Chronic sleep reduction in adolescents
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„So einfach wie möglich. Aber nicht einfacher.“

-Albert Einstein-
Chapter 9

General Discussion
9.1. The contribution of this thesis
Due to an interaction of biological (e.g., changes in the circadian system) and environmental changes (e.g., social activities, media usage, academic demands), many adolescents experience insufficient and/or poor sleep, which can have severe consequences on their daytime functioning including cognitive performance, emotional well-being, behavior, and school performance (Carskadon, 2011; 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 most adolescents experience these sleep problems over relatively long time periods, many suffer from sleep debt and chronic sleep reduction, which means that they sleep less than their individual sleep need or experience poor sleep for a long time period (Loessl et al., 2008; Meijer, 2008).

This thesis extended our knowledge on this topic by using different study designs (meta-analysis, cross-sectional design, quasi-experimental design, experimental design) and measurements (e.g., self-reports, actigraphy). More specifically, the aims of this thesis were (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).

9.2. Studying adolescents’ sleep and its effects on daytime functioning
As described earlier, sleep duration and sleep quality seem to represent two different aspects of sleep as evidenced by low or non-significant correlations (Liu & Zhou, 2002; Meijer, Habekothe, & van den Wittenboer, 2000). However, many studies did not include sleep duration and sleep quality as separate variables within the same study when assessing their relationship with other outcome variables. Due to differences between studies (e.g., operationalization, study design), results can not directly be compared. Chapter 2 addressed this problem by conducting a meta-analysis that compared the relationships of sleep duration, sleep quality, and sleepiness with school performance. The overall results showed the strongest relationship with school performance for sleepiness, followed by sleep quality and sleep duration. Furthermore, as the confidence intervals of the three associations did not overlap, Chapter 2 highlighted the need to treat sleep duration, sleep quality, and sleepiness as separate sleep variables when studying their effects on
daytime functioning. Smaller effects of sleep duration might be caused by the fact that sleep duration does not take individual sleep need and differences in vulnerability to sleep loss into account, which is defined as the magnitude of performance impairment given a fixed amount of sleep reduction (van Dongen, Baynard, Maislin, & Dinges, 2004). As these concepts are difficult to measure, it was argued in Chapter 2 that the construct of chronic sleep reduction might be more relevant for assessing the consequences of sleep reduction or poor sleep. Based on this result, the following chapters mainly focused on adolescents’ chronic sleep reduction constituting an important step in adolescent sleep research.

9.3. Assessment of chronic sleep reduction in adolescents

Although different aspects of sleep (e.g., sleep duration, sleep quality) are related to adolescents’ daytime functioning (e.g., school performance), results may be limited in their interpretability as they do not account for individual sleep need. As large individual differences in sleep need have been reported by previous studies (van Dongen, Rogers, & Dinges, 2003; van Dongen et al., 2004), an assessment method that takes this factor into account can give important additional information when studying the effects of sleep on other outcome variables. Therefore, Meijer (2008) developed the Chronic Sleep Reduction Questionnaire (CSRQ) that overcomes this problem by measuring symptoms of insufficient and/or poor sleep rather than assessing sleep variables (e.g. sleep duration) directly. Although previous research indicated that this questionnaire is a reliable instrument, more information on its psychometric properties, including the validity of the questionnaire, was highly needed. Furthermore, an English version would enable its usage in international research. Chapter 3 contributed to this research field by validating a Dutch and an English CSRQ version and relating it to self-reported school performance. Results from this study showed good psychometric properties of the CSRQ and demonstrated that the CSRQ is a reliable and valid assessment tool to measure chronic sleep reduction in adolescents. Due to the advantages of studying symptoms of insufficient and/or poor sleep (accounting for individual sleep need and for chronicity), it was concluded that this measurement is a more promising indicator of the effects of sleep problems on adolescents’ daytime functioning than sleep duration.

