Sleep patterns are associated with common illness in adolescents

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SUMMARY

This prospective, field-based study examined the association between actigraphically measured total sleep time and incident illness including cold, flu, gastroenteritis and other common infectious diseases (e.g. strep throat) in adolescents during the course of a school semester. Participants were 56 adolescents ages 14–19 years (mean = 16.6, standard deviation = 1.2, 39% male) from five high schools in Rhode Island. Beginning in late January, adolescents wore actigraphs [mean 91 (19) days, range 16–112 days] and were assigned *post-hoc* to longer or shorter sleep groups based on median splits. Adolescents were interviewed weekly across as many as 16 weeks (modal number of interviews = 13) using a structured protocol that included 14 health event questions. Illness events and illness-related school absences were coded for 710 completed interviews, with 681 illness events and 90 school absences reported. Outcomes (illness bouts, illness duration and absences) were compared among sex, sleep and academic year groups using non-parametric regression. In a subset of 18 subjects, mean actigraphically estimated total sleep time six nights before matched illness/wellness events was compared using multivariate analysis of variance (MANOVA). Longer sleepers and males reported fewer illness bouts; total sleep time effects were more apparent in males than females. A trend was found for shorter total sleep time before ill events. The present findings in this small naturalistic sample indicate that acute illnesses were more frequent in otherwise healthy adolescents with shorter sleep, and illness events were associated with less sleep during the previous week than comparable matched periods without illness.

INTRODUCTION

A common belief is that shorter sleep and infection susceptibility are linked, particularly for viral infection. Indeed, this ‘old wives’ tale’ has been substantiated by research showing interactions between sleep and both the innate and adaptive immune systems (Majde and Krueger, 2005). This putative link between sleep and infection susceptibility is particularly critical for adolescents, as they frequently obtain too little sleep, getting by with 7–7.5 h on week-nights (Hansen *et al*., 2005; Wolfson and Carskadon, 1998) versus the 9+ h researchers have shown to be adequate for individuals with still-developing bodies and brains (Carskadon, 1999; Dahl and Lewin, 2002).

Using short-duration laboratory studies, cross-sectional epidemiological studies, and longitudinal studies of chronic illness, researchers have shown an association between shorter sleep and illness. Researchers have demonstrated interactions between sleep and both the innate and adaptive immune systems, and the interaction of sleep with both of these systems may indicate a critical function of sleep (Majde and Krueger, 2005). Total and partial sleep deprivation have been implicated in the dysregulation of immune (Faraut *et al*., 2012; Opp *et al*., 2007) and endocrine factors (Okun, 2011). Such outcomes as decreased T cell function and suppressed immune response to vaccination are consistent across total and partial sleep deprivation, while others, such as natural killer cell activity, reverse under conditions of total versus partial deprivation (see Lange *et al.*, 2010 for a review). These findings suggest that shorter or absent sleep may increase susceptibility to diseases, especially those mediated by inflammation, including cardiovascular disease, diabetes, metabolic disease and depression (Okun, 2011). Most sleep and immune response studies, however, have been performed in the laboratory under conditions of total sleep deprivation and may not mirror immune response to an illness challenge under natural conditions. Partial sleep deprivation studies also have been set in artificial conditions for a limited time-frame (1–5 days) (cf. Bryant *et al.*, 2004).

In addition to laboratory studies of sleep and immunity, findings from studies of vaccinations given under varying circumstances support an association of shorter sleep and reduced immune response. Investigators have shown that limiting sleep to 4 h for four nights before influenza vaccination is related to a significant negative effect on mean antibody titres in men 10 days after immunization (Spiegel *et al.*, 2002). In a recent study, Prather *et al.* (2012) showed that shorter sleep duration, measured by actigraphy, was associated with a lower secondary antibody response to hepatitis B immunization, and that shorter sleep, whether measured by actigraphy or self-report sleep diary, predicted a decreased likelihood of being clinically protected from hepatitis B 6 months after vaccination. This work parallels earlier work on sleep and hepatitis A immunity (Lange *et al.*, 2003, 2011).

While researchers have explored associations between sleep and dysregulated immune factors in humans, few have addressed effects of shorter sleep on common illnesses. In an experimental study, Cohen *et al.* (2009) found that participants with fewer than 7 h of sleep were 2.94 times more likely to develop a cold when infected with a cold virus than those with 8 h or more of sleep. Patel *et al.* (2012) also examined incident pneumonia in the Nurse's Health study among women (ages 37–57) who were free of cancer, cardiovascular disease, diabetes and asthma, with no previous history of pneumonia (n = 56 953); compared to 8-h sleepers, women sleeping <5 h/night or >9 h/night had a significantly higher relative risk of contracting pneumonia.

