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RESEARCH ARTICLE

# Effects of sleep stage and sleep episode length on the alerting, orienting, and conflict components of attention

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**Abstract** Awakening from different sleep stages, percentage of different stages of sleep subsumed within a sleep episode, and sleep episode length, have all been hypothesized to affect cognitive performance upon awakening. To further examine the contribution of these factors, 14 healthy participants slept for 3 h (0300–0600 hours) and 6 h (2400–0600 hours), with each sleep episode separated by 1 week. Electroencephalographic measures were taken throughout each sleep episode, and participants completed the Attentional Network Test, which measures alerting, orienting, and executive functioning (conflict) components of attention, upon awakening. Overall, mean reaction time (RT) was slower in the 3- and 6-h post-sleep conditions than in a baseline (pre-sleep) condition. Alerting, orienting, and conflict measures of attention did not significantly differ across the baseline and two post-sleep conditions. Awakening from REM sleep resulted in slower overall RT than awakening from lighter sleep (stages 1 and 2). In multiple regression analyses, overall RT was predicted by the duration of slow wave sleep (SWS), such that more time spent in SWS was associated with an overall slowing of RT. Conflict scores were predicted by the duration of REM; that is, more time spent in REM was associated with greater amounts of conflict (i.e., larger flanker effects). These data provide more information about the process of awakening and suggest that SWS and REM influence different aspects of attention upon awakening.

**Keywords** Attention · Cognition · REM · Sleep length · Sleep stage · Slow wave sleep

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## Introduction

The process of sleeping has a beneficial effect on variables such as mood and cognitive performance (Amin et al. 2012; Bonnet 1991; Ficca et al. 2010), while sleep deprivation can have deleterious effects on these same variables (Dagys et al. 2012; Irwin et al. 2012; Wimmer et al. 1992). Given this enhancing effect of sleep, it is paradoxical that the time period shortly after awakening from an episode of sleep is characterized by cognitive and motor performance that may be worse than what it was prior to the sleep episode. This transient state of hypovigilance, disorientation, and slowed mental processing is known as sleep inertia (Lubin et al. 1976; see Ferrara and De Gennaro (2000), Matchock (2010), or Tassi and Muzet (2000) for a review) and is experienced by virtually all people at least once per day, persisting for at least 2 h (Jewett et al. 1999). Considering the daily occurrence of waking from monophasic sleep in the morning, as well as waking from naps (which are taken by approximately three-quarters of all young to middle-aged adults in the United States; Pilcher et al. 2001), the function and beneficial effects of sleeping (e.g., Dinges 1992; Lovato and Lack 2010) need to be assessed relative to the commonly experienced performance deficits upon awakening in the morning.

In addition, little is known about how sleep stage mechanisms and sleep length affect not only simple reaction time (RT), but various aspects of attentional resources. Matchock and Mordkoff (2007) tested participants at 2400, 0300, and

0600 h after sleep episodes of 1, 4, and 7 h, respectively, and found that greater impairments in selective attention shortly after awakening (as measured using a Flankers Task) were associated with longer sleep episodes. The authors suggested that perhaps sleep depth as indexed by the amount of slow wave sleep (SWS) subsumed within the sleep bout could explain these effects. Consistent with this, Ferrara et al. (2000) found more deficits in mental computation (as measured with a descending subtraction task) after longer sleep bouts when participants slept for 2, 5, or 7.5 h. In an experimental condition in which SWS was actively suppressed during these same-length episodes, longer sleep episodes were then associated with fewer cognitive deficits. The one weakness to this evidence is that sleep episode length and time-of-day are often confounded in this research. When Tassi et al. (2006) controlled for this variable by comparing long and short sleep bouts that both ended at the same time (i.e., participants slept from 2300 to 0700 h or from 0500 to 0700 h), they found for the 2-h sleep group increases in RT during the first half of the testing session and increases in error rates during the second half of the session, suggesting a two-phase process (as assessed by the Stroop Task).