However, the associations between the CSRQ subscales and objective sleep variables varied across the two CSRQ versions. Correlations were especially low for the subscale ‘Irritation’. Based on this result, it was speculated that symptoms of irritation may not be a universal symptom of chronic sleep loss that can be observed in all adolescents. Therefore, in Chapter 4 a short form of the CSRQ, the CSRQ-SF, was developed in order to identify universal symptoms of chronic sleep reduction. Results from these analyses showed
that none of the items that belong to the Irritation subscale remained in the CSRQ-SF, supporting the idea that these items represent a different cluster of symptoms. Chapter 4 furthermore demonstrated that the 9-item CSRQ-SF has equivalent psychometric properties as the original CSRQ. Additionally, the questionnaire can distinguish well between clinical and non-clinical cases. Due to the limited number of items and the availability of cut-off scores, the CSRQ-SF can therefore be seen as a practical tool for clinical and research purposes.

Although this thesis showed that the CSRQ is a promising assessment tool to measure chronic sleep reduction in adolescents, more research has to be done to understand the complex interplay between the different symptoms of chronic sleep reduction and their relationship with other sleep and daytime functioning variables. Furthermore, even though the CSRQ captures important symptoms of insufficient and/or poor sleep, prior studies also demonstrated consequences of sleep problems on attention, concentration, cognitive performance, and school performance (e.g., Dahl & Lewin, 2002). Future research should address the question to which extent these consequences represent symptoms of chronic sleep reduction and should therefore be added to the CSRQ.

The underlying assumption of the CSRQ is that symptoms of chronic sleep reduction only become present if somebody is sleeping less than one’s individual sleep need or experiences poor sleep over a long time period (Meijer, 2008). Therefore, the CSRQ has the advantage that it addresses aspects of chronicity. The present CSRQ version refers to symptoms of insufficient and/or poor sleep that occurred during the previous two weeks, however, it does not indicate for how long chronic sleep reduction has been present. Concerning this last point, it might be interesting to examine in future, preferably longitudinal studies, how much time is needed to develop symptoms of chronic sleep reduction and to investigate whether relations with daytime functioning occur after a specific time period.

As described in Chapter 1, a natural shift in sleep timings occurs during adolescence when adolescents prefer later bedtimes in the evening and later rise times in the morning (Crowley, Acebo, & Carskadon, 2007; Gradisar, Gardner, & Dohnt, 2011). Consequently, due to early school times, adolescents get insufficient sleep during the school week which is often compensated by extended sleep durations in the weekends (‘catch-up sleep’) (Crowley et al., 2007). The timing of sleep of a typical adolescent is therefore characterized by large differences in amount of sleep that are obtained on school nights and on weekend nights. It should be mentioned that some CSRQ questions refer to school nights only (e.g., ‘Do you feel well rested at school?’; ‘I have to struggle to stay awake in class’; ‘I feel very alert at school’), whereas others capture consequences of sleep in general (e.g., ‘Do you feel sleepy during the day’, ‘When I do not get enough sleep it is more likely that I start an argument’, ‘I
am a person who does not get enough sleep’). At present it remains unknown which aspect of sleep problems (e.g., sleep debt during the week or differences between sleep times on school nights and on weekend nights) particularly contributes to chronic sleep reduction and impairments throughout the day. As this is an important question especially for the development of treatment programs, future research should address these relationships in more detail. Findings from such studies can be used for the focus of future sleep improvement programs. For some individuals such programs can for instance focus more on sleep extension during the week and for others more on regular sleep schedules.

