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Adolescents' Sleep in Low-Stress and High-Stress (Exam) Times: A Prospective Quasi-Experiment

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This prospective quasi-experiment ($N = 175$; mean age = 15.14 years) investigates changes in adolescents' sleep from low-stress (regular school week) to high-stress times (exam week), and examines the (moderating) role of chronic sleep reduction, baseline stress, and gender. Sleep was monitored over three consecutive weeks using actigraphy. Adolescents' sleep was more fragmented during the high-stress time than during the low-stress time, meaning that individuals slept more restless during stressful times. However, sleep efficiency, total sleep time, and sleep onset latency

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remained stable throughout the three consecutive weeks. High chronic sleep reduction was related to later bedtimes, later sleep start times, later sleep end times, later getting up times, and more time spent in bed. Furthermore, low chronic sleep reduction and high baseline stress levels were related to more fragmented sleep during stressful times. This study shows that stressful times can have negative effects on adolescents' sleep fragmentation, especially for adolescents with low chronic sleep reduction or high baseline stress levels.

Stress is closely related to impaired sleep in cross-sectional studies (Åkerstedt, 2006). However, experimental and longitudinal research on this complex relation is limited. From experimental studies in animals, it is known that acute stress (Pawlyk, Morrison, Ross, & Brennan, 2008), as well as mild chronic stressors (Cheeta, Ruigt, van Proosdij, & Willner, 1997), were found to cause changes in rats' sleep architecture and reductions in their sleep efficiency (Papale, Andersen, Antunes, Alvarenga, & Tufik, 2005). The limited findings from human studies are in line with this animal research, as they show that higher cortisol levels, indicating higher stress levels, were related to shorter subjective and objective total sleep time (TST) and poorer sleep quality (El-Sheikh, Buckhalt, Keller, & Granger, 2008). Furthermore, individuals' perceptions of stress were associated with an increased risk of subjectively measured poor sleep (Fortunato & Harsh, 2006; Tworoger, Davis, Vitiello, Lentz, & McTiernan, 2005), as well as objectively measured decreased sleep efficiency (Åkerstedt, 2006). Moreover, psychosocial (e.g., stressful life events) and physiological stress (e.g., norepinephrine levels) were associated with increased nightly variability in individuals' TST and sleep fragmentation, which can be interpreted as an indicator of restlessness (Mezick et al., 2009). Results from a study in college students demonstrated that stress about examination was accompanied by suppression of the cardio respiratory resting function during sleep (Sakakibara, Kanematsu, Yasuma, & Hayano, 2008).

To summarize, animal studies, as well as human studies, indicate that stress negatively affects sleep. However, insufficient sleep over time can become a source of stress on its own (Åkerstedt, 2006), and can result in severe psychological and physiological consequences such as behavioral problems, poor emotional well-being, impaired cognitive and school performance, and even detrimental neurobiological changes (Curcio, Ferrara, & De Gennaro, 2006; Fallone, Owens, & Deane, 2002; Wolfson & Carskadon, 2003). Considering the high prevalence of sleep problems in adolescents (Liu & Zhou, 2002; Russo, Bruni, Lucidi, Ferri, & Violani, 2007) and its impairments on daytime functioning, research examining the influence of stressful times on adolescents' sleep is of high importance. To date, no study has been conducted that investigates changes in adolescents' sleep from low-stress to high-stress times.

Experiments manipulating children's psychological stress to measure stress-related consequences over a longer time (e.g., sleep changes) involve ethical and methodological problems. A quasi-experiment in a natural situation can overcome some of these problems and give an accurate picture of individuals' stress perceptions. One situation in which adolescents experience stress is just before and during exam weeks. Therefore, this time provides a natural stressful situation, which can be used to study the effects of stressful times. To our knowledge, to date, only one study exists investigating the relation between adolescents' sleep and stress prior to their examination (Robinson, Alexander, & Gradisar, 2009). Results from this study show no significant relation between self-reported sleep duration and stress; however, the study only included self-reports, and did not compare adolescents' sleep during the stressful examination time to their sleep during a stress-free period. Therefore, the question of whether stressful times were related to changes in students' sleep remained unanswered. To examine the relation between stress and changes in sleep in adolescents, we chose a design consisting of a low-stress period (baseline week), a stress anticipation period (pre-exam week), and a high-stress period (exam week). This design enables us to study effects of stressful times, as well as anticipate the stressful time on adolescents' sleep. To test our assumption that stress would increase over time, perceived daily stress was assessed during three consecutive weeks.

