Chronic sleep reduction in adolescents
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„Wenn du eine weise Antwort verlangst musst du vernünftig fragen.“

-Johann Wolfgang von Goethe-
Chapter 1

General introduction
1.1. Sleep in adolescents

During adolescence most individuals experience a shift in the preferred time of their sleep. Whereas young children tend to go to bed early in the evening and also wake up spontaneously early in the morning, adolescents prefer to go to bed later in the evening and also to get up later in the morning (Roenneberg et al., 2004). These changes in sleep timing have been reported world-wide (Crowley, Acebo, & Carskadon, 2007; Gradisar, Gardner, & Dohnt, 2011) and are at least partly caused by internal biological changes in the circadian system as indicated by a delayed dim light melatonin onset (DLMO) (a reliable marker of the circadian timing system) in the evening (Carskadon, 2011a; Crowley et al., 2007). Additionally, external factors, such as less parental control, increased media usage, and social activities in the evening, often delay bedtimes and sleep onset times (Dahl & Lewin, 2002). However, due to school times adolescents have to get up early in the morning. As a consequence many adolescents experience sleep problems caused by shortened sleep as well as by an accumulating sleep debt in the course of the week. This experienced sleep debt during the week is often compensated by extended sleep durations (‘catch-up sleep’) in the weekends (Carskadon, 2011a; Crowley et al., 2007). Therefore, in many adolescents the misalignment between their endogenous biological time and their social time (early rise times due to school start times) results in a so-called social jetlag (i.e. shifting their sleep and activity times several hours between the week and weekends).

Changes in sleep timing and sleep debt in adolescents mainly concern their sleep durations. However, an additional aspect of sleep refers to adolescents’ sleep quality. Although sleep duration and sleep quality may overlap to some extent, qualitative differences exist between them. Differences can already be found in the definition of sleep duration and sleep quality. Sleep duration is the time somebody is sleeping (e.g., time between sleep onset and wake-up time, corrected for intermittent wakefulness), whereas sleep quality refers to the subjective indices of how sleep is experienced, including the feeling of being rested when waking up and satisfaction with sleep (Pilcher, Ginter, & Sadowsky, 1997). Furthermore, correlations between sleep duration and sleep quality appear to be low or not significant (Liu & Zhou, 2002; Meijer, Habekotte, & van den Wittenboer, 2000). This suggests that sleep quality and sleep duration also differ in their impact on daytime functioning including school performance. However, most studies did not include both sleep measures in one study design. Due to differences between studies (e.g., operationalization, study design), results can not directly be compared. To date, this limits the understanding of the effects of adolescents’ sleep on other outcome variables (e.g., school performance).
Indications for the high prevalence of sleep problems come from studies that found that 45% of the adolescent population sleep less than 8 hours per night (Gibson et al., 2006; Pagel, Forister, & Kwiatkowki, 2007), 11% to 47% report poor sleep (Liu & Zhou, 2002; Russo, Bruni, Lucidi, Ferri, & Violani, 2007), and approximately 46% experience daytime sleepiness (Pagel et al., 2007), which is one of the most obvious and prevalent consequences of insufficient and/or poor sleep (Moore & Meltzer, 2008). The negative impact of such sleep problems is demonstrated by studies showing that sleep problems are related to impairments throughout the day, which include negative effects on emotional well-being, cognitive performance, behavior, and school performance (Carskadon, 2011b; Curcio, Ferrara, & De Gennaro, 2006; Fallone, Owens, & Deane, 2002; Meijer, Reitz, Deković, van den Wittenboer, & Stoel, 2010; Mitru, Millrood, & Mateika, 2002; Moore & Meltzer, 2008; Wolfson & Carskadon, 2003). As these sleep problems (including insufficient and/or poor sleep) often occur over a relatively long time period, they become chronic in many adolescents. Therefore, it is not surprising that chronic sleep reduction constitutes a severe problem in this age group (Loessl et al., 2008; Meijer, 2008).

Taken together, during adolescence an interaction of intrinsic and extrinsic factors causes delayed bedtimes while rise times remain unchanged during the week. Due to this interaction, adolescents often experience insufficient and/or poor sleep over a long time period, often resulting in chronic sleep reduction. Sleep problems (including insufficient and/or poor sleep) are prevalent problems in adolescents and can have severe negative effects on adolescents’ functioning throughout the day.