9.4. Individual differences in vulnerability to sleep loss
A previous study demonstrated that performance of sleep-deprived individuals can be predicted by three distinct performance phenotypes: relatively vulnerable to sleep loss, relatively average sensitivity to sleep loss, and relatively resilient to sleep loss (Rajaraman, Gribok, Wesensten, Balkin, & Reifman, 2008). The results from Chapter 5 extended this idea and suggested that vulnerability to sleep loss might especially be expressed by the amount of chronic sleep reduction (as measured by the CSRQ). Chapter 5 addressed this question by examining whether daytime functioning variables (including depressive symptoms, attention problem, sleepiness, school functioning, school performance) could discriminate between individuals with high and low chronic sleep reduction and long and short sleep durations (upper and lower quartiles were used to identify extreme groups). The presented study clearly demonstrated that daytime functioning was more (and even clinically) impaired in adolescents with high chronic sleep reduction and adolescents with short sleep durations than in the total sample. On the other hand, adolescents with low chronic sleep reduction and long sleep durations showed less impairment in the daytime functioning variables when compared to the total sample. Therefore, Chapter 5 supported the idea of individual differences in vulnerability to sleep loss. Furthermore, Chapter 5 demonstrated that symptoms of insufficient sleep (as measured by the CSRQ) may be a better conceptualization to capture the full picture of chronic sleep loss than sleep duration, being in line with the idea that has been raised in the previous chapters of this thesis.

9.5. Sleep and stress in adolescents
Although cross-sectional studies showed that stress is closely related to impaired sleep (Åkerstedt, 2006), experimental and longitudinal research on this complex relationship is limited. The lack of such research may at least partly be the result of ethical and methodological problems that arise when manipulating children’s psychological stress to measure stress-related consequences over a longer time period (e.g., sleep changes). To
overcome this problem, a prospective quasi-experimental design was used in Chapter 6, in which sleep was measured over a period of three weeks (two weeks prior to the exam week and during the exam week). This design was based on the assumption that the time just before and during exam weeks is a time during which adolescents are naturally confronted with stress. Based on the idea that chronic sleep reduction acts as an additional stressor (Åkerstedt, 2006; Meerlo, Sgoifo, & Suchecki, 2008), it was also investigated whether chronic sleep reduction moderates changes in sleep from low-stress to high-stress times.

In summary, results from this quasi-experiment revealed that adolescents’ total sleep time (TST) and sleep efficiency did not change during stressful school times, whereas participants did sleep more restless during these weeks. Chronic sleep reduction did not affect TST, supporting the results from Chapter 3 that indicated non-significant relationships between the two CSRQ versions and adolescents’ TSTs. One possible explanation may be that TST does not take individual differences in sleep need into account. Based on this idea, it might be assumed that adolescents scoring high on the CSRQ are individuals that are characterized by a higher sleep need than adolescents scoring low on the CSRQ. An alternative explanation could be found in the scoring of the actigraphy data. A recent study demonstrated that actigraphy may overestimate adolescents’ wake times after sleep onset (WASO), consequently leading to smaller values for TSTs (Short, Gradisar, Lack, Wright, & Carskadon, 2012). It can be speculated that this overestimation may especially be present for adolescents who spend more time in bed and sleep longer.

Furthermore, the sleep of participants with low chronic sleep reduction was more fragmented during the high-stress period (exam week) than the sleep of participants with high chronic sleep reduction. This finding may indicate a buffering effect of chronic sleep reduction on adolescents’ sleep fragmentation, resulting from a higher sleep pressure which is comparable to the effect of sleep restriction on insomnia complaints (Guilleminault et al., 2003). The finding that sleep restriction in adolescents results in better sleep efficiencies (Morgenthaler et al., 2007) supports this idea.