During adolescence, individuals often experience poor and insufficient sleep over a long time period, which can result in chronic sleep reduction (Loessl et al., 2008; Meijer, 2008). Sleep duration may not always be the best indicator of chronic sleep reduction, as it does not account for the large differences in sleep need between individuals (van Dongen, Rogers, & Dinges, 2003). The Chronic Sleep Reduction Questionnaire (CSRQ; Meijer, 2008) overcomes this problem by directly measuring adolescents' symptoms of insufficient or poor sleep, rather than sleep variables (e.g., sleep duration). These symptoms include shortness of sleep, sleepiness, irritation, and loss of energy, which affect adolescents' daytime functioning. It can be speculated that symptoms of chronic sleep reduction act as an additional stressor on individuals' sleep (Åkerstedt, 2006). Based on this idea, we can expect that changes in sleep from low-stress to high-stress times may be moderated by adolescents' chronic sleep reduction. Such an effect implies that individuals with higher chronic sleep reduction may not only differ in sleep, in general, but also experience different changes in sleep during high-stress times compared to individuals with lower chronic sleep reduction. Moreover, due to the relation between stress and sleep described earlier, baseline stress levels may also differentially affect sleep during high-stress times. Finally, we examine gender differences. Although it is known that sleep problems are more common in females than in males (Arber, Bote, & Meadows, 2009; Groeger, Zijlstra, & Dijk, 2004), few gender differences have been reported for sleep, in general (Meijer, Habekothe, & Van Den Wittenboer, 2000; Voderholzer, Al-Shajlawi, Weske, Feige, & Riemann, 2003). However, bedtimes and TSTs change during puberty (Laberge et al., 2001; Park et al., 2001) and may differ for boys and girls due to earlier puberty onset of girls. Besides this, females often experience more stress than males, especially when being confronted with stressful situations (Huizinga et al., 2005; Matud, 2004). Based on this evidence, it is likely that changes in sleep from low-stress times to high-stress times may be moderated by individuals' chronic sleep reduction, baseline stress level, or gender.

This study explores the relations between stress and sleep in a sample of 175 adolescents by using a natural prospective quasi-experiment (exam stress) during three consecutive weeks while assessing sleep with objective sleep measures (actigraphy). The aim of this study is twofold: First, we examine changes in sleep from low-stress times (baseline week) to high-stress times (exam week). Second, we try to gain more insight into the (moderating) effects of chronic sleep reduction, baseline stress level, and gender.

METHOD

Participants

Participants were recruited from high schools in and around Amsterdam, Netherlands. Schools were included in the study if they met the following criteria: (a) Students had an exam week during which exams had to be taken on almost every day of the week, and (b) the two weeks prior to the exam week were considered as standard school weeks, meaning that no exams had to be taken and students had regular school times. No further selection criteria for the students were applied. The response rate of students who were willing to participate was 59.09% ($N = 182$). From this group, seven students had to be excluded from the analyses because they did not wear their actiwatch (6 students) or because of a technical failure of the device (1 student). The final sample consisted of 175 participants (70.8% girls), who were recruited from five different schools in and around Amsterdam. All participants were attending Year 3 or 4 preparing for university level. Ages ranged from 12.18 years to 16.50 years (mean age = 15.14 years). Because socioeconomic status and race appears to moderate the relation between sleep and cognitive functioning (Buckhalt, El-Sheikh, & Keller, 2007), we included only students of comparable educational levels. The number of children in the family ranged from one to eight ($M = 2.29$ children). The sample consisted of 66.9% of families with two working parents, 25.1% of families with one working parent, and 1.7% of families with two non-working parents (5.1% were missing these data). The majority of the parents were married or lived together (71.4%), whereas 18.3% were divorced (5.6% of the participants reported a different family situation; 4.7% were missing these data). Most of the fathers (81.7%) and mothers (79.4%) were born in the Netherlands. More than one-half of our participants reported being an “evening person” (54.3%), whereas only 13.1% considered themselves as a “morning person.”

