t*-tests for school days compared to the vacation.
### Table 10

**Means (Standard Deviations) and Results of Paired-Sample t-Tests for School Days versus the Vacation**

<table>
<thead>
<tr>
<th></th>
<th>School days</th>
<th>Vacation</th>
<th>df</th>
<th>t</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BT&lt;sub&gt;acti&lt;/sub&gt; (min)</strong> ‡</td>
<td>11:17 p.m. (61.26)</td>
<td>00:38 a. m. (81.36)</td>
<td>141</td>
<td>-16.44**</td>
<td>-2.06***</td>
</tr>
<tr>
<td><strong>RT&lt;sub&gt;acti&lt;/sub&gt; (min)</strong> ‡</td>
<td>7:20 a. m. (42.49)</td>
<td>9:37 a.m. (80.13)</td>
<td>141</td>
<td>-24.38**</td>
<td>-3.33***</td>
</tr>
<tr>
<td><strong>TIB&lt;sub&gt;acti&lt;/sub&gt; (min)</strong></td>
<td>482.92(48.64)</td>
<td>538.70(49.75)</td>
<td>141</td>
<td>-13.59**</td>
<td>-1.61***</td>
</tr>
<tr>
<td><strong>TST&lt;sub&gt;acti&lt;/sub&gt; (min)</strong></td>
<td>393.55(44.71)</td>
<td>429.14(46.95)</td>
<td>141</td>
<td>-10.56**</td>
<td>-1.25***</td>
</tr>
<tr>
<td><strong>SOL&lt;sub&gt;acti&lt;/sub&gt; (min)</strong></td>
<td>17.37(10.82)</td>
<td>20.84(13.39)</td>
<td>141</td>
<td>-3.66**</td>
<td>-.44†</td>
</tr>
<tr>
<td><strong>SE&lt;sub&gt;acti&lt;/sub&gt; (%)</strong></td>
<td>81.53(4.93)</td>
<td>79.64(5.32)</td>
<td>141</td>
<td>9.00**</td>
<td>1.80***</td>
</tr>
<tr>
<td><strong>%WASO (%)</strong></td>
<td>12.55(4.31)</td>
<td>13.75(4.82)</td>
<td>141</td>
<td>-6.33**</td>
<td>-.77***</td>
</tr>
<tr>
<td><strong>BTsd</strong></td>
<td>45.36(24.80)</td>
<td>73.88(46.08)</td>
<td>139</td>
<td>-7.75**</td>
<td>-1.01***</td>
</tr>
<tr>
<td><strong>RTsd</strong></td>
<td>36.84(25.84)</td>
<td>80.63(46.84)</td>
<td>139</td>
<td>-10.78**</td>
<td>-1.37***</td>
</tr>
<tr>
<td><strong>TIBsd</strong></td>
<td>48.89(27.80)</td>
<td>84.47(31.02)</td>
<td>139</td>
<td>-12.41**</td>
<td>-1.49***</td>
</tr>
<tr>
<td><strong>TSTsd</strong></td>
<td>46.21(25.27)</td>
<td>74.12(26.96)</td>
<td>139</td>
<td>-10.80**</td>
<td>-1.29***</td>
</tr>
<tr>
<td><strong>SOLsd</strong></td>
<td>13.37(11.08)</td>
<td>17.38(11.79)</td>
<td>139</td>
<td>-3.87**</td>
<td>-.46†</td>
</tr>
<tr>
<td><strong>SEsd</strong></td>
<td>4.51(2.57)</td>
<td>5.48(2.39)</td>
<td>139</td>
<td>-4.08**</td>
<td>-.50††</td>
</tr>
<tr>
<td><strong>%WASOSd</strong></td>
<td>2.60(1.47)</td>
<td>3.35(1.66)</td>
<td>139</td>
<td>-5.06**</td>
<td>-6.1††</td>
</tr>
<tr>
<td><strong>BTvari (min)</strong></td>
<td>43.67(25.82)</td>
<td>72.91(40.04)</td>
<td>140</td>
<td>-8.79**</td>
<td>-1.10†††</td>
</tr>
<tr>
<td><strong>RTvari (min)</strong></td>
<td>28.60(23.51)</td>
<td>78.66(34.33)</td>
<td>140</td>
<td>-16.47**</td>
<td>-2.02†††</td>
</tr>
<tr>
<td><strong>TIBvari (min)</strong></td>
<td>54.64(34.63)</td>
<td>96.49(46.04)</td>
<td>140</td>
<td>-10.52**</td>
<td>-1.28†††</td>
</tr>
<tr>
<td><strong>TSTvari (min)</strong></td>
<td>52.50(31.77)</td>
<td>88.75(36.91)</td>
<td>140</td>
<td>-10.83**</td>
<td>-1.30†††</td>
</tr>
<tr>
<td><strong>SOLvari (min)</strong></td>
<td>13.87(9.78)</td>
<td>17.00(10.41)</td>
<td>140</td>
<td>-3.28**</td>
<td>-.39†</td>
</tr>
<tr>
<td><strong>SEvari (%)</strong></td>
<td>4.98(2.48)</td>
<td>5.81(2.37)</td>
<td>140</td>
<td>-3.37**</td>
<td>-.40†</td>
</tr>
<tr>
<td><strong>%WASOvari (%)</strong></td>
<td>2.82(1.36)</td>
<td>3.45(1.71)</td>
<td>140</td>
<td>-4.21**</td>
<td>-.51††</td>
</tr>
</tbody>
</table>

*Note.* *p*<.05, **p**<.01; effect size being †small, ††moderate, and †††large; ‡ mean values presented as clock time.
3.1.1.3 Transitions Between School Days and Vacations

School days vs SunDay. The averaged values of school days sleep variables (i.e., Mondays to Thursdays) were compared to that of the Sunday (5:59 p.m. Sunday night till 6:00 a.m. Monday). Sleep timing (BT_{acti} and RT_{acti}) and %WASO were not significantly different between SunDay and school days (all $p > .05$), but both sleep duration and sleep quality were significantly lower during SunDay. Compared to school days, TIB_{acti} (480.89±47.77 vs. 470.93±70.99 min., $t[133]=2.11$, $p < .05$, $d = .28$), TST_{acti} (391.79±43.78 vs. 372.51±59.18 min., $t[132]=, p < .01$, $d = .63$), and SE_{acti} (81.48±5.03 vs. 79.14±6.78, $t[132]=5.17$, $p < .01$, $d = .67$) were significantly lower, and SOL_{acti} (17.53±10.86 vs. 26.20±26.53 min., $t[133]=4.41$, $p < .01$, $d = .68$) was significantly longer on SunDay.

FriDay vs SatDay. Bedtimes were significantly earlier on FriDay compared to SatDay, 16.37±82.88 vs. 40.88±107.39 min., $t(124)=3.01$, $p < .01$, $d = .39$. All other sleep variables were comparable between FriDay and SatDay.

3.1.2 Day-to-Day Changes over the Vacation Period

3.1.2.1 Outliers

For each day, data points that were more than 3.29 standard deviations above or below the mean within a variable were screened, and outliers were identified on a case-by-case basis. Each variable contained at least 2190 available participant time points, and outliers removed did not exceed 0.5% for a given variable. Statistical modelling was applied to datasets both with and without outliers, and although model fit was either not different or better when outliers were removed, the findings were the same. Findings were based on results without outliers. The following paragraphs list outliers that were removed from latent growth curve (LGC) modelling.

BT_{acti}. Five data points past 6:00 a.m. were removed from four participants; Vacation data were removed from one participant whose bedtimes were past 6:00 a.m. on nine of the 15 days of the vacation;

RT_{acti}. Three data points past 6:00 p.m. were removed from one participant;

TIB_{acti}. One data point was removed due to unusually long TIB (>12 hours); one data point was removed due to no TIB (0 minute).

TST_{acti}. Eight data points from 8 participants were removed due to unusually short (<2 hours) sleep; one data point was removed due to being unusually long sleep (>12 hours) after total sleep deprivation the previous night.
SE\textsubscript{acti}. Thirteen data points were removed from 12 participants due to low sleep efficiency (<50%).

%WASO. Three data points were removed from 3 participants due to high %WASO (>40%); one participant was list-wise deleted for %WAKE analysis due to reported sleep disruption caused by an electric blanket.

3.1.2.2 Analysis Overview

Linear latent growth curves were applied to individual sleep variables with time scores specified as 0, 1, 2, and so forth. A systematic approach to model fitting was used for all sleep variables. When non-linear changes were fitted, freely estimated time scores and piece-wise modelling were used. Only vacation Sundays (V2 and V9, which were observed to have earlier bedtimes that resulted in higher TIB and TST) and the last three days of the vacation (V13-V15 when there were cases of variable plateauing) were allowed to be freely estimated. Two-piece growth curves were applied to TST, SE, and %WASO, with the first and the second segments being the first and the second vacation week. Models were first fitted without correlated residuals. When modification was required to improve model fit, the following correlated residuals that provided the best fit were selected for the final model: the same days of the week (e.g., V1 with V8, V2 with V9), consecutive days (e.g., V1 with V2, V2 with V3), both the same days of the week and consecutive days. Age, sex, and MEQ (morningness-eveningness) were introduced to the final fitted models as time-invariant covariates.

3.1.2.3 Findings

Daily means and standard errors of sleep variables over the 28 days’ actigraphy recording are displayed in Figure 6. Summary of model fit statistics with and without covariates are displayed in Table 11. Overall, latent growth curve models applied on objective sleep variables during the vacation had satisfactory fit, with slightly less good fit for the SRMR criterion. For SE\textsubscript{acti}, SRMRs were considerably larger than desired both with and without covariates. Freeing time scores or allowing for additional pairs of correlated residuals did not result in meaningful improvement. For TIB\textsubscript{acti}, TST\textsubscript{acti}, and SOL\textsubscript{acti}, SRMRs were only slightly higher than desired. By allowing for one to two additional pairs of correlated residuals, it was possible to lower SRMR to under .08. However, as doing this did not change outcomes, it was decided to report model results without additional correlated residuals. This suggests that the models performed well in estimating linear changes over time, but factors unrelated to time might have also contributed to the variability of the data.
Model results for growth factors and for covariates age, sex, and MEQ are displayed in Table 12, and detailed model specification and results are discussed below.

Table 11
*Model Fit Statistics for Latent Growth Curve Models With and Without Covariates*

<table>
<thead>
<tr>
<th></th>
<th>( \chi^2 ) (df), ( p )</th>
<th>RMSEA (90% CI)</th>
<th>CFI</th>
<th>SRMR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without covariates</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( BT_{acti} )</td>
<td>142.85(105), .01</td>
<td>0.05(0.03-0.07)</td>
<td>0.96</td>
<td>.06</td>
</tr>
<tr>
<td>( RT_{acti} )</td>
<td>98.59(91), .28</td>
<td>0.02(0.00-0.05)</td>
<td>0.99</td>
<td>.07</td>
</tr>
<tr>
<td>( TIB_{acti} )</td>
<td>114.69(113), .44</td>
<td>0.01(0.00-0.04)</td>
<td>0.99</td>
<td>.08</td>
</tr>
<tr>
<td>( TST_{acti} )</td>
<td>109.26(96), .17</td>
<td>0.03(0.00-0.06)</td>
<td>0.95</td>
<td>.09</td>
</tr>
<tr>
<td>( SOL_{acti} )</td>
<td>106.70(90), .11</td>
<td>0.04(0.00-0.06)</td>
<td>0.95</td>
<td>.08</td>
</tr>
<tr>
<td>( SE_{acti} )</td>
<td>132.07(111), .08</td>
<td>0.04(0.00-0.06)</td>
<td>0.97</td>
<td>.20</td>
</tr>
<tr>
<td>%WASO</td>
<td>90.98(96), .63</td>
<td>0.00(0.00-0.04)</td>
<td>1.00</td>
<td>.06</td>
</tr>
<tr>
<td>With Covariates</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( BT_{acti} )</td>
<td>193.07(144), .01</td>
<td>0.05(0.03-0.07)</td>
<td>0.95</td>
<td>.06</td>
</tr>
<tr>
<td>( RT_{acti} )</td>
<td>139.91(130), .26</td>
<td>0.02(0.00-0.05)</td>
<td>0.99</td>
<td>.07</td>
</tr>
<tr>
<td>( TIB_{acti} )</td>
<td>161.71(152), .28</td>
<td>0.02(0.00-0.05)</td>
<td>0.95</td>
<td>.08</td>
</tr>
<tr>
<td>( TST_{acti} )</td>
<td>145.80(129), .15</td>
<td>0.03(0.00-0.05)</td>
<td>0.95</td>
<td>.08</td>
</tr>
<tr>
<td>( SOL_{acti} )</td>
<td>149.44(129), .11</td>
<td>0.03(0.00-0.06)</td>
<td>0.95</td>
<td>.08</td>
</tr>
<tr>
<td>( SE_{acti} )</td>
<td>155.31(147), .30</td>
<td>0.02(0.00-0.05)</td>
<td>0.99</td>
<td>.17</td>
</tr>
<tr>
<td>%WASO</td>
<td>133.83(132), .44</td>
<td>0.01(0.00-0.04)</td>
<td>1.00</td>
<td>.05</td>
</tr>
</tbody>
</table>

*Note.* RMSEA= Root Means Square Error of Approximation, CI=confidence interval, CFI=Comparative Fit Index, SRMR= Root Means Square Error of Approximation.

**BT_{acti}**. A linear latent growth curve (LGC) with correlated residuals for the same days of the week were fitted to V1 to V15, with time scores of Sundays V2 (b=-6.72, SE=4.57) and V9 (b=4.96, SE=3.93) being freely estimated. At the start of the vacation, BT was 00:24 a.m. (mean of intercept). The slope factor, being significantly larger than 0, suggested a significant linear delay at the rate of 1.89 min/day (mean of slope). Significant variance in the intercept was likely explained by covariates, as they collectively explained 36% of its variance. Older age, evening preference, and being male were associated with significantly later BT intercept. These covariates did not play significant roles in the slope factor.
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**RT_{acti}**. A linear LGC with correlated residuals for both consecutive days and the same days of the week were fitted to V1 to V15, with time scores of V14 ($b=9.74$, SE=1.79) and V15 ($b=9.26$, SE=1.37) being freely estimated to reflect an earlier rise-time, possibly in anticipation of the start of school. Rise-time significantly delayed at 2.66 min/day from 09:21 a.m. at the start of the vacation. Covariates explained 24% of the significant variance in the intercept, with older age and evening preference associated with significantly later RT. Significant variance in the slope factor was not related to age, sex, or MEQ, but those with earlier RT at the start of the vacation showed faster RT delays, as the correlation between intercept and slope was negative and statistically significant ($p<0.05$).

**TIB_{acti}**. A linear LGC was fitted to V1 to V15, with time scores of Sundays V2 ($b=35.04$, SE=24.92) and V9 ($b=39.24$, SE= 29.50) being freely estimated to reflect longer time-in-bed as a consequence of earlier Sunday bedtimes. The slope factor was not significantly different from 0, indicating that TIB did not change significantly during the vacation from its initial status of 533.42 min. The significant individual variability in the intercept is partially due to gender difference, with being female associated with significantly longer TIB.

**TST_{acti}**. A single linear LGC freeing the time scores of Sundays (V2 and V9) with ($\chi^2[\text{df}]=145.30[105], p<.01$, RMSEA=.05, CFI/TLI=.85, SRMR=.1) or without (model did not converge) correlated residuals provided poor fit for the model. Two-piece linear LGC with correlated residuals for consecutive days were therefore fitted to V1-V8 and V9-V15 with two intercepts ($i_1$ and $i_2$) and two slopes ($s_1$ and $s_2$). Initial estimates revealed negative variance for $s_2$, which was then fixed at 0 for the final model. Intercept mean was 441.79 min for the first half of the vacations and 443.36 min for the second half, and Wald test of parameter constraint showed no significant difference between these two means ($p>0.05$). During the first half of the vacation, TST significantly decreased at 2.82 min/day; after an abrupt increase on the Sunday before the second vacation week, TST significantly decreased at 3.02 min/day during the second half of vacations. There were significant individual differences in both intercepts (but not slopes), and covariates analyses showed that being female was associated with longer TST.

**SOL_{acti}**. A linear LGC with correlated residuals for consecutive days and the same days of the week were fitted to V1 to V15, with the time scores of V13 ($b=6.55$, SE=2.07), V14 ($b=7.07$, SE=1.23), and V15 ($b=4.80$, SE=1.58) being freely estimated. Intercept mean was 14.52 min, and SOL increased significantly at the rate of 1.01 min/day. Based on the freely estimated time scores of V13, V14, and V15 this increase ceased towards the end of the vacation. Significant variance in intercept might be partly due to females having larger SOL. Other factors might also have contributed, as the covariates examined explained only 8% of the intercept variance.
SE<sub>acti</sub>. A piecewise LGC with one intercept and two slopes (s<sub>1</sub> and s<sub>2</sub>) were fitted to the first (V1-V8) and second (V9-V15) half of the vacation. Intercept mean was 81.17%, and whilst s<sub>1</sub> was negative and significantly different from 0, s<sub>2</sub> was not statistically significantly different from 0. This suggested that during the first half of the vacation, sleep efficiency linearly decreased at the rate of .23% per day but remained unchanged during the second half of the vacation. There were significant individual differences in intercept, but covariates examined in this analysis did not make significant contribute to it.

%WASO. A piecewise LGC with one intercept and two slopes (s<sub>1</sub> and s<sub>2</sub>) were fitted to the first (V1-V8) and second (V9-V15) half of the vacation. The time score of V2 (b=3.56, SE=1.66) was freely estimated and correlated residuals were allowed for consecutive days. Intercept mean was 12.95%, and its significant individual differences were explained mainly by males having higher %WASO. The values of s<sub>1</sub> (0.15%/day) and s<sub>2</sub> (-0.11%/day) being significantly greater and less than 0 respectively, suggested that %WASO increased during the first half of the vacation and decreased during the second. None of the covariates examined made significant contributions to the change rate.
Table 12
Parameter Estimates (Standard Errors) for the Mean and Variances of Growth Factors, and the Effects of Covariates

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mean</th>
<th>$\sigma^2$</th>
<th>Covariates</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Age</td>
</tr>
<tr>
<td>$BT_{acti}$</td>
<td>24.30(6.70)**</td>
<td>5002.27(648.63)**</td>
<td>17.35(5.03)**</td>
</tr>
<tr>
<td></td>
<td>1.89(0.39)**</td>
<td>3.48(2.91)</td>
<td>0.09(0.31)</td>
</tr>
<tr>
<td>$RT_{acti}$</td>
<td>200.59(6.89)**</td>
<td>6228.59(932.69)**</td>
<td>17.05(5.84)**</td>
</tr>
<tr>
<td></td>
<td>2.66(0.66)**</td>
<td>35.83(9.26)**</td>
<td>-0.83(0.65)</td>
</tr>
<tr>
<td>$TIB_{acti}$</td>
<td>533.42(5.43)**</td>
<td>1634.02(278.34)**</td>
<td>-5.62(5.65)</td>
</tr>
<tr>
<td></td>
<td>0.64(0.52)</td>
<td>0.03(0.65)</td>
<td>-0.25(0.68)</td>
</tr>
<tr>
<td>$TST_{acti}$</td>
<td>441.79(5.39)**</td>
<td>2700.70(621.76)**</td>
<td>1.95(4.64)</td>
</tr>
<tr>
<td></td>
<td>-2.82(0.97)**</td>
<td>36.87(25.33)**</td>
<td>-1.77(0.83)*</td>
</tr>
<tr>
<td></td>
<td>443.36(5.16)**</td>
<td>1673.32(327.10)**</td>
<td>-2.02(5.94)</td>
</tr>
<tr>
<td></td>
<td>-3.02(1.09)**</td>
<td>Fixed at 0(--)</td>
<td>-1.86(1.12)</td>
</tr>
<tr>
<td>$SOL_{acti}$</td>
<td>14.52(1.08)**</td>
<td>88.65(31.19)**</td>
<td>-0.02(0.87)</td>
</tr>
<tr>
<td></td>
<td>1.01(0.18)**</td>
<td>2.32(1.47)</td>
<td>0.17(0.13)</td>
</tr>
<tr>
<td>$SE_{acti}$</td>
<td>81.17(0.51)**</td>
<td>28.63(5.39)**</td>
<td>-0.24(0.47)</td>
</tr>
<tr>
<td></td>
<td>-0.23(0.06)**</td>
<td>0.11(0.09)</td>
<td>-0.01(0.05)</td>
</tr>
<tr>
<td></td>
<td>-0.002(0.07)</td>
<td>0.18(0.09)*</td>
<td>0.01(0.06)</td>
</tr>
<tr>
<td>$%WASO$</td>
<td>12.95(0.43)**</td>
<td>18.82(3.01)**</td>
<td>0.62(0.38)</td>
</tr>
<tr>
<td></td>
<td>0.15(0.05)**</td>
<td>0.11(0.06)</td>
<td>-0.08(0.05)</td>
</tr>
<tr>
<td></td>
<td>-0.11(0.05)*</td>
<td>0.15(0.06)*</td>
<td>0.02(0.04)</td>
</tr>
</tbody>
</table>

Note. To assist interpretation of results, unstandardized parameter estimates were reported. i=intercept, s=slope, $i_1$ and $s_1$ are intercepts and slopes for the first vacation week, and $i_2$ and $s_2$ are intercepts and slopes for the second vacation week; other than those specified in-text, correlations between intercepts and slopes were not statistically significant. $\sigma^2$=variance. Parameter estimates for means and $\sigma^2$ of intercepts and slopes were based on model results without covariates. *p<0.05, **p<0.01.
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Figure 6 Daily means and standard errors for actigraphy-measured sleep across school days (solid circle), non-school days (open circle), and transitional days (cross) between school and non-school days
3.2 Subjective Sleep

3.2.1 Changes across School Term

One-piece latent growth curves with linear slopes were applied to subjective sleep variables measured at the three school term time points with time scores specified as 0, 1, and 2. Ordinal variables SQpsqi and DDpsqi were treated as categorical variables instead of continuous. Given there were only 6, 5, and 7 participants who endorsed “3” on SQpsqi, this category was merged with “2” during analyses of this section. Unstandardized model results and fit statistics are presented in Table 13. For SOLpsqi, SEpsqi, SDpsqi, and SQpsqi, model fits were excellent without modification. For TSTpsqi the initial model revealed negative variance for the slope factor, which, when fixed at 0, led to good overall fit but elevated SRMR, $\chi^2(3)=3.14, p=0.37$, CFI=1.00, RMSEA=0.02, SRMR=0.16. Modification using autocorrelated residuals substantially reduced SRMR to .02 and the final model was a good fit to the data.

Based on model results, none of the slope factors for subjective sleep variables were significantly different from 0, suggesting that these variables remained stable across the three school term time points.
### Table 13

Parameter Estimates (Standardized Errors) and Fit Statistics for Latent Growth Models on Subjective Sleep Variables Across the Three School Time Points

<table>
<thead>
<tr>
<th>Model Results</th>
<th>Fit statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
</tr>
<tr>
<td><strong>TST</strong>&lt;sub&gt;psqi&lt;/sub&gt;</td>
<td>i 441.54(6.04)**</td>
</tr>
<tr>
<td></td>
<td>s 1.68(2.54)</td>
</tr>
<tr>
<td><strong>SOL</strong>&lt;sub&gt;psqi&lt;/sub&gt;</td>
<td>i 27.77(2.09)**</td>
</tr>
<tr>
<td></td>
<td>s -1.63(1.02)</td>
</tr>
<tr>
<td><strong>SE</strong>&lt;sub&gt;psqi&lt;/sub&gt;</td>
<td>i 89.52(0.77)**</td>
</tr>
<tr>
<td></td>
<td>s -0.12(0.42)</td>
</tr>
<tr>
<td><strong>SD</strong>&lt;sub&gt;psqi&lt;/sub&gt;</td>
<td>i 3.35(0.22)**</td>
</tr>
<tr>
<td></td>
<td>s -0.07(0.10)</td>
</tr>
<tr>
<td><strong>SQ</strong>&lt;sub&gt;psqi&lt;/sub&gt;</td>
<td>i 0&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>s -0.15(0.14)</td>
</tr>
<tr>
<td><strong>DD</strong>&lt;sub&gt;psqi&lt;/sub&gt;</td>
<td>i 0&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>s -0.08(0.04)</td>
</tr>
</tbody>
</table>

Note. Unstandardized results were reported to assist interpretation. *TST*<sub>psqi</sub>, *SOL*<sub>psqi</sub>, *SE*<sub>psqi</sub>, *SD*<sub>psqi</sub>, *SQ*<sub>psqi</sub>, *DD*<sub>psqi</sub> are Pittsburg Sleep Quality Index assessed total sleep time (min), sleep onset latency (min), sleep efficiency (%), sleep disturbance, sleep quality, and sleep-related daytime dysfunction. 

* a. intercept was held at 0 for categorical variables; b. fit indices were not available when MLR estimator was used for categorical outcomes. 

σ² = variance, RMSEA= Root Means Square Error of Approximation, CI= confidence interval, CFI= Comparative Fit Index, SRMR= Root Means Square Error of Approximation. *p<.05, **p<.01 significantly different from 0.

#### 3.2.2 School Term versus Vacation Period

Given all subjective sleep variables remained stable across the three school term time points, the average values of available school term time points were compared to that of the vacation using paired-samples t-tests (see Table 14 for results and descriptive statistics). Compared to vacation, participants reported significantly shorter TST but lower SE for the school term, with the effect sizes being large and small respectively. They also reported significantly greater sleep-related daytime dysfunction during school term than the vacation with moderate effect size. Differences in sleep disturbance and sleep quality were marginally significant with small effect sizes, suggesting...
that participants perceived their sleep to be less disturbed but of lower quality during school term than the vacation.