A recent study in adults showed that the feeling of stress/worries at bedtime significantly predicted worse subjective sleep quality (Åkerstedt et al., 2012). As the study about changes in sleep from low-stress to high-stress times, being presented in Chapter 6, did not include subjective sleep quality measures, results from this thesis cannot directly be compared with this recent study. However, as it can be assumed that exam times are particularly characterized by bedtime worries, which may affect subjective sleep quality to a larger extent than reduction of TSTs, it is of high interest to address this research question in future studies.
9.6. Sleep extension in adolescents with chronic sleep reduction

As described earlier, one important source of changes in sleep timings during adolescence can be found in changes in the circadian system (e.g., delayed melatonin onset), causing a preference of later bedtimes in the evening and late rise times in the morning. However, due to early school start times, adolescents have to get up early in the morning, resulting in a misalignment of their biological sleep-wake rhythm with societal demands. Some attempts have been made in the past that aimed to meet adolescents’ needs by delaying school start times. In these studies sleep (e.g., sleep durations, satisfaction with sleep) and daytime functioning variables (e.g., daytime sleepiness, mood, attention level, late arrivals to school, school absenteeism, academic performance) improved significantly (Lufi, Tzischinsky, & Hadar, 2011; O’Malley & O’Malley, 2008; Owens, Belon, & Moss, 2010, Wahlstrom, 2002). Interestingly, in contrast to concerns that this approach could encourage adolescents to delay their bedtimes even more, adolescents used the opportunity to actually obtain more sleep (Lufi et al., 2011; Owens et al., 2010). However, as later school start times in high schools are often not supported by the society (Kirby, Maggi, & D’Angiulli, 2011), this thesis addressed the idea of extending adolescents’ sleep by changing their bedtimes in the evening.

Chapter 7 and Chapter 8 used an experimental design in which sleep was gradually extended by advancing bedtimes in the evening. Extending adolescents’ sleep gradually is especially important because the circadian system cannot adapt well to rapid changes of advanced bedtimes. Furthermore, as this approach seems to be in conflict with adolescents’ natural sleep-wake rhythm (including different sleep schedules on school nights and on weekend nights) at first sight, adolescents were instructed not to delay their bedtimes (bed-and rise time) by more than one hour on weekend nights. One important research question of the study described in Chapter 7 and Chapter 8 was to investigate whether adolescents can actually shift their bedtimes and sleep onset times. Results from this experiment demonstrated that adolescents were indeed capable to advance their bedtimes and also their sleep onset times in the evening. This is an important finding which shows that, although adolescents’ sleep onset latencies (SOLs) increased during the experimental weeks, they fell asleep earlier than the control group. Furthermore, we did not find significant changes in sleep efficiency and wake after sleep onset (WASO) times, suggesting that the experimental manipulation did not negatively affect adolescents’ sleep. Still, although not significant, sleep efficiencies decreased in the sleep extension group. This result is in line with previous research showing that longer times in bed (TIBs) are associated with lower sleep efficiencies (van Dongen et al., 2003). The effects of the experimental manipulation on the sleep variables are extremely important for the following analyses of the data from this
study (e.g., effects on depressive symptoms and cognitive performance) as they demonstrate that changes in sleep can be the cause of the changes on other outcome variables (e.g., depressive symptoms).

Based on the results presented in Chapter 7 and Chapter 8, it can be concluded that sleep extension, applied by advancing individuals' bedtimes in the evening, seems to be indeed an attractive alternative to sleep extension by delayed school start times. However, advanced bedtimes are in contrast to therapeutic techniques of cognitive behavioral therapy for insomnia (CBT-i) which has been shown to be a successful treatment for insomnia (Morgenthaler, 2006; Morin, 1999). One important technique of CBT-i is sleep restriction, meaning that individuals' TIB is restricted by delaying bedtimes in the evenings or advancing rise times in the morning. When sleep is restricted by delaying the bedtimes, the technique especially aims to decrease patients’ SOLs and to weaken the conditioned association between 'lying in bed' and 'being awake'. SOLs in Chapter 7 and Chapter 8 increased in the sleep extension group after they advanced their bedtimes in the evening. In the experimental study of this thesis, the inclusion of participants was based on their CSRQ score (≥ 40), however, no exclusion criteria, such as excluding adolescents with insomnia, were applied. As the CSRQ measures symptoms of insufficient and/or poor sleep, a high overlap with insomnia can be expected. Therefore, it is not unlikely that the sample in Chapter 7 and Chapter 8 also included adolescents meeting the criteria for insomnia. However, sleep extension may not be the most beneficial approach for adolescents suffering from chronic sleep reduction as a consequence of their insomnia. Therefore, future studies should address this question and examine whether gradual sleep extension is beneficial for all adolescents or only for particular (sub) groups.