Procedure

The study was conducted with the approval of the University of Amsterdam review board. High schools in and around Amsterdam were contacted for participation, and active informed consent was obtained from participating schools, parents, and participants. Demographic data and baseline stress levels were assessed during school times. After participants filled in the questionnaires, they received an actiwatch and their login information for the daily sleep diary. Sleep diaries included questions on daily perceived stress (on school days), bedtimes, and getting up times, which were needed for the actigraphy analyses. Sleep was monitored during 3 consecutive weeks (15 school nights: Sunday–Thursday; and 4 weekend nights: Friday and Saturday). The first week was considered a low-stress period (baseline week), the second week was the week prior to the exams (pre-exam week), and the last week was the exam week (high-stress period). We assumed that stress would increase from the baseline week to the exam week. A measure of chronic sleep reduction (see the Measures section) was included in the online sleep diaries at the first day. After the actiwatches were returned, participants received a summary of their actigraphy data, were thanked, and debriefed.

Measures

Objective sleep assessment. Actigraphy involves the use of a wristwatch-like portable device that can record movements over an extended period of time (e.g., a few weeks), and is known to be a reliable and valid measure to study sleep in a natural environment (Kushida et al., 2001; Morgenthaler et al., 2007). Subjective sleep measurements have some disadvantages, as they often over- or underestimate sleep and wakefulness. Furthermore, individuals may give socially desirable answers that do not accurately represent their sleep. As actigraphy overcomes these disadvantages, resulting in more precise and reliable sleep measures (Wolfson et al., 2003), participants' sleep activity was monitored using AW4 Actiwatches (Cambridge Neurotechnology Ltd., Cambridge, England). Nocturnal activity data were logged at 1-min epochs and scored with the Actiwatch Sleep Analysis 7 software. As recommended by the manufacturer, we used the medium sensitivity sleep algorithm. It has been shown that this algorithm corresponds well with polysomnographic estimates (Kushida et al., 2001).

Participants were instructed to wear the actiwatch on their nondominant wrist when they went to bed and remove it in the morning after they got up. The following sleep parameters were calculated: (a) time in bed (TIB): time between a participant's bedtime and rise time, (b) sleep onset latency (SOL): time spent awake before falling asleep (time between bedtime and sleep start), (c) TST: number of minutes that were actually slept, which is the time between sleep start and sleep end corrected for the amount of wake time during the sleep time, (d) sleep efficiency (defined as $100 \times$ [TST/TIB]): percentage of uninterrupted night sleep, and (e) sleep fragmentation measured by the fragmentation index: The fragmentation index is defined as the sum of (a) the percentage of movement minutes (number of minutes moving/assumed sleep period) and (b) the percentage of immobility. The percentage of immobility refers to the number of immobile phases of <1 min as a proportion of the number of immobile phases. The fragmentation index is generally used as an indicator of restlessness. As recommended elsewhere (Littner et al., 2003; Sadeh & Acebo, 2002), we visually examined all actigraphy data and corrected them if deemed necessary. In cases in which data obtained from the sleep diaries or the Actiwatch marker did not match the visual inspection, we applied the following general rule: If the sleep diary indicated a bedtime at which it was obvious that the individual was already sleeping, we set the bedtime to the first peak before the dropoff. If the reported getting up time was indicated at a time at which it was obvious that the individual was still sleeping, we corrected the data by changing the getting up time to the first peak after the indicated time.

Chronic sleep reduction. Chronic sleep reduction was measured with the CSRQ (Meijer, 2008). The questionnaire refers to the previous two weeks and taps into four different consequences of chronic sleep reduction; shortage of sleep (e.g., "I am a person who does not get enough sleep"), irritation (e.g., "Others think I am easily irritated"), loss of energy (e.g., "Do you have enough energy during the day to do everything?"), and sleepiness (e.g., "Do you feel sleepy during the day?"). These are measured by 20 closed-ended questions with three ordinal response categories ranging from 1 to 3 (higher scores indicate more chronic sleep reduction). The CSRQ has been shown to be a reliable and valid measurement for chronic sleep reduction in preadolescents and adolescents (Dewald, Short, Gradisar, Oort, & Meijer, 2012; Meijer, 2008). Cronbach's $\alpha = .86$.

Perceived daily stress. To check the assumption that stress would increase from the baseline week to the exam week, we assessed perceived daily stress on school days by two items: "I feel stressed at the moment," and "I felt stressed at school," which participants had to rate in the sleep diary each day on a 5-point Likert scale ranging from 1 (*this is not at all true for me*) to 5 (*this is completely true for me*). Cronbach's $\alpha = .71$.

