Assessing the benefits of napping and short rest breaks on processing speed in sleep-restricted adolescents

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SUMMARY

Achievement-oriented adolescents often study long hours under conditions of chronic sleep restriction, adversely affecting cognitive function. Here, we studied how napping and rest breaks (interleaved off-task periods) might ameliorate the negative effects of sleep restriction on processing speed. Fifty-seven healthy adolescents (26 female, age = 15–19 years) participated in a 15-day live-in protocol. All participants underwent sleep restriction (5 h time-in-bed), but were then randomized into two groups: one of these groups received a daily 1-h nap opportunity. Data from seven of the study days (sleep restriction days 1–5, and recovery days 1–2) are reported here. The Blocked Symbol Decoding Test, administered once a day, was used to assess time-on-task effects and the effects of rest breaks on processing speed. Controlling for baseline differences, participants who took a nap demonstrated faster speed of processing and greater benefit across testing sessions from practice. These participants were also affected significantly less by time-on-task effects. In contrast, participants who did not receive a nap benefited more from the rest breaks that were permitted between blocks of the test. Our results indicate that napping partially reverses the detrimental effects of sleep restriction on processing speed. However, rest breaks have a greater effect as a countermeasure against poor performance when sleep pressure is higher. These data add to the growing body of evidence showing the importance of sleep for good cognitive functioning in adolescents, and suggest that more frequent rest breaks might be important in situations where sleep loss is unavoidable.

INTRODUCTION

Levels of cognitive performance vary over time, and these dynamics are affected by a number of interacting factors. Among these are time-on-task (TOT; the duration of time spent on continuous performance), circadian and homeostatic influences on alertness, and time spent on off-task activity (i.e. taking a rest break). Although much is known about the impact of these variables individually, many open questions remain about how they interact to determine behaviour, information that could be valuable in calculating the optimal length and timing of work bouts.

Processing speed and sleep restriction

Processing speed is one of the cognitive domains in which fluctuating performance levels are commonly observed. In adults, cognitive throughput is lower following periods of total sleep deprivation (SD; Lim and Dinges, 2010) and partial sleep restriction (SR) (Banks *et al.*, 2010). Recently, we demonstrated that processing speed is also susceptible to TOT effects, even over relatively short periods of work, but that rest can partially restore performance following this decrement (Lim *et al.*, 2016).

As speed of processing is a contributor to full-scale IQ (Benson *et al.*, 2010) and an important factor in effective work performance, understanding its temporal dynamics is more than just a theoretical exercise. Efficient speed of processing is particularly crucial for school-going adolescents who need to manage high cognitive throughput in academic settings. Poor processing speed adversely affects creativity and intelligence, which in turn has a negative impact on school performance (Rindermann and Neubauer, 2004). While early studies failed to find an effect of SR on processing speed in adolescents (Carskadon *et al.*, 1981; Randazzo *et al.*, 1998), more recent work (including our own) has been able to demonstrate a significant impact on this function (Lo *et al.*, 2015; Louca and Short, 2014).

The studies discussed above describe a logical path connecting sleep reduction to poorer school performance via decrements in processing speed. Underscoring the relevance of these finding are statistics about the worrying levels of sleep curtailment experienced by contemporary adolescents. In competitive East Asian societies, school-going adolescents sleep on average 1–2 h less than their counterparts in Western countries (Gradisar *et al.*, 2011; Olds *et al.*, 2010). There are numerous reasons why adolescents get less sleep than necessary in modern society, including early school start times, social influences, high homework load, and increased use of light-emitting electronic devices in the evening (Carskadon, 2011).

Countermeasures: napping and rest breaks

In the recently conducted Need for Sleep (NFS) study (Lo *et al.*, 2015), we monitored 57 adolescent volunteers as they underwent a 2-week partial SR protocol while living in a school dormitory, and found that reduced sleep resulted in impairments in a number of cognitive functions, including speed of processing and sustained attention. These results motivated us to investigate the effects of a common countermeasure used by adolescents against sleepiness – daytime napping. Studies have found that naps are taken by a substantial proportion of adolescents in North America (31%; National Sleep Foundation, 2006), Australia (32%; Gradisar *et al.*, 2008) and Asia (38.7%; Mak *et al.*, 2012), and are not restricted to the weekends (Gradisar *et al.*, 2008). Despite this, little is known about the effects of napping on cognitive performance in this population.