The effect of duration of sleep episodes on cognitive performance is partially addressed with napping studies, but they are somewhat problematic due to the relatively short sleeping times that are compared. Nonetheless, Stampi et al. (1999) compared daytime naps of various lengths (all under 90 min) and found that the longer naps were followed by greater deficits on a computational task, while middle-length naps showed the greatest deficits on a memory and search test. Takahashi et al. (1999) observed a positive correlation between nap length and self-reported fatigue, but, again, only naps up to 120 min were investigated. In contrast, Kubo et al. (2010) compared early and late naps of differing lengths and found that short naps were associated with worse performance on a visual vigilance test. However, a limitation of this study is that the sleep stage from which the participants were awakened varied across nap lengths (e.g., in the early 60 min nap, 66.7 % of the participants were in SWS, compared to only 25 % in the 120 min nap) which makes causal interpretation difficult. In shorter napping studies, sleep-stage-at-awakening effects may be a more robust determinant of post-sleep cognitive performance. Awakening from SWS has generally been associated with performance impairments on a variety of tasks (Bruck and Pisani 1999; Dinges et al. 1985; Splaingard et al. 2007; Tassi and Muzet 2000). The extent to which the duration of various sleep stages experienced during a sleep episode contributes to performance upon awakening is not fully understood.

In order to combine the strengths of these various previous studies, control for some of their limitations, and more systematically explore how sleep stage factors affect cognitive performance, the present experiment compared two different sleep length conditions (3 and 6 h). Awakening time of the participants was held constant, and the study included EEG measures of the stages of sleep. This experiment also employed a commonly used measure of attention, the Attentional Network Test (ANT; Fan et al. 2002), to assess any deficits upon awakening. The ANT provides three separate and orthogonal measures of attention which are the *alerting*, *orienting*, and *executive control* components, which are thought to be mediated by independent and distinct neural networks (Fan et al. 2005, but see MacLeod et al. 2010) associated with different neurotransmitter systems (Beane and Marrocco 2004; Davidson and Marrocco 2000; Foote et al. 1991). The alerting network increases (phasic) and sustains (tonic) alertness or activation. The orienting network is involved with the allocation of attention to relevant stimuli, and the executive component participates in inhibitory control and conflict resolution (Fan and Posner 2004).

Although the extent to which sleep stage and sleep length variables affect attention has not been previously measured with the ANT, sleep deprivation (SD) has been widely recognized to affect attention (Kjellberg 1977), including the components of attention as measure with the ANT (Martella et al. 2011; Roca et al. 2012). Martella et al. (2011) found that 24 h of wakefulness produced an overall increase in RT and deficits in the orienting and executive control mechanisms. Using a modified version of the ANT which utilizes an auditory warning signal instead of a visual cue (to measure the alertness component of attention independently) and non-predictive flankers (to obtained a more fine-grained measure of the orienting component), Roca et al. (2012) found that both phasic and tonic alertness and orienting were negatively affected by SD.

Finally, the present study included standard measures of chronotype, as well as several measures of sleep and wakefulness prior to participation. The goal of this work was to test the idea that the relationship between sleep bout length and cognitive performance is at least partially mediated by the amount of SWS, as well as to provide some exploratory results concerning the role of other sleep stages subsumed within the sleep episode and, additionally, how sleep stage at awakening affects performance. Stemming from sleep inertia and inopportune circadian phase effects, we also hypothesized that post-sleep assessment would be associated with more degraded ANT performance than the pre-sleep assessment.

## Method

### Participants

Fourteen undergraduate students (8 women, 6 men; 13 Caucasians, 1 Asian-American; 12 right-handed, 2 left-handed)

from the Pennsylvania State University, Altoona campus, served as volunteer participants in the present study (mean age = 22.57 years). All participants were in good self-reported physical and mental health with no chronic medical conditions, and all reported having normal or corrected-to-normal visual acuity. All participants reported to be healthy sleepers with stable sleep/wake cycles and no diagnosed sleep problems. They were also asked to refrain from ingesting any alcohol or using products containing caffeine on the day prior to testing.