Results from Chapter 7 contribute to the ongoing debate about the bi-directional relationship between sleep and depression (e.g., Gregory & Sadeh, 2012) as they showed that depressive symptoms could be reduced when bedtimes and sleep onsets are gradually advanced. Therefore, they support evidence from longitudinal research indicating that sleep problems are a potential risk factor for the development of depressive symptoms, whereas less evidence was found for the opposite relationship (Gregory, Caspi, Eley, Moffitt, O’Connor, & Poulton, 2005; Gregory, Rijssdijk, Lau, Dahl, & Eley, 2009). Still, the reverse question, i.e. whether depression treatment also improves sleep in adolescents, should be investigated in future studies.

As only a few experimental studies in adolescents exist investigating the effects of sleep extension on cognitive performance, the study presented in Chapter 8 addressed an important topic. Results from this chapter showed that the experimental manipulation did not affect speed of simple reaction time (RT) tasks, however speed on correct responses
increased in tasks assessing cognitive performance that involve higher order cognitive functions. In contrast with the control group, error rates increased significantly in the sleep extension group from the pre- to the posttest, however, the overall process efficiency was not negatively affected. These findings support previous research which demonstrated that, in opposite to adult studies, sleep deprivation in children especially affects higher order cognitive functions rather than performance on simple RT tasks (Astill, van der Heijden, van IJzendoorn, & van Someren, 2012; Randazzo, Muehlbach, Schweitzer, & Walsh, 1998). Adolescents have to rely on a wide range of intellectual abilities, including different cognitive functions, in order to perform well at school. Therefore, the results from Chapter 8 can be used to explain the relationships between sleep problems and school performance that have been presented in the meta-analysis in Chapter 2. Still, to what extent these results can be used to improve adolescents’ school performance by extending their sleep remains to be investigated.

Despite these positive findings, results from the experiment have to be carefully interpreted. Depressive symptoms and cognitive performance were measured at the end of the experiment, but adolescents' sleep was extended until the last day. In other words, adolescents had just reached the peak of the extended sleep time at the last day of the experiment. Whether or not changes in sleep and on the outcome variables remain present at follow-up measures needs to be investigated in future studies. Such studies should include a stabilization period in which adolescents are asked to keep their last given bedtimes for a longer time period (e.g., one week). It is not unlikely that some changes (e.g., changes on daytime sleepiness) may require a longer time period of sufficient sleep to become present. Furthermore, a follow-up measurement (e.g., after one month) should be included in order to investigate whether adolescents are capable to follow the learned sleep rules independently after the end of the study.

9.7. General remarks

Taken together, the presented studies showed relatively little effect of and on sleep efficiency. Although sleep efficiency is sometimes used as a measure of objective sleep quality, it appears to be generally uncorrelated with subjective sleep quality. As its calculation depends on TST and TIB, it can be questioned whether the percentage of obtained sleep should be interpreted as a measure of sleep duration rather than of sleep quality. In order to gain more insight into the effects of sleep quality, future studies should include standardized daily self-reports assessing indices such as initiating and maintaining sleep, feeling rested when waking up, and satisfaction with sleep (Carney et al., 2012). The usage of daily measures would give more insight into fluctuations of perceived sleep quality.
(e.g., differences between school nights and weekend nights) and into its relationship with
daily actigraphy data. Furthermore, using standardized measurements allows for comparison
of different studies, which would contribute to a better overall understanding of sleep quality
in adolescents. Still, whether or not the awareness about and confrontation with one’s sleep
(due to daily reports in sleep diaries) is a helpful method for individuals with sleep problems
(especially for adolescents with chronic sleep reduction) remains to be investigated.