In addition to napping, short rest breaks during long periods of work are a ubiquitous and commonsense way of dissipating cognitive fatigue. A review by Tucker (2003) concluded that rest breaks are generally beneficial in workplace settings in relieving subjective feelings of fatigue and reducing the risk of accidents and errors. This finding is also borne out in laboratory tests using controlled computerized paradigms (Helton and Russell, 2015; Lim and Kwok, 2016) where rest breaks interrupt the trajectory of TOT declines. In educational settings, Sievertsen *et al.* (2016) studied a large cohort of Danish students and found that test performance improved significantly following 20–30-min breaks during the school day. The balance of evidence is thus that rest pauses have positive effects on cognitive functioning, at least in the short term.

The principal aim of the current experiment was to investigate the independent and interactive effects of napping and rest breaks on the dynamics of processing speed during SR. To accomplish this, we employed a modified version of the Symbol-Digit Modality Test (Smith, 1982), the Blocked Symbol Decoding Task (BSDT; Lim *et al.*, 2016), which contains interleaved work and rest periods. We have previously demonstrated that performance on this task closely mirrors findings obtained using longer sustained attention paradigms. Accordingly, we deployed the BSDT to test the effect of naps on cognition in a group of healthy adolescents who underwent multiple nights of SR.

MATERIALS AND METHODS

Participants

Fifty-seven healthy adolescents (26 female, age = 15–19 years) from the NFS Study 2 (NFS2) participated in this experiment as part of a 15-day live-in study on the effects of napping and SR. Details of this protocol are reported in Lo *et al.* (2016). The protocol for this study was approved by the Institutional Review Board of the National University of Singapore, and all participants signed written informed consent. Consent was also obtained from the parents or guardians of all participants. Participants were compensated a total of S$1000 for completing the study.

All participants met the following selection criteria: 15–19 years old; healthy; no sleep disorder; body mass index (BMI) $\leq$30 kg m^{-2}; not habitual short-sleepers [where short-sleepers were identified as having an actigraphically estimated average time-in-bed (TIB) of <6 h and no sign of sleep extension for >1 h on weekends]; consumption of $\leq$5 cups of caffeinated beverages a day; and did not travel across >2 time zones 1 month prior to the experiment.

Participants were randomized into the nap and the no-nap group (refer to the ‘Procedure’ section below). These two groups did not differ in age, gender distribution, BMI, habitual consumption of caffeinated beverages, morningness–eveningness preference (Horne and Ostberg, 1976), levels of daytime sleepiness (Johns, 1991), symptoms of chronic sleep reduction (Meijer, 2008), and self-reported (Buysse *et al.*, 1989) and actigraphically assessed sleep parameters during term time ($P > 0.12$; Table 1).

Procedure

Study participants were housed in a boarding school in Singapore, during which sleep and wake periods were closely controlled and monitored by actigraphy (Actiwatch 2, Philips Respironics, Pittsburgh, PA, USA) at all times, and PSG (SOMNOtouch recorder; SOMNOmedics GmnH, Randersacker, Germany) on selected nights and nap periods. The schedule for this SR protocol is shown in Fig. 1a. After two baseline nights (9 h TIB; 23:00–08:00 hours) for acclimatization and baseline assessment, participants underwent 5 nights of SR ($M_1$1–$M_1$5; 5 h TIB; 01:00–06:00 hours), two recovery nights ($R_1$1 and $R_1$2; 9 h TIB; 23:00–08:00 hours), three further nights of SR ($M_2$1–$M_2$3; 5 h TIB; 01:00–06:00 hours) and two further nights of recovery sleep ($R_2$1 and $R_2$2; 9 h TIB; 23:00–08:00 hours). While the nap group received a 1-h nap opportunity in the afternoon (14:00–