Table 14
Means (Standard Deviations) and Results of Paired-Samples t-Tests for School Term and Vacation

<table>
<thead>
<tr>
<th></th>
<th>School term</th>
<th>Vacation</th>
<th>df</th>
<th>t</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>TST_psqi (min)</td>
<td>443.13(61.6)</td>
<td>499.38(88.02)</td>
<td>142</td>
<td>-8.49**</td>
<td>-1.04†††</td>
</tr>
<tr>
<td>SOL_psqi (min)</td>
<td>26.34(19.8)</td>
<td>25.26(26.00)</td>
<td>142</td>
<td>0.54</td>
<td>0.07</td>
</tr>
<tr>
<td>SE_psqi (%)</td>
<td>89.45(7.35)</td>
<td>86.76(10.84)</td>
<td>142</td>
<td>3.04*</td>
<td>0.38†</td>
</tr>
<tr>
<td>SD_psqi</td>
<td>3.22(2.39)</td>
<td>3.53(2.81)</td>
<td>142</td>
<td>-1.96</td>
<td>-0.24†</td>
</tr>
<tr>
<td>SQ_psqi</td>
<td>1.25(0.58)</td>
<td>1.15(0.77)</td>
<td>142</td>
<td>1.90</td>
<td>0.23†</td>
</tr>
<tr>
<td>DD_psqi</td>
<td>0.76(0.58)</td>
<td>0.45(0.58)</td>
<td>142</td>
<td>5.97**</td>
<td>0.70††</td>
</tr>
</tbody>
</table>

Note. TST\_psqi, SOL\_psqi, SE\_psqi, SD\_psqi, SQ\_psqi, DD\_psqi are Pittsburg Sleep Quality Index assessed total sleep time (min), sleep onset latency (min), sleep efficiency (%), sleep disturbance, sleep quality, and sleep-related daytime dysfunction. *p<.05, **p<.01; effect size being †small, ‡moderate, and ††large.
3.3 Summary

Objective sleep at the start and end of a school term was similar with only minor differences. Between school days and the vacation period however, adolescents exhibited two distinct sleep patterns. Compared to school days, sleep during the vacation was characterized by later timing, longer duration, lower quality, and greater variability. The removal of school-related sleep restriction was associated with an abrupt delay in sleep timing and increase in sleep duration. Subsequently, BT and RT showed further linear delays throughout the vacation. However, changes in TIB during the vacation were non-significant. SOL increased linearly, peaking in the middle of the second vacation week. Across the first vacation week, TST and SE linearly decreased while %WASO increased. These changes stabilized during the second vacation week. Older age and eveningness were associated with later BT and RT, whilst females had longer TIB, TST, and SOL.

There were several minor changes in subjective sleep across Time-S, Time-M, and Time-E, suggesting that perceived sleep duration or quality remained relatively similar across the school term. Consistent with findings for actigraphy, adolescents self-reported longer TST and lower SE during the vacation period compared to school terms. Other than significantly higher sleep-related daytime dysfunction during school terms, other aspects of subjective sleep quality (i.e., SOLpsqi, SDpsqi, and SQpsqi) were comparable between the vacation and school term periods.

Therefore, actigraphy-measured sleep supported hypotheses H 1.1 that school weekdays are associated with restricted sleep opportunity with shorter sleep duration and more consolidated sleep, H 1.2 that evening preference and older age are associated with later sleep timing, and H 1.3 that significant differences in sleep timing and duration between the school term and vacation largely occurs on the first night of transition; self-reported sleep supported hypothesis H 1.1 that during school weekdays sleep duration is shorter, but participants did not perceive sleep to be more consolidated.
3.4 Discussion

3.4.1 Overall Sleep during School Terms versus Vacations

3.4.1.1 Objective Sleep

Comparisons of school day versus the vacation objective sleep in this study confirmed findings from subjective sleep studies that vacations were associated with later sleep timing and extended sleep opportunities. Later RT was the key mechanism through which adolescents achieved extended sleep opportunity during the vacation. Whilst on average, vacation BT was 1hr 21min later than that during school days, RT was 2hr 16min later, resulting in 56min longer TIB.

Adding to the current literature, we found altered sleep structure over the vacation as measured by greater SOL and %WASO, and reduced SE. It should be noted that, although statistically significant, overall differences between the vacation and school days in SOL (3.5min), SE (1.9%), and %WASO (1.2%), were of relatively small magnitude, despite large increases in TIB. Further, daily variation in all aspects of sleep was significantly greater during vacations than during school days. The average daily variations in BT and RT during vacations were 1hr 13min and 1hr 19min respectively. Such daily variation in sleep timing was higher than that reported among retired older adults, who presumably also have relatively extended sleep opportunities (Monk et al., 2011). Regular sleep timing is often recommended by interventions that aim to improve sleep (Bei et al., 2013; Moseley & Gradisar, 2009), and studies on younger children have associated more variable sleep patterns with poorer emotional (Pesonen et al., 2010) and physical (Spruyt, Molfese, & Gozal, 2011) health. In the context of the vacation when the absence of school-related sleep restriction is likely to play a positive role in wellbeing, it is not clear what impact such daily variations might have on adolescents’ wellbeing. It does appear that during extended sleep opportunities in naturalistic settings, even though sleep restriction is no longer the main concern, there might be other challenges to adolescents’ sleep, such as more variable sleep timing.

3.4.1.2 Subjective Sleep

In this study, none of the self-report sleep domains were significantly different at the start, middle, and end of a school term. This suggests that under school-related sleep restriction, perceived sleep duration, quality, as well as sleep-related daytime dysfunction did not change
significantly across a school term. This has practical implications for the timing of data collection in studies that measure adolescents’ sleep subjectively during school terms.

Findings on differences between school term and vacation subjective sleep duration and quality are consistent with those measured using actigraphy. Compared to school terms, vacation self-report sleep duration was significantly longer with large effect size, whilst sleep efficiency was lower and sleep disturbance greater with small effect sizes. The substantially longer sleep duration during the vacation might have directly contributed to the significantly lower sleep-related daytime dysfunction, as well as somewhat better perceived sleep quality perceived by participants. These findings on self-report sleep highlighted the conscious awareness of school-related sleep restriction and their impact on daytime functioning in adolescents.

3.4.2 Sleep Over the Vacation

The differences in sleep variables averaged across school days versus vacations need to be interpreted and understood in the context of the changes in these variables during vacations. Changes identified in this study appear to have primarily resulted from two simultaneous processes: a shift towards later sleep timing, and a recovery from sleep restriction.

3.4.2.1 Transition from Restricted into Extended Sleep Opportunities

Transitions into non-school days were characterized by immediate changes in sleep timings and durations. Upon entering the vacation, there were initial rapid delays in both BT and RT compared to school day sleep timing. The substantially delay in RT at the start if the vacation led to immediate increase in TIB and TST. This rapid change is consistent with findings from previous studies on weekday-weekend differences in adolescents’ sleep, and suggests that during school periods, both sleep duration and timing are externally constrained, and that upon removal of these constraints, adolescents very quickly adopt preferred sleep/wake behaviors. Sleep structure as measured by SOL, SE, and %WASO however, remained at school day levels during this transition. This pattern presumably indicates that recovery sleep was taking place at least during the first few days of the vacation.

3.4.2.2 Changes in Sleep Variables over the Vacation

After the rapid delays in sleep timing upon transitioning into vacations, both BT and RT followed a slower linear delay that extended throughout the two-week vacation period. This pattern might reflect a drift in the position of the circadian oscillator, or changes towards a preferred
circadian phase of the oscillator, however, in the absence of a measurement of the circadian oscillator, these alternatives cannot be distinguished by the present study. We speculate that the initial rapid change upon removal of school-related sleep restriction is a shift to the actual position of the oscillator, while the gradual change is a subsequent delay of the oscillator caused by the new sleep-wake schedule.

Existing laboratory-based studies have not measured recovery sleep beyond three nights (Belenky et al., 2003), and the course of recovery from sleep restriction is not well understood. The observations in this study could help further current understanding of sleep recovery. Firstly, TIB remained relatively stable throughout the two-week vacation, averaging 8hr 59min (longer TIB on V2 and V9, both Sundays, might be due to earlier household BT in anticipation of early RT on Monday morning). Secondly, over the first vacation week, TST decreased, whilst SOL and %WASO increased linearly, resulting in progressively less time spent asleep in proportion to TIB (i.e., reduced SE). These changes suggest reduced homeostatic drive, and are consistent with a possible recovery from sleep restriction and sleep debt (Banks & Dinges, 2007). Thirdly, by the second week of the vacation, sleep structure ceased to change, and the increase in SOL plateaued. Whilst TIB remained elevated, sleep was less consolidated during the second vacation week. This suggests that elevated TIB in the absence of sleep restriction was at the cost of consolidated sleep. In summary, our data suggested that recovery from sleep restriction was completed within two weeks’ extended sleep opportunity, possibly as early as the end of the first week.

3.4.2.3 Sleep Duration with Extended Sleep Opportunity

In the present study, TST during the vacation was 7.15 hr whilst TIB was 9 hr, both of which were substantially lower than in an earlier laboratory-based study with an experimentally imposed fixed TIB of 10 h and a TST of approximately 9.15 hr (Carskadon et al., 1980). The fundamental question then becomes, which procedure most closely identifies sleep need in adolescent populations? On one hand, sleep measured in the home environment might be shorter because of individuals’ daily activities and commitments. However, if this was the case, the participants would not have been attaining their sleep need, and it would be anticipated they would continue to show a sleep debt. Contrary to this, the current data suggest that sleep duration and sleep need were in balance towards the end of the second vacation week.

It is also important to consider that, as described in the Limitation section, the shorter TST found here could be due to an overestimation of WASO by actigraphy in an adolescent sample. This might also have contributed to the changes in sleep variables (e.g. increase in %WASO and SOL and decrease in SE) over the vacation period. As the sleep debt wanes over the vacation period, sleep may become ‘lighter’ with increased restlessness, which actigraphy may identify as
wakefulness. However, such an interpretation would not be inconsistent with the view that sleep had stabilized by the end of the vacation period.

Actigraphy-based TIB is likely to have been relatively accurate, as it was based on daily BT and RT registered using the Event Marker. Discrepancy between actigraphy and self-reported TIB was likely due to self-report being less accurate as participants were asked to estimate typical values over the past week at a time when sleep timing was highly variable. Therefore, although TST might not be as low as 7.15 hr, it is highly likely to be less than the actigraphy-assessed TIB of 9 hr and, assuming realistic values for SOL and WASO, probably < 8.5 hr. Consistent with this interpretation, community-based studies on adolescents’ weekend sleep using sleep diaries show comparable TIB durations to the current data (Olds, Maher, Blunden, & Matricciani, 2010b; Short, Gradisar, Lack, Wright, & Dohnt, 2013). Finally, as suggested by some researchers, sleeping longer does not necessarily mean needing more sleep. Longer sleep duration in extended laboratory studies could result from few incentives to remain awake (Harrison & Horne, 1995).

Without relating sleep measures to mental/physical health outcomes, it is not possible to draw definite conclusions regarding adolescents’ sleep needs. However, our data suggest that in a home setting where sleep opportunity is relatively unconstrained over the period of two weeks, adolescents’ TIB was approximately 9 hr, and TST was likely to be under 8.5 hr. Further, SOL increased, and SE decreased over the first week and then reached plateaus. This pattern suggests that the obtained sleep was sufficient to repay the sleep debt present at the beginning of the vacation period, and was sufficient to achieve a balance with the ongoing sleep requirement.

3.4.2.4 Individual Differences and Covariates

Significant individual differences were found in the initial status of all sleep variables. Consistent with the literature, older age and more evening preference were associated with later BT and RT, explaining about a quarter of their variances. Being female was associated with earlier BT, longer sleep duration (TIB and TST), longer SOL, and less %WASO. Whilst it is not clear what might have contributed to earlier BT in females, it is possible that higher screen-based media use in males (Marshall, Gorely, & Biddle, 2006) might have played a role. The longer sleep duration found in females is consistent with normative data from Australian adolescents (Olds et al., 2010b) and a recent meta-analysis on worldwide data (Olds, Blunden, Petkov, & Forchino, 2010a), and might be related to earlier BT in females in this study. Conflicting results have been reported regarding gender differences in SOL (Lazaratou, Diokes, Anagnostopoulos, Sbokou, & Soldatos, 2005; K. A. Lee, McEnany, & Weekes, 1999; Short et al., 2013). It is possible that later BT and lower TIB in males contributed to their shorter SOL. Gender differences in %WASO suggested that compared to females, males had more wrist movements after sleep onset, which may or may
not reflect more restless sleep (Short, Gradisar, Lack, Wright, & Carskadon, 2012). It is worth noting that other factors were likely to have played roles in sleep duration and structure, as covariates examined in this study accounted for a relatively small (8%-16%) proportion of their intercept variances.

Significant individual differences in the rate of change were found for RT, with rates of delay faster among those with earlier RT at the start of the vacation. Individual differences in change rates were small for all other sleep variables, suggesting that the rate of change in sleep over the vacation, and possibly the rate of recovery from sleep restriction, were similar across individuals, even though their initial status varied significantly.

3.4.3 Other Findings

3.4.3.1 Effects of Extended Sleep Opportunity on Subsequent School Night Sleep

Comparisons of weekday sleep between the end and the start of a school term suggested that participants had more difficulty falling asleep when school-related sleep restriction was reinstated after a two-week (as in the start of a term) compared to a two-day (as in the end of a term) unconstrained sleep period. A study on adolescents of the same age group to those studied here showed that a typical weekend sleep-in could cause measurable delays in DLMO (S. J. Crowley & Carskadon, 2010). Our findings suggested that a two-week vacation might shift adolescents’ circadian timing to a later phase to a greater extent than does a two-day weekend.

3.4.3.2 Defining School and Non-school Days

Results on FriDay, SatDay, and SunDay suggested that among adolescents, it is more appropriate to examine sleep from Mondays to Thursdays as school days (or “weekdays”), whilst Fridays and Saturdays as non-school days (or “weekend”). Sleep on Sundays is better examined separately as it might be of shorter duration and lower quality compared to either weekday or weekend sleep.
AIM 2: ASSOCIATIONS BETWEEN OBJECTIVE AND SUBJECTIVE SLEEP AND THE ROLE OF DBAS

4.1 Correlations and Differences

Table 15 summarises results from Pearson correlation and paired-sampled t-tests between actigraphy and self-report TIB, TST, and SOL at Time-V, -S, and -E. Although correlation coefficients were significant between self-report and actigraphy measured TIB, TST, and SOL for all time points (r ranges 0.32-0.56, all p<0.05), the differences between them were also significant. Compared to actigraphy measures, self-report TIB, TST, and SOL were longer for all time points, and these differences were of small to large effect sizes. For TIB and TST, discrepancies between actigraphy and self-report were greater during the vacation (38.19 and 69.23 min for TIB and TST respectively) than during school terms (11.22 and 50.36 min for Time-S; 11.75 and 45.18 min for Time-E), whilst the over-estimation of SOL was greater at Time-E (8.6 min) and Time-S (7.57 min), than at Time-V (4.52 min).

Table 15

**Correlations and Differences Between Actigraphy and Self-report Sleep Variables**

<table>
<thead>
<tr>
<th></th>
<th>M(SD)</th>
<th>r</th>
<th>df</th>
<th>t</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actigraphy</td>
<td>Self-report</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TIB-V</td>
<td>539.43(50.36)</td>
<td>577.62(86.15)</td>
<td>0.49**</td>
<td>140</td>
<td>-6.40**</td>
</tr>
<tr>
<td>TIB-S</td>
<td>480.35(57.90)</td>
<td>491.57(69.56)</td>
<td>0.56**</td>
<td>129</td>
<td>-1.82</td>
</tr>
<tr>
<td>TIB-E</td>
<td>486.08(50.64)</td>
<td>497.83(68.72)</td>
<td>0.53**</td>
<td>136</td>
<td>-1.72</td>
</tr>
<tr>
<td>TST-V</td>
<td>430.15(48.32)</td>
<td>499.38(88.02)</td>
<td>0.44**</td>
<td>140</td>
<td>-10.99**</td>
</tr>
<tr>
<td>TST-S</td>
<td>389.35(52.75)</td>
<td>439.71(72.15)</td>
<td>0.37**</td>
<td>129</td>
<td>-7.89**</td>
</tr>
<tr>
<td>TST-E</td>
<td>398.01(46.07)</td>
<td>443.19(66.51)</td>
<td>0.53**</td>
<td>136</td>
<td>-8.81**</td>
</tr>
<tr>
<td>SOL-V</td>
<td>20.74(13.39)</td>
<td>25.26(26.00)</td>
<td>0.54**</td>
<td>140</td>
<td>-2.60*</td>
</tr>
<tr>
<td>SOL-S</td>
<td>19.97(15.71)</td>
<td>27.54(24.82)</td>
<td>0.31**</td>
<td>129</td>
<td>-3.35**</td>
</tr>
<tr>
<td>SOL-E</td>
<td>15.80(11.82)</td>
<td>24.40(20.29)</td>
<td>0.32**</td>
<td>136</td>
<td>-5.11**</td>
</tr>
</tbody>
</table>

Note. TIB=time-in-bed, TST=total sleep time, SOL=sleep onset latency; V=vacation, S=start of the term, E=end of the term; *p<.05, **p<.01; effect size being †small, ††moderate, and †††large.
4.2 Roles of Dysfunctional Beliefs and Attitudes about Sleep

4.2.1 Analysis Overview

This section tests the first part of the cognitive model presented in Figure 2, in which DBAS was hypothesised to moderate the relationship between objective and subjective sleep. First, Pearson correlation analysis, independent samples t-test, and linear regression were used to examine whether DBAS was related to age, sex, and global cognitive vulnerability (DAS). Pearson correlation analyses were also used to explore the relationships between DBAS and objective/subjective TST and SOL. Then, DBAS was examined as a moderator in the relationship between objective and subjective TST as well as SOL (see Figure 7 for a single time point diagram). Given that both objective and subjective sleep were available at Time-V, Time-S, and Time-E, moderation analyses were conducted and parameters were estimated simultaneously in Mplus for all three time points in one model within the frameworks of multiple group analysis, with the groups being Time-V, Time-S, and Time-E. In each moderated regression for a given time point, the dependent variable was the subjective sleep variable, and independent variables were (a) the objective sleep variable, (b) DBAS, and (c) the interaction term between the objective sleep variable and DBAS. The objective sleep variable and DBAS were mean-centred. This allowed the simple effects of DBAS and the objective sleep variable to be estimated when the other was at its mean, instead of being 0, this assists interpretation of their simple effects on the dependent variable.

![Figure 7 Dysfunctional Beliefs and Attitudes about Sleep (DBAS) as a moderator of the relationship between objective and subjective sleep.](image-url)
4.2.2 DBAS Descriptive Statistics and Correlates

In this study, the total score of DBAS averaged 72.02 (SD=26.24). Pearson correlation analysis revealed no relationship between DBAS and age ($r=.04$, $p=.62$). Females ($M=75.36$, $SD=26.79$) scored higher than males ($M=68.35$, $SD=25.31$), although this difference was small and not statistically significant based on an independent samples $t$-test: $t(143)=1.62$, $p=.11$, $d=.27$. Linear regression showed that global cognitive vulnerability DAS was significantly associated with DBAS, explaining 9.50% of its variance, $F(1, 143)=14.98$, $p<.001$.

4.2.3 Total Sleep Time

Correlational analyses showed overall weak relationships between DBAS and objective and subjective TST at school term and the vacation time points. Higher DBAS was associated with longer objective TST at Time-V ($r=.19$, $p<.05$) and Time-S ($r=.15$, $p=.07$), but not at Time-E; DBAS shared a non-significant relationship with subjective TST at all time points (see Table 16).

Table 16

Pearson Correlation Coefficients between DBAS and Objective and Subjective Sleep

<table>
<thead>
<tr>
<th></th>
<th>Time-V</th>
<th>Time-S</th>
<th>Time-E</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Objective</td>
<td>Subjective</td>
<td>Objective</td>
</tr>
<tr>
<td>df</td>
<td>142</td>
<td>143</td>
<td>135</td>
</tr>
<tr>
<td>TST</td>
<td>.19*</td>
<td>-.02</td>
<td>.15, $p=.07$</td>
</tr>
<tr>
<td>SOL</td>
<td>.09</td>
<td>.09</td>
<td>.01</td>
</tr>
</tbody>
</table>

Note. DBAS = Dysfunctional Beliefs and Attitudes about Sleep; TST=total sleep time, SOL= sleep onset latency, V=vacation, S=start of the term, E=end of the term; *$p<.05$.

Based on moderation analyses, at all three time points, objective TST, DBAS, and their interaction terms accounted for significant amounts of the variance in subjective TST, with $R^2$ being .20, .16, and .28 for Time-V, Time-S, and Time-E respectively. For all time points, objective TST was a significant predictor for subjective TST, whilst neither the simple nor the moderating effect of DBAS was significant. This suggests that DBAS did not make a significant contribution to subjective TST, nor did it play a significant moderating role in the relationship between objective and subjective TST. Results for the TST model are summarized in Table 17.
Table 17

*Standardized Parameter Estimates (Standard Errors) for Moderation Analyses on Total Sleep Time*

<table>
<thead>
<tr>
<th>DV: TST&lt;sub&gt;psqi&lt;/sub&gt;</th>
<th>Time-V</th>
<th>Time-S</th>
<th>Time-E</th>
</tr>
</thead>
<tbody>
<tr>
<td>TST&lt;sub&gt;acti&lt;/sub&gt;</td>
<td>0.45(0.07)**</td>
<td>0.36(0.08)**</td>
<td>0.53(0.06)**</td>
</tr>
<tr>
<td>DBAS</td>
<td>-0.10(0.08)</td>
<td>0.06(0.08)</td>
<td>0.03(0.07)</td>
</tr>
<tr>
<td>TST&lt;sub&gt;acti&lt;/sub&gt;×DBAS</td>
<td>-0.03(0.08)</td>
<td>-0.14(0.08)</td>
<td>0.04(0.07)</td>
</tr>
<tr>
<td>Intercept</td>
<td>6.06(0.37)**</td>
<td>6.21(0.39)**</td>
<td>6.99(0.43)**</td>
</tr>
</tbody>
</table>

| R<sup>2</sup>         | .20**        | .16**        | .28**        |

*Note.* DV=Dependent variables; TST=total sleep time, V=vacation, S=start of the term, E=end of the term; ×: interaction; **p<.01.

**4.2.4 Sleep Onset Latency**

Based on correlative analyses, DBAS shared a non-significant relationship with objective and subjective SOL at all time points (see Table 16). There was a trend for higher DBAS to be associated with longer subjective SOL at Time-E (r=.16, p=.06).

Based on moderation analyses (see Table 18), objective SOL, DBAS, and their interaction term accounted for a significant amount of the variance in subjective SOL at all three time points, although the variance accounted for was greater at Time-V (33%) than Time-S (13%) or Time-E (12%). During Time-S and Time-E when sleep opportunity was restricted, the simple effects of objective SOL were significant, whilst there is a trend (p=.10 and .08 for Time-S and Time-E respectively) for higher DBAS to be related to longer subjective SOL. The moderating effects of DBAS were, however, not significant. Parameters of Time-S and Time-E were compared simultaneously using Wald test of parameter constraints, which showed that these parameters were not significantly different (p=.99). This means that the effects of objective SOL, DBAS, and their interaction term on subjective SOL were likely to be equivalent during these two time points. During Time-V with extended sleep opportunity, the simple effect of objective SOL was significant, but that of DBAS was not significant. However, the interaction between objective SOL and DBAS was significant, suggesting that at Time-V, the association between objective and subjective SOL depended upon the levels of DBAS.
Table 18

*Standardized Parameter Estimates (Standard Errors) for Moderation Analyses on Sleep Onset Latency*

<table>
<thead>
<tr>
<th>DV: SOL_psqi</th>
<th>Time-V</th>
<th>Time-S</th>
<th>Time-E</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOL_acti</td>
<td>0.54(0.06)**</td>
<td>0.32(0.09)**</td>
<td>0.31(0.08)**</td>
</tr>
<tr>
<td>DBAS</td>
<td>0.03(0.07)</td>
<td>0.13(0.08), p=.10</td>
<td>0.14(0.08), p=.08</td>
</tr>
<tr>
<td>SOL_acti×DBAS</td>
<td>-0.19(0.07)**</td>
<td>0.03(0.09)</td>
<td>0.05(0.08)</td>
</tr>
<tr>
<td>Intercept</td>
<td>1.00(0.09)**</td>
<td>1.09(0.11)**</td>
<td>1.20(0.11)**</td>
</tr>
</tbody>
</table>

| $R^2$ | .33** | .12* | .13* |

*Note. DV=Dependent variables; SOL= sleep onset latency, V=vacation, S=start of the term, E=end of the term; ×: interaction; *p<.05, **p<.01.*

Simple slope analyses were conducted to further explore the effects of objective SOL on subjective SOL when DBAS was low (one $SD$ below the mean), medium (at the mean), and high (one $SD$ above the mean). Results from all three time points are summarized in Table 19 and effects of high and low DBAS are depicted in Figure 8. For all time points, objective SOL had significant positive association with subjective SOL, irrespective of the level of DBAS. Further, higher DBAS was generally associated with longer subjective SOL. For Time-V where the interaction between objective SOL and DBAS was significant, lower DBAS was associated with higher objective SOL parameter estimates (see Table 19), and therefore stronger effects of objective SOL on subjective SOL.