Baseline stress level. Baseline stress level was measured with the Stress Questionnaire for Children (Hartong et al., 2003). This questionnaire consists of 19 items (e.g., "I am often in a hurry," "I am tensed," and "I get easily upset") rated on a 4-point Likert scale ranging from 1 (*this is not at all true for me*) to 4 (*this is true for me*). Cronbach's $\alpha = .80$.

Statistical Analyses

To examine changes in sleep from low-stress to high-stress times (baseline, pre-exam, and exam week), we used linear mixed-model analyses. The daily measured observations are considered as nested within subjects. In mixed-model analyses, we can make use of all available data, including participants with incomplete data (Snijders & Bosker, 1999). Therefore, all participants that provided baseline data (regardless of missing data at 1 or more assessment points) were included in the data analyses. Missing values for baseline stress level (5.1% missing) and chronic sleep reduction (6.9% missing) were entered through the expectation maximization method. Independent t-tests showed that the group with and without missing values on chronic sleep reduction and baseline stress level did not significantly differ from each other on any of the assessed sleep variables (all ps $> .05$).

Changes in Sleep From Low-Stress to High-Stress Times

To investigate changes in sleep from low-stress (baseline week) to high-stress times (exam week), we fitted a model with a random intercept (to account for individual differences at baseline) and regression coefficients that represent deviations from baseline in the pre-exam and exam week, as well as during the weekends. To assess effects of chronic sleep reduction, baseline stress level, and gender, we also included regression coefficients for these variables. To test moderating effects of chronic sleep reduction, baseline stress level, and gender with time period (pre-exam week and exam week), we added interaction effects (Snijders & Bosker, 1999). Model fit improvement was tested by comparing the fit of the models. Parameters of the last model were only interpreted if the model fit significantly improved.

Changes in Perceived Daily Stress (Manipulation Check)

To test whether participants experienced more daily stress during the exam week than during the baseline week (manipulation check), we applied the same analyses as described earlier, using perceived daily stress as the dependent variable. This manipulation check revealed that participants' perceived daily stress level increased over time, showing that individuals experienced more stress during the exam week than during the baseline week ($\beta = .29$, $p < .001$). Perceived daily stress during the pre-exam week did not significantly differ from the baseline week ($\beta = .03$, $p > .05$). Results show that participants with high chronic sleep reductions ($\beta = .20$, $p < .01$) and high baseline stress levels ($\beta = .22$, $p < .01$) experienced more daily stress, in general, as compared to those with low chronic sleep reductions and low baseline stress levels. Furthermore, girls experienced more daily stress than boys ($\beta = .24$, $p < .05$). However, no moderation effects were found for chronic sleep reduction, baseline stress level, or gender (all ps $> .05$).

RESULTS

Changes in Sleep From Low-Stress to High-Stress Times

An overview of the descriptive statistics of the sleep variables of all three weeks are presented in Table 1. Table 2 presents parameter estimates of the model, including all main effects (time effects and individual differences) and tests of model fit improvement for all sleep variables. During the pre-exam week, participants had later getting up times and later sleep end times compared to the low-stress period (baseline week). As bedtimes did not change during this week, longer TIBs were present during the pre-exam week. Furthermore, participants had more fragmented sleep during more stressful times (pre-exam and exam week) compared to the low-stress time (baseline week), indicating that they experienced more restlessness during times that were characterized by more stress. No significant changes in SOL and sleep efficiency were found during the pre-exam and exam weeks compared to the baseline week. During the high-stress time (exam week) adolescents had later bedtimes, later getting up times, later sleep start times, and later sleep end times than during the low-stress time (baseline week).

Furthermore, we found strong weekend effects for most of the sleep variables, meaning that adolescents went to bed later, fell asleep later, and woke and got up later in the morning. Consequently, they spent more TIB and slept longer than during the baseline week. Their SOL was significantly shorter on the weekends. It is interesting to note that their sleep was more fragmented during the weekends than during the baseline week. We found no main effect for baseline stress level and gender for any of the sleep variables. Adolescents with higher chronic sleep reduction had later bedtimes, later sleep start times, later sleep end times, and later getting up times than adolescents with lower chronic sleep reduction. It is interesting to note that we did not find differences with regard to TST, although adolescents spent less TIB (see Table 2). Individuals with higher chronic sleep reduction also had less fragmented sleep. However, significance of this effect disappeared when adding the interaction effect with time period. The moderation analysis shows that chronic sleep reduction moderated the effect of