Table 1 Characteristics of the nap and no-nap groups

	Nap group		No-nap group			
	Mean	*SD*	*Mean*	*SD*	t/χ^2	P
N	29	–	28	–	–	–
Age (years)	16.75	0.94	16.91	1.14	0.55	0.59
Gender (% males)	55.20	–	57.10	–	0.02	0.88
BMI (kg m^{-2})	20.19	2.71	20.92	2.77	1.01	0.32
Caffeinated drinks per day	0.81	0.75	0.75	0.91	0.27	0.79
Morningness–eveningness Questionnaire score	52.62	7.27	50.25	7.66	1.20	0.24
Epworth Sleepiness Scale score	6.57	2.86	6.52	2.57	0.08	0.94
Chronic sleep reduction questionnaire						
Total score	33.62	4.12	34.21	5.07	0.49	0.63
Shortness of sleep	12.83	1.75	12.36	2.31	0.87	0.39
Irritation	6.28	1.51	6.36	1.50	0.20	0.84
Loss of energy	7.21	1.35	7.93	2.05	1.57	0.12
Sleepiness	7.31	1.23	7.57	1.60	0.69	0.49
Pittsburgh Sleep Quality Index						
TIB on weekdays (h)	6.50	0.90	6.52	0.72	0.13	0.90
TIB on weekends (h)	9.05	1.07	8.76	1.09	1.02	0.31
TST on weekdays (h)	6.05	0.91	6.13	0.73	0.37	0.71
TST on weekends (h)	8.57	1.03	8.40	1.02	0.63	0.53
Global score	5.28	1.89	5.39	2.25	0.21	0.83
Actigraphy						
TIB on weekdays (h)	6.20	1.03	6.44	0.99	0.86	0.40
TIB on weekends (h)	8.18	0.82	8.15	0.70	0.15	0.88
TST on weekdays (h)	5.43	0.95	5.69	0.89	1.04	0.30
TST on weekends (h)	7.31	0.86	7.23	0.63	0.39	0.70
Sleep efficiency (%)	88.00	4.98	88.51	4.10	0.42	0.68

BMI, body mass index; SD, standard deviation; TIB, time-in-bed; TST, total sleep time.

15:00 hours) each day after a night of restricted sleep opportunity, the no-nap group watched documentaries. Data reported in this work were taken from the second baseline day (B_2), the first 5 days following SR ($M_1$1–$M_1$5) and the 2 days following recovery sleep ($R_1$1 and $R_1$2), as rebound effects are beyond the scope of the current report.

Prior to the first testing session, participants underwent three practice sessions (see description in 'Materials and methods') in the first 3 days of the protocol. In the first of these (on the evening prior to B1), they were shown an onscreen legend mapping the symbols to the corresponding letters. The second and third practice sessions (on B1 and B2) were identical to the test sessions. All participants achieved 90% (criterion) accuracy by the third practice session.

To assess the effect of work periods and rest breaks, participants completed seven blocks of a self-paced symbol-decoding task interleaved with six rest periods, the BSDT (Fig. 1b; Lim *et al*., 2016). In this test, participants first learned a mapping of four symbols ('$\perp$' '$+$' '$\times$' 'Λ') to four key presses (in this case, the letters F, G, H and J on a standard QWERTY keyboard), before performing this coding on a sequential series of these stimuli. Accuracy and speed were both emphasized in the task instructions. Symbols were presented centrally, one at a time, at approximately one degree of visual angle, and were replaced by a blank screen for 100 ms following each response. Each block of the BSDT consisted of 150 trials, followed by a rest break of either 12 or 28 s. We did not test for differences between rest breaks of different lengths in the analyses presented here. For the purposes of this paradigm, we define a rest break as an interval between on-task periods where no goal-directed cognitive activity is required.

Stimuli were presented using E-Prime 2.0 (Psychology Software Tools, Sharpsburg, PA, USA; Schneider *et al*., 2012) on identical laptop computers (Acer Aspire E11, Acer, Taipei, Taiwan). Test bouts of the BSDT occurred at the same time every day (18:00 hours) and lasted approximately 12–18 min depending on how quickly the participant was able to perform the task.