1.2. The assessment of chronic sleep reduction
As was pointed out in 1.1, chronic sleep reduction is an important phenomenon in adolescents, although it remains a concept that is challenging to assess. Most studies operationalized chronic sleep reduction in terms of shortened sleep durations over a certain time period (Roberts, Roberts, & Xing, 2010; van Dongen, Rogers, & Dinges, 2003). However, this operationalization does not account for differences in individual sleep need (i.e. the amount of sleep somebody would need to be fully awake and not sleepy during the day), which is an important factor for the effects of sleep loss on daytime functioning. A relatively new assessment method to measure chronic sleep reduction in adolescents is the Chronic Sleep Reduction Questionnaire (CSRQ; Meijer, 2008). The CSRQ is a questionnaire that measures symptoms of insufficient and/or poor sleep over a relatively long time period rather than assessing for instance sleep duration directly. Based on the assumption that these symptoms only occur in individuals that sleep less than the amount of sleep they would need to function optimally throughout the day, it accounts for their individual sleep need.
Additionally, as these symptoms may only become present after a longer time period, this method also addresses the aspect of chronicity (Meijer, 2008). Although Meijer (2008) reported good reliabilities of the CSRQ, the questionnaire has not yet been validated. Furthermore, an English version of the CSRQ is highly needed for international studies. Research that gains more insight into the psychometric properties of this original questionnaire constitutes an important step in adolescent sleep research.

1.3. Individual differences in vulnerability to sleep loss
Several studies have been conducted that examine the relationship between sleep problems and their daytime consequences (e.g., Carskadon, 2011b). However, whether all adolescents are equally susceptible to chronic sleep reduction and to its consequences remains an important research questions. Rajaraman, Gribok, Wesensten, Balkin, and Reifman (2008) demonstrated that performance of sleep-deprived individuals can be distinguished by three distinct performance phenotypes: relatively vulnerable to sleep loss, relatively average sensitivity to sleep loss, and relatively resilient to sleep loss. Although previous studies reported individual differences in vulnerability to sleep loss (Rajaraman et al., 2008; van Dongen, Baynard, Maislin, & Dinges, 2004), it is still unknown whether comparable individual differences in vulnerability to chronic sleep reduction as operationalized by the CSRQ exist. More concretely, this idea suggests that differences in performance can be attributed to the amount of adolescents’ chronic sleep reduction as measured by the CSRQ.

1.4. Sleep and stress in adolescents
Empirical evidence from animal as well as from human studies indicates that stress and sleep are closely related (Åkerstedt, 2006). Experimental animal studies showed that acute stress (Pawlyk, Morrison, Ross, & Brennan, 2008) as well as mild chronic stressors (Cheeta, Ruigt, van Proosdij, & Willner, 1997) cause changes in rats’ sleep architecture and reductions in their sleep efficiency (Papale, Andersen, Antunes, Alvarenga, & Tufik, 2005). The limited findings from human studies support these findings by demonstrating that higher stress levels are related to shorter sleep times and poorer sleep quality (El-Sheikh, Buckhalt, Keller, & Granger, 2008; Fortunato & Harsh, 2006; Tworoger, Davis, Vitiello, Lentz, & McTiernan, 2005). Considering these relationships and the earlier described high prevalence of sleep problems in adolescents, research on this topic is extremely relevant.

In addition to this evidence, it has been shown that chronic sleep loss in rats is not only a mild activator of the hypothalamic-pituitary-adrenal (HPA) axis, but also affects the
subsequent response to stress, indicating that chronic sleep reduction can act as a stressor itself (Meerlo, Sgoifo, & Suchecki, 2008). These findings are an important basis for studies on adolescents’ sleep as they support the assumption that individuals with high chronic sleep reduction may react differently to stressful times than adolescents with low chronic sleep reduction.

Experiments that manipulate psychological stressors to measure stress related consequences over a longer time (e.g., sleep changes) can involve ethical and methodological problems in research with children and adolescents. This may explain why this topic has not been addressed by previous studies. A quasi-experiment in a natural situation (e.g., during exam weeks) can overcome some of these problems and gives an accurate picture of individuals’ stress perception. Therefore, such an approach is an elegant way to gain more insight into the effects of stressful times on adolescents’ sleep.