TABLE 1
Means and Standard Deviations of Sleep Actigraphy Data

Variable	*Baseline Week*	*Pre-Exam Week*	*Exam Week*	*Weekend 1*	*Weekend 2*
Bedtime (hour:minute)	22:56 (00:39)	22:55 (00:40)	23:08 (00:43)	00:01 (00:58)	23:52 (00:55)
Getting-up time (hour:minute)	07:26 (00:46)	07:31 (00:55)	07:42 (01:03)	09:41 (01:00)	09:36 (01:05)
Sleep start (hour:minute)	23:18 (00:41)	23:15 (00:41)	23:29 (00:47)	00:18 (00:58)	00:08 (00:55)
Sleep end (hour:minute)	07:23 (00:23)	07:28 (00:36)	07:37 (00:38)	09:33 (00:59)	09:29 (01:05)
TIB (hour:minute)	08:30 (00:32)	08:36 (00:44)	08:34 (00:44)	09:40 (00:56)	09:44 (00:55)
SOL (hour:minute)	00:22 (00:17)	00:20 (00:19)	00:21 (00:22)	00:16 (00:16)	00:17 (00:14)
TST (hour:minute)	06:49 (00:33)	06:54 (00:41)	06:51 (00:38)	07:43 (00:50)	07:50 (00:50)
Sleep efficiency (%)	80.94 (4.79)	80.20 (4.99)	79.88 (5.33)	80.10 (5.85)	80.49 (5.57)
Sleep fragmentation	30.31 (9.09)	31.21 (9.40)	31.17 (9.15)	32.13 (8.97)	32.57 (9.68)

Note. TIB = time in bed (time between bedtime and getting up time); SOL = sleep onset latency (time between bedtime and sleep start); TST = total sleep time (number of minutes of actually obtained sleep); Weekend 1 = weekend between baseline week and pre-exam week; Weekend 2 = weekend between pre-exam week and exam week.

TABLE 2
Model Including Changes of Sleep From Low-Stress to High-Stress Times

Variable	*Bedtime* β *(SE)*	*Getting-Up Time* β *(SE)*	*Sleep Start* β *(SE)*	*Sleep End* β *(SE)*	*TIB* β *(SE)*	*SOL* β *(SE)*	*TST* β *(SE)*	*Sleep Efficiency* β *(SE)*	*Sleep Fragmentation* β *(SE)*
Parameter Estimates									
Time effects on sleep (compared to baseline)									
Pre-exam week	.00(.04) *ns*	.12(.05)**	−.02(.04) *ns*	.11(.04)*	.12(.05)*	−.02(.02) *ns*	.08(.04) *ns*	−.20(.25) *ns*	.83(.40)*
Exam week	.22(.03)***	.29(.05)***	.23(.04)***	.26(.05)***	.08(.05) *ns*	−.00(.02) *ns*	.02(.04) *ns*	−.47(.25) *ns*	.80(.40)*
Weekend 1	1.14(.05)***	2.30(.06)***	1.08(.05)***	2.24(.06)***	1.16(.07)***	−.07(.02)**	.91(.06)***	−.26(.33) *ns*	1.66(.53)**
Weekend 2	.98(.05)***	2.20(.06)***	.90(.05)***	2.12(.06)***	1.22(.07)***	−.08(.02)**	1.00(.06)***	.15(.33) *ns*	1.52(.54)**
Main effects									
Gender	−.03(.05) *ns*	−.02(.04) *ns*	−.05(.05) *ns*	−.02(.04) *ns*	.02(.05) *ns*	−.02(.01) *ns*	.06(.05) *ns*	.53(.38) *ns*	−.17(.69) *ns*
Baseline stress	−.04(.06) *ns*	.04(.05) *ns*	−.07(.06) *ns*	.04(.05) *ns*	.08(.05) *ns*	−.02(.02) *ns*	.04(.06) *ns*	−.24(.44) *ns*	1.41(.80) *ns*
Chronic sleep reduction	.22(.06)***	.09(.04)*	.24(.06)***	.09(.04)*	−.12(.06)*	.02(.02) *ns*	−.06(.05) *ns*	.27(.42) *ns*	−1.90(.77)**
Tests[a]	χ^2 *(df)*	χ^2 *(df)*	χ^2 *(df)*	χ^2 *(df)*	χ^2 *(df)*	χ^2 *(df)*	χ^2 *(df)*	χ^2 *(df)*	χ^2 *(df)*
Time effects on sleep (a)	784.60(4)***	1,771.38(4)***	631.93(4)***	1,736.97(4)***	534.21(4)***	19.83(4)***	478.24(4)***	5.13(4) *ns*	13.89(4)*
Main effects (b)	17.80(3)***	11.01(3)**	19.33(3)***	10.55(3)**	5.80(3) *ns*	5.47(3) *ns*	3.64(3) *ns*	3.08(3) *ns*	6.20(3) *ns*
Moderation effects (c)	3.57(6) *ns*	7.65(6) *ns*	7.96(6) n.s	9.22(6) *ns*	4.77(6) *ns*	12.03(6) *ns*	1.72(6) *ns*	8.74(6) *ns*	14.28(6)*