As part of a separate test battery (Lo *et al*., 2016) administered three times a day at 10:00, 15:45 and 20:00 hours, participants completed the Karolinska Sleepiness Scale (KSS; Akerstedt and Gillberg, 1990) to assess their subjective level of sleepiness. Data from this test battery also show that the effects of napping on cognitive function were observed beyond the time of BSDT administration (i.e. in the 20:00 hours tests).

Parameter extraction

Response time (RT) data from self-paced tasks typically contain a small number of extremely slow responses (RT $>$ 5 SD; Bills, 1931), which can skew the estimates obtained from curve fitting. These RTs were thus removed before further data analysis. In MATLAB R2012A (http://www.mathworks.com), we used linear fits to estimate the effects of TOT within each 150-trial task block for each subject. RT data were smoothed by applying a sliding window over the time series to average RTs over sets of 20 responses. We regressed these against the sequential number of the window in each block to obtain a slope value, an intercept value (predicted RT at the start of the block) and a predicted RT for the end of the block. Based on the latter two variables we calculated the % change in estimated RT from the end of each task block (prior to a break) to the start of the following task block. These six estimates were averaged to obtain a measure of recovery from breaks for each test. The seven slope estimates were averaged to obtain a measure of TOT for each test. Finally, each participant's median RT was calculated for every test bout they underwent. This analysis approach is similar to what was used in our previous experiments (Lim and Kwok, 2016; Lim *et al*., 2016).

Statistical analysis

Statistical analyses were performed using SAS 9.3 (SAS Institute, Cary, NC, USA). A general linear mixed model with PROC MIXED was used to examine the effects of group, day