Table 19

*Parameter Estimate (Standard Errors) from Simple Slope Analyses for the Effects of Objective SOL on Subjective SOL at Low, Medium, and High DBAS*

<table>
<thead>
<tr>
<th>Time-V</th>
<th>Time-S</th>
<th>Time-E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low DBAS (-1 $SD$)</td>
<td>1.51(0.21)**</td>
<td>0.47(0.14)**</td>
</tr>
<tr>
<td>Medium DBAS (M)</td>
<td>1.07(0.14)**</td>
<td>0.51(0.14)**</td>
</tr>
<tr>
<td>High DBAS (+1 $SD$)</td>
<td>0.64(0.21)**</td>
<td>0.54(0.21)*</td>
</tr>
</tbody>
</table>

*Note. SOL=sleep onset latency, DBAS=Dysfunctional Beliefs and Attitudes about Sleep; *p<.05, **p<.01.*
Figure 8 Simple slope analyses for low and high dysfunctional belief about sleep (DBAS) as a moderator in the relationship between objective and subjective sleep onset latency (SOL).
4.3 Summary

The analyses confirmed hypotheses H 2.1 and H2.2, which stated that whilst there were would be significant correlations between objective and subjective sleep, there were also significant differences between them. Participants overestimated TIB, TST, as well as SOL, and these differences were greater during the vacation when sleep was more variable.

Dysfunctional beliefs about sleep did not make a significant direct contribution to subjective TST or SOL during either restricted or extended sleep opportunities. However, during the vacation when sleep opportunity was unrestricted, DBAS interacted significantly with objective SOL, and the effects of objective SOL on subjective SOL were stronger among those with lower DBAS. Significant interaction effects were not found for SOL when sleep opportunity was restricted during school terms, nor for TST during either extended or restricted sleep opportunities. Therefore, hypothesis H 2.3 that DBAS will moderate the relationship between objective and subjective sleep was confirmed for SOL during extended (but not restricted) sleep opportunity, and rejected for TST.
4.4 Discussion

4.4.1 Objective vs. Subjective Sleep

The significant correlation between actigraphy and self-report TIB, TST, and SOL are expected, and consistent with the previously reviewed literature. The two measurements also differed, with self-report values significantly longer than that measured using actigraphy.

The differences between actigraphy versus self-report SOL were relatively small, but subjective SOL was longer than that measured by actigraphy during both vacations and school terms. On one hand, it is possible that in this age group, a combination of decreased sleep propensity and presleep activities such as schoolwork and the use of telecommunication devices at bedtime might have contributed to high physical and mental presleep arousals (e.g., “a tight, tense feeling in your muscles”, “can't shut off your thoughts”). As reported by a study that investigated time-estimating ability in groups of individuals with and without insomnia, in both groups, time overestimation correlated positively with cognitive and physical arousal experienced during the time estimation (Tang & Harvey, 2005). On the other hand, actigraphy SOL was based on the average of daily data, whilst subjective SOL was based on the estimation of what was “typical” over the past week. Such recall might be subjected to intensity and recency biases. For example, a study on global evaluation of pain (Redelmeier & Kahneman, 1996) reported that peak pain (most intense period of pain) and end pain (most recent experience of pain), but not the duration of the painful procedure, were strongly correlated with memory of pain. In the context of sleep perception, it is possible that retrospective recall of SOL was biased by the worst (peak/most intense) and the most recent (end/most recent) night of sleep.

Sleep duration variables TIB and TST, were substantially lower on actigraphy compared to self-report, particularly during the vacation. It is likely that actigraphy registered TIB was more accurate than estimates derived from self-report on questionnaire, because it was largely based on daily RT and BT entered by participants on the actigraphs, whilst self-report reflected recall of typical TIB over the past week. This might also explain the larger discrepancy during vacations (38 min) than school days (11.22 min for Time-S and 11.75 min for Time-E), as sleep-wake behaviours were more variable during vacations. It is likely that the large difference between actigraphy and self-report TST might be related to multiple factors, including inaccuracy in self-report, and a possible underestimation of TST using movement based measurement of sleep.
4.4.2 Dysfunctional Beliefs and Attitudes about Sleep

4.4.2.1 DBAS and ItsCorrelates

In this study, DBAS did not correlate significantly with age, and whilst a small sex difference was found with females endorsing higher DBAS, the difference was not statistically significant. Global cognitive vulnerability measured using DAS made a significant contribution to DBAS, suggesting that participants who endorsed more overall dysfunctional attitudes and beliefs, were also more likely to endorse dysfunctional beliefs about sleep. However, DAS explained <10% of the variance in DBAS, suggesting factors unexamined in this study, such as childhood history of sleep, parental beliefs about sleep (Ng et al., 2012), might have also made meaningful contributions.

Correlational analyses showed that, unlike a previous study that reported that higher DBAS was associated with longer actigraphy SOL (Ng et al., 2012), little relationship was found between DBAS and either objectively or subjectively measured SOL in this study. Higher DBAS was associated with longer objective TST during the vacation and start of the term. One interpretation is that, as a part of the response to the DBAS, those who scored higher on DBAS also had greater concerns regarding not having sufficient sleep, and as a result, were more likely to engage in compensatory/safety behaviours such as spending longer time in bed (Morin & Espie, 2003). Vacation time, with relatively unconstrained sleep opportunity was permissive of such safety behaviours in that individuals have more personal control over bedtimes and rise-times. The start of the term marks the transition from extended to restricted sleep opportunity, and compromises in sleep duration is likely to be perceived as a threat by those with sleep concerns (i.e. higher DBAS), thus the likelihood of safety behaviours such as going to bed early among those with higher DBAS might have contributed to their longer TST. It is also possible that being female was a common cause for the association between higher DBAS and longer TST: as reported in the previous section, being female was associated with significantly longer sleep duration over the vacation period, whilst females were also more likely to score higher on DBAS. Although the latter difference was small in size, it might have also contributed to the positive correlation between DBAS and TST.

4.4.2.2 DBAS and Sleep Perception

Moderation analyses showed that objective TST and SOL were both significant predictors of their respective subjective perception. This is consistent with the evidence that subjective recall provides reasonable estimation of TST and SOL in this age group (Wolfson et al., 2003). Sleep-specific vulnerability (i.e., DBAS) had differential effects on subjective TST and SOL, as well as in restricted and extended sleep opportunities.
In this study, DBAS did not contribute significantly to subjective TST, nor did it moderate the relationship between objective and subjective TST, in either restricted or extended sleep opportunity. This suggests that in a community sample of adolescents, beliefs and attitudes about sleep made little contribution to overall perceived sleep duration. In contrast, the relationship between DBAS and objective and subjective SOL was somewhat complex, and, as discussed in the following paragraphs, depended on whether sleep opportunity was restricted or extended.

**Restricted sleep opportunity.** The non-significant differences in parameter estimates at Time-S and Time-E suggested that the relationships among objective/subjective SOL and DBAS were comparable at both time points when school-related sleep restriction was present. During these restricted sleep opportunities, those with higher DBAS showed a tendency \( p < .1 \) to self-report longer SOL than those with lower DBAS. Although only a small percentage of participants reported a past or current diagnosis of insomnia, symptoms of insomnia are common (e.g., up to 25% in a recent study; Dohnt, Gradisar, & Short, 2012) among adolescents. The association between longer subjective SOL and higher DBAS is consistent with the aforementioned robust finding that individuals with insomnia show higher endorsement of DBAS compared to healthy individuals.

Whilst the association of longer subjective SOL with higher DBAS might be caused by common method variance due to the subjective nature of both measurements (P. M. Podsakoff, MacKenzie, Lee, & Podsakoff, 2003), the following two streams of research might also help interpret this finding. First, the significant contribution of global cognitive vulnerability (i.e., DAS) to sleep-specific cognitive vulnerability (i.e., DBAS) suggests that those who scored higher on DBAS also endorse higher levels of dysfunctional attitudes related to the self and the world more generally. As reviewed previously, higher cognitive vulnerability as measured by DAS has been associated with higher risk for depressive disorders, to which sleep onset difficulties are among the core symptoms. Further, it has been reported that in adolescents, episodes of depression followed bouts of insomnia (Johnson, Roth, & Breslau, 2006), suggesting that in vulnerable individuals, sleep complaints might be an area of particular concern.

Second, individual differences in vulnerability to stress-related sleep disturbance might have played a role. A study on young adults examined the relationship between DBAS and the insomnia response to stress in good \((n=132)\) and bad \((n=307)\) sleepers based on the PSQI (Yang, Chou, & Hsiao, 2011). The authors reported that in both good and bad sleepers, higher DBAS was associated with higher vulnerability to stress-related sleep disturbance as measured by the Ford Insomnia Response to Stress Test (FIRST; Drake, Richardson, Roehrs, Scofield, & Roth, 2004). In a laboratory-based study (Drake et al., 2004), individuals who scored higher in vulnerability on the FIRST had lower SE and longer latency to Stage 1 as well as sustained sleep on the first night of
PSG study; further, on the Multiple Sleep Latency Test\(^3\), high-scoring individuals also showed elevated SOL that was suggestive of physiological arousal, a phenomenon that is consistently demonstrated in patients with insomnia (Bonnet & Arand, 2010). The authors suggested that vulnerability identified using the FIRST on the first night of PSG study may reflect vulnerability to transient sleep disturbance associated with other sleep-disrupting factors (Drake et al., 2004). As will be demonstrated in the next section, the start and the end of a school term were associated with higher levels of life stress compared to vacation periods. Individuals who scored higher on DBAS might also have higher vulnerability to stress-related sleep disturbance, and therefore more likely to experience poorer sleep as indicated in longer SOL in this study.

**Extended sleep opportunity.** As with the data during school terms, the intercept of subjective SOL was higher among those with higher DBAS than those with lower DBAS during the vacation (see Figure 8), suggesting that the association between higher DBAS and longer self-reported SOL was present during both restricted and extended sleep opportunities.

During vacation periods with extended sleep opportunity, DBAS moderated the relationship between objective and subjective SOL. With increasing DBAS, the slope of objective SOL on subjective SOL decreased, suggesting that the effects of objective SOL on subjective SOL were weaker among those with higher DBAS. It is not surprising that those who held stronger dysfunctional attitudes and beliefs about sleep were more biased in their sleep perception, whilst the sleep perception of those who endorsed those beliefs to a lesser degree were more likely to be informed by their actual sleep. This finding is consistent with studies that have consistently shown sleep misperception among insomnia patients who typically score high on the DBAS, highlighting the importance of sleep-specific cognitive vulnerability in subjective perception of SOL.

It is worth noting that across Time-V, Time-S, and Time-E, the slope of objective SOL on subjective SOL (parameter estimates in Table 19 and linear slopes shown in Figure 8) did not vary substantially among those who scored high on DBAS. For participants who scored medium and low on DBAS, however, the slope was substantially (twice for medium- and three times for low-DBAS individuals) larger at Time-V than at Time-S or Time-E. This suggested that the interaction between DBAS and objective SOL at Time-V but not Time-S or Time-E, was mainly caused by low/medium-DBAS individuals having less subjectively biased sleep perception at Time-V compared to Time-S or Time-E, whilst high-DBAS individuals seemed to have similar degrees of sleep misperception across all time points. As suggested by a recent review that aimed to examine evidence for and against a series of resolutions for sleep misperception in insomnia (Harvey &

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\(^3\) The Multiple Sleep Latency Test is considered an objective measurement of daytime sleepiness. The test is typically conducted in a sleep laboratory, and consists of four or five 20-min daytime nap opportunities set two hours apart. Sleep onset latency is measured using PSG and averaged across multiple nap opportunities. Shorter SOL is associated with higher objectively daytime sleepiness.
Tang, 2012), these findings can be interpreted in light of confirmation bias, a tendency to agree with conclusions that fit prior beliefs regardless of actual logical status. The tendency to gather evidence that confirms beliefs rather than evidence that challenges them has been consistently demonstrated in social psychology literature (Nickerson, 1998). Inspired by the notion that individuals have implicit theories of stability and change with respect to the self and that these theories guide the construction of personal histories (Ross, 1989), Harvey and Tang (2012) argued that implicit attribution of stability (or belief) such as “I am a bad sleeper”, may guide the recall of sleep duration and quality obtained. It is possible that those with higher DBAS might have more significant history of poor sleep, hold firmer the belief that poor sleep is a stable and unchangeable feature, and be more inflexible in their perceived sleep regardless of actual sleep quality.

**Restricted versus extended sleep opportunity.** The significant moderating role of DBAS during the vacation but not school terms needs to be interpreted in the context of extended and restricted sleep opportunities in the two conditions. The absence of a moderating effect of DBAS during restricted sleep opportunity might be due to a number of factors.

First, when sleep was restricted, increased sleep propensity as a consequence of accumulated sleep debt during the school week might have made a greater impact on SOL and its subjective perception than individuals’ attitudes and beliefs. When sleep opportunity was ample, the moderating role of DBAS on SOL might be less likely to be masked by the effects of sleep propensity, which was expected to be lower than that during sleep restriction.

A second interpretation is that during restricted sleep opportunity, those with low DBAS showed a bias in subjective SOL that was similar to that of those with higher DBAS, albeit with a lower intercept. As mentioned earlier, concerns regarding school-related sleep restriction and its daytime consequences are commonly reported among adolescents. It is possible that during sleep restricted periods, concerns regarding not obtaining sufficient sleep might have contributed to stronger subjective biases in those who otherwise hold relatively lower DBAS.
5. AIM 3: SLEEP AND MOOD

5.1 Mood and Life Stress across the School Term and Vacation Periods

5.1.1 Analysis Overview

To examine changes in symptoms of depression and anxiety, as well as daily life stress across
the vacation and over the school term, CESD, SCAS, and STRESSOR measured over Time-V,
Time-S, Time-M, and Time-E were assessed using linear latent growth curve (LGC) modelling,
with time scores specified as 0, 2, 6, and 10 respectively. Descriptive statistics of changes over
time for these variables are shown in Table 20 and illustrated in Figure 9. Model specifications and
findings are described in text below, and results are summarized in Table 21.

Table 20

<table>
<thead>
<tr>
<th></th>
<th>Time-V</th>
<th>Time-S</th>
<th>Time-M</th>
<th>Time-E</th>
</tr>
</thead>
<tbody>
<tr>
<td>CESD</td>
<td>11.23(8.40)</td>
<td>12.55(8.67)</td>
<td>12.53(10.08)</td>
<td>13.21(9.29)</td>
</tr>
<tr>
<td>SCAS</td>
<td>19.08(13.56)</td>
<td>17.59(14.00)</td>
<td>16.67(14.12)</td>
<td>23.50(14.84)</td>
</tr>
<tr>
<td>STRESSOR</td>
<td>68.55(19.61)</td>
<td>71.58(19.49)</td>
<td>70.53(19.34)</td>
<td>78.78(19.83)</td>
</tr>
</tbody>
</table>

Notes. CESD, SCAS, and STRESSOR are the total scores of the Centre for Epidemiological Studies Depression, Spence Children’s Anxiety Scale, and the Inventory of High-School Students’ Recent Life Experiences respectively.
5.1.2 Symptoms of Depression

The initial LGC on CESD with a negative variance for the slope factor fixed at 0 provided inadequate fit, $\chi^2(7)=15.92$, $p=.03$, CFI=0.89, SRMR=.09, RMSEA=0.09. Allowing for correlated residuals between Time-V and the three school time points improve model fit significantly with significant change in Chi-square statistics, $\chi^2_{\text{Diff}}(3)=9.43$, $p<.05$, and led to a well-fitted model (CESD M.1 in Table 21). In this model, where all time scores were fixed, the mean of CESD intercept factor was 11.66, and its significant variance suggested individual differences were considerable at Time-V. The mean of the slope factor was 0.17, significantly greater than 0. This suggested that from Time-V to Time-E, there was a small but statistically significant increase in symptoms of depression.

To further assess changes in CESD across school term, the time score for Time-V was freely estimated and the above fitted model was re-estimated (CESD M. 2 in Table 21). This resulted in some improvement in model fit $\chi^2_{\text{Diff}}(1)=2.32$, $p=.13$, suggesting that CESD showed a trend to be lower at Time-V. Unlike CESD M. 1 with Time-V time score fixed, the slope factor was not significantly different from 0 in this model. This indicated that even though the linear increase in CESD from Time-V to Time-E in the previous model was statistically significant, this might be resulted from lower CESD at Time-V, and that the change in CESD over the school term was not significant.
### Table 21

**Parameter Estimates (Standardized Errors) and Fit Statistics for Well-Fitted Latent Growth Models on Mood and Life Stress Across the Vacation and School Term Periods**

<table>
<thead>
<tr>
<th>Model Results</th>
<th>Fit statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\chi^2(df), p$</td>
</tr>
<tr>
<td><strong>CESD M. 1</strong></td>
<td></td>
</tr>
<tr>
<td>Fixed time scores</td>
<td>11.66(0.66)**</td>
</tr>
<tr>
<td>s 0.17(0.06)**</td>
<td>Fixed at 0 (--)</td>
</tr>
<tr>
<td><strong>CESD M. 2</strong></td>
<td></td>
</tr>
<tr>
<td>Free Time-V</td>
<td>12.46(0.83)**</td>
</tr>
<tr>
<td>s 0.07(0.09)</td>
<td>Fixed at 0 (--)</td>
</tr>
<tr>
<td><strong>SCAS</strong></td>
<td></td>
</tr>
<tr>
<td>Free Time-E</td>
<td>18.81(1.10)**</td>
</tr>
<tr>
<td>s -0.22(0.14)</td>
<td></td>
</tr>
<tr>
<td><strong>STRESSOR M.1</strong></td>
<td></td>
</tr>
<tr>
<td>Fixed time scores</td>
<td>68.58(1.52)**</td>
</tr>
<tr>
<td>s 0.95(0.11)**</td>
<td>Fixed at 0 (--)</td>
</tr>
<tr>
<td><strong>STRESSOR M.2</strong></td>
<td></td>
</tr>
<tr>
<td>Free Time-M</td>
<td>68.98(1.54)**</td>
</tr>
<tr>
<td>s 1.06(0.11)**</td>
<td>Fixed at 0 (--)</td>
</tr>
</tbody>
</table>

*Note.* Unstandardized results were reported to assist interpretation. CESD, SCAS, and STRESSOR are the total scores of the Centre for Epidemiological Studies Depression, Spence Children’s Anxiety Scale, and the Inventory of High-School Students’ Recent Life Experiences respectively. $\sigma^2 =$ variance, RMSEA= Root Means Square Error of Approximation, CI= confidence interval, CFI= Comparative Fit Index, SRMR= Root Means Square Error of Approximation. **p<.01 significantly different from 0.

#### 5.1.3 Symptoms of Anxiety

A linear LGC over four time points with fixed time scores provided an inadequate fit to the data, $\chi^2(5)=27.90, p<.01$, CFI=0.90, SRMR=.10, RMSEA=0.18. Modification by freely estimating the time score at Time-E revealed negative variance of the slope factor, which when fixed at 0, did not lead to model convergence. Allowing for correlated residuals between Time-S and Time-M improved fit significantly, $\chi^2_{Diff}(2)=18.96, p<.01$, and led to a positive slope factor variance as well as an excellent model fit, $\chi^2(3)=3.86, p=.28$, CFI=1.00, SRMR=.03, RMSEA=.04. In this final model, the intercept mean was 18.81 and its significant variance suggested large individual differences in symptoms of anxiety at Time-V. The mean of the slope factor was -0.22, which was not significantly different from 0, suggesting that across Time-V, Time-S, and Time-M, symptoms
of anxiety did not vary significantly. Freely estimated time score of Time-E was -21.96, indicating that despite small changes in anxiety symptoms across earlier three time points, Time-E was associated with significantly elevated symptoms of anxiety.

5.1.4 Life Stress

A linear LGC over four time points with fixed time scores and negative slope variance fixed at 0 provided adequate fit to the data (STRESSOR M.1 in Table 21). The intercept mean was 68.58, and its significant variance suggested considerable individual differences at Time-V. The mean of the slope factor was 0.95, significantly greater than 0, which suggested that there was an overall increase in daily life stress from Time-V to Time-E.

To further examine changes in life stress across the school term, time scores for Time-M were freely estimated and the above model re-estimated. This resulted in significant improvement of model fit, $\chi^2_{\text{Diff}}(1) = 22.56, p<.01$, and excellent overall fit of the final model (STRESSOR M.2 in Table 21). Time score for Time-M was estimated at 1.75, close to that of Time-S, which was fixed at 2. This suggested that even though daily life stress increased from Time-V to Time-E overall, the change from Time-S to Time-M was small, and that increases in life stress occurred from Time-V to Time-S, and then again from Time-M to Time-E.
5.2 Effects of Objective versus Subjective Sleep on Mood

5.2.1 Analysis Overview

First, correlation matrices were used to visually explore the relationships between objective versus subjective sleep and mood at all four time points. Correlations were based on Pearson correlation with missing data addressed using FIML. Multiple regression analyses were then used to further examine these relationships quantitatively. Analyses were conducted cross-sectionally for each time point, with the dependent variable being the total scores of CESD or SCAS. Independent variables were selected sleep variables measured using actigraphy for objective sleep, and the PSQI for subjective sleep. The selection of these variables was based on theoretical considerations, and the requirement that each included variable represents a conceptually unique aspect of sleep-wake behaviours. Actigraphy sleep variables included: TST_{acti}, BT_{acti}, RT_{acti}, SOL_{acti}, and SE_{acti}. In addition, a measure reflecting sleep restriction was calculated by subtracting Time-S or Time-E TST from that of Time-V, and included in the regression analyses conducted for Time-S and Time-E. Subjective sleep variables were: TST_{psqi}, SOL_{psqi}, SD_{psqi}, and DD_{psqi}. As SE_{psqi} and SQ_{psqi} assess the overall quality of sleep, they were not included to avoid multicolinearity.

Statistical diagnostic analyses showed the absence of collinearity and heteroscedasticity, as well as reasonable normal distributions of residuals for all regression analyses reported below.

5.2.2 Correlation Matrices

Correlation matrices for objective sleep, subjective sleep, and mood at Time-V, Time-S, Time-E, and Time-M are displayed in Figure 10, Figure 11, Figure 12, and Figure 13 respectively. In each figure, variable names are displayed in the x and y axes with corresponding correlation coefficients displayed in individual cells. Positive correlations between variables are coloured red, whilst negative correlations are coloured blue. Darker colours indicate stronger positive or negative correlations.

At each time point, total scores of CESD and SCAS shared a stronger relationship with subjective than objective sleep. This is evident in the higher correlation coefficients (darker shades) between mood and subjective sleep variables compared to objective ones. These associations were further examined using multiple regression analyses.
Figure 10 Correlation matrices for objective sleep, subjective sleep, and mood at Time-V.
Aim 3: Sleep and Mood

Figure 11 Correlation matrices for objective sleep, subjective sleep, and mood at Time-S
**Aim 3: Sleep and Mood**

**Figure 12** Correlation matrices for objective sleep, subjective sleep, and mood for Time-E.

---

**Time-E Objective Sleep and Mood**

<table>
<thead>
<tr>
<th></th>
<th>CESD</th>
<th>SCAS</th>
<th>Btacti</th>
<th>Rtacti</th>
<th>Tsacti</th>
<th>Restriction</th>
<th>Solacti</th>
<th>Sectl</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEacti</td>
<td>.16</td>
<td>.02</td>
<td>.00</td>
<td>.12</td>
<td>.44</td>
<td>.03</td>
<td>.46</td>
<td></td>
</tr>
<tr>
<td>SOLacti</td>
<td>.20</td>
<td>.14</td>
<td>.08</td>
<td>.08</td>
<td>.10</td>
<td>.01</td>
<td>.46</td>
<td></td>
</tr>
<tr>
<td>Restriction</td>
<td>.02</td>
<td>.08</td>
<td>.38</td>
<td>.05</td>
<td>.43</td>
<td>.01</td>
<td>.03</td>
<td></td>
</tr>
<tr>
<td>Tsacti</td>
<td>.11</td>
<td>.02</td>
<td>.64</td>
<td>.07</td>
<td>.43</td>
<td>.10</td>
<td>.44</td>
<td></td>
</tr>
<tr>
<td>Rtacti</td>
<td>.02</td>
<td>.05</td>
<td>.58</td>
<td>.07</td>
<td>.05</td>
<td>.08</td>
<td>.12</td>
<td></td>
</tr>
<tr>
<td>Btacti</td>
<td>.03</td>
<td>.38</td>
<td>.58</td>
<td>.64</td>
<td>.38</td>
<td>.08</td>
<td>.00</td>
<td></td>
</tr>
<tr>
<td>Scas</td>
<td>.64</td>
<td>.06</td>
<td>.05</td>
<td>.02</td>
<td>.08</td>
<td>.14</td>
<td>.02</td>
<td></td>
</tr>
<tr>
<td>CESD</td>
<td>.64</td>
<td>.03</td>
<td>.02</td>
<td>.11</td>
<td>.02</td>
<td>.20</td>
<td>.16</td>
<td></td>
</tr>
</tbody>
</table>

**Time-E Subjective Sleep and Mood**

<table>
<thead>
<tr>
<th></th>
<th>CESD</th>
<th>SCAS</th>
<th>Tspsqi</th>
<th>Solspsi</th>
<th>Dpsqi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ddpsqi</td>
<td>.38</td>
<td>.29</td>
<td>.27</td>
<td>.03</td>
<td>.19</td>
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<tr>
<td>Dpsqi</td>
<td>.50</td>
<td>.50</td>
<td>.18</td>
<td>.19</td>
<td>.19</td>
</tr>
<tr>
<td>Solspsi</td>
<td>.18</td>
<td>.13</td>
<td>.04</td>
<td>.19</td>
<td>.03</td>
</tr>
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<td>Tspsqi</td>
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<td>.05</td>
<td>.04</td>
<td>.18</td>
<td>.27</td>
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<td>.64</td>
<td>.05</td>
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<td>.64</td>
<td>.14</td>
<td>.18</td>
<td>.50</td>
<td>.38</td>
</tr>
</tbody>
</table>

**Correlation**

- +1
- +.5
- 0
- -.5
- -1
Figure 13 Correlation matrix for subjective sleep and mood at Time-M (objective sleep unavailable for this time point).
5.2.3 **Objective Sleep and Mood**

As summarized in Table 22, the selected objective sleep variables did not make significant contributions to depressive symptoms during Time-V or Time-S, explaining only 4% of the variance in CESD at each time point. During Time-E, objective sleep made a small but statistically significant contribution to symptoms of depression, such that longer SOL was associated with significantly higher levels of depressive symptoms.