Note. Weekend 1 = weekend between baseline week and pre-exam week; Weekend 2 = weekend between pre-exam week and exam week; TIB = time in bed (time between bedtime and getting up time); SOL = sleep onset latency (time between bedtime and sleep start); TST = total sleep time (number of minutes of actually obtained sleep). Sleep fragmentation was measured with the fragmentation index (i.e., an indicator of restlessness).

[a]Omnibus tests for the significance of (a) the combined time effects, (b) the combined main effects, and (c) the combined moderation effects. Chi-square represents a chi-square test of the difference in model fit between a model and the previous model (e.g., the Chi-square of the model 'Time effects on sleep' refers to the difference in model fit between a model without any predictors and the model including the 3 weeks and weekends as predictors of the outcome variable. A significant Chi-square indicates a better model fit of the second model).

$^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

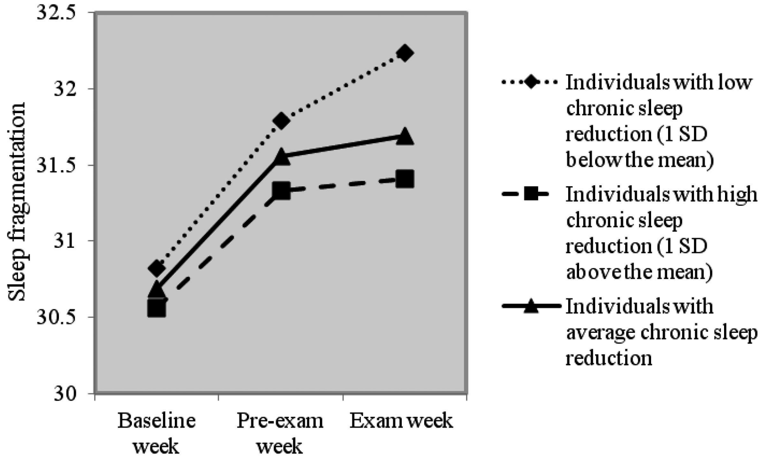

FIGURE 1 Changes in sleep fragmentation from the baseline week to the pre-exam week and the exam week for adolescents with low and high chronic sleep reduction.

time period (exam week) on sleep fragmentation ($\beta = -.98$; $p < .05$). More specifically, during the high-stress period (exam week), the effects for sleep fragmentation were especially present for adolescents with lower chronic sleep reduction.

Figure 1 presents changes in sleep fragmentation over the three consecutive weeks for the moderating variable, chronic sleep reduction. For the interpretation of the results, lines represent changes across time for individuals with mean chronic sleep reduction scores, 1 *SD* above the mean, and 1 *SD* below the mean. In addition, baseline stress level moderated the effects for sleep fragmentation for both the pre-exam ($\beta = .97$; $p < .05$) and the exam weeks ($\beta = .96$; $p < .05$), indicating that individuals with higher baseline stress levels had more fragmented sleep during the pre-exam and exam weeks than did individuals with lower baseline stress levels. Figure 2 presents changes in sleep fragmentation over the three consecutive weeks for different baseline stress levels. Again, for the interpretation of the results, lines represent changes across time for individuals with mean baseline stress scores, 1 *SD* above the mean, and 1 *SD* below the mean.