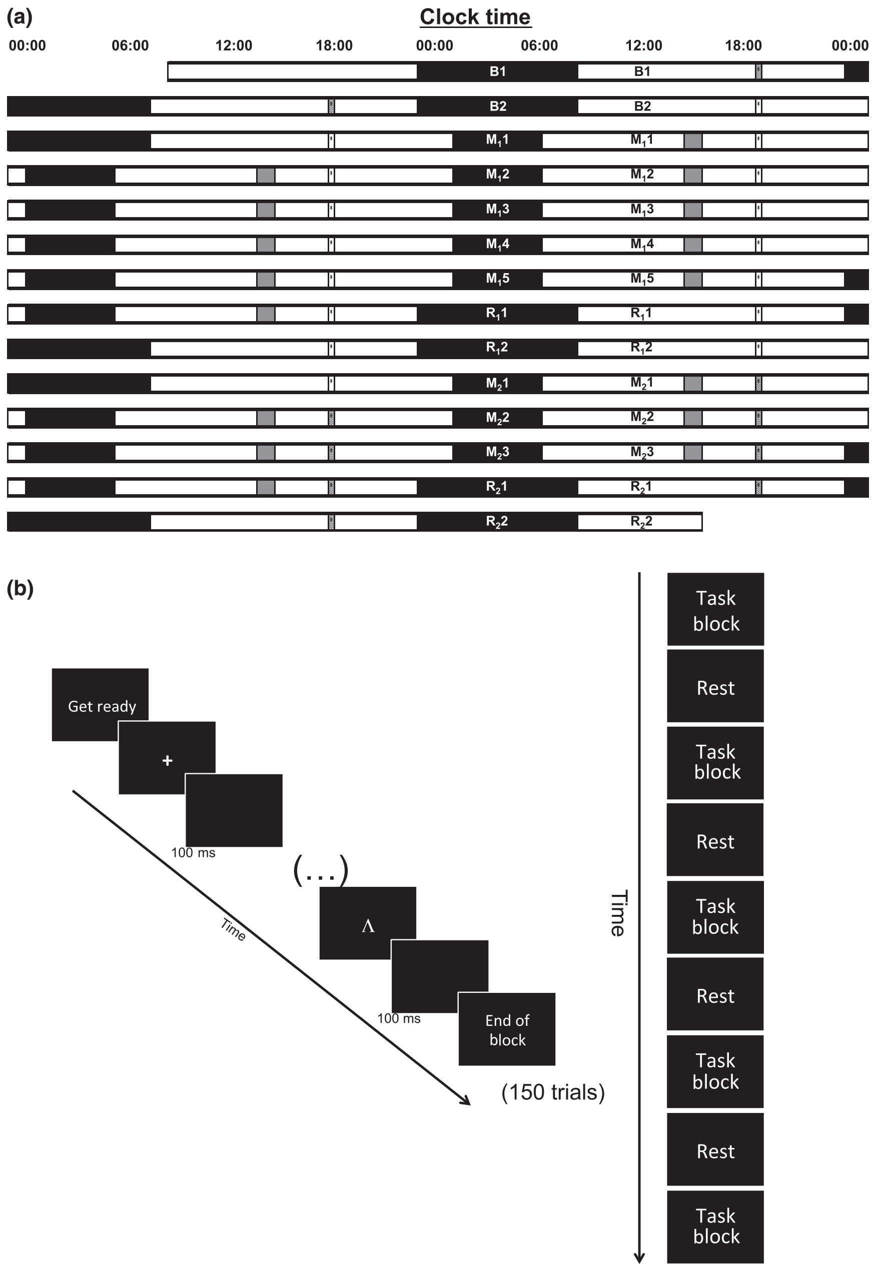

Figure 1. (a) Study protocol. Participants underwent a total of 14 days and 13 nights in the study. Black bars indicate sleep [23:00–08:00 hours on baseline (B) and recovery (R) nights, and 01:00–06:00 on manipulation (M) nights]. Grey bars indicate when nap opportunities were provided for the nap group (14:00–15:00 hours). The Blocked Symbol Decoding Test (BSDT) was administered from 18:00 hours to approximately 18:20 hours every day. Data from shaded BSDT blocks were not included in the current analysis. (b) BSDT paradigm: participants performed seven blocks of the BSDT with interleaved rest opportunities (12 or 28 s).

(from day $M_1$1 to $R_1$2) and the group × day interaction on the three extracted dependent variables. Data were corrected for baseline levels of performance on day B2.

RESULTS

Sleep parameters

During baseline nights, the nap and no-nap groups had equivalent total sleep time (TST; 496 and 500 min, respectively). In the sleep-restricted nights, the nap group slept less than the no-nap group on 1 night (night $M_2$3; 6.6 min less, $P < 0.05$). Details of the nap durations are reported in Lo *et al.* (2016). In brief, PSG assessment showed that the nap group slept 37–53 min more than the no-nap group each day ($P < 0.001$), incurring a lower sleep debt over the course of the protocol. This was corroborated by KSS scores: an independent-samples *t*-test of the average KSS from $M_1$1 to $M_1$5 revealed significantly lower subjective sleepiness levels in the nap group than the no-nap group

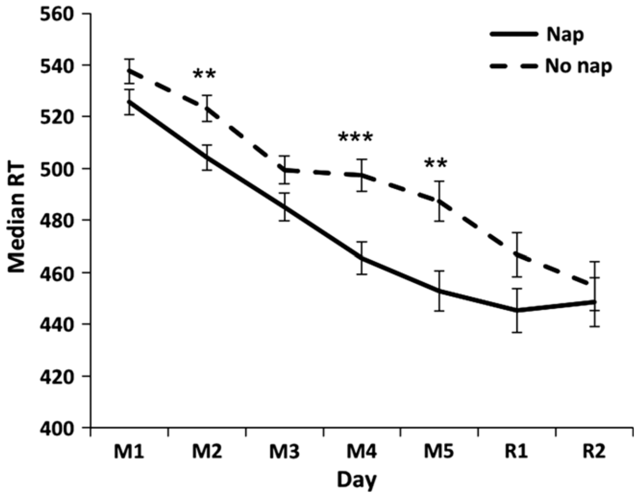

Figure 2. Median reaction time (RT) on the Blocked Symbol Decoding Test (BSDT) during the 5 days following sleep restriction (SR) (M_1–M_5) and the 2 days following recovery sleep (R_1, R_2). Values are estimated means and SEM adjusted for baseline levels of performance. $^{**}P < 0.01$; $^{***}P < 0.001$.