1.5. Sleep extension in adolescents
As explained before, many adolescents experience sleep problems over long time periods, which often result in chronic sleep reduction. These sleep problems are at least partly caused by an interaction of delayed bedtimes in the evening and early school start times in the morning. Although this world-wide occurring phenomenon and its negative consequences on adolescents' daytime functioning has often been studied, to date surprisingly few experimental studies have been conducted in adolescents investigating the potential benefits of extended sleep times. A limited number of studies in which school start times were delayed, providing the opportunity to obtain more sleep, reported positive effects on adolescents’ sleep (e.g., sleep durations, satisfaction with sleep) and daytime functioning (e.g., daytime sleepiness, mood, attention level, late arrivals at school, school absenteeism, and academic performance) (Lufi, Tzischinsky, & Hadar, 2011; O'Malley & O'Malley, 2008; Owens, Belon, & Moss, 2010; Wahlstrom, 2002). Despite these findings, for several reasons (e.g., interruption of school employees’ schedule, worsening of rush-hour congestion, overlap with extracurricular and athletic activities, etc.) the idea of later school start times in high schools is often not supported by the society (Kirby, Maggi, & D'Angiulli, 2011).

An alternative for extending adolescents’ sleep by delaying their rise times in the morning comes from the idea to extend sleep by advancing bedtimes in the evening. At present, Sadeh, Gruber, and Raviv (2003) conducted the only experimental study to investigate the effects of sleep extension on children’s cognitive performance. In this study school-aged children were instructed to either extend or restrict their sleep for three consecutive nights. In spite of the promising reported results revealing improvement in sleep and some aspects of cognitive performance, there is no evidence replicating this finding and
no studies exist that apply this approach to older age groups. This is an important research omission as many adolescents sleep less than their individual sleep need and consequently suffer from chronic sleep reduction (Meijer, 2008). Therefore, this group of adolescents would benefit from extended sleep times in particular. In experimental studies and clinical settings sleep extension approaches should take adolescents’ circadian system into account, as it changes only slowly. It is therefore necessary to extend their sleep by *gradually* advancing their bedtimes in the evening. In addition, as outlined in 1.1, many adolescents compensate insufficient sleep during the week by extending their sleep in the weekends, resulting in irregular sleep timings and jet-lag like symptoms (Dahl & Lewin, 2002). These adverse effects can be overcome by preventing bedtime shifts during weekends. Such an approach can be used to answer the question whether adolescents are capable of advancing their sleep onsets and consequently extending their sleep by gradually advancing their bedtimes. Additionally, it sheds more light on the effects of gradual sleep extension on sleep and other outcome variables, such as depressive symptoms and cognitive performance.

One interesting outcome measure when manipulating adolescents’ sleep is depression. Whether or not gradual sleep extension can diminish depressive symptoms is highly relevant as sleep problems are known to have a high co-morbidity with symptoms of depression, not only in adults but also in children and adolescents (Gregory & Sadeh, 2012). Although most studies reported a significant link between sleep and depression, their relationship is extremely complex and most likely bidirectional (Gregory & Sadeh, 2012). Sleep deprivation studies showed that mood can be affected by reduced sleep (Dinges et al., 1997) and longitudinal studies indicated that sleep problems are a potential risk factor for the development of depressive symptoms, whereas less evidence was found for the opposite relationship (Gregory et al., 2005; Gregory, Rijsdijk, Lau, Dahl, & Eley, 2009). Since earlier bedtimes and longer sleep times are associated with less depressive symptoms (Gangwisch et al., 2010), it may be assumed that extending sleep by advancing bedtimes improves sleep and reduces depressive symptoms of adolescents with chronic sleep reduction.