**Table 22**

*Parameter Estimates (Standard Errors) and Results Summary for Multiple Regression Analyses Predicting Symptoms of Depression Using Objective Sleep Variables*

<table>
<thead>
<tr>
<th>Parameter Estimates (Standard Errors)</th>
<th>DV: CESD</th>
<th>Time-V</th>
<th>Time-S</th>
<th>Time-E</th>
</tr>
</thead>
<tbody>
<tr>
<td>TST&lt;sub&gt;acti&lt;/sub&gt;</td>
<td>0.08(0.10)</td>
<td>0.00(0.03)</td>
<td>0.00(0.08)</td>
<td></td>
</tr>
<tr>
<td>Restriction&lt;sub&gt;acti&lt;/sub&gt;</td>
<td>--</td>
<td>0.02(0.02)</td>
<td>0.00(0.02)</td>
<td></td>
</tr>
<tr>
<td>BT&lt;sub&gt;acti&lt;/sub&gt;</td>
<td>0.05(0.08)</td>
<td>-0.02(0.02)</td>
<td>0.02(0.06)</td>
<td></td>
</tr>
<tr>
<td>RT&lt;sub&gt;acti&lt;/sub&gt;</td>
<td>-0.05(0.07)</td>
<td>0.03(0.03)</td>
<td>-0.01(0.07)</td>
<td></td>
</tr>
<tr>
<td>SOL&lt;sub&gt;acti&lt;/sub&gt;</td>
<td>0.02(0.06)</td>
<td>0.03(0.06)</td>
<td>0.14(0.07)*</td>
<td></td>
</tr>
<tr>
<td>SE&lt;sub&gt;acti&lt;/sub&gt;</td>
<td>-0.46(0.54)</td>
<td>-0.13(0.17)</td>
<td>-0.15(0.43)</td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td>21.24(18.56)</td>
<td>18.16(14.66)</td>
<td>24.81(16.36)</td>
<td></td>
</tr>
<tr>
<td>F(df)</td>
<td>0.93(5, 121)</td>
<td>0.86(6, 120)</td>
<td>2.35(6, 120)*</td>
<td></td>
</tr>
<tr>
<td>R&lt;sup&gt;2&lt;/sup&gt;</td>
<td>0.04</td>
<td>0.04</td>
<td>0.11*</td>
<td></td>
</tr>
</tbody>
</table>

*Note.* All sleep variables were based on actigraphy measures. TST=total sleep time, Restriction=sleep restriction calculated by subtracting Time-S or Time-E TST from that of Time-V, BT=bedtime, RT=rise-time, SOL=sleep onset latency, SE=sleep efficiency; *p<.05, **p<.01.

As shown in Table 23, objective sleep variables made a statistically significant contribution to symptoms of anxiety at all three time points, explaining 14%, 10%, and 11% of the variance in total scores of SCAS at Time-V, Time-S, and Time-E respectively. Regression coefficients showed that at all time points, SOL was the variable that had the most unique effect. This is particularly the case at Time-V when longer SOL was associated with significantly higher symptoms of anxiety. For both Time-S and Time-E, the unique effects of individual variables were not statistically significant, although the overall effect of objective sleep was statistically significant.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Time-V</th>
<th>Time-S</th>
<th>Time-E</th>
</tr>
</thead>
<tbody>
<tr>
<td>TST&lt;sub&gt;acti&lt;/sub&gt;</td>
<td>0.21(0.13)</td>
<td>0.02(0.08)</td>
<td>0.05(0.15)</td>
</tr>
<tr>
<td>Restriction&lt;sub&gt;acti&lt;/sub&gt;</td>
<td>--</td>
<td>0.02(0.04)</td>
<td>0.03(0.03)</td>
</tr>
<tr>
<td>BT&lt;sub&gt;acti&lt;/sub&gt;</td>
<td>0.13(0.10)</td>
<td>-0.04(0.05)</td>
<td>0.02(0.12)</td>
</tr>
<tr>
<td>RT&lt;sub&gt;acti&lt;/sub&gt;</td>
<td>-0.14(0.10)</td>
<td>0.01(0.06)</td>
<td>-0.05(0.13)</td>
</tr>
<tr>
<td>SOL&lt;sub&gt;acti&lt;/sub&gt;</td>
<td>0.21(0.09)*</td>
<td>0.12(0.11), p=.28</td>
<td>0.20(0.12), p=.10</td>
</tr>
<tr>
<td>SE&lt;sub&gt;acti&lt;/sub&gt;</td>
<td>-1.01(0.79)</td>
<td>-0.14(0.37)</td>
<td>-0.15(0.79)</td>
</tr>
<tr>
<td>Intercept</td>
<td>29.70(29.70)</td>
<td>16.94(21.03)</td>
<td>14.54(29.59)</td>
</tr>
</tbody>
</table>

**Note.** All sleep variables were based on actigraphy measures. TST=total sleep time, Restriction= sleep restriction calculated by subtracting Time-S or Time-E TST from that of Time-V, BT=bedtime, RT=rise-time, SOL=sleep onset latency, SE=sleep efficiency; *p<.05, **p<.01.
5.2.4  Subjective Sleep and Mood

As shown in Table 24, selected subjective sleep variables made significant contributions to symptoms of depression at each time point, explaining 19% of the variance in CESD during Time-V, and around 30% for all three school term time points. This suggests that perception of sleep might be more strongly associated with symptoms of depression during school terms than during the vacation. At each time point, the two subjective sleep variables that contributed significantly to the significant sleep and mood association, were SD_{psqi} and DD_{psqi}, with greater sleep disturbance and higher sleep related daytime dysfunction associated with high levels of depressive symptoms.

Table 24
Parameter Estimates (Standard Errors) and Results Summary for Multiple Regression Analyses Predicting Symptoms of Depression Using Subjective Sleep Variables

<table>
<thead>
<tr>
<th>DV: CESD</th>
<th>Time-V</th>
<th>Time-S</th>
<th>Time-M</th>
<th>Time-E</th>
</tr>
</thead>
<tbody>
<tr>
<td>TST_{psqi}</td>
<td>0.00(0.01)</td>
<td>0.00(0.02)</td>
<td>-0.02(0.02)</td>
<td>-0.01(0.02)</td>
</tr>
<tr>
<td>SOL_{psqi}</td>
<td>0.02(0.03)</td>
<td>0.08(0.05)</td>
<td>0.04(0.08)</td>
<td>0.06(0.06)</td>
</tr>
<tr>
<td>SD_{psqi}</td>
<td>0.93(0.25)**</td>
<td>0.86(0.37)*</td>
<td>1.14(0.38)*</td>
<td>1.32(0.46)*</td>
</tr>
<tr>
<td>DD_{psqi}</td>
<td>2.69(1.22)*</td>
<td>3.05(1.25)*</td>
<td>4.16(1.67)*</td>
<td>4.24(1.31)**</td>
</tr>
<tr>
<td>Intercept</td>
<td>5.24(3.91)</td>
<td>6.73(7.62)</td>
<td>13.53(11.99)</td>
<td>9.49(7.35)</td>
</tr>
<tr>
<td>F(4, 117)</td>
<td>6.72**</td>
<td>12.40**</td>
<td>11.10**</td>
<td>14.72**</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.19**</td>
<td>0.30**</td>
<td>0.28**</td>
<td>0.33**</td>
</tr>
</tbody>
</table>

Note. All sleep variables were based on the Pittsburgh Sleep Quality Index. TST=total sleep time, SOL=sleep onset latency, SE=sleep efficiency, SD=sleep disturbance, DD=sleep related daytime dysfunction; *p<.05, **p<.01.

As shown in Table 25, selected subjective sleep variables collectively made a significant contribution to symptoms of anxiety at all time points, explaining 24%-41% of the variance. The highest percentage variance in SCAS was explained by subjective sleep at Time-S, suggesting perception of sleep had a strong association with symptoms of anxiety early in the school term. Similar to findings on depressive symptoms, SD_{psqi} contributed significantly to the sleep and anxiety association at all time points, whilst DD_{psqi} only contributed significantly at Time-S and Time-E. TST_{psqi} and SOL_{psqi} were not found to be statistically significant predictors of anxiety symptoms when SD_{psqi} and DD_{psqi} were also included in the regression.
### Table 25

*Parameter Estimates (Standard Errors) and Results Summary for Multiple Regression Analyses Predicting Symptoms of Anxiety Using Subjective Sleep Variables*

<table>
<thead>
<tr>
<th>Parameter Estimate</th>
<th>Time-V (SE)</th>
<th>Time-S (SE)</th>
<th>Time-M (SE)</th>
<th>Time-E (SE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TST&lt;sub&gt;psqi&lt;/sub&gt;</td>
<td>0.00(0.01)</td>
<td>0.03(0.03)</td>
<td>0.01(0.04)</td>
<td>0.01(0.02)</td>
</tr>
<tr>
<td>SOL&lt;sub&gt;psqi&lt;/sub&gt;</td>
<td>0.05(0.04)</td>
<td>0.03(0.06)</td>
<td>0.03(0.08)</td>
<td>0.01(0.08)</td>
</tr>
<tr>
<td>SD&lt;sub&gt;psqi&lt;/sub&gt;</td>
<td>1.86(0.41)**</td>
<td>2.81(0.55)**</td>
<td>2.32(0.67)*</td>
<td>2.10(0.43)**</td>
</tr>
<tr>
<td>DD&lt;sub&gt;psqi&lt;/sub&gt;</td>
<td>3.26(1.89)</td>
<td>4.80(1.58)**</td>
<td>2.79(2.43)</td>
<td>5.21(2.05)*</td>
</tr>
<tr>
<td>Intercept</td>
<td>8.02(6.49)</td>
<td>-10.83(12.03)</td>
<td>4.78(21.03)</td>
<td>10.18(10.33)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Time-V</th>
<th>Time-S</th>
<th>Time-M</th>
<th>Time-E</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>9.09**</td>
<td>20.69**</td>
<td>12.68**</td>
<td>9.40**</td>
</tr>
<tr>
<td>R²</td>
<td>0.24**</td>
<td>0.41**</td>
<td>0.30**</td>
<td>0.24**</td>
</tr>
</tbody>
</table>

*Note.* All sleep variables were based on the Pittsburgh Sleep Quality Index. TST=total sleep time, SOL=sleep onset latency, SE=sleep efficiency, SD=sleep disturbance, DD=sleep related daytime dysfunction; *p<.05, **p<.01.
5.3 Summary

Analyses of the changes in CESD, SCAS, and STRESSOR across the vacation and the three school term time points suggested that (a) symptoms of depression were lower during the vacation compared to school terms, whilst its change over the school term was not significant; (b) symptoms of anxiety were highest at the end of a school term, whilst its changes over the vacation and the early to middle part of the school term were not significant; (c) overall, levels of life stress increased linearly from the vacation to the end of the school term, with changes from the start to middle of the school term being small. Therefore hypothesis H 4.1 that symptoms of depression and anxiety will be lowest at Time-V, followed by Time-S, and highest at Time-E was partially confirmed, whilst hypothesis H 4.2 that life stress will be lowest at Time-V, followed by Time-S and Time-M, and highest at Time-E was confirmed.

Overall, both objective and subjective sleep were shown to be associated with mood, although subjective sleep variables shared a stronger relationship with mood than objective sleep variables. Objective sleep shared a stronger relationship with anxiety symptoms than with depressive symptoms, and longer objective SOL was significantly associated with higher levels of depression at Time-E and higher levels of anxiety at Time-V. Subjective sleep variables, on the other hand, made significant contributions to symptoms of both depression and anxiety, with sleep disturbance and sleep-related daytime dysfunction being the most significant predictors. Therefore, hypotheses H 3.1 and H 3.2 with regards to the relationship between objective/subjective sleep and mood were partially confirmed.
5.4 Discussion

5.4.1 Changes in Mood and Life Stress

To the best of my knowledge, there has not been a previous study that examined changes in symptoms of depression, anxiety, or life stress over the school term and vacation periods in adolescents using a within subjects longitudinal design. Findings in the current study suggest that adolescents’ experiences with these constructs are not static, but change dynamically over the school term and vacation periods.

5.4.1.1 Life Stress

The observation that life stress was lower during the vacation and higher during the school term, is consistent with the body of literature that has shown school to be a major contributing factor to life stress in adolescents (Ang & Huan, 2006; Torsheim & Wold, 2001). Life stress changed minimally from the start to the middle of the school term, but increased substantially towards the end of the school term. Whilst it is beyond the scope of this thesis to examine the specific types of life stress that might have contributed to this increase, it is reasonable to speculate that school exams that typically occur at the end of the school term might have contributed to this. One study that assessed adolescents at one-month prior, during, and 2-3 weeks after exams showed that exams were salient causes of stress-related immune responses (Kang, Coe, & McCarthy, 1996).

5.4.1.2 Symptoms of Anxiety

Symptoms of anxiety were comparably low during the vacation, start of the term, and middle of the term, but increased substantially at the end of the school term. This increase can be interpreted in the context of an increase in life stress that are likely caused by higher academic demands, which have been associated with higher levels of anxiety symptoms in high-school students (Wahab et al., 2013). Examinations, in particular, typically occur at the end of school terms, and have been associated with significant increases in anxiety as well as stress-related physiological reactions, especially during the anticipation/preparation phase (Spangler, Pekrun, Kramer, & Hofmann, 2002; Stöber, 2004).

It is worth noting that although, on average, the total score of SCAS ($M=23.50$, $SD=14.84$) at the end of the school term was about 40% above the middle of the school term, it was nevertheless within the normal range ($\leq 32$ for males and $\leq 38$ for females). It is not clear whether such degrees of increase in anxiety would lead to impairment in functioning. Although on the other hand,
evidence suggests that a mild increase in arousal under certain circumstances could facilitate problem solving and help mobilize internal and external resources (Teigen, 1994).

5.4.1.3 Symptoms of Depression

Symptoms of depression were lower during the vacation than during the school term, but this difference was small. Further, total scores of CESD did not change significantly over the school term, suggesting an overall stability of depressive symptoms throughout the vacation and school term periods. This is consistent with a number of longitudinal studies that demonstrated overall stability of depressive symptoms during both long and short follow-ups in adolescents. A 6-year longitudinal study which investigated the absolute and relative stability in depressed mood on a sample of 538 adolescents between 13 and 19 years, found a tendency for adolescents to retain relative level in depressed mood, particularly from age 15 to 19 years (Holsen, Kraft, & Vittersø, 2000). A recent population study on 2230 adolescents confirmed this finding and reported that anhedonia and depressed mood, two key components of depressive symptoms, were stable across the age of 11 and 19 (Bennik, Nederhof, Ormel, & Oldehinkel, 2013). More pertinent to findings in this study is a study that assessed the stability of depressive symptoms in 268 young adolescents (mean age 13) at three time points over six months (Charman, 1994). In this study, the levels of depressive symptoms as measured across a range of scales were stable overall, including in a subgroup that scored high on symptom severity, suggesting a stably depressed mood similar to that found in clinical populations (Charman, 1994). It is worth noting that in this study (Charman, 1994), the levels of depressive symptoms were low on average (mean CESD around 11-13). This is consistent with the findings in a longitudinal epidemiological study that although depressive symptoms were common among adolescents, most of those with minimal symptoms (CESD < 16) maintained their status at one year follow-up (Rushton, Forcier, & Schectman, 2002).

5.4.2 Sleep and Mood

Variance in depressive and anxiety symptoms accounted for by objective sleep variables was 4-11% and 10-14% respectively, compared to substantially higher 19-33% and 24-41% accounted for by subjective sleep variables. This is consistent with both adolescent (Moore et al., 2009) and adult (Bei, Milgrom, Ericksen, & Trinder, 2010) literature that perception of sleep shares a stronger relationship with mood than its objective duration and quality.

The following paragraphs discuss findings specific to objective and subjective sleep on mood.
5.4.2.1  **Objective Sleep**

During the vacation and the start of the term, objective sleep variables were not significantly associated with symptoms of depression, whilst at the end of the school term, longer objective SOL was associated with significantly higher levels of depression. In light of higher life stress at the end of the school term, it is possible that in response to stressors, those who were at greater risk for depression were more likely to engage in bedtime rumination, which has been shown in children (aged 8 - 10) to contribute to higher presleep cognitive arousals and longer SOL (Gregory, Willis, Wiggs, Harvey, & STEPS Team, 2008), and in adolescents to exacerbate symptoms of depression (Hyde, Mezulis, & Abramson, 2008). This finding also suggested that when life stress is relatively low, the impact of school-related sleep restriction on depressive symptoms might be relatively small, and that life stress, either alone or combined with sleep restriction, might play a more important role than the duration or quality of objective sleep per se.

Overall, objective sleep variables made significant contributions to symptoms of anxiety during both school term and vacation periods. At all time points, SOL was the sleep variable that made the most unique contribution, with longer SOL associated with higher symptoms of anxiety. This is consistent with the findings that adolescents with anxiety disorders tend to have longer objective SOL compared to healthy controls (Forbes et al., 2008; Rapoport et al., 1981). The parameter estimate of SOL on anxiety symptoms was statistically significant for the vacation but not for school terms, suggesting stronger association between objective SOL and anxiety symptoms when sleep opportunities were extended than restricted. It is possible that lower constraints on sleep timing and longer TIB were permissive of cognitive-behavioural processes, such as bedtime ruminations, that could contribute to higher anxiety.

5.4.2.2  **Subjective Sleep**

The strong relationship between subjective sleep variables and mood is consistent with previously reviewed literature in both adults and adolescents (Rosen, Gimotty, Shea, & Bellini, 2006; Warner, Murray, & Meyer, 2008). Sleep disturbance and sleep-related daytime dysfunction were variables that made the most unique contributions to symptoms of depression and anxiety. Although the stronger relationship between subjective sleep when compared to objective sleep and mood might also be due to common method biases (Podsakoff et al., 2003), these findings suggest that perception of sleep quality and its impact on daytime functioning are the key areas of sleep concerns that affect adolescents’ psychological wellbeing.

Higher sleep disturbance and sleep-related daytime dysfunction were associated with higher symptoms of depression at all time points. As reviewed earlier, it is possible that those who
experience higher levels of psychopathology were more likely to have higher levels of sleep disturbance. On the other hand, it is also possible that those who evaluate sleep quality more negatively were more likely to also report more negative mood states.

As for symptoms of depression, higher sleep disturbance was associated with higher anxiety symptoms at all time points. Higher sleep-related daytime dysfunction was associated with higher anxiety symptoms at Time-S and Time-E but not Time-V or Time-M. The lack of significant association at Time-V might be due to lower sleep-related daytime dysfunction as a consequence of extended sleep opportunity as previously demonstrated. Findings during the school term time points can be interpreted from several perspectives. As demonstrated previously, compared to other time points, SOL was longer and TST shorter at the start of the school term, when adolescents made transition from extended to restricted sleep opportunities. This suggests that Time-S is associated with a rapid build up of sleep debt and its daytime consequences. These changes, together with an increase in overall life stress as adolescents enter a school term, might be particularly challenging and anxiety provoking. The significant association between higher sleep-related daytime dysfunction and anxiety symptoms at Time-E could be interpreted in the context of higher life stress at that time. It is possible that at the end of a school term when adolescents were more likely to be challenged by stressors such as exams, impairments to daytime functioning such as ability to concentrate, might be particularly anxiety provoking.

5.4.2.3 Sleep Duration/Timing versus Sleep Quality

Amongst the objective and subjective sleep variables examined, sleep quality, but not duration or timing variables, were found to have made unique contributions to mood. During the vacation with extended sleep opportunity, the lack of relationship between sleep duration and timing with mood was not surprising, as the effects of insufficient sleep on mood was expected to be small at a time when adolescents were likely to follow preferred sleep/wake timing and obtain adequate sleep. During school terms with restricted sleep opportunity, however, findings in this study were somewhat inconsistent with the body of adolescent literature that showed significant associations between insufficient sleep, later sleep timing, and poorer psychological wellbeing.

First, as reviewed earlier, most studies that found such relationship measured sleep subjectively, and the findings regarding objective sleep duration/timing and mood have been mixed and inconclusive (Moore et al., 2009). Second, sleep duration/timing during the school term in a relatively healthy sample of adolescents in this study, was likely to be predominantly affected by school starting time, a non-psychological factor. This might also lead to a weak relationship between sleep duration/timing and mood. Third, the role of subjective sleep duration was examined together with other subjective sleep variables. It is possible that the variance in mood accounted for
by TST$_{psq}$ was also accounted for by other variables such as SD$_{psq}$ and DD$_{psq}$, which had strong and unique effects on mood that overshadowed the effects of subjective sleep duration.

The differential effects of sleep duration/timing versus sleep quality on mood in this study highlighted the importance of examining different aspects of sleep in the adolescent population. The association between worse mood and poorer sleep quality, particularly perceived sleep quality, suggested that psychological processes that influence one’s evaluation of sleep might have particular relevance to the mechanism through which subjective sleep affects mood. One of these processes, dysfunctional attitudes, is examined in the next section as a moderator in the strong subjective sleep—mood relationship reported in this section.
AIM 4: SUBJECTIVE SLEEP, MOOD, AND COGNITIVE VULNERABILITY

6.1 Analysis Overview

To examine the relationship between subjective sleep and mood, and how cognitive vulnerability, as measured by the Dysfunctional Attitudes Scale (DAS), played a role in this relationship, the three school time points and the vacation time point were analyzed separately. This allowed the relationship between these variables to be examined under restricted and extended sleep opportunities.

In order to arrive at an overall representation of subjective sleep quality, SOL_{psqi}, SD_{psqi}, SQ_{psqi}, and DD_{psqi} were first standardized as z-scores. Standardization for school term variables was based on the mean and standard deviation for collective observations from all three school term time points; standardization for the vacation was based on the mean and standard deviation obtained from the vacation time point. For each time point, z-scores of the four subjective sleep components were summed to produce a composite score SUBJ, which represented overall subjective sleep quality. The sleep duration component (TST_{psqi}) was not included in this measure and the effects of restricted and extended sleep opportunity were examined in separate analyses of school term and the vacation time points.

For the three school term time points, the following two steps were performed separately on the two mood scales, with CESD and SCAS as dependent variables: 1) Mood at the three time points were fitted to a linear latent growth model as the base model; 2) STRESSOR measured at three time points was added as a time-varying covariate so that the effects of STRESSOR on Mood at each time point was controlled; SUBJ at three time points was added as a time-varying covariate with a random slope; the growth factors of Mood (i.e., intercept and slope) and the random slope of SUBJ was regressed on DAS, so that the effects of DAS on the changes in Mood (after controlling for STRESSOR and SUBJ), as well as on the strength of the relationship between SUBJ and Mood could be examined. The path diagram of the final model with both steps is illustrated in Figure 14, and detailed model specifications have been described below.

For the vacation time point, which consisted of cross-sectional data, two separate moderated regression analyses were performed, with the dependent variable being CESD or SCAS, and independent variables being STRESSOR, SUBJ, DAS, and the interaction term of SUBJ and DAS.
Figure 14 Latent growth curve model examining the relationships among mood, subjective sleep, life stress, and dysfunctional attitude (DAS) across school terms. Squares indicate observed variables, circles indicate latent variables, solid lines from one variable to another indicate regression paths, arrows pointing to a variable from no other variable represent variances or residual variances, dotted arrows represent random slopes.
6.2 The School Term Period

6.2.1 Symptoms of Depression

The base latent growth model for CESD across Time-S, Time-M, and Time-E with time scores specified as 0, 1, 2, provided excellent fit without any modification, $\chi^2(1)=0.003, p=.96$, CFI=1.00, SRMR=.001, RMSEA=0.00. As shown in Table 26, the fact that the slope factor was not significantly different from 0 suggested that symptoms of depression did not change significantly across the school term. This is consistent with findings from the previous section where changes were examined across both the vacation and school term time points. Time-varying covariates SUBJ and STRESSOR were added to this base model, and the random slope of SUBJ, as well as the growth factors of CESD, were regressed on DAS (see results summarized in Table 27). In this model, higher STRESSOR was significantly associated with higher symptoms of depression at all time points (all $p<.01$). Initial status of CESD was not significantly associated with DAS, but the slope factor was. This suggested that after controlling for STRESSOR and SUBJ, higher DAS was associated with a greater increase in CESD across school terms. The random slope of SUBJ was not significantly associated with DAS, suggesting that DAS did not play a significant role in the association between subjective sleep and symptoms of depression across school terms.