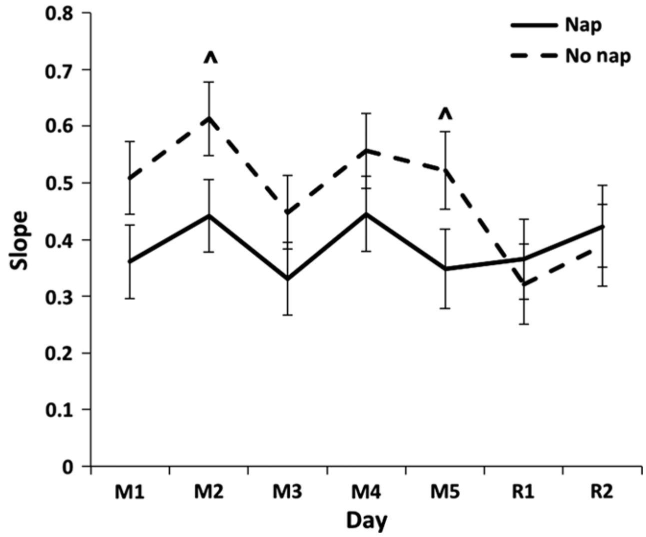

Figure 3. Mean within-block slope of performance (estimated) on the Blocked Symbol Decoding Test (BSDT) during the 5 days following sleep restriction (SR) (M_1–M_5) and the 2 days following recovery sleep (R_1, R_2). Values are estimated means and SEM adjusted for baseline levels of performance. $^{\wedge}P < 0.10$.

($t_{55} = 3.06$, $P = 0.003$, $d = 0.83$). We note that all participants in the nap group obtained at least some sleep during every nap opportunity monitored with PSG (minimum nap TST: $M_1$1: 20.5 min; $M_1$3: 45 min; $M_1$5: 29 min).

Effects of nap on median RT

Mixed model analysis of reaction time data revealed a significant effect of DAY ($F_{6,320} = 24.78$, $P < 0.0001$), indicating that in both groups there was continuous improvement in speed (median RT) over the entire 8-day period (Fig. 2). This was likely due to practice effects. The effect of GROUP ($F_{1,320} = 8.98$, $P = 0.003$) and the DAY $\times$ GROUP interaction ($F_{6,320} = 2.37$, $P < 0.03$) were also significant. Specifically, participants who had the nap opportunity were faster and had greater gains due to repeated task exposure over time. *Post hoc* tests revealed that the difference between study groups was significant on M2 ($P = 0.008$), M4 ($P = 0.0004$), M5 ($P = 0.002$), and approached significance on M3 ($P = 0.06$; Table S1).

Effects of nap on within-block TOT

We next tested whether participants in the nap and no-nap groups showed different rates of TOT within each 150-trial task block. To accomplish this, we used an identical mixed model as above with mean within-block TOT slope as a dependent variable. In this analysis, we found a significant effect of GROUP ($F_{1,320} = 4.54$, $P = 0.03$), but no effect of DAY ($F_{6,320} = 1.87$, $P = 0.08$) and no DAY $\times$ GROUP interaction ($F_{6,320} = 0.94$, $P = 0.46$; Fig. 3). Participants in the no-nap group tended to have steeper TOT declines within block than those in the nap group. *Post hoc* tests showed trend-level differences between groups on M2 ($P = 0.06$) and M5 only ($P = 0.08$; Table S2).

Effects of nap on recovery following breaks

Finally, we examined whether the nap opportunity had an effect on the amount of recovery afforded by a break. We first tested if this variable was confounded with TOT – that is to say, participants who recovered more after a break may have done so because their performance declined more steeply in the preceding block. We found that these two variables (TOT slope and average recovery) were highly correlated on the first baseline day ($r = -0.88$). We thus added mean within-block TOT slope (on each day) as a covariate in this mixed model. This analysis revealed a significant effect of GROUP ($F_{1,320} = 7.14$, $P = 0.008$), a significant effect of DAY ($F_{6,320} = 2.84$, $P = 0.01$), and no significant interaction ($F_{6,320} = 0.79$, $P = 0.58$; Fig. 4). Participants in the no-nap group tended to show greater recovery after breaks than participants in the nap group. *Post hoc* tests revealed a trend to significance between groups on M2 ($P = 0.06$), and a significant difference on R1 ($P = 0.03$; Table S3).