Participants were screened with the Horne and Ostberg (1976) morningness/eveningness questionnaire (MEQ) so as not to be extreme evening or morning types (mean for sample = 49.36; range = 36–66). The MEQ consists of 19 questions and generates scores ranging from 16 to 86 with higher numbers reflecting more morning type individuals. Participants were also naive as to the purpose of the experiment and received monetary compensation for participating. The protocol for the present study was approved in advance by the local Institutional Review Board and has been performed in accordance with the Declaration of Helsinki. Each participant provided written informed consent before participating.

## Procedure

Upon successful completion of screening criteria, participants were invited to join the sleep study which was conducted at the sleep laboratory unit of the Lung Disease Center of Central Pennsylvania (Altoona, PA). All participants spent three nights at the laboratory, with each night separated by approximately 1 week (see Fig. 1). Arrival time was 2100 h for the first night which served as a habituation session. Each participant had his/her private sleeping room with a bed, television, and a constant room temperature of 70 °F. Participants were given 120 practice trials on the ANT, and electrodes were attached (see PSG section) with no electrophysiological recordings taken, but they were otherwise free to relax from 2100 to 2400 h. Lights were turned off at 2400 h, and participants slept from then until 0600 h, when they were awakened by a sleep technician. On this first night, no other measures were taken. All participants had access to shower/bathroom facilities and were provided a light breakfast before leaving.

For the two testing nights, participants slept for either 3 or 6 h, with the order of conditions being random. They were also randomly assigned to complete one 2100 h (pre-sleep) ANT on one of these nights. As before, arrival time was 2100 h for both testing nights. In order to determine any homeostatic sleep pressure, upon arriving participants were asked to report sleep onset and offset times (and therefore the length of sleep episode) from their previous night of sleep. These data were used as covariates in regression analyses. For the 6-h sleep episode, participants could relax from 2100 to 2400 h, and they slept from 2400 to 0600 h; for the 3-h sleep episode, participants relaxed from 2100 to 0300 h and slept from 0300 to 0600 h. Polysomnographic recordings were taken for both the 3- and 6-h sleep episodes. All participants were monitored to ensure that they did not fall asleep during this relaxation period. Immediately after awakening, participants were escorted from their sleeping room to a testing room where they completed the ANT, which lasted approximately 20 min. A few participants had to use the bathroom upon awakening, but the average interval between awakening and ANT testing was less than 5 min. Participants were instructed to respond as quickly and as accurately as possible during the ANT trials.

## Measurements

### *The attention network task (ANT)*

The adult version of the ANT (available at https://www.sacklerinstitute.org/cornell/assays_and_tools/)