Our project complements existing studies by examining prospective, naturalistic data collected in 1997–2000 on total sleep time and illness in 56 adolescents. Links between sleep and illness behaviours in this sample were addressed from as many as 112 nights of actigraphically measured sleep and 16 weeks of weekly in-person interviews, allowing examination of the association between shorter total sleep time and susceptibility to common illnesses during a school term. From detailed interview notes we also prepared qualitative case reports capturing factors contributing to short sleep and illness in adolescents.

The mixed-methods analyses presented in this paper extend sleep literature by (i) drawing on quantitative and qualitative data collected in a naturalistic setting and (ii) rigorously measuring total sleep time and incident illness among healthy adolescents across a school semester to draw conclusions about associations between total sleep time and common illness. Our specific hypotheses for this study were that (i) shorter sleepers would experience more frequent illness across the study period and (ii) adolescents would experience shorter sleep duration prior to illness than prior to a matched period of wellness.

METHODS

Participants

Participants were 56 adolescents aged 14.5–19.3 years [mean = 16.6, standard deviation (SD) = 1.2] who were high school students in Rhode Island between 1997 and 2000. Males comprised 39% of the sample. Adolescents participated in the current study for one school semester from late January to mid-May. The sample included students from independent and public (state-supported and administered) schools in Rhode Island: 11 from a co-educational parochial high school (1997), nine from an independent girls' school (1998), 11 from an independent co-educational school (1998), 15 from a suburban public high school (1999) and 10 from an urban public high school (2000). All were non-boarding day students. See Table 1 for participant demographics. The Lifespan Institutional Review Board (IRB) approved the study, and informed consent was obtained from parents (for participants under age 18) or students aged 18 or older (n = 6). Students and their parents were compensated with gift certificates to local stores. Adolescents were recruited from a larger pool of

Table 1 Participant demographics (n = 56)

Characteristics	*Number*	*Percentage*
Age (years)		
14	10	17.9
15	12	21.4
16	19	33.9
17	9	16.1
18	5	8.9
19	1	1.8
Mean age (SD)	16.6 years (1.2)	
Sex		
Male	22	39.3
Female	34	60.7
Ethnicity		
White	47	83.9
Black	3	5.4
Hispanic	3	5.4
Multi-ethnic	2	3.6
Other	1	1.8
School type		
Independent	31	55.4
Public	25	44.6

SD, standard deviation.

students ($n = 309$) who participated in a previous study (described in Wolfson *et al*., 2003). Students were not invited to participate in the current study if they had been diagnosed with sleep apnea, narcolepsy, restless legs, major depressive disorder, bipolar disorder, schizophrenia or a major chronic medical condition such as cancer. Students with a current eating disorder diagnosis, head trauma with a loss of consciousness, repeated involvement with the juvenile court system or current use of psychoactive substances known to affect the sleep/wake cycle or daytime alertness were excluded. Adolescents were assigned to longer ($n = 27$, 11 male) or shorter ($n = 29$, 11 male) sleep groups based on their week-night actigraphically measured sleep from January to May (see Measures section for details of actigraphy). Longer sleepers slept an average of 7 h 28 min (SD = 30 min) on school nights across the semester, while shorter sleepers slept 6 h 24 min (SD = 40 min) on average.

To assess whether sleep differed before episodes of illness versus wellness, a subsample of 18 adolescents (ages 14–18 years, seven male) was selected based on the presence within the same participant of useable ill and well events preceded by six well days (see below). Of these 18 adolescents, 14 had one matched event and four had two. Adolescents in the subsample reported 215 illness events in 247 interviews, and 100% completed 12 or more interviews (mean 13.7 interviews). Useable ill events were defined as a report of illness preceded by six well days that did not occur within 1 week after the spring daylight saving time (DST) shift. Well events for the same participants were also sought within the same month and were preceded by six well days. Well events also did not occur within 1 week after the DST shift. Of 52 participants who reported illness, only 18 met these strict criteria for illness and wellness timing. A particular challenge was clusters of illness where participants were not well for six consecutive days, but the 6-day window was maintained to limit potential sleep duration bias.