DISCUSSION

We investigated the effect of a daily 1-h nap opportunity during multiple nights of SR on the dynamics of task performance in a self-paced symbol-decoding paradigm in adolescents. After controlling for baseline performance, we found that the nap opportunity significantly affected several aspects of performance. Specifically, participants who napped had: (1) faster response speed; (2) greater gains from practice effects; and (3) lower vulnerability to TOT. However, participants who did not receive a nap showed more benefit from the short break opportunities provided between task blocks.

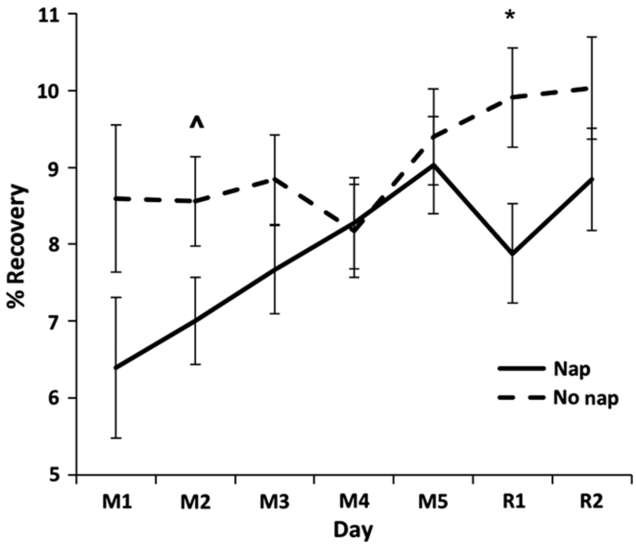

Figure 4. Mean recovery (% improvement in reaction times resulting from the break) during the 5 days following sleep restriction (SR) (M_1–M_5) and the 2 days following recovery sleep (R_1, R_2). Values are estimated means and SEM adjusted for baseline levels of performance. ^$P < 0.10$; *$P < 0.05$.

Napping benefits speed of processing

In adults, there is good evidence that performance on speed-of-processing tasks (e.g. the Digit Symbol Substitution Test) is significantly impaired by SR (Banks *et al.*, 2010; Van Dongen *et al.*, 2003) and SD (Pilcher *et al.*, 2007; Tucker *et al.*, 2010), with meta-analysis showing that 24 h of total SD causes impairments with effect sizes in the small to moderate range (Lim and Dinges, 2010). In contrast, studies of children and adolescents have yielded more mixed results, with early studies reporting no effect of SD on processing speed (Carskadon *et al.*, 1981; Randazzo *et al.*, 1998; Sadeh *et al.*, 2003), and others reporting a detrimental effect (Louca and Short, 2014). In a protocol conducted by our laboratory similar to that of the current study (Lo *et al.*, 2015), large and significant deficits were observed on the Symbol-Digit Modalities Test over 7 nights of SR (5 h TIB; Cohen's $f^2 = 0.72$).

Here, we found that a 1-hour daily nap could partially reverse detrimental effects of SR on processing speed when comparing performance on individual days. Furthermore, across multiple days, we observed that practice gains were greater in the nap group, suggesting that greater sleep pressure hampered these natural improvements. Processing speed correlates with intelligence, creativity and academic ability (Rindermann and Neubauer, 2004), and the present findings may have implications for scholastic test performance.

Napping reduces vulnerability to TOT effects

Despite the relatively short duration of the BSDT, we previously observed robust TOT effects both between and within blocks (Lim and Kwok, 2016). Here, we found support for the hypothesis that napping reduces the severity of these TOT declines, suggesting that the intervention has a prophylactic effect on the accumulation of fatigue during cognitive performance.