Table 26

*Parameter Estimates (Standard Errors) of Growth Factors for Base Latent Growth Models of Mood Across School Terms*

<table>
<thead>
<tr>
<th></th>
<th>CESD</th>
<th>SCAS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>$\sigma^2$</td>
</tr>
<tr>
<td>Intercept</td>
<td>12.57(0.73)**</td>
<td>74.40(14.07)**</td>
</tr>
<tr>
<td>Slope</td>
<td>0.28(0.35)</td>
<td>12.88(5.33)**</td>
</tr>
</tbody>
</table>

*Note.* CESD and SCAS are the total scores of the Centre for Epidemiological Studies Depression and Spence Children’s Anxiety Scale respectively; $\sigma^2$=variance; *$p<.05$, **$p<.01$. 
Table 27
*Unstandardized Parameter Estimates (Standard Errors) for Latent Growth Models Examining the Relationships Amongst Mood, Subjective Sleep, Life Stress, and Dysfunctional Attitude during School Terms*

<table>
<thead>
<tr>
<th>DV</th>
<th>CESD</th>
<th>SCAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept of DV ON DAS</td>
<td>0.02(0.02)</td>
<td>0.03(0.03)</td>
</tr>
<tr>
<td>Slope of DV ON DAS</td>
<td>0.02(0.01)*</td>
<td>0.04(0.02)*</td>
</tr>
<tr>
<td>Random slope of SUBJ ON DAS</td>
<td>0.00(0.01)</td>
<td>0.012(0.006)*</td>
</tr>
<tr>
<td>Time-S</td>
<td>0.14(0.03)**</td>
<td>0.29(0.04)**</td>
</tr>
<tr>
<td>STRESSOR ON DV Time-M</td>
<td>0.19(0.03)**</td>
<td>0.24(0.04)**</td>
</tr>
<tr>
<td>Time-E</td>
<td>0.20(0.03)**</td>
<td>0.28(0.04)**</td>
</tr>
</tbody>
</table>

*Note. DV=Dependent variable; CESD, SCAS, DAS, and STRESSOR are the total scores of the Centre for Epidemiological Studies Depression, Spence Children’s Anxiety Scale, Dysfunctional Attitude Scale, and the Inventory of High-School Students’ Recent Life Experiences respectively; SUBJ=Subjective Sleep; *p<.05, **p<.01.*

6.2.2 Symptoms of Anxiety

The base latent growth model for SCAS across Time-S, Time-M, and Time-E with time scores specified as 0, 1, 2 and the time score of Time-M freely estimated, provided adequate fit without any modification, $\chi^2(2)=5.75, p=.06$, CFI=0.98, SRMR=.08, RMSEA=0.11. As shown in Table 26, the slope factor was significantly greater than 0, suggesting that symptoms of anxiety increased across the school term, consistent with findings from the previous section where changes were examined across both the vacation and school term time points. Model results after adding time-varying covariates are summarized in Table 27. As was found for symptoms of depression, higher STRESSOR was significantly associated with higher symptoms of anxiety at all time points (all $p<.01$). Although a non-significant association between DAS and the initial status of SCAS was found, higher DAS was associated with greater increase in symptoms of anxiety towards the end of the term after controlling for STRESSOR and SUBJ. The random slope of SUBJ was significantly associated with DAS, suggesting that across school term, the association between subjective sleep and symptoms of anxiety was stronger among those with higher DAS.
6.3 The Vacation Period

Moderated regression analyses during Time-V (see Table 28) showed that higher STRESSOR and poorer subjective sleep were significantly associated with both symptoms of depression and anxiety, as indicated by the significant simple effects of both variables on CESD and SCAS. The simple effect of DAS was significant on SCAS, and approached statistical significance ($p=.06$) for CESD, suggesting that higher DAS was associated with higher mood disturbance, particularly higher symptoms of anxiety. The interaction term of SUBJ and DAS made a significant contribution to symptoms of depression but not anxiety. Simple slope analyses (see Table 29 and Figure 15) showed that compared to those with lower DAS, those with higher DAS experienced a higher association between SUBJ and symptoms of depression.

Table 28
Parameter Estimates (Standard Errors) of Moderation Analyses Examining Relationships Amongst Sleep, Mood, and Dysfunctional Attitudes During the Vacation

<table>
<thead>
<tr>
<th>DV</th>
<th>CESD</th>
<th>SCAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUBJ</td>
<td>0.20(0.07)*</td>
<td>0.23(0.07)**</td>
</tr>
<tr>
<td>DAS</td>
<td>0.10(0.07), $p=.06$</td>
<td>0.15(0.07)*</td>
</tr>
<tr>
<td>SUBJ×DAS</td>
<td>0.20(0.07)*</td>
<td>0.07(0.07)</td>
</tr>
<tr>
<td>STRESSOR</td>
<td>0.40(0.08)**</td>
<td>0.41(0.08)**</td>
</tr>
<tr>
<td>Intercept</td>
<td>-0.10(0.30)</td>
<td>-0.03(-0.10)</td>
</tr>
</tbody>
</table>

$R^2$ .38** .40**

Note. DV=Dependent variable; CESD, SCAS, DAS, and STRESSOR are the total scores of the Centre for Epidemiological Studies Depression, Spence Children’s Anxiety Scale, Dysfunctional Attitude Scale, and the Inventory of High-School Students’ Recent Life Experiences respectively; SUBJ=Subjective Sleep; *$p<.05$, **$p<.01$. 

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Table 29

Simple Slope Analyses for Moderated Regression Examining Relationships Amongst Sleep, Mood, and Dysfunctional Attitudes

<table>
<thead>
<tr>
<th></th>
<th>CESD</th>
<th>SCAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low DAS (-1 SD)</td>
<td>0.12(0.30)</td>
<td>0.78(0.50)</td>
</tr>
<tr>
<td>Medium DAS (M)</td>
<td>0.53(0.22)*</td>
<td>1.09(0.40)**</td>
</tr>
<tr>
<td>High DAS (+1 SD)</td>
<td>0.94(0.27)**</td>
<td>1.42(0.40)**</td>
</tr>
</tbody>
</table>

*Note.* CESD, SCAS, and DAS are the total scores of the Centre for Epidemiological Studies Depression, Spence Children’s Anxiety Scale, and Dysfunctional Attitude Scale; *p < .05, **p < .01.

Figure 15 Simple slope analyses for low and high dysfunctional attitude (DAS) as a moderator in the relationship between subjective sleep and mood during the vacation period.
6.4 Summary

During both school terms and the vacation, higher levels of life stress were significantly associated with greater symptoms of depression and anxiety. After controlling for life stress and subjective sleep, higher global cognitive vulnerability, as measured by DAS was related to a greater increase in depressive and anxiety symptoms during both the school term and vacation periods. In addition, DAS played different moderating roles in the relationship between subjective sleep and mood over school terms and vacations. During school terms, the association between subjective sleep and symptoms of anxiety was stronger among those with higher DAS, but DAS did not play a significant role in the relationship between subjective sleep and depressive symptoms. During vacations, DAS moderated the relationship between subjective sleep and symptoms of depression (but not anxiety), and there was a stronger positive association between subjective sleep and symptoms of depression among those with higher DAS.

Therefore hypothesis H 4.3 that symptoms of depression and anxiety will share a stronger relationship with poor sleep among individuals with higher cognitive vulnerability was confirmed for anxiety (but not depression) during school terms, and was confirmed for depression (but not anxiety) during the vacation period.
6.5 Discussion

Findings reported in this section suggested that symptoms of depression and anxiety share a similar relationship with life stress and dysfunctional attitudes, but the moderating role of dysfunctional attitudes in the relationship between subjective sleep and mood was different for symptoms of depression versus anxiety, as well as between the school term and vacation periods. These similar and differential effects can be interpreted in light of the common and distinctive features of depression and anxiety. The following sections will first give the background on the general perspectives on the overlap and differences between depression and anxiety, and then discuss their relevance to findings in this section. Given the paucity of empirical evidence with regard to the psychological mechanisms underlying the sleep-mood relationship, discussion in this section will integrate a few general psychological theories and constructs and speculate how they are applicable to interpreting the findings.

6.5.1 General Theories of the Common and Distinctive Features of Depression and Anxiety

There are substantial overlaps between symptoms of depression and anxiety in adolescents. First, self-report measures of depression and anxiety symptoms share strong correlations, which typically range from $r = .50$ to $r = .70$ in youth samples (Brady & Kendall, 1992). These correlations were not merely caused by items with overlapping content in both measures, as both correlation (Stark & Laurent, 2001) and shared variance measures (Cole, Truglio, & Peeke, 1997) remained high after items with similar content were excluded, suggesting that depression and anxiety are highly correlated constructs with common features. Second, comorbidity between depressive and anxiety disorders were common in both community (~16%) and clinical (28%-62%) adolescent samples who were identified as anxious or depressed (Brady & Kendall, 1992), with comorbid anxiety in primary depressive disorders being more common than comorbid depression in primary anxiety disorders (Axelson & Birmaher, 2001; Merikangas & Avenevoli, 2002). This suggests a temporal relationship between anxiety and depression, and that anxiety disorders may lead to subsequent depression. Indeed, this notion is supported by much evidence in both the adult and adolescent literatures, indicating that anxiety disorders tend to precede the onset of depressive disorders (Bittner et al., 2004; Kovacs, Gatsonis, Paulaustkas, & Richards, 1989) and increase the risk of subsequent depressive episodes (Bittner et al., 2004; Cole, Peeke, Martin, Truglio, & Seroczynski, 1998). However, despite considerable overlaps, depression and anxiety have been differentiated in a variety of youth samples. For example, in community (S. L. Crowley & Emerson, 1996; Epkins & Meyers, 1994) and psychiatric inpatient (Stavrakaki, Vargo, Boodoosingh, & Roberts, 1987) children, although depression and anxiety were strongly associated,
they were differentiable using factor analytic models. Similarly, in adolescents, exploratory factor analysis has revealed that anxiety and depression load on separate and distinct factors (Boyd & Gullone, 1997).

Clark and Watson (1991) proposed a tripartite model to better capture the common and distinctive characteristics of depression and anxiety. This model proposed that depression and anxiety share the common underlying construct of negative affect (NA), but can be differentiated using positive affect (PA) and physiological hyperarousal (PH). Negative affect represents a variety of negative and distressing affective states such as angry, sad, and worried. Positive affect encompasses pleasurable mood states such as delighted, interested, proud, and the absence of it is reflected in terms such as fatigued and sluggish. Physiological hyperarousal includes somatic tension, short of breath, dizziness, lightheadedness, and dry mouth.

In adults, depression has been shown to be associated with high NA and low PA, whilst anxiety with high NA and high PH (Clark & Watson, 1991; Tellegen, Watson, & Clark, 1999). When applied to the adolescent population, the tripartite model has also gained empirical support in both clinical and nonclinical samples (for a review see Anderson & Hope, 2008). For example, among psychiatric inpatient youths, combinations of high NA and low PA was found to be a risk factor for development and/or maintenance of depressive, but not anxiety, symptoms. Further, over time, changes in depressive, but not anxiety, symptoms were associated with the combination of low PA and high NA (Joiner & Lonigan, 2000). More directly relevant to this study, the tripartite model was well supported in a normative sample of 4039 Australian adolescents aged 12 – 18 (Tully, Zajac, & Venning, 2009), as well Australian community youths in grades three to nine youths aged 7 – 14 years (Turner & Barrett, 2003), suggesting that symptoms of depression and anxiety could be differentiated across a range of age groups.

These general perspectives on the common and distinctive features of depression and anxiety are particularly relevant in relation to the common and distinctive findings regarding symptoms of depression and anxiety reported in this section, as is discussed below.

6.5.2 Effects of Life Stress and Global Cognitive Vulnerability on Mood

In the current study, on all measurement occasions, higher life stress was associated with higher levels of both depression and anxiety. Among all variables examined, life stress appeared to be the one that made the greatest contribution to mood, whether sleep opportunity was restricted or extended. This is consistent with a large body of literature that has shown stressful life events and daily hassles play precipitating and maintaining roles in psychopathology among youths (Grant et al., 2003; 2006).
During the school term, dysfunctional attitudes were not found to be significantly associated with the intercepts of depressive and anxiety symptoms. This finding needs to be interpreted in the context of how the model was structured, such that life stress and subjective sleep were regressed on mood at each measurement occasion, accounting for a potentially substantial proportion of its basal variance in mood. With life stress and subjective sleep controlled for, higher dysfunctional attitudes were associated with greater increase in both symptoms of depression and anxiety. This is consistent with Beck’s cognitive model (see 1.4), in which dysfunctional attitudes serve as a critical aspect of cognitive vulnerability that predisposes individuals to psychopathology when encountering life stress (Beck, 1987). During the vacation period, which was associated with relatively low life stress, those with higher dysfunctional attitudes also tended to report higher levels of depression and anxiety. On one hand, this can be interpreted in light of the findings during the school term. Those with higher dysfunctional attitudes had a greater increase in both symptoms of depression and anxiety across the school term, hence they were more likely to experience elevated symptoms at the end of the school term before entering the vacation period. Even though the vacation had an overall mood-improving effect as shown in the last section, it is possible that higher symptom levels upon entering the vacation, which was not measured in this study, might have contributed to more vulnerable individuals having overall worse mood duration the vacation. On the other hand, it is also possible that those with higher cognitive vulnerability were more likely to experience clinical levels of depression and anxiety, and thus more likely to experience symptoms that persist over periods with both high and low life stress.

These overlapping findings are consistent with the notion reviewed in the previous section, that depression and anxiety are closely related constructs that share a common affective component (Clark & Watson, 1991). In this study, Beck’s cognitive model (Beck, 1987) appeared to be applicable in relation to both symptoms of depression and anxiety, over both the school term and vacation periods. The effects of life stress and dysfunctional attitudes on mood, after the effects of subjective sleep were accounted for, also highlighted that multiple factors, include both sleep and non-sleep related factors, collectively contribute to adolescents’ psychological wellbeing during both school terms and vacations.

6.5.3 The Moderating Role of Global Cognitive Vulnerability

Global cognitive vulnerability as measured by dysfunctional attitudes played a moderating role in the relationship between subjective sleep and mood. However, this moderating role was different over school terms and vacations for symptoms of depression and anxiety.
6.5.3.1 School Terms

Over the school term, higher dysfunctional attitudes were associated with a significantly stronger relationship between subjective sleep and symptoms of anxiety (but not depression). In other words, cognitively vulnerable individuals were more likely to experience anxiety upon perceived poor sleep. Two factors need to be considered when interpreting this finding. First, school terms, particularly the end of school terms, were associated with higher life stress compared to vacations. Typical school-related life stress, for example, anticipation/preparation and sitting in for examinations, have been associated with increased levels of anxiety and stress-related physiological responses such as elevated salivary cortisol (Spangler et al., 2002; Stöber, 2004). The second factor is school-related sleep restriction as an additional life stress. Perceived poor/inadequate sleep and its daytime consequences might be particularly stressful at a time when cognitive functioning such as attention and concentration were called upon to deal with academic demand, thus contributing to school-related anxiety.

The combined effects of school-related life stress and sleep restriction on emotional responses might depend on the quality of one’s emotional regulation and coping. On one hand, based on Beck’s cognitive model (Beck, 1967), those with higher global cognitive vulnerability might be more likely to catastrophize about the consequence of poor sleep on school performance, hence respond to perceived poor sleep with anxiety. On the other hand, although coping was not directly measured in the current study, it may provide a fruitful direction for future research into the mechanisms that might underlie these findings. Based on the traditional differentiation of coping (Lazarus & Folkman, 1984), when approaching a stressor, coping can be directed at the stressor itself (i.e., problem-focused) or aimed at minimizing distress (i.e., emotion-focused). Problem-focused coping involves using personal and social resources such as investing effort, asking for help, whilst emotion-focused coping could involve strategies such as positive reinterpretation, using methods of relaxation. Cognitively vulnerable individuals might have more difficulties utilizing both problem- and emotion-focused coping, as they might be more likely to engage in unhelpful behaviours such as ruminations and jumping-to-conclusions that hinder effective problem-solving, and more likely to have inflexible cognitive style that might lead to difficulties in adopting alternative interpretation and positive reframing.

The non-significant finding with regards to depressive symptoms might be due to several factors. The school term represents a period in which adolescents actively engage in the academic and social life at school. School-related stressors are more likely to lead to approach (versus avoidance) oriented coping styles that involve proactively activating internal and external resources to deal with the stressor or related emotions (S. Roth & Cohen, 1986). Such behavioural activation might trigger cognitive and physiological hyperarousal (Johnson, Kamilaris, Chrousos, & Gold,
Aim 4: Subjective Sleep, Mood, and Cognitive Vulnerability

1992), which based on the tripartite model, is a key feature of anxiety but not depression. In addition, Spangler et al. (2002) reported that even though NA was high before or at the beginning of examinations, PA increased during the examinations. This suggests dynamic relationships between NA, PA, and school-related life stress, and that depression as characterized by low PA, might not be the predominant emotional response.

6.5.3.2 The Vacation Period

Over the vacation period, higher endorsement on dysfunctional attitudes was associated with significantly stronger relationship between subjective sleep and symptoms of depression (but not anxiety). In other words, cognitively vulnerable individuals were more likely to experience depression upon perceived poor sleep. This finding is consistent with those by Sadler and colleagues (2013), who found that hopelessness, characterized by negative attitudes and pessimism, partially mediated the impact of insomnia on depressive symptoms.

Similar to the school term period, findings during the vacation need to be interpreted in light of extended sleep opportunity and relatively low life stress. During extended sleep opportunity, subjective sleep was less likely to be affected by sleep duration, and more likely, by sleep quality, such as SOL and sleep disturbance. Individuals with higher global cognitive vulnerability might be more likely to respond to everyday life stress with unhelpful cognitive processes such as black-and-white-thinking, maximising negative and minimising positive, and negative misinterpretation. Extended sleep opportunity may be permissive of these cognitive processes during time-in-bed, leading to perceived poor sleep, as well as facilitating associations amongst bedtime, poor sleep, and negative emotional experiences. On the other hand, school-related life stress such as academic demands were likely to be low during the vacation, and adolescents were likely to have more time for leisure and activities of their own choices. Hence pleasure and reward oriented activities were more likely to be a feature of the vacation compared to the school term. Consistent with the behavioural activation theory of depression, fewer and less frequent pleasurable activities were associated with more depressed mood (Lewinsohn & Graf, 1973). Individuals with higher global cognitive vulnerability might perceive poor sleep and its daytime consequences as particularly bothersome (e.g., “my sleep is poor, just like so many other things that don’t work out in my life”), and respond more negatively to their interference with otherwise pleasurable activities (e.g., deriving less joy/pleasure, and engaging in less activities due to poor sleep), leading to lowered mood.

Several interpretations could be made to understand the significant findings on symptoms of depression but not anxiety. First, over the vacation period when life stress was relatively low, a proactive approach-oriented coping style that mobilizes resources and activates physiological
arousals is less likely to be called upon compared to during school terms. Second, whilst PH in response to academic stress might be a feature of the school term, PA in response to pleasurable activities might be a feature of the vacation period. A reduction in PA, a characteristic that is associated with depression but not anxiety, is a more likely outcome in response to perceived poor sleep as a form of life stress. In addition, it is possible that for most participants, mood spontaneously improved after school-related life stress was removed during the vacation period. However, individuals with greater psychopathology might continue to experience mood problems as (a) they might be more likely to experience comorbid depression and anxiety, and (b) also have higher vulnerability to depression, and more likely to develop symptoms of depression following bouts of anxiety given the previously mentioned aetiological importance of anxiety to depression.

Therefore, Beck’s cognitive theory (Beck, 1987) was applicable to interpreting the current findings with regard to the direct effects of cognitive vulnerability on mood, as more cognitively vulnerable individuals were more likely to experience symptoms of depression and anxiety in face of life stress. On the other hand, the different moderating roles of global cognitive vulnerability on the relationship between subjective sleep and depression/anxiety over the school term and vacation periods can be interpreted in light of the overlaps and differences between depression and anxiety based on the tripartite model involving PA, NA, and PH (Clark & Watson, 1991), as well as speculations based on coping and behavioural activation theories.
Primary findings in this thesis were discussed in the individual sections where results relevant to the four Aims were presented. These four Aims can be grouped into two broad areas that correspond to the two areas identified in the INTRODUCTION as corresponding to inadequacies in the current literature. Specifically, Aim 1 assessed longitudinal changes in adolescents’ sleep/wake behaviours over naturalistically restricted and extended sleep opportunities using objective and subjective measurements of sleep. This area addressed empirical gaps and methodological issues in relation to sleep patterns over the school term and vacation periods as identified in 1.4.

Aims 2, 3, and 4 collectively assessed a cognitive model of the impact of changes in objective sleep on mood, as laid out in Figure 2 of 1.4.3. This area focused on the relationships amongst objective sleep, subjective sleep, and mood, and explored the roles of sleep-specific and global cognitive vulnerability in these relationships.

This section begins with the implications of the findings from the above-mentioned two broad areas, followed by the limitations and strengths of the current study, and ends with directions for future studies.

7.1 Implications

7.1.1 Aim 1

7.1.1.1 Theoretical and Methodological Implications

Aim 1 revealed several new findings that helped us better understand adolescents’ sleep/wake behaviours over restricted and extended sleep opportunities. First, results from the current study suggested that sleep/wake patterns were stable across the school term. While actigraphy SOL was longer at the start than at the end of the school term, other aspects of objective sleep were comparable at these two time points. In addition, subjective sleep did not change significantly over the start, middle, and end of the school term. Therefore, adolescents’ sleep patterns over the school term can be conceptualized as involving systematic sleep restriction over school weekdays, where the degree of school-related sleep restriction was likely to be similar across the school term. This suggests that to assess typical adolescent sleep patterns, the timing of the assessment in relation to the school term could be flexible, particularly when sleep is measured using self-report. However,
researchers need to be mindful of potentially elevated SOL measurable using objective methods at the start of a school term as adolescents make transitions from extended sleep opportunity during the vacation into school-related sleep restriction.

Second, by examining sleep patterns on Fridays, Saturdays, and Sundays, the current study demonstrated rapid changes in sleep/wake behaviours as adolescents transited between restricted and extended sleep opportunities. This provides insight into the mechanisms of the widely reported weekday-weekend differences in adolescents’ sleep/wake behaviours. In addition, findings in this study inform future studies on weekday-weekend sleep differences during the school term, and provided evidence that Mondays to Thursdays could be collectively considered as “weekdays”, Fridays and Saturdays as “weekends”, whilst it is more appropriate to examine Sundays separately due to its differences from both weekday and weekend sleep.

Third, as mentioned in the INTRODUCTION, current adolescent research focuses primarily on sleep restriction (Carskadon & Acebo, 2002; Short, Gradisar, Lack, Wright, & Dohnt, 2013), with few investigations of unconstrained sleeping (Crowley, Acebo, Fallone, & Carskadon, 2006; Warner, Murray, & Meyer, 2008). The current study demonstrated the potential of utilizing the vacation period as a naturalistic window for studying sleep/wake behaviours during extended sleep opportunity and the recovery from sleep restriction. By carefully examining the changes of sleep/wake behaviours over the vacation period, this study provided a detailed description on how recovery from school-related sleep restriction took place over a two-week naturally extended sleep opportunity. This extended the current literature that describes recovery sleep from three nights (Belenky et al., 2003) to two weeks, and added to the understanding of how sleep debt is repaid in a naturalistic setting by showing the change trajectories in sleep duration/quality.

7.1.1.2 Practical Implications

The findings relevant to Aim 1 have a number of practical implications for adolescents, parents/guardians, and the educational system. First, the large differences in sleep/wake behaviours between the school term and vacation periods highlighted the substantial sleep restriction effect that school schedules have on adolescents. Elevated sleep-related daytime dysfunction over the school term suggested that adolescents were aware of the daytime consequences of insufficient sleep. As mentioned in the INTRODUCTION, such school-related sleep restriction might have a range of effects on cognitive, emotional, and health functioning, such as impaired cognitive performance (Wolfson & Carskadon, 1998), greater risk for mood problems (Moore et al., 2009) and obesity (Spruyt, Molfese, & Gozal, 2011).

Second, consistent with the literature, early rise-times over the school term were a major contributing factor to school-related sleep restriction. Findings from this study support the effort to
delay school starting time as a method of reducing sleep restriction (Owens, Belon, & Moss, 2010), and suggest that such policy changes might have benefits on adolescents’ wellbeing via increasing their sleep duration on school days. In addition, bedtimes were also an important factor that contributed to adolescents’ restricted sleep duration. Whilst school schedules can be inflexible, a number of factors that contribute to bedtimes are modifiable. For example, parental guidance on earlier bedtimes, reducing evening occupational and extracurricular activities, better time-management to reduce late night school work, and reducing the use of electronic communication devices in the bedroom, will help encourage earlier bedtimes, and increase sleep duration on school nights. While introducing these behavioural changes, it is important to recognize that many evening activities, such as the use of electronic media, hobbies and social interests, compete with intention to sleep at bedtime. Therefore, adolescents’ motivation to opt for sleep over activities that tend to be rewarding in the short-term is important in intervention programs that aim to improve/increase sleep. Psychoeducation on the importance of sleep, as well as therapeutic approaches that engage adolescents’ motivations for behavioural changes (Cain, Gradisar, & Moseley, 2011), might be particularly helpful in promoting earlier bedtimes in adolescents. In addition, in the current sample of community adolescents, a small proportion reported current sleep and psychiatric disorders. Identifying and treating conditions such as delayed circadian phase disorder, insomnia, and depressive and anxiety disorders can help address sleep difficulties in affected adolescents (Gradisar et al., 2011).