Measures

Actigraphy

Each participant wore an actigraph [Mini-motionlogger; Ambulatory Monitoring Inc. (AMI), Ardsley, NY, USA] on the non-dominant wrist throughout the day and night for the duration of the study (mean = 91 days, SD = 19 days, range 16–112 days), except when the actigraph might become wet or while engaging in a contact sport. The actigraph was set for 1-min recording bins, zero crossing mode and a sensitivity of 0.05 g in a frequency range of 2–3 Hz. Participants completed a daily sleep diary indicating total sleep times ('slept this much last night' answered as hours and minutes), bedtimes ('attempted to fall asleep at' answered as specific time) and wake times ('finally woke at'), as well as times when the actigraph was off (i.e. shower or sports practice). Participants called our time-stamped telephone answering machine before bedtime and after rise-time. Actigraph exchanges took place weekly during an in-person interview (described below), and daily sleep diaries were also collected from participants at that time, allowing the research assistant interviewers to check the diary for completeness and evaluate the actigraph data in the context of the diary data.

Actigraph data were analysed according to the procedures of Acebo *et al.* (1999) to estimate sleep using Action-W2 software (AMI) and the validated Actigraphic Scoring Analysis (ASA) algorithm, also called the 'Sadeh' algorithm (Sadeh *et al*., 1994). This procedure relies heavily upon the concurrent behavioural self-report obtained by the sleep diaries. For actigraphy and diary data, nights were defined as school nights if the participant went to school the following day, and weekend nights were Friday and Saturday nights only. We excluded individual nights of actigraphy data if the actigraph was off or not working for all or part of the documented nocturnal sleep episode or if the actigraph record included unusual external motion. Our senior research team (CA, RS, MAC) examined such questionable records and made consensus judgements regarding acceptability of the data. For this report we examined total sleep time (minutes of scored sleep during sleep period between reported bedtime and wake-time) from nightly actigraphy scoring.

In-person interviews

Adolescents were interviewed weekly from January to May. Interviews were performed face-to-face by trained research assistants using a structured interview protocol that covered 10 life domains[1] and included 14 questions about health events asked for each day of the week since the participant's previous interview. Absences from school and the reason for those absences were also queried; 87% of participants completed 12 or more weekly interviews. Events were coded and entered into SPSS (IBM, Armonk, NY, USA) for 710 completed interviews across the 56 participants. Participants reported 681 illness events and 90 illness-related school absences. Outcome variables derived from the interview data included number of illness bouts (calculated as reported illness separated by at least one calendar day), illness duration (calculated as the sum of days ill within a single illness bout) and absences from school (included if participants attributed absence to illness). For analysis, mean illness duration was calculated as total days ill/number of illness bouts.

Identification of illnesses was determined from analysis of weekly interviews. In the health section of the interview, students were asked 'were you sick this week?' and interviewers wrote down what type of illness they reported (often symptoms such as sore throat, menstrual cramps or

[1]Interview instrument available upon request from corresponding author.

back pain) and the days and times that this illness had affected them since their last interview. If a student missed an interview because of illness, the interview was rescheduled and the interviewer collected daily illness data back to the date of the previous interview. Illness did not include accidental injuries, such as cuts, sprains, falls, etc., that might have been caused by lack of sleep, nor did it include status changes in chronic illnesses such as asthma. Type of illness was classified into the following categories by a research assistant, based on the participant's report of their illness or the symptoms noted on the interview sheet: cold, flu-like, gastroenteritis, menstrual complication, pain and other. KMO and a second research assistant subsequently checked the classifications for accuracy. In instances where the illness type was not clear, a consensus meeting among several of the authors (KMO, RS, MAC) determined the final coded illness.