Furthermore, the studies presented in this thesis showed short TSTs that
consequently resulted in low sleep efficiencies (about 80%), which is less than what is
usually indicated in studies using polysomnography (about 90%). This discrepancy threatens
the general validity of actigraphy in adolescents. As mentioned above, it has been shown
that actigraphy may overestimate adolescents’ WASOs, consequently causing shorter TSTs
and lower sleep efficiencies (Short et al., 2012). Careful interpretation of actigraphy data in
adolescent samples is therefore recommended and further research is needed in order to
investigate the validity of actigraphy in adolescents.

9.8. Clinical relevance and implications
The results from this thesis are clinically relevant as they indicate that adolescents’ sleep is
related to their emotional well-being, cognitive performance, and school performance. As the
CSRQ and the CSRQ-SF appeared to be reliable and valid instruments to measure chronic
sleep reduction in adolescents, this questionnaire could be used to screen adolescents that
show problems at school or at home. Screening for chronic sleep reduction can especially
be useful in clinical settings as it can help to identify individuals who would benefit from
treatment programs that mainly focus on the improvement of sleep and consequently also
improve other aspects of their life (e.g., emotional well-being). This idea is strengthened by
the positive results of the experimental study providing evidence that it is possible to improve
sleep by applying relatively simple techniques in adolescents’ home environment. These
techniques included a personal sleep schedule in which bedtimes were gradually advanced,
the prevention of bedtime shifts on weekend nights, and advise on sleep hygiene rules.
These techniques are easy to apply and could therefore become a cost-efficient part of
clinical intervention programs. Furthermore, they could be used in school settings to advice
adolescents and parents on how they can influence adolescents’ sleep in order to improve
daytime functioning. In this sense, the results from the last chapters of this thesis may even
provide a first step in developing a (guided) self-help program for adolescents with chronic
sleep reduction.
Despite the positive findings of the experimental study (Chapter 7 & Chapter 8) demonstrating the possibility to advance adolescents’ bedtimes and sleep onset times in the evening, delayed school start times in the morning should still be considered as an alternative way to improve adolescents’ daytime functioning. In opposite to the idea of advancing sleep in the evening, aiming at changing adolescents’ circadian system, later school start times would per definition be in better alignment with their circadian system (Roenneberg et al., 2004). In other words, the two approaches target two different (political) viewpoints: Whereas one aims to change adolescents' biological rhythm in order to meet the demands of the society (advancing bedtimes and sleep onset times), the other argues that the biological system should be considered in setting societal rules and demands. Whether or not the long-term effects of these two approaches are comparable remains to be investigated in future research.

9.9. Conclusions
Based on the findings of this thesis, it can be concluded that different aspects of sleep (sleep duration, sleep quality, sleepiness) have to be differentiated when studying the relationship between sleep and daytime functioning (e.g., school performance) in adolescents. Furthermore, it can be concluded that chronic sleep reduction as assessed by the CSRQ, may be a more accurate measure as it takes individual sleep need into account. The CSRQ and the CSRQ-SF appeared to be reliable and valid questionnaires which can be used to study chronic sleep reduction in adolescents. Adolescents scoring high on the CSRQ showed severe impairments on sleep and daytime functioning (including psychological well-being, school functioning, and school performance) and increased clinical prevalence rates. Only subtle changes in sleep were found from adolescents’ low-stress to high-stress (exam) times, however, chronic sleep reduction moderated the changes in sleep fragmentation. From the results of the experimental study, it can be concluded that gradual sleep extension during the week in combination with the prevention of bedtime shifts on weekend nights seems to be an efficient strategy to advance sleep onsets, improve sleep, depressive symptoms, and at least some aspects of cognitive performance in adolescents with chronic sleep reduction.
9.10. References


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