The finding that transitions (i.e., Friday, Saturday, Sunday) between restricted and extended sleep opportunities were accompanied by substantial shifts in sleep timing, and that adolescents showed elevated SOL at the start of the school term, suggested that the arrival of a new term might be particularly challenging for adolescents, with elevated daytime sleepiness emerging as adolescents establish a sleep/wake pattern that is substantially different from that over the proceeding vacation period. This might also apply when adolescents transit from weekends to a subsequent school week. The linear delays in sleep timing over the vacation period provided indirect evidence for a gradual shift of the circadian oscillator to a later phase. This suggests that the transition from vacation to the subsequent school term might be more challenging than a typical school weekend to weekday transition. It is possible that allowing longer and more gradual transitions (e.g., gradual shift to earlier sleep timing during the second half of the vacation) and reducing sleep-timing differences (e.g., promoting early sleep timing over school term weekends) between school and non-school days, might help make transitions into school days easier for adolescents.

Finally, as discussed previously in Aim 1, when adolescents’ sleep need and actual sleep was likely to be in balance over the second half of the vacation period, their TST was < 8.5 hr on
average. This challenges the 9 hrs’ TST commonly depicted in the scientific literature and the media as recommended sleep duration for adolescents in this age group (Matricciani, Olds, Blunden, Rigney, & Williams, 2012). As a recent review (Matricciani, Blunden, Rigney, Williams, & Olds, 2013) and associated editorial (Feinberg, 2013) have pointed out, currently there is little empirical evidence regarding the amount of sleep recommended for children and adolescents. Historically, recommended sleep duration to children and adolescents has been consistently ~37 min longer than their actual sleep, and this “extra allowance” was based on the assumption that children and adolescents were not sleeping enough (Matricciani et al., 2012). Although without measurements of health and wellbeing outcomes, it was not possible to draw definitive conclusions on sleep needs, findings in this study raised the possibility that the current sleep duration recommended to adolescents is longer their actual need. There are several implications if this speculation were true. First, a recommendation for a sleep duration based on adolescents’ sleep during naturalistic extended sleep opportunity would be more in line with their actual experiences in everyday life. Second, there would be a less marked discrepancy between recommended and actual sleep durations in adolescents. There is substantial apprehension regarding adolescents “not getting enough sleep”. The current sleep recommendation of 9 hrs might not be realistic for adolescents, particularly during the school term. Such expectation might increase sleep-related anxiety in adolescents and their parents/guardians, and in some cases (e.g., insomnia), might have negative effects on adolescents’ sleep and wellbeing (Morin & Espie, 2003). Finally, even though the current study supports a shorter recommended TST of < 8.5 hr, this duration is nearly an hour longer than that typically obtained during the school term. This further highlights the substantial sleep-restricting effect of school schedules on adolescents, and does not contradict the current notion that steps are needed to increase the sleep duration that adolescents obtain on school days.

7.1.2 Aims 2, 3, and 4

7.1.2.1 Theoretical and Methodological Implications

The longitudinal assessments of sleep, mood, and life stress over the school term and vacation periods, as well as the integration of cognitive vulnerability as a moderator in this study, made it possible to further understand the potential mechanisms underlying the relationship between sleep changes and mood. Several aspects of the findings in Aims 2, 3, and 4 were new to the literature.

First, this study revealed changes in mood and life stress over the school term and vacation periods. The timing of measurements in studies with adolescent samples is intimately linked to the school-vacation cycles of adolescent life. However, most adolescent studies do not take into
consideration the timing of data collection, and varying mood and life stress over the school term and vacation periods could confound findings. The finding that the vacation period was associated with better average mood and lower life stress, whilst the end of the school term was associated with elevated anxiety and life stress, has implications for the designs and planning of future adolescent studies.

Second, the finding that poor sleep quality, but not short sleep duration or sleep restriction, was associated with worse mood has several implications. On one hand, these findings highlighted the importance of examining different aspects of sleep in relation to adolescents’ health and wellbeing due to potentially different roles they play. On the other hand, when examining the relationship between sleep and mood, the existing literature does not make a distinction between poor/inadequate sleep due to school-related sleep restriction (i.e., an external and non-psychological factor) and poor/inadequate sleep due to prodromal/existing symptoms of depression/anxiety/insomnia (i.e., internal and psychological factors). Sleep quality factors that were identified as being related to mood in this study, such as, elevated SOL and perceived poor sleep, were known in the literature to be closely related to the presence of psychopathology (Alfano, Ginsburg, & Kingery, 2007; Ivanenko, Crabtree, & Gozal, 2005). Findings in this study suggest some resilience towards school-related sleep restriction among healthy adolescents, whilst for those with existing psychopathology, such sleep restriction might be perceived as particularly bothersome, and are more likely to have detrimental effects on wellbeing.

Third, results from this study highlighted the importance of subjective experiences in individuals’ responses to restricted and extended sleep opportunities. By examining sleep-specific and global cognitive vulnerabilities as the mechanistic links between objective sleep, subjective sleep, and mood, this study provided a theoretical framework for better understanding the psychological processes underlying adolescents’ subjective experience of sleep. Findings suggested that adolescents’ beliefs and attitudes towards sleep, as well as the world and themselves, play an important role in their psychological wellbeing. This encourages further examinations of other aspects of cognitive vulnerability, such as attributional styles and coping, in relation to adolescents’ sleep and wellbeing. Further, this study raises the possibility that cognitive vulnerability might be a shared risk factor for the development of both sleep problems and emotional disorders.

Finally, the moderating roles of cognitive vulnerability were different between restricted and extended sleep opportunities. This suggests dynamic interactions among environmental, physiological, and psychological factors, and that an integrative approach is needed when studying adolescents’ sleep and wellbeing.
7.1.2.2 Practical Implications

First, findings in this study help teachers and parents/guardians better understand changes in adolescents’ mood over the school term and vacation periods with high and low life stress. Providing practical and psychological support at the end of a school term, for example, might be helpful as adolescents were more likely to experience elevated anxiety and stress.

Second, the importance of individuals’ subjective experiences of sleep and the associated roles of cognitive vulnerability, has several practical implications:

(a) Sleep restriction on school days is widely experienced by school-attending adolescents, and there is increasing publicity in the media regarding the impact of such sleep restriction on adolescents’ mental health. Findings in this study suggested that sleep restriction might not be universally detrimental, particularly among adolescents who are healthy and have low vulnerability towards emotional disorders. A balanced attitude towards sleep, integrating the importance of adequate sleep, as well as normalising some degrees of sleep restriction without depicting sleep loss as necessarily being a threat to wellbeing, might be helpful and appropriate in adolescents. For adolescents who have sleep onset difficulties in particular, a balanced attitude towards sleep would help reduce anxiety at bedtime and have beneficial effects on their sleep quality (Espie, Broomfield, MacMahon, Macphee, & Taylor, 2006).

(b) The findings of this study highlighted the importance of identifying individuals who are vulnerable to school-related sleep restriction (e.g., existing sleep onset difficulties, high cognitive vulnerability) and the need for interventions that targeted these vulnerable individuals. As reviewed in the INTRODUCTION, interventions that targeted selected adolescents with identified sleep difficulties (Bootzin & Stevens, 2005) have shown better effectiveness than programs that were given to unselected groups (Cain et al., 2011; Moseley & Gradisar, 2009). In addition, selective interventions also have the benefits of lowering costs as well as stigma around sleep and mood problems.

(c) The strong association between subjective sleep and mood provides support to the notion that sleep problems might be a risk factor (Johnson, Roth, & Breslau, 2006a), as well as play a maintaining role (Alvaro, Roberts, & Harris, 2013) in, the development of emotional disorders. Therefore, interventions that aim to improve sleep, particularly the subjective experience of sleep, might have beneficial effects on existing mood symptoms, as well as preventative effects on the development of future mood problems (Bei et al., 2013).

(d) Results in this study provided empirical support for therapeutically targeting cognitive vulnerability as a risk factor for sleep complaints, as well as sleep loss-related mood disturbance. On one hand, it is important for sleep interventions to incorporate cognitive strategies that are effective in addressing unhelpful thoughts and beliefs. On the other hand, identifying cognitive
vulnerability prior to intervention would help match individuals’ cognitive profiles with appropriate interventions. This is particularly relevant when sleep interventions were also intended to reduce coexisting mood symptoms or lower the risk for future mood disorders (Bei et al., 2013; Bootzin & Stevens, 2005). Existing prevention trials for depression that are based on cognitive-behavioural principals, for example, have infrequently screened for cognitive vulnerability, causing potential mismatch between vulnerability and the intervention, thus potentially contributing to the low success rate where 59% of programs have failed to reduce depressive symptoms and 77% failed to lower the risk (Lakdawalla, Hankin, & Mermelstein, 2007).
7.2 Strengths

To the best of my knowledge, this is the first study that examined changes in objective and subjective sleep in adolescents over the school term and vacation periods using a longitudinal design. This is also the first study that has examined a cognitive vulnerability model of how objective sleep affects mood. The strengths of this study stemmed from identifying and overcoming a number of gaps and limitations in the current adolescent literature.

Methodologically, the current study had the following strengths:

(a) *A naturalistic design*. This study utilized naturalistic changes in adolescents’ sleep/wake patterns over school terms and vacation periods to study the effects of restricted and extended sleep opportunities. Compared to laboratory-based studies, findings in this study are more likely to reflect adolescents’ everyday experiences, thus are more readily applicable to the real world.

(b) *An unselected community sample*. Participants in this study were recruited from nearly 70 public and private schools, primarily across metropolitan and regional Victoria. Participants were relatively well balanced in gender and age, and proportions of self-reported sleep and psychiatric disorders were close to those found in larger epidemiological studies. This suggests that results from this study have the potential to be generalized to community adolescents.

(c) *A within-participant longitudinal observation over school terms and vacations*. Compared to a cross-sectional design, the longitudinal design in this study allowed assessment of changes in sleep, mood, and life stress over time, as well as factors that predicted change trajectories within participants. It also allowed examination of temporal relationships among these factors under different conditions. In addition, data collection was carried out on multiple occasions over a relatively long period of time (four time points over ~12 weeks for questionnaire data and four weeks’ daily data for actigraphy). The multiple repeated measures allowed better characterization of changes in variables of interest over time.

(d) *The incorporation of objective sleep measurement*. Despite the limitations of actigraphy described in 7.3, its use as an objective measurement of sleep helped overcome the limitations of subjective sleep measures mentioned in INTRODUCTION 1.4. Meanwhile, it is necessary to obtain objective duration and quality of sleep when examining hypotheses related to individuals’ subjective perception of sleep. In addition, being a small and non-intrusive device, actigraphy allowed assessment of sleep in home and school environment with little interference with adolescents’ naturalistic sleep/wake behaviours.

(e) *Online surveys and remote participation*. Given the multi-wave nature of the study design, the integration of online surveys helped reduce participant burden and increase compliance, and might have contributed to the relatively low rates of missing data and dropouts in this study.
(f) Use of appropriate statistical methods. Statistical modelling techniques in this study made use of longitudinal data, and allowed the examination of within-person changes over time, as well as between-person differences in these changes. This is particularly relevant in the analyses of daily sleep over the vacation period, as these analyses showed dynamic changes of sleep that would have otherwise been lost if sleep variables were averaged using conventional methods. In addition, appropriate use of missing data handling techniques helped make use of all available data.

Conceptually, a key strength of this study is the integration of theoretical frameworks and empirical evidence from both sleep (e.g., the two processes model; Borbély, 1982) and psychological (e.g., Beck’s cognitive model for depression, Beck, 1987; the tripartite model for depression and anxiety, Clark & Watson, 1991) sciences. Such integrative approach is particularly important in studying the interaction between sleep and mood. Further, this study made an attempt to study not just the association, but also the underlying mechanisms in the relationship between sleep and mood, and has the potential to address limitations in the current understanding of this relationship.
7.3 Limitations

Findings in this study also need to be interpreted in light of some methodological and conceptual limitations. First, there are limitations to the use of actigraphy as the objective measurement of sleep. Potential overestimation of WASO using actigraphy in adolescents has been identified as a concern (Short, Gradisar, Lack, Wright, & Carskadon, 2012). As mentioned in the METHODS, actigraphy was found to have high sensitivity in detecting sleep but low specificity in detecting wakefulness when compared to PSG among children and pre-schoolers (Meltzer, Montgomery-Downs, Insana, & Walsh, 2012b). However, few validation studies have been carried out on adolescents. In this study, there were relatively few differences between actigraphy versus self-report SOL, whilst TIB and TST were substantially lower on actigraphy compared to self-report, particularly during the vacation. It is likely that actigraphy registered TIB was more accurate than that self-reported on questionnaire, because it was largely based on daily RT and BT entered by participants on the actigraphs, whilst self-report reflected recall of typical TIB over the past week. This might also explain the larger discrepancy during the vacation (51 min) than school days (18 min), as sleep-wake behaviours were more variable during the vacation. The large difference between actigraphy and self-report TST is likely to be related to multiple factors, including inaccuracy in self-report, and a possible underestimation of TST using movement based measurement of sleep. This means that absolute values of TST, %WASO, and SE needed to be interpreted with caution, as over-estimation of WASO by actigraphy cannot be ruled out. However, findings regarding changes in these variables, as well as all findings regarding BT, RT, TIB, and SOL were unlikely to be compromised even if device limitations relating to wakefulness were indeed present. In addition, actigraphy-measured sleep was not obtained for Time-M as the actiwatch’s continuous recording capacity does not exceed four weeks, and that an additional wave of data collection would increase cost substantially.

Second, although the PSQI is well validated in the adult population and has demonstrated good reliability in the adolescent population (Zhou et al., 2011), a full validation has not been carried out among adolescents. A global score that reflects overall sleep quality based on all PSQI domains was not calculated due to a lack of normative data in adolescents. This limitation was overcome in the current study by (a) using raw scores of PSQI subscales (e.g., self-report SOL in minutes), and (b) quantifying overall subjective sleep quality by summing z-scores of subscales standardized based on the current sample. However, it was not possible to examine findings with regards to “good” versus “bad” sleepers as is typically done in adult studies that used the PSQI.

Third, although the current sample size was adequate for testing hypotheses described in this study, it was not sufficient to examine the following aspects. (a) Sex differences: It is well established that the experiences of emotional disorders are different between males and females.
For example, among older adolescents, the prevalence of both anxiety (P. M. Lewinsohn, Gotlib, Lewinsohn, Seeley, & Allen, 1998) and depressive (Nolen-Hoeksema & Girds, 1994) disorders were twice higher in females than in males. In addition, sex differences in cognitive vulnerability have previously been reported, and features such as lower levels of positive thinking, higher need for approval and success, and higher self-focused negative cognitions in females compared to males, were found to partially mediate sex differences in depressive symptoms (Calvete & Cardeñoso, 2005). A larger sample would have facilitated the examination of sex differences with regards to findings in this study. (b) Symptoms versus diagnoses: Depression and anxiety were examined on the symptom level in this study. In the current sample, less than 10% of participants reported a current diagnosis of insomnia or an anxiety/depressive disorder. Whilst this rate is considered representative of a community sample (Johnson, Roth, Schultz, & Breslau, 2006b; Merikangas & Avenevoli, 2002), the number of participants who would meet diagnostic criteria was too small to allow an investigation into the relationship between sleep and depression/anxiety on the diagnosis level. (c) Specific types of anxiety: Overall symptoms of anxiety as measured by the total score of the SCAS were examined, but specific types of anxiety as measured by subscales of the SCAS were not. Given the relatively low prevalence of some anxiety disorders (e.g., 2%–3% for panic, 3%–4% for agoraphobia (Beesdo, Knappe, & Pine, 2009)), the examination of their symptoms in a community sample of 146 might not have been necessary. However, some subtypes of anxiety, particularly generalized anxiety, which has been shown to be related to sleep onset difficulties in youths (Alfano, Pina, Zerr, & Villalta, 2010), could be further explored.

Fourth, some missing data and attrition were present. Missing rate on actigraphy (8.6%) was low compared to findings from other studies which have indicated that up to 28% of weekly actigraphy recordings of children and adolescents may be lost (Acebo et al., 1999). Given the multi-wave nature of the current study, the rate of missing on questionnaire data was also low, with 85% completing all assessment questionnaires at all time points. Further, missing data were handled using appropriate statistical methods.

Fifth, the following factors might be relevant to hypotheses tested in this thesis, but were not measured in this study. (a) The lack of measurements on endogenous circadian rhythms, such as dim light melatonin onset, limited our interpretation on the delay in sleep timing over the vacation period. (b) A number of factors mentioned in the INTRODUCTION affect adolescents’ sleep/wake behaviours were not assessed in this study, for example, presleep activities and parental control of bedtimes. These factors might have contributed to the sleep-wake patterns observed in this study. (c) Even though signs of sleep restriction were not apparent during the second half of the vacation, definitive interpretation regarding sleep need were not possible due to the lack of outcome measures on wellbeing. (d) Only one aspect of global cognitive vulnerability, dysfunctional attitudes, was
assessed, and other aspects, such as attributional styles and coping, might be relevant to the relationship between sleep and mood, were not examined. (e) The role of puberty status was not assessed as most participants (95.89%) were ≥15 years old, and they were likely to be of Tanner stage V (Tanner & Whitehouse, 1976).

Finally, it is important to note that participants in the current study were mostly older adolescents, and results might not be generalizable to younger adolescents.
7.4 Future Directions

Future studies need to address the limitations and integrate the strengths of the current study, while further exploring worthy questions that arose from current findings.

Methodologically, the naturalistic design of the current study over the school term and vacation periods can be applied in future studies that study adolescents’ sleep and wellbeing under restricted and extended sleep opportunities. The incorporation of objective measurements of sleep, particularly in-home portable PSG measures, will help provide further insight into changes in sleep architecture over restricted and extended sleep opportunities, which the current study could not provide. By including an objective measurement of the circadian phase such as dim light melatonin onset, future studies can help understand how endogenous circadian rhythms are affected by school-vacation-school transitions. The roles of other unmeasured factors in this study, such as presleep activity, presleep arousals, parental control of bedtimes, could be integrated in future studies for better understanding of adolescents’ sleep/wake behaviours. As noted above, a larger sample size with a wider age range will help examine the effects of sex and age in the current findings. A larger sample will also help capture meaningful samples of individuals who present with clinically significant emotional disorders so sleep characteristics of these individuals can be studied.

This study identified two under-researched areas in the current adolescent sleep literature that might be fruitful for future studies. First, adolescents’ sleep/wake behaviours during the vacation period require further investigation, as the vacation provides a valuable opportunity to study adolescents’ sleep needs in a naturalistic environment. By integrating health and wellbeing outcomes, future studies will be able to have more conclusive findings regarding optimal sleep duration for adolescents. In addition, school-related sleep restriction might interfere with the assessment of sleep disorders such as insomnia and delayed sleep phase disorder, as elevated SOL is a likely feature of both conditions during the school term. Extended sleep opportunity over the vacation period can be utilized by future studies to better assess and differentiate these sleep disorders. Second, findings from this study demonstrated the importance of subjective experiences of sleep restriction, as well as individual differences in cognitive vulnerability in relation to adolescents’ sleep and wellbeing. Future studies could expand the scope of this study by incorporating other aspects of cognitive vulnerability such as attributional and coping styles in the sleep-mood relationship. The development of brief and reliable screening instruments for cognitive vulnerability will help identify adolescents who might be more emotionally vulnerable under school-related sleep restriction. Results in this study also provide empirical support for future studies to develop sleep-improving programs for adolescents with the reduction of mood problems and improvement in overall psychological wellbeing as secondary outcomes. In particular, the
cognitive model proposed and tested in this study provided a rationale for therapeutically targeting cognitive vulnerability in future intervention trials.
7.5 Conclusions

This study examined longitudinal changes in adolescents’ sleep, mood, and life stress over the school term and vacation periods. School terms were associated with earlier sleep timing, restricted sleep opportunity, more mood symptoms, and higher life stress, whilst vacations were associated with later sleep timing, extended sleep opportunity, less mood symptoms, and lower life stress. Daily changes in actigraphy-measured sleep over the vacation period showed that sleep debt over the prior school week was repaid within two-week’s extended sleep opportunity. An average time-in-bed of 9 hr over the second vacation week suggested that sleep requirements in adolescence may be less than conventionally described in the media and in scientific literature. Poorer sleep quality, particularly poorer subjective perception of sleep quality, was associated with higher symptoms of depression and anxiety. Sleep-specific, as well as global cognitive vulnerabilities played important roles in the relationship between sleep and mood. Adolescents with high cognitive vulnerability might be more emotionally vulnerable towards school-related sleep restriction. These findings have theoretical implications for future studies, as well as practical implications for adolescents’ wellbeing.


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predictors of individual change over time. *Psychological bulletin, 116*, 363–381.


APPENDIX A. PLAIN LANGUAGE STATEMENTS AND CONSENT FORMS

- School Information
- Parent/Guardian Information and Consent Form
- Participant Information and Consent Form
School Information

**Project Title:** Youth Sleep and Wellbeing  
**Principle Researchers:** Professor John Trinder, Professor Nick Allen, Dr Bei Bei

**Overview**
There is growing recognition that adequate and good quality sleep is essential for young people. Poor sleep could interfere with school performance and overall wellbeing. In this project, we are interested in factors that might affect adolescents’ sleep during school terms and holidays, as well as how changes in sleeping patterns affect their emotional wellbeing. We are inviting students in Year 10, 11, and 12 from Victorian schools to participate in this project. This sheet contains information on what participating in this project will involve for both the school and students.

**Involvement of the school**

**Role of the school.** Interested schools will play a **simple yet important** role in recruiting students who might be interested in participating in this project. Below are some examples of possible involvement of the school:

- **Example 1.** Forwarding an information sheet on the project to all Year 10, 11, and 12 students via post or email. If a student is interested in participating in this project, he/she will be able to contact us directly, and participation will occur outside school hours in his/her own time. An example of the information sheet can be accessed [here](#). Wording and layout can be adjusted to suit your school's needs and preferences.

- **Example 2.** The school could also utilize this project as an opportunity for students in psychology classes to learn how psychological research is done by personally participating in one.

**Benefits to the school.** Schools who participated in this and other related projects have reported that the project helped raise awareness of the importance of sleep among students and their families. Upon request, we are also able to provide the following to participating schools:

- A brief report on overall findings for each school. Please note that we will not provide feedback to schools regarding individual student’s participation.
- Handouts and information sheets developed by our research team on improving sleep among adolescents that the school is free to use.
- Referral information on local sleep specialists.
Whilst we hope that your school can be involved in this research opportunity, participation of your school is entirely voluntary.

**Involvement of students and parents/guardians**

**Online consent.** If a student or parent/guardian is interested in participating, he/she can contact us via email, telephone, or text messages. A researcher will arrange a discussion with the student regarding a suitable time for participation, as well as recording his/her, as well as his/her guardian’s names and contact details. A student will only be included in this project if a parent/guardian has also given consent, and this can be done by filling out a brief form online. Participants will not be asked to enter personal identification information when completing questionnaires online, and will only be identified via a code based on their initials and date of birth. The online information and consent forms can be accessed at the following links:

- For students: [http://sleepwellbeing.teenconsent.sgizmo.com/s3/](http://sleepwellbeing.teenconsent.sgizmo.com/s3/)

**Participation.** Participating in this project involves the following two tasks for each student:

1. **Filling out a series of questionnaires about sleep and emotional wellbeing.** Each participating student will be asked to do this on four occasions shown in the graph below. The "Starter Survey" takes about 45 minutes to complete and the student only need to fill it in once; the "Repeated survey" takes about 20 minutes to complete. Students will be able to fill out these questionnaires online or on paper at their own homes, and a researcher will contact them on each occasion to remind them to complete the questionnaires.

   ![Graph showing the four questionnaires](image)

2. **Wearing an Actiwatch.** This is a watch-like device that measures sleep-wake patterns by monitoring wrist movements. The Actiwatch is compact and light-weight, and we have previously successfully collected data in young people with little inconvenience in participants' everyday life. Students will be asked to wear the Actiwatch during both day and night for 4 weeks, from the start of the last term week till the end of the first term week of the next term (including the 2 weeks' school holidays). The Actiwatch could be delivered via post to their homes, and a prepaid envelope will be provided for returning the device to our office.

   ![Actiwatch](image)

**Risks.** To our knowledge, there is no specific risk associated with participation. Once enrolled, a 24hr number to a clinical psychologist on the team will be made available to all participants in the unlikely event of concerns or distress related to their participation.
Benefits. Those who completed this project will be given two movie vouchers to compensate for their time. Interested students can also request a copy of their sleeping pattern during the period they wear the Actiwatch. This report will include information on total sleep time as well as sleep efficiency with a reference to community data in the same age group. If sleep data indicate concerns regarding a student’s sleep (e.g. very short or poor sleep), a clinical psychologist on the team will contact the participating student and discuss referral options if needed.

Confidentiality. Information collected in this project is strictly confidential, and all data will be stored securely at the School of Psychological Sciences at the University of Melbourne. Participant data will be protected subject to the law. Participants will be given a numerical identifier and all data will be stored in locked files and will be identified using these numerical identifiers, not the names of the students participating in the project or any other identifying information. Only investigators and a small number of the research staff working on the project will have access to the raw data. The results of the project will only be reported in ways that do not identify individual participants. Moreover, all data provided by participating students will be destroyed 5 years after the date of the last publication based on this study. Paper copies will be shredded and computer files will be deleted.