Data analysis

Due to variation in the number of completed interviews, variables were computed as a function of the number of interviews the participant completed: mean illness bouts per interview, mean duration of illness per interview and mean days absent per interview. Non-parametric regression (i.e. localized regression; Cleveland, 1979) was used to examine the relationships graphically between total sleep time and the three illness outcomes (Fig. 1). Separate non-parametric regression lines were fitted for adolescents based on academic year (9th/10th versus 11th/12th) and based on sex. Due to the non-linear relationships between total sleep time and some of the illness outcomes, median splits were used to define long and short sleep groups. To calculate these, total sleep time was stratified by sex and academic year, given the known decline in total sleep time across high school in adolescents (Feinberg *et al.*, 2012; Wolfson and Carskadon, 1998). Individuals whose sleep lengths fell above the median were considered longer sleepers, and those below the median were shorter sleepers. To classify values on the median, the mid-point of the two adjacent values was taken and the median value was compared to and classified as above (longer sleeper) or below (shorter sleeper) this mid-point. Median values for each sex and academic year group appear in Table 3. Multivariate analyses of variance (MANOVA) were used to test the association of total sleep time and illness outcomes, with sex, academic year and sleep group being included as between subject factors. A full-factorial model was used which included interactions between factors as well as a higher-order interaction term between all three factors. To analyse sleep before illness versus wellness, mean actigraphically estimated total sleep times for the six nights before illness/wellness events were compared using two-way repeated-measures analysis of variance, with sex as a between-subjects factor.

Adolescents who did not report illness were excluded from the matched analysis, as were adolescents who reported too many illness bouts, where it was not possible to find matched illness and non-illness bouts preceded by six well days. In order to incorporate adolescents at these extremes of illness, cases were selected and qualitative reports prepared by KMO. For these case reports, original interview notes and descriptive statistics about the sleep of individual participants were examined and two cases of short sleepers were selected, one of whom reported few illnesses and the other many. Notes were made on their week-by-week illness reports and sleep patterns, including notations about academic activities, social activities and schedule changes (such as school vacation or a change in work schedule) that may have led to reduced or increased sleep. These notes were then synthesized into a brief case report that presents major factors affecting that student's sleep and illness experience. All the student names given in these case reports are pseudonyms.

RESULTS

Study participants were 16.6 years old on average and 39% were male. Eighty-four per cent were white and 45% attended public schools in Rhode Island; see Table 1.

Participants reported a variety of common illnesses that were grouped *post-hoc* into illness categories that included cold, flu-like, gastroenteritis, menstrual complaints, pain and 'other'. The number of ill-days captured by each category and the number of participants reporting each illness category are reported in Table 2.

Associations between sleep group and January–May illness

Omnibus tests for the interaction terms among the factors total sleep time, sex and sleep group showed no significant interactions, nor was the omnibus test for academic year significant. Conversely, the omnibus tests for sex (Wilks' $\Lambda = 0.72$, $F_{3,46} = 5.92$, $P = 0.002$) and sleep group (Wilks' $\Lambda = 0.81$, $F_{3,46} = 3.55$, $P = 0.02$) showed statistically significant effects. These findings are highlighted in Table 3, showing the means and standard deviations of the three illness outcomes (mean number of illness bouts per interview, mean duration of illness per interview and mean absences per interview) stratified by sex, sleep group and academic year. ANOVAs run on each outcome indicated significant differences on mean number of illness bouts per interview between males and females ($F_{1,48} = 17.70$, $P < 0.001$, $\eta^2 = 0.27$) and between longer and shorter sleepers ($F_{1,48} = 10.09$, $P = 0.003$, $\eta^2 = 0.17$), with males and longer sleepers reporting fewer illness bouts per interview. Fig. 1 shows mean illness bouts, mean duration of illness and mean illness-related absences in relation to sex, academic level and mean week-night total sleep time from January to May. Overall, reported bouts of illness per interview declined with longer sleep for males and females,