DISCUSSION

This study investigated changes in adolescents' sleep during a natural stressful situation consisting of a time period of three consecutive weeks (baseline week, pre-exam week, and exam week). Perceived daily stress was significantly higher in the exam week, was in between in the pre-exam week, and was lowest in the baseline week, suggesting that the natural manipulation did indeed represent differences in perceived stress. Girls reported more daily stress than boys. The same held for participants with higher chronic sleep reduction and higher baseline stress levels, supporting previous studies which showed that girls generally experience more stress

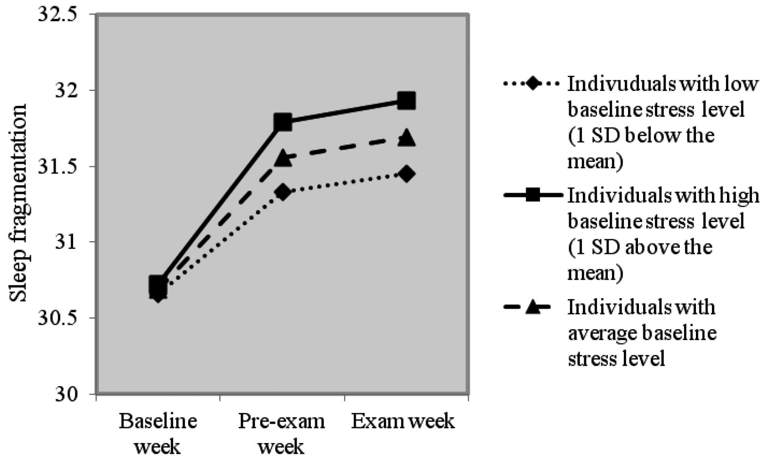

FIGURE 2 Changes in sleep fragmentation from the baseline to the pre-exam week and exam week for adolescents with low and high baseline stress levels.

than boys (Matud, 2004), and studies demonstrating a relation between sleep problems that may lead to chronic sleep reduction and stress (Fortunato & Harsh, 2006).

Although our study shows that TST and sleep efficiency are not affected by stressful school times, adolescents were more restless during the pre-exam and exam weeks, demonstrating that stressful school times can negatively influence adolescents' sleep. The different results for TST, sleep efficiency, and sleep fragmentation show that individuals' sleep during stressful times was characterized by more movement and immobility; however, they did not have more wake times after they fell asleep. The changes in sleep fragmentation were already present during the pre-exam week; however, participants only reported significantly more stress during the exam week, and not during the pre-exam week. This raises the idea that sleep can be influenced by the anticipation of stressful times (Åkerstedt, 2006) without conscious awareness of stress during the day. Individuals often experience worry and rumination concerning future and daily events when trying to fall asleep (Brand, Gerber, Puhse, & Holsboer-Trachsler, 2010). It is known that pre-sleep worries are especially present during stress (Brand et al., 2010). Measuring the content of different stress-related (dysfunctional) thoughts and cognitions, as well as adolescents' perceived stress levels right before their sleep onset, could give more insight into this idea. Based on evidence showing that pre-sleep cognitions of good and poor sleepers (e.g., insomniacs) differ from each other (Harvey, 2000; Harvey & Espie, 2004) differences between individuals can be assumed.

We found strong weekend effects, indicating that adolescents delayed their bedtimes and getting up times, as well as their sleep start and sleep end times. As a consequence, they spent more TIB and slept longer while decreasing their SOLs. Our findings support the general idea that adolescents try to compensate for their insufficient sleep during the week by extending their weekend sleep. This phenomenon may at least partly contribute to the development and maintenance of sleep disorders, such as insomnia and delayed sleep phase syndrome, which are prevalent, world-wide-occurring sleep disorders in adolescents (Gradisar, Gardner, & Dohnt, 2011).

Different school start times during exam periods could explain our results showing that participants had later sleep end and getting up times in the pre-exam and exam weeks. Bedtimes and sleep start times were extended during the exam week, but not during the pre-exam week, also causing longer TIBs during the pre-exam week. During regular school times, schools usually start in Amsterdam between 8:00 a.m. and 8:30 a.m.; however, schools often have irregular schedules just before and during exam weeks, resulting in later school-start times, which may explain individuals' extended sleep end and getting up times. Later bedtimes during the exam week can, for instance, be caused by studying and exam preparations in the evenings.

In conclusion, we can state that adolescents' TSTs and sleep efficiencies do not change during stressful school times, whereas they tend to be more restless during these weeks. Although sleep efficiency is sometimes used as a measure of objective sleep quality, it generally appears to be uncorrelated with subjective sleep quality (Sadeh, 2008). As its calculation depends on TST and TIB, it can be speculated whether the percentage of obtained sleep should be interpreted as a measure of sleep duration, rather than sleep quality. Consequently, as we did not find changes in TST, it is not surprising that adolescents' sleep efficiency did not change during the stressful school times. To gain more insight into the effects of stressful times on subjective sleep quality, future studies should include standardized daily self-reports assessing indexes, such as initiating and maintaining sleep, feeling rested when waking up, and satisfaction with sleep (Carney et al., 2012).