Contacts

Questions regarding participation. If you have any questions relating to your school's participation in this project, or would like to know more, please do not hesitate to contact us at beib@unimelb.edu.au 03 8344 4911.

Concerns. This project has been approved by the 'University of Melbourne Human Research Ethics Committee'. If you have any concerns about how this study is conducted, you can contact the Executive Officer, Human Research Ethics at the University of Melbourne on 8344 2073 (fax: 03 9347 6739).

This project has been approved by the University of Melbourne Human Research Ethics Committee (project nr. 1035080).

Thank you for your interest!
Parent/Guardian Information and Consent Form

Project title: Sleep and Wellbeing in Young People
Principle Researchers: Professor John Trinder, Professor Nick Allen, Dr Bei Bei

About this Project

There is growing recognition that adequate and good quality sleep is essential for young people. Poor sleep could interfere with school performance and overall wellbeing. We are researchers from the University of Melbourne and Orygen Youth Health, interested in factors that might affect adolescents' sleep during school terms and holidays, as well as how changes in sleeping patterns affect their emotional wellbeing.

We are inviting students in Year 10, 11, and 12 from Victorian schools to participate in a project called "Sleep and Wellbeing in Young People". In the next section, you can find out what will be involved if your teenager participates in this project. We hope you can go through the information carefully and make sure you understand it before giving consent for your teen to participate.

While we will greatly appreciate if you and your teen decide to take part, whether or not you do is completely up to you. If at any time during the project you or your teen would like to withdraw from the project, you can, and your teen's responses will not be used.

What will my teen be asked to do during participation?

All participants will start the project at the end of a school term and finishes at the middle of the next term. You and your teen can choose which term you would like to be involved. Everything your teen needs to do for this project can be completed at home.

There are two main tasks your teen will be asked to do when involved in this project:

1. Filling out a series of questionnaires about sleep and emotional wellbeing. Your teen will be asked to do this on four occasions shown in the graph below.
The "Starter Survey" takes about 45 minutes to complete and your teen only need to fill it in once; the "Repeated survey" takes about 20 minutes to complete. Your teen will be able to fill out these questionnaires online or on paper at your own home, and a researcher will contact him/her on each occasion to remind him/her to complete them.

2. Wearing an Actiwatch. This is a watch-like device that measures sleep-wake patterns by monitoring wrist movements. The Actiwatch is compact and light-weight, and we have previously successfully collected data in young people with little inconvenience in participants' everyday life. Your teen will be asked to wear the Actiwatch during both day and night for 4 weeks, from the start of the last term week till the end of the first term week of the next term (including the 2 weeks' school holidays). The Actiwatch will be posted to your home and a prepaid envelope will be provided for returning the device to our office.

What do I need to do as a parent or guardian?

If you are happy for your teen to participate in this project, please give your consent by selecting "Yes, I would like to give my consent." and filling in a brief form on the next page. Please note that your teen will not be included in this project until we have received permission from you.

Once your teen is involved in this project, we will greatly appreciate your support during his/her participation. This could be reminding your teen to use the Actiwatch, encourage him/her to complete the survey questionnaires, and getting in touch with us if you or your teen has any questions or concerns.

What else do I need to know?

Risk and benefits. This project will provide us with a unique opportunity to understand sleep and its impact on young people's emotional wellbeing. To our knowledge, there is no specific risk associated with participation. Once enrolled, a 24hr number to a clinical psychologist on the team will be made available to your teen in the unlikely event of concerns or distress related to his/her participation.

After completing the project, we will give your teen two movie vouchers as a thank you present. Upon request, he/she will also be provided with a copy of his/her sleeping pattern during the period he/she is wearing the Actiwatch. This report will include information on total sleep time as well as sleep efficiency with a reference to community data in the same age group. If sleep data indicate concerns regarding your teen's sleep (e.g. very short or poor sleep), a clinical psychologist on the team will make contact and discuss referral options if needed.

Confidentiality. Information collected in this project is strictly confidential, and all data will be stored securely at the School of Psychological Sciences at the University of Melbourne. Participant data will be protected subject to the law. Your teen will be given a numerical identifier and all data will be stored in locked files and will be identified using this identifiers, not the name, or any other identifying information of your teen. Only investigators and a small number of the research staff working on the project will have access to the raw data. The results of the project will only be reported in ways that do not identify your teen. Moreover, all data provided by your teen will be
destroyed 5 years after the date of the last publication based on this project. Paper copies will be shredded and computer files will be deleted.

Questions regarding participation. If you have any questions relating to your teen participating in this project, or would like to know more before giving your consent, please do not hesitate to contact us at beib@unimelb.edu.au 03 8344 4911 or 041 555 2267.

Concerns. This project has been approved by the 'University of Melbourne Human Research Ethics Committee'. If you have any concerns about how this study is conducted, you can contact the Executive Officer, Human Research Ethics at the University of Melbourne on 8344 2073 (fax: 03 9347 6739).

This project has been approved by the University of Melbourne Human Research Ethics Committee (project nr. 1035080).

Please indicate whether you would like to give your consent for your teen to participate in this project, then click "Next" to fill in a brief form on the next page.
( ) Yes, I would like to give my consent.
( ) No, I do not wish to give me consent.
Appendix A

Project title: Sleep and Wellbeing in Young People  
Principle Researchers: Professor John Trinder, Professor Nick Allen, Dr Bei Bei

Please complete this form if you give permission for your teen to participate in this project. Your teen will not be able to start this project until we receive your permission.

My teen’s initials ____________________
This is the first letters of your teen's first and last names without space. To protect you and your teen's privacy, the answers we collect during the survey will be identified using a code based on your teen's initials, not his/her actual names. For example, Michael Brant's initials are MB.

My teen’s date of birth ____________________
dd/mm/yyyy

My initials __________________________

My Email address ________________ My contact number __________________________

My relation to the teen for whom I am giving consent
( ) Father  ( ) Mother  ( ) Other: ______________________

Please read the following terms carefully and tick the boxes in front of each item to give your consent for your child to participate in this project.

( ) I confirm that I am a parent/guardian of the teen for whom I am giving my consent.
( ) I consent to give permission for my child to participate in the above research project, the particulars of which - including details of tests or procedures have been explained to me to my satisfaction.
( ) In my consenting to my child participating in the above project, I acknowledge the following:
  • The possible effects of the tests or procedures have been explained to me to my satisfaction;
  • I have been informed that I am free to withdraw my child from the project at any time and to withdraw any unprocessed data previously supplied;
  • The project is for the purpose of research and not for treatment;
  • I have been informed that what my child or I disclose while participating in this study is confidential. Only the above listed researchers will have access to these information, and that in the process of data analyses, our information will be de-identified, safeguarded, and subject to legal requirements.
  • I give my permission to be contacted regarding my child’s participation through previously supplied information.
  • This form will be returned to, and retained by, the researchers.

Thank you for your interest!
If you have just agreed for your teen to participate in this project, an email containing all the information on the previous page will be sent to your email address shortly (check your spam folder if it doesn't reach your inbox).
If you decided no to give consent at this stage, we would like to wish you all the very best for the future!
Participant Information and Consent Form

Project title: Sleep and Wellbeing in Young People
Principle Researchers: Professor John Trinder, Professor Nick Allen, Dr Bei Bei

About the Project

Human beings spend one third of our lives sleeping, and sleep is a very important part of our everyday life. Science is yet to fully understand the relationship between sleep and our wellbeing, in particular among young people like you. We are researchers from the University of Melbourne and Orygen Youth Health Research Centre, trying to find out what affects young people's sleep, and how sleep affects their emotional health.

You, and other Year 10 to 12 students can help us by participating in this project. In the next section, you can find out what joining in will involve. We hope you can go through the information carefully and make sure you understand it before making up your mind whether or not to participate. While we will greatly appreciate if you decide to take part, whether or not you do is completely up to you. You don't have to participate if you don't want to. If at any time during the project you would like to finish being involved, you can, and your responses will not be used.

We understand your time is precious, and we will provide the following to each student who completed this project:

- Two movie tickets as a thank you present;
- A report on how you slept during your participation;
- A report on the morningness-eveningness of your body clock based on your survey results.

What will I be asked to do if I join in?

Everyone starts the project at the end of a school term and finishes at the middle of the next term. You can choose which term you would like to be involved. Everything you need to do for this project can be completed at home.

There are two main tasks you will be asked to do when involved in this project:

1. Filling out a series of questionnaires about your sleep and emotional wellbeing. You will be asked to do this on four occasions shown in the graph below. The "Starter Survey" takes about 45 minutes to complete and you only need to fill it in once; the "Repeated survey" takes about 20 minutes to complete. You will be able to fill out these questionnaires online or on paper at your own home, and a researcher will contact you on each occasion to remind you to complete them.
2. Wearing an Actiwatch. This is a watch-like device that measures sleep-wake patterns by monitoring how much you move your wrist. The Actiwatch is compact and light-weight (see photo), and is unlikely to cause inconvenience in your everyday life. **You will be asked to wear the Actiwatch during both day and night for 4 weeks.** That is, from the start of the last term week till the end of the first term week of the next term (including the 2 weeks' school holidays). The Actiwatch will be posted to your home and a prepaid envelope will be provided for posting it back to our office.

How do I join in?

If you are interested in participating in this project, simply complete the following two steps.

**Step 1.** Let us know you are interested by selecting "Yes, I would like to participate" at the bottom of this page, then follow the prompts and fill out a brief form to give your consent to participate.

**Step 2.** Get permission from one of your parents or guardians. Tell one of your parents/guardians that you are interested in participating in this project. If they have not already read about this project, ask them to log on to [http://sleepwellbeing.guardianconsent.sgizmo.com/s3/](http://sleepwellbeing.guardianconsent.sgizmo.com/s3/) where they can go through relevant information, and fill in a brief form giving you permission to join this project. You do not have to write down the link now, as all information contained on this page will be emailed to you once you agreed to participate on the next page.

You are officially joined once we have received your parent or guardian's permission. One of our researchers will get in touch with you when you need to fill in the questionnaires.

What else do I need to know?

**Risk and benefits.** This project will provide us with a unique opportunity to understand sleep and its impact on young people's emotional wellbeing. To our knowledge, there is no specific risk associated with participation. Once enrolled, a 24hr number to a clinical psychologist on the team will be made available to you in the unlikely event of concerns or distress related to your participation. If you want to know what your sleep pattern was like while you were wearing the Actiwatch, we can provide a copy of the sleep report at the end of your participation. This report will include information on total sleep time as well as sleep efficiency with a reference to community data in your age group. If your sleep data indicate concerns (e.g. very short or poor sleep), a clinical psychologist on the team will contact you and discuss referral options if needed.

**Confidentiality.** All of your answers will be kept private – this means we don't tell anyone what you have said, including your parents/guardians and teachers, unless we believe that you or someone
else would come to serious harm if we did not tell someone. Your responses will be coded and only a small number of our team will have access to your answers. What we want to know is what young people are like in general.

**Questions regarding participation.** If you have any questions relating to participating in this project, or would like to know more before making up your mind, please do not hesitate to contact us at beib@unimelb.edu.au 03 8344 4911 or 041 555 2267.

**Concerns.** If you have any concerns about how this study is conducted, you can contact the Executive Officer, Human Research Ethics at the University of Melbourne on 03 8344 2073 (fax: 9347 6739).

This project has been approved by the University of Melbourne Human Research Ethics Committee (project nr. 1035080).

Please indicate whether or not you would like to participate in this project, then click "Next" to fill in a brief form on the next page.

( ) Yes, I would like to participate! (proceed to fill out online consent)
( ) No, I'm no longer interested.
**Project title: Sleep and Wellbeing in Young People**
**Principle Researchers: Professor John Trinder, Professor Nick Allen, Dr Bei Bei**

Please note that you will **not** be able to start this project until this form is submitted.

My initials ______________________
This is the first letters of your first and last names without space. To protect your privacy, the answers we collect during the survey will be identified using a code based on your initials, not your actual names. Please make sure you use the same initials when you fill out surveys at different stages. For example, Michael Brant's initials are MB.

Date of Birth ______________________
dd/mm/yyyy

My Email address ______________ My contact number ______________________

Please read the following terms carefully and tick the boxes in front of each item to give your consent to participate in this project.

( ) I consent to participate in the above project, and I have discussed the details of the participation with my parents/guardians and/or the researcher and understand what it involves

( ) I acknowledge the following:
- The possible effects of the tests or procedures have been explained to me;
- I can stop taking part in the project at any time;
- The purpose for the project is research;
- My answers to the questionnaires will be kept private;
- I give my permission to be contacted via previously supplied information regarding my participation.
- This form will be returned to, and retained, by the researchers.

Future contact?
( ) Please tick if you would be willing to be contacted for future related studies (Optional).

Sleep Report?
( ) Please tick if you would like to receive a copy of your sleep and wake analysis based on the Actiwatch data (Optional).

Thank you for your interest!
If you have just agreed to participate in this project, an email containing all the information on the previous page will be sent to your email address shortly (check your spam folder if it does not reach your inbox). Please note that you will **not** be formally enrolled in this project until one of your parents/guardians have informed us of his/her permission.
If you decided no to go ahead with this project, we would like to wish you all the very best for the future!

😊
APPENDIX B. QUESTIONNAIRES

- Starter Survey
  - Social Demographic Information
  - Morningness – Eveningness Questionnaire
  - Dysfunctional Beliefs and Attitudes About Sleep Scale
  - Dysfunctional Attitude Scale

- Repeated Survey
  - Centre for Epidemiological Studies Depression Scale
  - Spence Children’s Anxiety Scale
  - Pittsburgh Sleep Quality Index
  - Inventory of High-School Students’ Recent Life Experiences
Starter Survey

Social Demographic Information (SDI)

You only have to complete this part of the survey once. It will take approximately 45 minutes. Please continue on if you can stay online for this duration to complete the whole survey.

Your email

Your initials
This is the first letters of your first and last names without space. To protect your privacy, the answers we collect during the survey will be identified using a code based on your initials, not your actual names. Please make sure you use the same initials when you fill out surveys at different stages. For example, Michael Brant’s initials are MB

Date of Birth
dd/mm/yyyy

Sex
( ) Male ( ) Female

How tall are you and how much do you weigh?
Height in Centimetre (cm): ____________  Weight in Kilogram (Kg): ____________

Ethnic background
( ) Australian ( ) New Zealand or Oceania ( ) Europe  ( ) Middle East  ( ) Asia
( ) Africa ( ) North America ( ) South America  ( ) Other: ___________________

Year Level
( ) Year 9  ( ) Year 10  ( ) Year 11  ( ) Year 12

When do your school days usually start and finish? (This include any extra-curriculum activities at school)
Starts: ____________  Finishes: ____________

Are you currently experiencing any major medical conditions?
( ) No ( ) Yes (Please specify): ___________________

Are you currently taking any prescription medication (including sleep medication)?
( ) No ( ) Yes (Please specify): ___________________

Have you ever been diagnosed with any of the following psychiatric or psychological conditions?
( ) None, or not that I am aware of
( ) Depression (please specify when): ___________________
( ) Anxiety (please specify when): _________________
( ) Both depression and anxiety (please specify when): _________________
( ) Other (please specify what and when): _________________

Are you currently experiencing any of the following psychiatric or psychological conditions?
( ) None, or not that I am aware of  ( ) Depression  ( ) Anxiety
( ) Both depression and anxiety  ( ) Other (please specify): _________________

Have you ever been diagnosed with any of the following sleep-related conditions? You may choose more than one options.
( ) None, or not that I am aware of
( ) Insomnia (significant difficulty falling asleep or staying asleep)
( ) Hypersomnias (sleeping excessively, more than I would like to)
( ) Sleep apnea (abnormal pauses in breathing during sleep)
( ) Narcolepsy (excessive daytime sleepiness and possibly falling asleep at inappropriate times)
( ) Sleepwalking
( ) Sleep terrors (awakening from sleep with panic)
( ) Bruxism (teeth grinding)
( ) Periodic limb movement disorder (limbs move involuntarily during sleep)
( ) Restless legs syndrome (an irresistible urge to move a part of the body, often legs, to stop uncomfortable or odd sensations)

Are you currently experiencing any of the following sleep-related conditions? You may choose more than one options.
( ) None, or not that I am aware of
( ) Insomnia  ( ) Hypersomnia  ( ) Sleep apnea
( ) Narcolepsy  ( ) Sleep walking  ( ) Sleep terrors
( ) Bruxism  ( ) Periodic limb movement disorder  ( ) Restless legs syndrome

As a child, how good a sleeper are you?
Very poor, always had problem sleeping  Very good, rarely had problem sleeping
( ) 1  ( ) 2  ( ) 3  ( ) 4  ( ) 5  ( ) 6  ( ) 7  ( ) 8  ( ) 9  ( ) 10
Morningness - Eveningness Questionnaire (MEQ)

For each question, please select the answer that best describes you by checking the corresponding box. Make your judgments based on how you usually feel in general.

Approximately what time would you get up if you were entirely free to plan your day?
( ) 5:00 a.m. – 6:30 a.m.  ( ) 6:30 a.m. – 7:45 a.m.  ( ) 7:45 a.m. – 9:45 a.m.
( ) 9:45 a.m. – 11:00 a.m. ( ) 11:00 a.m. – 12 noon

Approximately what time would you go to bed if you were entirely free to plan your evening?
( ) 8:00 p.m. – 9:00 p.m.  ( ) 9:00 p.m. – 10:15 p.m.  ( ) 10:15 p.m. – 12:30 a.m.
( ) 12:30 a.m. – 1:45 a.m. ( ) 1:45 a.m. – 3:00 a.m.

If you usually have to get up at a specific time in the morning, how much do you depend on an alarm clock?
( ) Not at all  ( ) Slightly  ( ) Somewhat  ( ) Very much

How easy do you find it to get up in the morning (when you are not awakened unexpectedly)?
( ) Very difficult  ( ) Somewhat difficult  ( ) Fairly easy  ( ) Very easy

How alert do you feel during the first half hour after you wake up in the morning?
( ) Not at all alert  ( ) Slightly alert  ( ) Fairly alert  ( ) Very alert

How hungry do you feel during the first half hour after you wake up?
( ) Not at all hungry  ( ) Slightly hungry  ( ) Fairly hungry  ( ) Very hungry

During the first half hour after you wake up in the morning, how do you feel?
( ) Very tired  ( ) Fairly tired  ( ) Fairly refreshed  ( ) Very refreshed

If you had no commitments the next day, what time would you go to bed compared to your usual bedtime?
( ) Seldom or never later  ( ) Less that 1 hour later  ( ) 1-2 hours later  ( ) More than 2 hours later

You have decided to do physical exercise. A friend suggests that you do this for one hour twice a week, and the best time for him is between 7-8 a.m. Bearing in mind nothing but your own internal "clock," how do you think you would perform?
( ) Would be in good form  ( ) Would be in reasonable form
( ) Would find it difficult  ( ) Would find it very difficult

At approximately what time in the evening do you feel tired, and, as a result, in need of sleep?
( ) 8:00 p.m. – 9:00 p.m.  ( ) 9:00 p.m. – 10:15 p.m.  ( ) 10:15 p.m. – 12:45 a.m.
( ) 12:45 a.m. – 2:00 a.m. ( ) 2:00 a.m. – 3:00 a.m.

You want to be at your peak performance for a test that you know is going to be mentally exhausting and will last two hours. You are entirely free to plan your day. Considering only your "internal clock," which one of the four testing times would you choose?
( ) 8 a.m. – 10 a.m.  ( ) 11 a.m. – 1 p.m.  ( ) 3 p.m. – 5 p.m.  ( ) 7 p.m. – 9 p.m.

If you got into bed at 11 p.m., how tired would you be?
( ) Not at all tired  ( ) A little tired  ( ) Fairly tired  ( ) Very tired
For some reason you have gone to bed several hours later than usual, but there is no need to get up at any particular time the next morning. Which one of the following are you most likely to do?
( ) Will wake up at usual time, but will not fall back asleep
( ) Will wake up at usual time and will doze thereafter
( ) Will wake up at usual time, but will fall asleep again
( ) Will not wake up until later than usual

One night you have to remain awake between 4-6 a.m. in order to carry out a night watch. You have no time commitments the next day. Which one of the alternatives would suit you best?
( ) Would not go to bed until the watch is over
( ) Would take a good sleep before and nap after
( ) Would take a good sleep before and nap after
( ) Would sleep only before the watch

You have two hours of hard physical work. You are entirely free to plan your day. Considering only your internal "clock," which of the following times would you choose?
( ) 8 a.m. – 10 a.m.  ( ) 11 a.m. – 1 p.m.  ( ) 3 p.m. – 5 p.m.  ( ) 7 p.m. – 9 p.m.

You have decided to do physical exercise. A friend suggests that you do this for one hour twice a week. The best time for her is between 10-11 p.m. Bearing in mind only your internal "clock," how well do you think you would perform?
( ) Would be in good form
( ) Would be in reasonable form
( ) Would find it difficult
( ) Would find it very difficult

Suppose you can choose your own work hours. Assume that you work a five-hour day (including breaks), your job is interesting, and you are paid based on your performance. At approximately what time would you choose to begin?
( ) 5 hours starting between 4:00 a.m. – 8:00 a.m.  ( ) 5 hours starting between 8:00 – 9:00 a.m.
( ) 5 hours starting between 9:00 a.m. – 2:00 p.m.  ( ) 5 hours starting between 2:00 – 5:00 p.m.
( ) 5 hours starting between 5:00 p.m. – 4:00 a.m.

At approximately what time of day do you usually feel your best?
( ) 5:00 a.m. – 8:00 a.m.  ( ) 8:00 a.m. – 10:00 a.m.  ( ) 10:00 a.m. – 5:00 p.m.
( ) 5:00 p.m. – 10:00 p.m.  ( ) 10:00 p.m. – 5:00 a.m.

One hears about "morning types" and "evening types." Which one of these types do you consider yourself to be?
( ) Definitely a morning type
( ) Rather more a morning type than an evening type
( ) Rather more an evening type than a morning type
( ) Definitely an evening type
Dysfunctional Beliefs and Attitudes about Sleep Scale (DBAS)

Several statements reflecting people's belief and attitudes about sleep are listed below. Please indicate to what extent you personally agree or disagree with each statement. There is no right or wrong answer. For each statement, choose the number that corresponds to your own personal belief. Please respond to all items even though some may not apply directly to your own situation. Please rate how much you agree or disagree with the following statements.

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<thead>
<tr>
<th>Statement</th>
<th>0</th>
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<tr>
<td>I need 9 hours of sleep to feel refreshed and function well during the day.</td>
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<td>When I don't get proper amount of sleep on a given night, I need to catch up on the next day by napping or on the next night by sleeping longer.</td>
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<td>I am concerned that chronic poor sleep may have serious consequences on my physical health.</td>
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<td>I am worried that I may lose control over my abilities to sleep.</td>
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<td>After a poor night's sleep, I know that it will interfere with my daily activities on the next day.</td>
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<td>In order to be alert and function well during the day, I believe I would be better off taking a sleeping pill rather than having a poor night's sleep.</td>
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<td>When I feel irritable, depressed, or anxious during the day, it is mostly because I did not sleep well the night before.</td>
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<td>When I sleep poorly on one night, I know it will disturb my sleep schedule for the whole week.</td>
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<td>Without an adequate night's sleep, I can hardly function the next day.</td>
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<td>I can't ever predict whether I'll have a good or poor night's sleep.</td>
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<td>I have little ability to manage the negative consequences of disturbed sleep.</td>
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<td>When I feel tired, have no energy, or just seem not to function well during the day, it is generally because I did not sleep well the night before.</td>
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<td>I believe poor sleep is essentially the result of a chemical imbalance.</td>
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<td>I feel poor sleep is ruining my ability to enjoy life and prevents me from doing what I want.</td>
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<td>Medication is probably the only solution to sleeplessness.</td>
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<td>I avoid or cancel obligations (school, social, family) after a poor night's sleep.</td>
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Dysfunctional Attitude Scale (DAS)

This inventory lists different attitudes or beliefs which people sometimes hold. Read each statement carefully and decide how much you agree or disagree with the statement. There is no right or wrong answer to these statements. To decide whether a given attitude is typical of your way of looking at things, simply keep in mind what you are like most of the time.