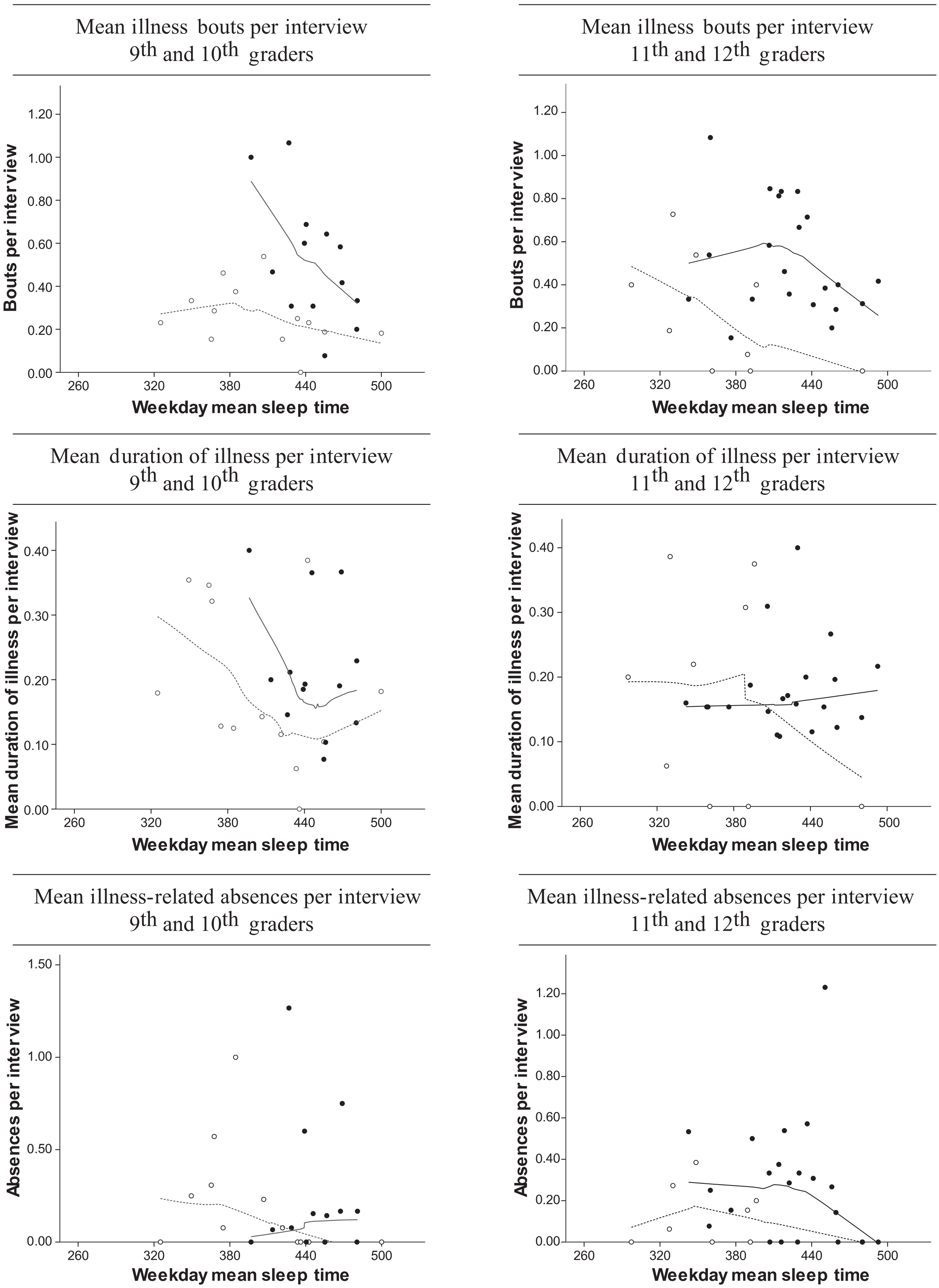

Figure 1. Mean illness bouts, mean duration of illness and mean illness-related absences by sex and academic level, with mean week-night total sleep time from January to May shown as a continuous variable. The left-hand graph shows 9th/10th graders, while the right-hand graph shows 11th/12th graders. Open circles represent males and filled circles represent females. Dotted lines show a line of best fit for males, while solid lines show a line of best fit for females.

Table 2 Illness categories reported by participants (n = 52)

Illness category	*Description*	*Frequency*	*Number of participants mentioning*
Cold	Clogged or running nose, sore throat, cough, slight or no fever	290	40
Flu-like	Fever, with 4 of 6: muscle pain, fatigue, sore throat, clogged or running nose, cough, headache	34	9
Gastroenteritis	Slight/no fever, gastritis, nausea, vomiting and/or diarrhoea	61	23
Menstrual	Menstrual cramps or pain	17	6
Pain*	Pain, not menstrual or stomach	131	28
Other†		140	29
Total		681	

52 ill adolescents: 18 male, 34 female.
*Most common pain: headache (69), sore throat (37).
†Most common other: sinus infection/sinusitis (33), strep throat (24), allergies (13), general sickness (e.g. did not feel well) (11).