Previous research has demonstrated that SD interacts with fatigue to augment the TOT effect (Lim and Dinges, 2008), particularly when cognitive demand is high (Dinges and Powell, 1988; Doran *et al.*, 2001) and during monotonous tasks (Richter *et al.*, 2005). In the current dataset, we show that this effect is reversible: reducing sleep pressure via a daily nap was an effective countermeasure against the detrimental consequences of sleep loss.

In many real-world situations, stable performance over time is critical to success, and TOT effects undermine this stability. For instance, workplace accidents may have a high probability of occurrence only after performance has declined beyond a critical threshold. Tucker *et al.* (2003) observed that accident risk is reduced directly after a break, but increases in parallel with the duration of work. In the context of academic performance, the ability to sustain performance over time is strongly related to classroom productivity (as measured by the number of math problems completed in a set time; Fosco and Hawk, 2015). These data suggest that naps may be an effective way to maintain subsequent performance at stable supra-threshold levels.

Breaks are less beneficial following nap opportunities

In a previous experiment using the BSDT, we found that the short, inter-block breaks significantly improved performance, with longer breaks associated with greater recovery (Lim *et al.*, 2016). Here, we were interested in whether the difference in sleep pressure between the nap and no-nap groups affected the amount of recovery conferred by these short task pauses. We found that this was the case: participants in the no-nap group showed relatively greater recovery of performance after breaks, even after controlling for the confounding factor of greater TOT declines in this group.

Previous studies have shown that breaks during bouts of SD have a beneficial effect on driving performance (Philip *et al.*, 2006) and subjective sleepiness (Neri *et al.*, 2002). In general, it has been recommended that more rest opportunities should be provided to those who have to work at an adverse circadian phase in order to counteract the effects of heightened TOT and fatigue (Rosa, 1995).

To our knowledge, this is the first study to explore the effects of sleep pressure on the benefits conferred by rest breaks. While the BSDT lacks the face validity of real-world work–rest schedules, we have previously shown its psychometric properties to mirror those of longer-duration tasks (Lim *et al.*, 2016), suggesting that the present pattern of results may still be applicable to operational settings. Interestingly, our results suggest that doubling up on countermeasures – that is, both taking naps and administering additional rest breaks, may not result in better mitigation of performance deficits in speeded tasks in sleep-restricted persons.

Limitations

A limitation of the current study is the lack of a well-rested control group. However, we note that performance on the digit-symbol substitution task in the first NFS study was significantly impaired in comparison to rested controls (Lo *et al.*, 2015), suggesting that BSDT performance in both the nap and no-nap groups here was worse during the sleep-restricted days, but that napping had some effect in reversing this deficit. Furthermore, our study design reflects the cycle of SR and 'catch-up' recovery sleep that many adolescents already experience, and the performance of the no-nap group may in fact be a valid indication of how processing speed declines over the course of a real school week for many.

CONCLUSION

In summary, reductions in homeostatic sleep pressure caused by napping change the dynamics of speed of processing over time. Napping led to better overall performance, as indexed by smaller TOT effects, faster responding and the acceleration of gains from practice. However, rest breaks were more recuperative for those under greater sleep pressure. These results reinforce the suggestion that rest breaks are particularly useful under conditions where SR is unavoidable (e.g. military settings), but ultimately still do not boost performance more than if sleep pressure is relieved through napping, or a full period of nocturnal sleep.

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CONFLICTS OF INTEREST

The authors of this manuscript have no financial conflicts of interest to disclose.

AUTHOR CONTRIBUTIONS

JL collected the data; JL and JCL analysed the data. All authors contributed to study design, interpretation of results, and manuscript preparation.

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SUPPORTING INFORMATION

Additional Supporting Information may be found online in the supporting information tab for this article:

Table S1. Raw and estimated values for median reaction times (RT).

Table S2. Raw and estimated values for time-on-task slopes within task blocks.

Table S3. Raw and estimated values for the average amount of recovery (% decrease/improvement in reaction time) in each testing session.