<table>
<thead>
<tr>
<th>Statement</th>
<th>Totally agree</th>
<th>Agree very much</th>
<th>Agree slightly</th>
<th>Neutral</th>
<th>Disagree slightly</th>
<th>Disagree very much</th>
<th>Totally disagree</th>
</tr>
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<tbody>
<tr>
<td>It is difficult to be happy unless one is good-looking, intelligent, rich, and creative.</td>
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<tr>
<td>Happiness is more a matter of my own attitude towards myself than the way other people feel about me.</td>
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<td>People will probably think less of me if I make a mistake.</td>
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<td>If I do not do well all the time, people will not respect me.</td>
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<td>Taking even a small risk is foolish because the loss is likely to be a disaster.</td>
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<td>It is possible to gain another person's respect without being especially talented at anything.</td>
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<td>I cannot be happy unless most people I know admire me.</td>
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<td>If a person asks for help, it is a sign of weakness.</td>
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<td>If I do not do as well as other people, it means I am an inferior human being.</td>
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<td>If I fail at my work, then I am a failure as a person.</td>
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<td>If you cannot do something well, there is little point in doing it at all.</td>
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<td>Making mistakes is fine because I can learn from them.</td>
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<td>If someone disagrees with me, it probably indicates he does not like me.</td>
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<td>If I fail partly, it is as bad as being a complete failure.</td>
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<tr>
<td>If other people know what you are really like, they will think less of you.</td>
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<td>I am nothing if a person I love doesn't love me.</td>
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<td>One can get pleasure from an activity regardless of the end result.</td>
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<td>People should have a reasonable likelihood of success before undertaking anything.</td>
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<td>My value as a person depends greatly on what others think of me.</td>
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</table>
If I don't set the highest standards for myself I am likely to end up a second-rate person. ( ) ( ) ( ) ( ) ( ) ( ) ( )

If I am to be a worthwhile person, I must be truly outstanding in at least one major aspect. ( ) ( ) ( ) ( ) ( ) ( ) ( )

People who have good ideas are more worthy than those who do not. ( ) ( ) ( ) ( ) ( ) ( ) ( )

I should be upset if I make a mistake. ( ) ( ) ( ) ( ) ( ) ( ) ( )

My own opinions of myself are more important to me than other's opinions of me. ( ) ( ) ( ) ( ) ( ) ( ) ( )

To be a good, moral, worthwhile person, I must help everyone who needs it. ( ) ( ) ( ) ( ) ( ) ( ) ( )

If I ask a question, it makes me look inferior. ( ) ( ) ( ) ( ) ( ) ( ) ( )

It is awful to be disapproved of by people important to you. ( ) ( ) ( ) ( ) ( ) ( ) ( )

If you don't have other people to lean on, you are bound to be sad. ( ) ( ) ( ) ( ) ( ) ( ) ( )

I can reach important goals without slave-driving myself. ( ) ( ) ( ) ( ) ( ) ( ) ( )

It is possible for a person to be scolded and not get upset. ( ) ( ) ( ) ( ) ( ) ( ) ( )

I cannot trust other people because they might be cruel to me. ( ) ( ) ( ) ( ) ( ) ( ) ( )

If others dislike you, you cannot be happy. ( ) ( ) ( ) ( ) ( ) ( ) ( )

It is best to give up your own interests in order to please other people. ( ) ( ) ( ) ( ) ( ) ( ) ( )

My happiness depends more on other people than it does on me. ( ) ( ) ( ) ( ) ( ) ( ) ( )

I do not need the approval of other people in order to be happy. ( ) ( ) ( ) ( ) ( ) ( ) ( )

If a person avoids problems, the problems tend to go away. ( ) ( ) ( ) ( ) ( ) ( ) ( )

I can be happy even if I miss out on many of the good things in life. ( ) ( ) ( ) ( ) ( ) ( ) ( )

What other people think about me is very important. ( ) ( ) ( ) ( ) ( ) ( ) ( )

Being isolated from others is bound to lead to unhappiness. ( ) ( ) ( ) ( ) ( ) ( ) ( )

I can find happiness without being loved by another person. ( ) ( ) ( ) ( ) ( ) ( ) ( )

Thank you for completing the "Starter Survey". We really appreciate your help!
Repeated Survey

This survey will take approximately 20 minutes. Please continue on if you can stay online for this duration to complete the whole survey. Please answer all questions related to how you sleep and how you feel based on your experience over the past week.

Your email

Your initials
This is the first letters of your first and last names without space. To protect your privacy, the answers we collect during the survey will be identified using a code based on your initials, not your actual names. Please make sure you use the same initials when you fill out surveys at different stages. For example, Michael Brant's initials are MB.

Date of Birth
dd/mm/yyyy

It is now
Term __________ Week __________
and
( ) It is now towards the end of a term and it is the first time I fill out the "Repeated Survey".
( ) It is now around the beginning of a term and it is the 3rd time I fill out the "Repeated Survey".
( ) It is now around the middle of a term and it is the 4th and last time I fill out the "Repeated Survey".

Do you have any holiday job(s) or other scheduled activities that have fixed time commitment?
( ) Yes (please specify): ____________________________  ( ) No

Is your sleep schedule affected by this/these commitment(s)?
( ) Yes  ( ) No

Over the past week, how many days were affected?
( ) 1  ( ) 2  ( ) 3  ( ) 4  ( ) 5  ( ) 6  ( ) 7

Please describe how your sleep schedule is affected (e.g. I have to get up at 7am for my day job even though I would normally sleep till 9am during school holidays; I can't go to bed till mid-night even though I would normally go to bed before 11pm during school holidays)
**Centre for Epidemiological Studies Depression Scale (CES-D)**

For each item below, please indicate how often you have felt or behaved that way during the past week.

<table>
<thead>
<tr>
<th>Item</th>
<th>Rarely or Not at All (less than 1 day)</th>
<th>Sometimes (1-2 days)</th>
<th>Occasionally (3-4 days)</th>
<th>Most of the Time (5-7 days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I was bothered by things that don't usually bother me</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td>I did not feel like eating; my appetite was poor</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td>I felt that I could not shake off the blues even with help from my family or friends</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td>I felt that I was just as good as other people</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td>I had trouble keeping my mind on what I was doing</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td>I felt depressed</td>
<td>( )</td>
<td>( )</td>
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<tr>
<td>I felt that everything I did was an effort</td>
<td>( )</td>
<td>( )</td>
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<tr>
<td>I felt hopeful about the future</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td>I thought my life had been a failure</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td>I felt fearful</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td>My sleep was restless</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
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<tr>
<td>I was happy</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
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<tr>
<td>I talked less than usual</td>
<td>( )</td>
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<td>( )</td>
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<tr>
<td>I felt lonely</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td>People were unfriendly</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td>I enjoyed life</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td>I had crying spells</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
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<tr>
<td>I felt sad</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td>I felt that people disliked me</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td>I could not get &quot;going&quot;</td>
<td>( )</td>
<td>( )</td>
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<td>( )</td>
</tr>
</tbody>
</table>
**Spence Children’s Anxiety Scale (SCAS)**

Please tick the word that shows how often each of these things happen to you over the past week. There are no right or wrong answers.

<table>
<thead>
<tr>
<th>Statement</th>
<th>Never</th>
<th>Sometimes</th>
<th>Often</th>
<th>Always</th>
</tr>
</thead>
<tbody>
<tr>
<td>I worry about things</td>
<td>()</td>
<td>()</td>
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<td>()</td>
</tr>
<tr>
<td>I am scared of the dark</td>
<td>()</td>
<td>()</td>
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</tr>
<tr>
<td>When I have a problem, I get a funny feeling in my stomach</td>
<td>()</td>
<td>()</td>
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<tr>
<td>I feel afraid</td>
<td>()</td>
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</tr>
<tr>
<td>I would feel afraid of being on my own at home</td>
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<tr>
<td>I feel scared when I have to take a test</td>
<td>()</td>
<td>()</td>
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</tr>
<tr>
<td>I feel afraid if I have to use public toilets or bathrooms</td>
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<tr>
<td>I worry about being away from my parents</td>
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<tr>
<td>I feel afraid that I will make a fool of myself in front of people</td>
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<tr>
<td>I worry that I will do badly at my school work</td>
<td>()</td>
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<tr>
<td>I am popular amongst other kids my own age</td>
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<td>()</td>
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<td>()</td>
</tr>
<tr>
<td>I worry that something awful will happen to someone in my family</td>
<td>()</td>
<td>()</td>
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<td>()</td>
</tr>
<tr>
<td>I suddenly feel as if I can't breathe when there is no reason for this</td>
<td>()</td>
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</tr>
<tr>
<td>I have to keep checking that I have done things right (like the switch is off, or the door is locked)</td>
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<td>()</td>
</tr>
<tr>
<td>I feel scared if I have to sleep on my own</td>
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<tr>
<td>I have trouble going to school (or going out of the house during holidays) in the mornings because I feel nervous or afraid</td>
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<tr>
<td>I am good at sports</td>
<td>()</td>
<td>()</td>
<td>()</td>
<td>()</td>
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<tr>
<td>I am scared of dogs</td>
<td>()</td>
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<tr>
<td>I can't seem to get bad or silly thoughts out of my head</td>
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<tr>
<td>When I have a problem, my heart beats really fast</td>
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<td>()</td>
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<tr>
<td>I suddenly start to tremble or shake when there is no reason for this</td>
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<td>()</td>
</tr>
<tr>
<td>I worry that something bad will happen to me</td>
<td>()</td>
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<td>()</td>
</tr>
<tr>
<td>I am scared of going to the doctors or dentists</td>
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<td>()</td>
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<tr>
<td>When I have a problem, I feel shaky</td>
<td>()</td>
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<tr>
<td>I am scared of being in high places or lifts (elevators)</td>
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<tr>
<td>I am a good person</td>
<td>()</td>
<td>()</td>
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<td>()</td>
</tr>
<tr>
<td>I have to think of special thoughts to stop bad things from happening (like numbers or words)</td>
<td>()</td>
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<tr>
<td>I feel scared if I have to travel in the car, or on a bus or a train</td>
<td>()</td>
<td>()</td>
<td>()</td>
<td>()</td>
</tr>
<tr>
<td>Item</td>
<td>Yes</td>
<td>Sometimes</td>
<td>Often</td>
<td>Always</td>
</tr>
<tr>
<td>----------------------------------------------------------------------</td>
<td>-----</td>
<td>-----------</td>
<td>-------</td>
<td>--------</td>
</tr>
<tr>
<td>I worry what other people think of me</td>
<td></td>
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<td></td>
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<tr>
<td>I am afraid of being in crowded places (like shopping centres, the movies, buses, busy playgrounds)</td>
<td></td>
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<tr>
<td>I feel happy</td>
<td></td>
<td></td>
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<tr>
<td>All of a sudden I feel really scared for no reason at all</td>
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<td></td>
<td></td>
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<tr>
<td>I am scared of insects or spiders</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I suddenly become dizzy or faint when there is no reason for this</td>
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<td></td>
<td></td>
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<tr>
<td>I feel afraid if I have to talk in front of my class</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>My heart suddenly starts to beat too quickly for no reason</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I worry that I will suddenly get a scared feeling when there is nothing to be afraid of</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I like myself</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I am afraid of being in small closed places, like tunnels or small rooms</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>I have to do some things over and over again (like washing my hands, cleaning or putting things in a certain order)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I get bothered by bad or silly thoughts or pictures in my mind</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>I have to do some things in just the right way to stop bad things happening</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>I am proud of my school work</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I would feel scared if I had to stay away from home overnight</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

Is there something else that you are really afraid of?
( ) Yes (Please specify): ________________________  ( ) No

How often are you afraid of this thing?
( ) Never  ( ) Sometimes  ( ) Often  ( ) Always
Appendix B

**Pittsburgh Sleep Quality Index (PSQI)**

The following questions relate to your usual sleep habits during the past week. Your answers should indicate the most accurate reply for the majority of days and nights during the past week.

During the past week, when did you usually go to bed? ____________________

During the past week, how long (in minutes) did it take you to fall asleep each night? ______

During the past week, when did you usually get up in the morning? ________________

During the past week, how many hours of actual sleep did you get? (this may be different than the number of hours you spend in bed) ________________

During the past week, how often did you have trouble sleeping because you…

<table>
<thead>
<tr>
<th>Reason</th>
<th>Not at all</th>
<th>Once or twice</th>
<th>Three or more times</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Could not get to sleep within 30 minutes</td>
<td>()</td>
<td>()</td>
<td>()</td>
</tr>
<tr>
<td>b. Woke up in the middle of the night or early morning</td>
<td>()</td>
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<tr>
<td>c. Had to get up to use the bathroom</td>
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<td>()</td>
</tr>
<tr>
<td>d. Could not breathe comfortably</td>
<td>()</td>
<td>()</td>
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</tr>
<tr>
<td>e. Coughed or snored loudly</td>
<td>()</td>
<td>()</td>
<td>()</td>
</tr>
<tr>
<td>f. Felt too cold</td>
<td>()</td>
<td>()</td>
<td>()</td>
</tr>
<tr>
<td>g. Felt too hot</td>
<td>()</td>
<td>()</td>
<td>()</td>
</tr>
<tr>
<td>h. Had bad dreams</td>
<td>()</td>
<td>()</td>
<td>()</td>
</tr>
<tr>
<td>i. Had pain</td>
<td>()</td>
<td>()</td>
<td>()</td>
</tr>
<tr>
<td>j. Other reason(s)</td>
<td>()</td>
<td>()</td>
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</tbody>
</table>

Please specify what other reason(s) if you selected "Once or twice" or "Three times or more" in the question above. __________________________________________

During the past week, how often did you take medicine (prescribed or "over the counter") to help you sleep? ( ) Not at all   ( ) Once or twice   ( ) Three or more times

During the past week, how often did you have trouble staying awake during class time, eating meals, or engaging in social activity? ( ) Not at all   ( ) Once or twice   ( ) Three or more times

During the past week, how much of a problem was it for you to keep up enthusiasm to get things done? ( ) No problem at all   ( ) Only a slight problem   ( ) Somewhat of a problem   ( ) A very big problem

During the past week, how would you rate your sleep quality over all? ( ) Very good   ( ) Fairly good   ( ) Fairly bad   ( ) Very bad
Inventory of High-School Students’ Recent Life Experiences (IHSSRLE)

Following is a list of experiences which many students have some time or other. Please indicate for each experience how much it has been a part of your life over the past week.

<table>
<thead>
<tr>
<th>Experience</th>
<th>Not at all part of my life</th>
<th>Only slightly part of my life</th>
<th>Definitely part of my life</th>
<th>Very much part of my life</th>
</tr>
</thead>
<tbody>
<tr>
<td>Being let down or disappointed by friends</td>
<td>()</td>
<td>()</td>
<td>()</td>
<td>()</td>
</tr>
<tr>
<td>Disagreements with teachers</td>
<td>()</td>
<td>()</td>
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<td>()</td>
</tr>
<tr>
<td>Being left out of things by people</td>
<td>()</td>
<td>()</td>
<td>()</td>
<td>()</td>
</tr>
<tr>
<td>Too many things to do at once</td>
<td>()</td>
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<td>()</td>
<td>()</td>
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<tr>
<td>Being taken for granted</td>
<td>()</td>
<td>()</td>
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<td>()</td>
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<tr>
<td>Disagreements with family members about money</td>
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<tr>
<td>Having your trust betrayed by a friend</td>
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<tr>
<td>Separation from people you care about</td>
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<tr>
<td>Having your ideas or efforts overlooked</td>
<td>()</td>
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</tr>
<tr>
<td>Struggling to meet your own standards of performance at school</td>
<td>()</td>
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<tr>
<td>Being taken advantage of</td>
<td>()</td>
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<tr>
<td>Not enough time to do the things you enjoy most</td>
<td>()</td>
<td>()</td>
<td>()</td>
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</tr>
<tr>
<td>Struggling to meet other people's standards of performance at school</td>
<td>()</td>
<td>()</td>
<td>()</td>
<td>()</td>
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<tr>
<td>A lot of responsibilities</td>
<td>()</td>
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<td>()</td>
<td>()</td>
</tr>
<tr>
<td>Dissatisfaction about romantic relationship(s)</td>
<td>()</td>
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<td>()</td>
</tr>
<tr>
<td>Decisions about romantic relationship(s)</td>
<td>()</td>
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<td>()</td>
</tr>
<tr>
<td>Not enough time to meet your responsibilities</td>
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<tr>
<td>Dissatisfaction with your mathematical ability</td>
<td>()</td>
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<tr>
<td>Important decisions about your future career</td>
<td>()</td>
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<tr>
<td>Money problems</td>
<td>()</td>
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<tr>
<td>Important decisions about your education</td>
<td>()</td>
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<tr>
<td>Loneliness</td>
<td>()</td>
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<tr>
<td>Lower grades than you hoped for</td>
<td>()</td>
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</tr>
<tr>
<td>Issue</td>
<td>Rating 1</td>
<td>Rating 2</td>
<td>Rating 3</td>
<td>Rating 4</td>
</tr>
<tr>
<td>----------------------------------------------------------------------</td>
<td>----------</td>
<td>----------</td>
<td>----------</td>
<td>----------</td>
</tr>
<tr>
<td>Not enough time for sleep</td>
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<tr>
<td>Disagreements with your family</td>
<td></td>
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<tr>
<td>Finding subjects at school too demanding</td>
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<tr>
<td>Disagreements with friends</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Hard effort to get ahead</td>
<td></td>
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<tr>
<td>Poor health of a friend</td>
<td></td>
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<tr>
<td>Disliking your studies</td>
<td></td>
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<tr>
<td>Getting &quot;ripped off&quot; or cheated in the purchase of services</td>
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<tr>
<td>Social disagreements over smoking or drinking</td>
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<tr>
<td>Disliking fellow student(s)</td>
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<tr>
<td>Disagreements with boyfriend/girlfriend</td>
<td></td>
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<tr>
<td>Dissatisfaction with your ability at written expression</td>
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<tr>
<td>Interruptions of your schoolwork</td>
<td></td>
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<tr>
<td>Being without company</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Being ignored</td>
<td></td>
<td></td>
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<tr>
<td>Dissatisfaction with your looks</td>
<td></td>
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<tr>
<td>Gossip concerning someone you care about</td>
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<tr>
<td>Dissatisfaction with your athletic skills.</td>
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</tr>
</tbody>
</table>

Thank you for taking this part of the survey. We really appreciate your help!
APPENDIX C OTHER DOCUMENTS AND INFORMATION

- How to Use the Actiwatch
- The Morningness - Eveningness Report (Sample)
- Report on Actiwatch Measured Sleep-Wake Patterns (Sample)
- R Packages Used in Data Manipulation and Analyses
How to Use the Actiwatch

“Youth Sleep and Wellbeing”

Please wear the Actiwatch on your non-dominant hand, like a normal watch. Make sure you wear it every day, during both day and night from:

\[ \text{xxx at 6pm until when you get up on xxx} \]

and post it in the Yellow Express Post Box using the prepaid envelop.

Please keep the bubble wrap and use it when posting the Actiwatch

The Actiwatch is an important research tool. Please look after it the way you would look after your own belongings. Thank you!

There is one simple task while you are wearing the Actiwatch: press the “Event Marker” button on the watch, once when you go to bed (when you intend to sleep), once when you get up. Do this way for both night-time sleep and daytime naps. This way, the Actiwatch will record your bedtimes and rise-times, so we can calculate how long it took you to fall asleep, and how efficient your sleep was.

Cautions

- The Actiwatch is water-resistant, so you don’t need to worry about getting it wet (e.g. hand-washing, showers). However, please take it off during a bath, or when you go swimming. You may have the Actiwatch off for up to 3 hours during the day, and please remember to put it on in the evening so it keeps track of your sleep.
- Please do not take the Actiwatch apart.
- Please do not let the Actiwatch be directly exposed to fire or electric shocks.
- Please take off the Actiwatch before you are exposed in the following situations:
  - Radiation (e.g., X-ray, CT)
  - Magnetic fields (e.g., MRI)
  - Electromagnetic fields
  - Defibrillators or short wave therapy equipment
  - Operation of high frequency (diathermy) equipment

By the way...

- The Actiwatch \textbf{DOES NOT} emit radiation or magnetic fields, or generate any other types of visible or invisible interaction with human body that could possibly be harmful to you.
- The Actiwatch only records how frequently you move your wrist and \textbf{DOES NOT} collect any audio or visual information of your everyday life.
- Each Actiwatch is sterilized before given to you.

Please contact us at beib@unimelb.edu.au 03 8344 4911 or 0415 552 267 if you have any questions or concerns.
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“Youth Sleep and Wellbeing”

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Are you a morning lark or a night owl?

We hear about “morning persons (larks)” and “evening persons (owls)”. These are everyday terms used to describe what is technically known as “chronotypes”. “Chrono-” comes from the Greek word “khronos”, meaning time. Chronotype refers to someone’s preferred time of day for optimal mental and physical activity.

Humans and animals go through sleep and wake cycles on a daily basis. Some individuals feel at their best during morning hours, some are more alert later in the day. Most people are neither morning nor evening types, but lie somewhere in between on a sliding scale. As we grow older, the degree to which we function better during morning hours or evening hours may vary. Researchers have found that from early to late adolescence and early adulthood, young people tend to move more towards the evening side of the scale; while later in life, older adults might become more alert during morning hours.

There are different ways to determine a person’s chronotype, and the Morningness - Eveningness Questionnaire you have completed as part of the Starter Survey is one of the most common and effective ways. The Morningness – Eveningness Questionnaire puts your score on a sliding scale: a higher score means stronger morningness, a lower score means stronger eveningness. The graph below shows the spectrum of scores on the sliding scale and what they mean.

<table>
<thead>
<tr>
<th>Score Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>16-30</td>
<td>Definitely Evening</td>
</tr>
<tr>
<td>31-41</td>
<td>Moderate Evening</td>
</tr>
<tr>
<td>42-58</td>
<td>Intermediate</td>
</tr>
<tr>
<td>59-69</td>
<td>Moderate Morning</td>
</tr>
<tr>
<td>70-86</td>
<td>Definite Morning</td>
</tr>
</tbody>
</table>

Your score on the Morningness - Eveningness Questionnaire is XX

If you have any questions or comments, please do not hesitate to contact us at beib@unimelb.edu.au or 03 8344 4911.
How to read the graph?

- The graphs give you an overview of what your sleeping pattern was like while you were wearing the Actiwatch.
- The black lines means movements and/or wakefulness.
- The green shade means possible wakefulness after going to bed.
- The blue shade means possible sleep periods – if you see black lines within blue shades, it means you were making movements during your sleep period, or have gotten up during the night.
- The blue dots on the top of each graph are times when the “Event Marker” button was pressed.

How to read the table?

- Bedtime and Rise-time: we generally used the Event Marker (button press) to determine the time you went to sleep and woke up. If you looked quite active in Actiwatch recording when the button was pressed, we estimated the actual sleep/wake time.
- Time Slept: the number of hours and minutes the Actiwatch considered you as asleep between bedtimes and rise-times. This does not include naps you took during the day.
- Minutes till Asleep: this is the minutes between bedtimes and when the Actiwatch thinks you might be asleep.
- Sleep Efficiency: this is the percentage of sleep time during time spent in bed.

How was my sleep?

- First of all, this report is produced for research purposes only, and cannot be used to diagnose any sleep condition on its own. If you are concerned about your sleep, please let your parents know and get in touch with your doctor.
- Students who participated in this project so far have slept on average 7 hours, had a mean sleep efficiency of 80.3%, and took 20 minutes to fall asleep across all nights.
- Many things can affect your sleep, for example your morning/evening preferences, your daily routines and obligations, your physical and your emotional wellbeing. A good indication of having had good sleep is waking up feeling refreshed. Most adolescents would say they need about 9 hours in bed each night to feel refreshed.

If you have any question or comment about this report, please contact us at
Sleep Research Centre, University of Melbourne, beib@unimelb.edu.au 03 8344 4911
<table>
<thead>
<tr>
<th>Day</th>
<th>Date</th>
<th>Bedtime</th>
<th>Rise-time</th>
<th>Time Slept</th>
<th>Minutes till Asleep</th>
<th>Sleep Efficiency %</th>
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<tr>
<td><strong>Week 1 Average</strong></td>
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## R Packages Used in Data Manipulation and Analyses

<table>
<thead>
<tr>
<th>Package</th>
<th>Functions used</th>
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<tbody>
<tr>
<td><strong>Exploratory analyses</strong></td>
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<tr>
<td>Amelia (Honaker, King, &amp; Blackwell, 2011)</td>
<td>Exploring missing data patterns</td>
</tr>
<tr>
<td>GGally (Schloerke, Crowley, Di Cook, Hofmann, &amp; Wickham, 2012)</td>
<td>Exploring relationships among variables</td>
</tr>
<tr>
<td>peqoud (Mirisola &amp; Seta, 2013)</td>
<td>Moderated regression utilities</td>
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<tr>
<td>psych (Revelle, 2013)</td>
<td>Factor analysis</td>
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<tr>
<td>reshape2 (Wickham, 2007)</td>
<td>Data restructuring</td>
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<tr>
<td><strong>Final analyses and graphics</strong></td>
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<td>car (Fox &amp; Weisberg, 2011)</td>
<td>Regression utilities</td>
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<tr>
<td>epicale (Chongsuvivatwong, 2012)</td>
<td>Calculation of Cronbach's alpha</td>
</tr>
<tr>
<td>ggplot2 (Wickham, 2009)</td>
<td>Generating plots</td>
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<tr>
<td>gridExtra (Auguie, 2012)</td>
<td>Combining plots</td>
</tr>
<tr>
<td>mice (Buuren &amp; Groothuis-Oudshoorn, 2011)</td>
<td>Multiple imputation</td>
</tr>
<tr>
<td>MplusAutomation (Hallquist &amp; Wiley, 2013)</td>
<td>Bridging R and Mplus, automating data and input of SEM models, extracting results, comparing nested models.</td>
</tr>
<tr>
<td>semutils (Wiley, 2013)</td>
<td>Correlation matrices, combining regression results from multiply imputed datasets</td>
</tr>
</tbody>
</table>
Author/s: BEI, BEI

Title: Sleep, mood, and cognitive vulnerability in adolescents: a naturalistic study over restricted and extended sleep opportunities

Date: 2013

Citation: Bei, B. (2013). Sleep, mood, and cognitive vulnerability in adolescents: a naturalistic study over restricted and extended sleep opportunities. PhD thesis, Medicine, Dentistry & Health Sciences - Melbourne School of Psychological Sciences, The University of Melbourne.

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