Table 3 Means and standard deviations of three illness outcomes stratified by sex, sleep group and academic year

Sex	*Male*	*Male*	*Male*	*Male*	*Female*	*Female*	*Female*	*Female*
Sleep group	*Short*	*Long*	*Short*	*Long*	*Short*	*Long*	*Short*	*Long*
Academic year	*9/10*	*9/10*	*11/12*	*11/12*	*9/10*	*9/10*	*11/12*	*11/12*
Median value (min)	406.78		361.28		445.85		422.23	
Mean illness bouts per interview	0.31	0.22	0.37	0.12	0.69	0.36	0.60	0.44
SD	0.11	0.16	0.29	0.19	0.30	0.20	0.29	0.20
Mean illness duration per interview	0.24	0.14	0.17	0.17	0.22	0.21	0.17	0.19
SD	0.11	0.12	0.15	0.20	0.09	0.12	0.06	0.08
Mean absences per interview	0.37	0.04	0.14	0.09	0.34	0.20	0.28	0.29
SD	0.37	0.09	0.18	0.10	0.51	0.25	0.21	0.36

SD, standard deviation.

with more pronounced effects for younger females. In younger participants, mean duration of illness per interview was shortest at approximately 7.5 h of sleep per week-night for males and females, while for older participants, mean week-night sleep time had little apparent association with illness duration. In terms of illness-related absences, longer sleep was protective in all age/sex groups except for younger females.

Differences in sleep before matched periods of illness and wellness

A trend was found for shorter total sleep time in the 6-day window before periods of illness. Before ill events, mean nightly total sleep time was 411 min (SD = 49 min); before well events, mean nightly total sleep time was 427 min (SD = 43 min), $F_{16} = 3.88$, $P = 0.066$. No main effect of individual night ($F_{12} = 1.68$, $P = 0.21$) or interactions of event type and night ($F_{12} = 1.11$, $P = 0.41$), event type and sex ($F_{16} = 0.45$, $P = 0.51$) or sex and night ($F_{12} = 0.45$, $P = 0.80$) were found. Fig. 2 shows mean total sleep time before ill events versus well events overall, and for each of the 18 participants included in this analysis.

Brief case reports

Adolescents who reported either no illness or illnesses so frequent to preclude a 6-day ‘well’ window before illness were not included in the matched-pairs assessment reported above. To incorporate such adolescents into our assessment of sleep and illness, we report qualitative impressions of sleep and alertness from the interviews of two participants in the case studies below. Both participants are 17-year-old males who are independent school students and classified as shorter sleepers. One, Eric, reported 0 days ill, while the other, Bob, reported 35 days ill across the school semester.

DISCUSSION

The negative consequences of shorter sleep in adolescents have been well documented in the literature, with investigated physical consequences including, for example, increased risk of obesity (Cappuccio *et al.*, 2008), higher adiposity measures and increased risk of high cholesterol, both of which were found to be more significant in females (Gangwisch *et al.*, 2010; Yu *et al.*, 2007). Known consequences also extend to psychiatric illness, substance abuse risk and suicidality (Lee *et al.*, 2012; Pasch *et al.*, 2010).

Eric: 12th grade, 17 years old
Eric describes himself as 'pretty much an A student'. His extracurricular activities include playing an instrument, participating in academic groups (i.e. Academic Decathalon) and involvement with a religious youth organization and an Arabic dancing group. He works on Sundays at a gas station.

During the semester, Eric sleeps by actigraph estimate an average of 6 h and 1 min per night (SD: 73 min) on week-nights (71 nights) and an average of 6 h and 4 min per night (SD: 122 min) on weekend nights (30 nights).

Eric reports struggling to stay awake or dozing in several circumstances, including nodding off while watching TV after 23:00 hours and when watching a movie with friends after midnight. He reports wanting to do homework at 23:30 hours on a Saturday but being too tired, even after taking a shower to wake himself up.

Eric manages his sleep by catching up over breaks and altering his work schedule. During spring break holiday from school he reports waking up 'naturally' every day. Although he says he works every Sunday 09:00–17:00 hours, from his weekly interviews he actually works only 4 of 13 possible Sundays. Some Sundays he engages in alternate activities such as going to church or participating in an Academic Decathalon. On at least 2 days, however, he calls in 'sick' to work to allow time for sleep. On both occasions, Eric reports conflicting feelings about calling in sick and getting much-needed sleep. On one 'sick' day, he describes his mood as negative because he took the day off and did not fulfil his commitment, but positive because he caught up on sleep and got work done.