The second aim of the study was to gain more insight into the (moderating) effects of chronic sleep reduction, baseline stress level, and gender. Regarding the influence of chronic sleep reduction on the different sleep variables, our results reveal that higher chronic sleep reduction was related to later bedtimes, later sleep start times, later getting up times, and later sleep end times. It seems that this group of adolescents managed to stay in bed a little bit longer in the morning, although they had the same school start times than their peers without chronic sleep reduction. However, the later sleep-end times in the morning could not compensate for the delayed bedtimes in the evening, resulting in less TIB. Chronic sleep reduction did not affect TST, supporting previous research (Dewald et al., 2012). This absent effect may result from the fact that TST does take the existing individual differences in sleep need into account. It may, therefore, be assumed that adolescents scoring high on the CSRQ may be individuals with higher sleep needs than adolescents scoring low on the CSRQ. Furthermore, an increase in sleep fragmentation during the high-stress period (exam week) was especially present for participants with lower chronic sleep reduction. This finding suggests that chronic sleep reduction moderates the effects of stressful times on sleep fragmentation, and it can be speculated that chronic sleep reduction might buffer the effect of stress on sleep fragmentation. This buffering effect could result from a higher sleep pressure, 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 assumption. Based on these results, it is not unlikely that sleep restriction prior to stressful exam times may prevent sleep fragmentation. Still, more research is needed to test this idea, its consequences on daytime functioning, and to identify the amount of sleep restriction being protective for fragmented sleep.

Individuals with higher baseline stress levels did not differ from individuals with lower baseline stress levels with respect to their sleep; however, they had more fragmented sleep during the pre-exam and exam weeks than individuals with lower stress levels. This result suggests that higher baseline stress levels seem to increase the risk that stressful times are related to more fragmented sleep. Boys and girls did not differ in sleep, in general, and changes in sleep were independent of gender. With a sample size of 175 and 19 observations for most participants, the power to detect such effects at a medium size is about .99, justifying the conclusion that, in this study, main effects for baseline stress level and gender were absent. The absence of gender differences supports the idea that, although females often report more sleep problems (Groeger et al., 2004), these differences seem to be weaker or absent when actual sleep variables are measured (Voderholzer et al., 2003).

On school nights, adolescents spent approximately 8.5 hr in bed, although they slept <7 hr, resulting in low sleep efficiencies (about 80%), which is less than what is usually indicated in studies using polysomnography (about 90%). This discrepancy targets the general validity of actigraphy in adolescents. A recent study demonstrated that actigraphy may overestimate adolescents' wake time after sleep onset, consequently causing shorter TSTs and lower sleep efficiencies (Short, Gradisar, Lack, Wright, & Carskadon, 2012). Careful interpretation of actigraphy data in adolescent samples is, therefore, recommended, and further research is needed to investigate the validity of actigraphy in adolescents.

Limitations

A few limitations have to be mentioned. First, the sample only consisted of students attending the third and fourth classes of the highest level of secondary school in and around Amsterdam. Although this homogeneous sample is assumed to hold other factors (e.g., age, IQ, socioeconomic status, general lifestyle, and parental control) relatively constant, it also reduces generalizability of the results. To investigate possible different effects concerning cultural differences and different background variables (Buckhalt et al., 2007), future research should also include participants from other countries, school levels, and different economic backgrounds. Second, as coping style has been shown to moderate sleep in undergraduate students (Sadeh, Keinan, & Daon, 2004), it is advised that the role of coping style in an adolescent population should also be examined. Third, we did not assess stressors that the students may have experienced during each week. As such information could add to a better understanding of adolescents' stress experience and perception and its possible influence on sleep, we recommend measuring additional stressors in future studies. Similarly, we did not assess the number of study hours, which may account for differences in bedtimes in the exam week. This should, therefore, be considered in the future.

CONCLUSION

To summarize, adolescents' stressful times did not influence their TST and sleep efficiency, but were characterized by more fragmented sleep. Individual differences, such as chronic sleep reduction and baseline stress level, moderated the effects of stressful times on sleep fragmentation, highlighting the importance of these factors during stressful times.

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