A second important outcome measure is cognitive performance as adolescents have to rely on a large amount of cognitive abilities to perform well at school. A recent meta-analysis in adults showed that total sleep deprivation leads to considerable performance deficits of some cognitive domains (e.g., simple attention, working memory), whereas others are not significantly affected by sleep (e.g., mental processing, crystallized intelligence) (Lim & Dinges, 2010). However, mixed results are reported in cross-sectional studies that addressed the question whether or not adolescents’ cognitive performance is related to sleep (e.g., Anderson, Storfer-Isser, Taylor, Rosen, & Redline, 2009; Buckhalt, El-Sheikh, &
Kelly, 2007; Gradisar, Johnston, & Douglas, 2008; Kopasz et al., 2010; Steenari et al., 2003). Although very relevant, not many experimental sleep restriction or sleep deprivation studies in children and adolescents have been conducted and results from the existing research are inconclusive (Carskadon, Harvey, & Dement, 1981; Randazzo, Muehlbach Schweitzer, & Walsh, 1998; Voderholzer et al., 2011; Fallone, Acebo, Arnedt, Seifer, & Carskadon, 2001; Gais, Luca, & Born, 2006). As these studies differ in their operationalization of cognitive performance and in study design, it is difficult to draw generalizable conclusions. A recent meta-analysis that combined different study results to examine the relationship between sleep and cognitive performance in children concluded that some cognitive domains, namely executive functions and cognitive performance involving multiple cognitive domains, are positively affected by longer sleep durations. Interestingly, opposite to findings from adult studies, no significant relationship of sleep duration with sustained attention and memory was found (Astill, van der Heijden, van IJzendoorn, & van Someren, 2012). However, the effects of extended sleep times on adolescents’ cognitive performance are still unknown.

1.6. Aims of this thesis
The aims of this thesis are (1) to disentangle the effects of different aspects of sleep on adolescents’ school performance (Chapter 2), (2) to enhance the knowledge about how chronic sleep reduction in adolescents can be measured (Chapter 3 & Chapter 4), (3) to examine individual differences in vulnerability to sleep loss (Chapter 5), (4) to gain more insight into the relationship between sleep and stress in adolescents (Chapter 6), and (5) to investigate the effects of gradual sleep extension on depressive symptoms (Chapter 7) and cognitive performance (Chapter 8).

1.7. Outline of this thesis
In the following chapters of this thesis, important and understudied research questions are addressed by using different types of studies (meta-analysis, cross-sectional design, quasi-experimental design, experimental design) and measurements (e.g., self-reports, actigraphy). Studies that examine the relation between sleep and school performance are difficult to compare as they differ in study design and operationalization of variables. Chapter 2, a meta-analysis, answers this question by systematically investigating the effects of different aspects of sleep, namely sleep duration, sleep quality, and sleepiness on adolescents’ school performance. Although chronic sleep reduction is a common phenomenon in adolescents which can have severe effects on their daytime functioning, assessing the construct of chronic sleep reduction is challenging. Chapter 3 and Chapter 4 shed more light on a relatively new assessment approach, the Chronic Sleep Reduction Questionnaire.
(CSRQ), by validating an English and a Dutch version of the CSRQ (Chapter 3) and the Chronic Sleep Reduction-Short Form (CSRQ-SF) (Chapter 4). In Chapter 5 a cross-sectional design is used to examine individual differences in vulnerability to sleep loss and therefore to answer the question whether all adolescents are equally susceptible to chronic sleep reduction and to its consequences. To overcome the ethical and methodological problems of conducting research on the effects of stress on sleep in adolescents, Chapter 6 reports data from a quasi-experimental design. Adolescents’ sleep is studied in a situation which is naturally characterized by stress (their exam times). Furthermore, in Chapter 6 it is examined whether chronic sleep reduction moderates changes in sleep from low-stress to high-stress (exam) times. As studies that focus on extending adolescents’ sleep are scarce, Chapter 7 and Chapter 8 address the question whether adolescents with high chronic sleep reduction are capable of gradually advancing their bedtimes and their sleep onsets and consequently extending their sleep. Additionally, in Chapter 7 the effects of gradual sleep extension on depressive symptoms are investigated. Furthermore, Chapter 8 aims to gain more insight into the effects of gradual sleep extension on adolescents’ cognitive performance.
1.8. References


Lufi, D., Tzischinsky, O., & Hadar, S. (2011). Delaying school starting time by one hour: some effects on attention levels in adolescents. *Journal of Clinical Sleep Medicine, 7*, 137-143.