BOB: 12th grade, 17 years old
Bob lives 35–40 min away from Providence, RI, where he attends high school. Because of the distance and his involvement in school activities, such as the school play, Bob spends one to two nights per week with friends who live near school. Bob describes his work style as 'nothing, punctuated by large intervals of work'. He reports starting projects at 17:00 or 18:00 hours and working through until 04:00 or 05:00 hours, napping at school the next day to catch up. He is self-employed, repairing computers a few hours per week.

During the semester, Bob sleeps by actigraph estimate an average of 5 h and 30 min per night (SD: 91 min) on week-nights (52 nights) and an average of 7 h and 19 min per night (SD: 115 min) on weekend nights (21 nights). Bob's reports of illness are dominated by colds and sinus infections.

Bob's sleep patterns are shaped by extracurricular activities and his social life, including week-night time at friends' houses and a relationship he develops with a girl after several late-night online chats, including from 24:00 to 07:00 hours one Sunday night. Bob chooses to complete schoolwork at the last minute, which requires him to stay up late. He also works at night; he reports 7 week-night work bouts, none occurring earlier than 20:00 hours.

Bob manages his sleep in both intentional (such as leaving social events to take naps) and unintentional ways. He reports falling asleep in school, always falling asleep as a passenger in a car and struggling to stay awake or falling asleep when he is doing homework, sitting inactive in a public place and even driving a car. He even reports sometimes falling asleep in the bathtub.

As the semester comes to a close, Bob's sleep does not improve. His sleep schedule is still driven by his social life, by the onset of sleep problems related to a break-up and reunion with his online girlfriend and a realization that he will begin college in a few months.

Consistent with the literature examining incident illness in the context of shorter sleep (Cohen *et al*., 2009; Patel *et al*., 2012), and pertinent to the ongoing debate about how much sleep adolescents need (Matricciani *et al*., 2012), our study found that adolescents classified as shorter sleepers based on an average of 91 days of actigraphy monitoring from January to May reported more frequent illness bouts than adolescents classified as longer sleepers during the school year. Sex differences were apparent, with males reporting significantly fewer illness bouts than females. This finding of males reporting better outcomes, even in the face of similar sleep durations, is consistent with results from a large European cross-sectional study that showed a lower impact of shorter sleep on adiposity in male adolescents (Garaulet *et al*., 2011), although more research in this vein is needed. School absences per interview also differed between longer and shorter sleepers, although this finding did not achieve statistical significance (see Fig. 1). Our work exploring the relationship between shorter sleep and common illness builds upon the literature cited above. It also extends this work by examining the potential everyday correlates of shorter sleep, such as common illness and school absences,

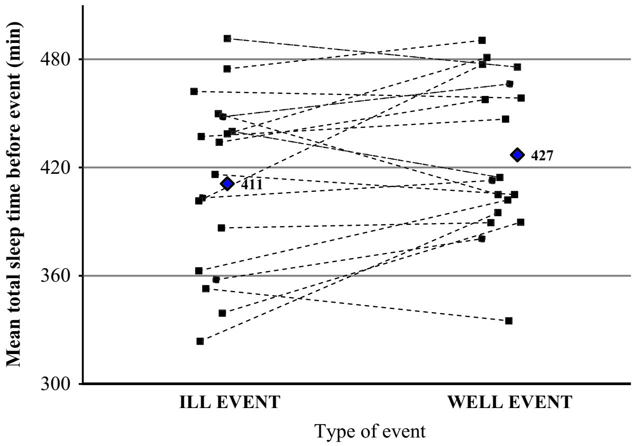

Figure 2. Mean sleep before ill and well events, by participant. Diamonds represent mean values across all participants (mean before ill events = 411 min of total sleep time, mean before well events = 427 min of total sleep time), and individual lines indicate participants' mean total sleep time values for six nights before matched ill and well events.

which do not require waiting months or years for a diagnosis of obesity, high cholesterol, depression or suicidal tendencies. The significance of this analysis of the everyday is that it provides another brick in the wall of evidence that adolescents need more sleep than they are getting, and these findings should encourage individuals in families, schools and policy-making positions to make additional sleep a priority for shorter-sleeping adolescents.

In addition to our main analysis of the relationship between shorter sleep and illness, analysing matched ill/well bouts in this naturalistic sample represents an innovative approach. Few, if any, researchers have collected and analysed sleep data in adolescents for up to 16 weeks across a school semester and paired those sleep data with detailed weekly interviews targeting such relatively low-incidence events as illness. These data demonstrated a trend that illness events in adolescents were associated with less sleep during the previous week than comparable periods before matched wellness episodes. This naturalistic approach lends modest support to findings from experimental studies showing that longer sleep is associated with better immune response and health outcomes (Faraut *et al*., 2012; Okun, 2011; Opp *et al*., 2007; Prather *et al*., 2012).

The two brief case reports contribute to understanding different ways in which sleep and illness may be associated in the lives of individual adolescents. Researchers investigating sleep and illness rarely use qualitative methods such as interviews or analyses examining and coding interview notes. When they do use these methods, it is typically to collect general perceptions of sleep (Noland *et al*., 2009; Owens *et al*., 2006) and not to explore the sleep lives of individuals in detail [although see Henry and Rosenthal (2013) for an example of close attention to sleep lives in individuals diagnosed with sleep apnea]. In this study, although both Eric and Bob were defined as shorter sleepers, Eric's more consistent sleep timing across the weekday and weekend may have been protective (Owens and Mindell, 2011). He may also have been exposed to fewer illnesses than Bob, who reported spending significant amounts of time at friends' houses. Bob's preference for scheduling his social time and work time (both for school and his business) at night also limited his sleep to an even greater extent than Eric's—while Eric reports trying (and failing) to do homework at 23:30 hours and struggling to stay awake during a movie past midnight, Bob reports finishing computer work successfully and chatting online with friends well into the overnight hours. Identifying specific issues in individual sleep patterns may be a useful way to begin to address factors that may be amenable to intervention in shorter-sleeping adolescents.

LIMITATIONS

While collecting sleep and illness reports in a naturalistic sample represents an innovation of this work, it also presents limitations, notably the lack of control of factors beyond sleep that lead to illness in these adolescents. To address this limitation, we used several analyses and included two brief case reports designed to contextualize reports of sleep and illness in the lives of adolescents. Other factors associated with sleep and illness in previous studies were not measured in this study, including family functioning and stress. Stress has known effects on both sleep and the immune system in animal models (Toth, 1995). A recent study by Prather et al., however, showed only a modest effect of perceived daily stress on their observed sleep–vaccination response link in humans (Prather *et al*., 2012). We were also not able to include extreme long sleepers in this study, due to our measurement of sleep among adolescents in school, although the extant literature addresses potential negative health consequences of longer sleep durations. In addition, the relationship between sleep duration, sex and age is complicated, and we did not have full statistical power to model this relationship due both to our limited sample size and the complex relationship between sex and sleep duration, such that more males showed shorter sleep durations.

CONCLUSION

Examining concurrent sleep and illness data, we found that acute illnesses were more frequent in otherwise healthy adolescents with shorter sleep across a school semester. We also found a trend in this small naturalistic sample showing that illness events in adolescents were associated with less sleep during the previous week than comparable periods before matched wellness. Qualitative case reports highlighted regularity of sleep timing, exposure to friends and preference for evening activity as potential contributors to illness; the latter may link to extroverted personality types and evening chronotypes. While many factors may affect incidence of common illnesses in adolescents, our findings indicate that further examination of the role of shorter total sleep time in the development of common illness may be a fruitful avenue for investigation.

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AUTHOR CONTRIBUTIONS

KMO provided the impetus to analyse total sleep time and health in this existing data set, and performed the initial statistical analyses to examine hypotheses about sleep and health. She also conducted the qualitative analysis to construct case studies, and was the primary author of the manuscript. CA was involved in the original design and implementation of the research project, specifically managing the actigraphy data collection and analysis. She was also instrumental in data reduction efforts. RS was involved in the original design and implementation of the research project, including data reduction efforts, and also its revival, serving as a statistical consultant and a member of a consensus team to decide issues such as how to classify sets of symptoms into disease categories. DB tutored KO in basic statistics and provided higher level statistical analysis for the revised manuscript. MAC wrote and received the grant for the original research project and was instrumental in both its design and implementation. She supervised the original data collection and data reduction of the interviews. She also supervised the analysis of total sleep time and health in this data set, and was the final editor of the manuscript prepared by KMO.

CONFLICTS OF INTEREST

Kathryn M. Orzech has no conflicts of interest to report. Christine Acebo is an employee of Jazz Pharmaceuticals. Her involvement on this study preceded this employment and the study has no affiliation with Jazz Pharmaceuticals. Ronald Seifer has no conflicts of interest to report. David Barker has no conflicts of interest to report. Mary A. Carskadon has no conflicts of interest to report.

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