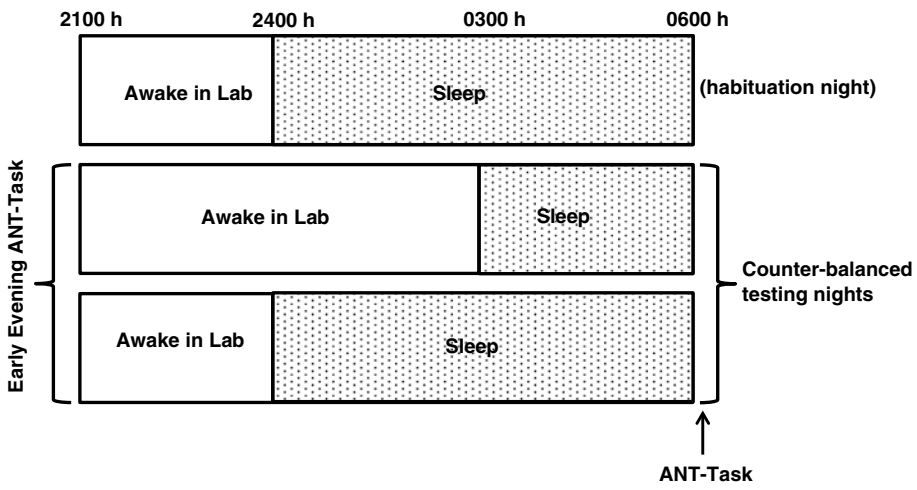


**Fig. 1** Experimental procedure of study

was administered to participants on a Dell computer running Windows 7.0 with a 16 inch color monitor set at 1,024 × 768 pixel resolution. Details of the ANT have been previously reported (see Fan et al. 2002). Participants were comfortably seated approximately 65 cm from the monitor, and after a random fixation period between 400 and 1,600 ms, a 100-ms center, double, spatial, or on some trials, no-cue was presented. After a 400-ms interval, a left or right pointing arrow (the target stimulus) appeared above or below fixation. The target stimulus was flanked by two arrows on each side. Trials that have flanking arrows pointing in the same direction as the target arrow are congruent trials, and trials that have flanking arrows pointing in the opposite direction are incongruent trials. Neutral trials contain no flanking arrows.

*Polysomnography (PSG)*

Silver–silver chloride electrodes were attached by two certified sleep technicians. The PSG recordings included EEG consisting of traces $F_4/M_1$, $C_4/M_1$, and $O_2/M_1$, as well electro-oculographic (left and right outer canthus) and submentalis electromyographic recordings (3 electrode placements). Backup electrodes were placed at $F_3/M_2$, $C_3/M_2$, and $O_1/M_2$. For EEG, the low-pass filter setting was 0.3 Hz and the high-pass filter setting was 35 Hz. Impedance measures of the leads were always less than 5 kΩ. Each 30-s epoch was scored to identify sleep stages according to Rechtschaffen and Kales (1968). All signals were sampled at a frequency of 500 Hz using Alice Sleepware (Respironics, USA).

*Data analysis*

For analysis purposes, sleep stages were categorized as Stage W (Wakefulness), non-REM Stage 1 (NREM 1), non-REM Stage 2 (NREM 2), non-REM Stage 3 or slow wave sleep (NREM 3 or SWS), and REM. With regard to the sleep stage at the time of awakening analysis, NREM1 and NREM2 were collapsed into a single value (light sleep) and compared to REM sleep. There were only two awakenings from SWS, and these cases were excluded from this analysis. Concerning the ANT, the alerting scores were calculated by subtracting mean RT on double-cue trials from mean RT on no-cue trials, and the orienting scores were calculated by subtracting mean RT on spatial-cue trials from mean RT on center-cue trials (by considering the means of congruent, incongruent, and neutral trials). Executive function scores were obtained by subtracting mean RT on congruent trials from mean RT on incongruent trials. Data were collapsed across target location (above/below fixation) and target direction (left/right arrow). RT scores more than three standard deviations from the mean were removed as statistical outliers.

## Results

In general, error rates in performing the ANT were extremely low (with overall accuracy above 96 % and never lower than 82 % in any condition) and did not systematically vary across conditions. A set of parallel analyses were conducted on the error data to match all of the reported analyses of mean response time (mRT), but none revealed any significant effect, all $F < 1$, all $p \geq .808$. Therefore, the error data will not be discussed.

In no case was the assumption of sphericity violated for the mRT data, as assessed using Mauchly's test, all $p \geq .109$, so no corrections to the degrees of freedom were ever necessary. Similarly, the distribution of mRTs across participants never significantly deviated from normal, as assessed using the Kolmogorov–Smirnov test, all $p \geq .299$, so no transformations of the data were needed. See Table 1 for mRT and standard deviation for all ANT trial types.

Sleep length (condition) analyses

See Table 2 for sleep stage data for each participant for the 3- and 6-h sleep episodes. The percentage of time spent in different sleep stages did not significantly vary between the 3- and 6-h sleep episodes, except for a small difference in SWS (3-h sleep episode: $M = 27.58$ %; 6-h sleep episode: $M = 19.16$ %, $p = .050$).

The first analysis provides a simple and general measure of cognitive performance by examining mRT across all trial types from the response time task as a function of condition: prior to sleep (hereafter: *pre-sleep*), after 3 h of sleep (*post-sleep 3*), and after 6 h of sleep (*post-sleep 6*). The

**Table 1** Mean RTs (±SD) for pre-sleep, 3-h post-sleep, and 6-h post-sleep conditions

| Cue type | Congruent | Incongruent | Neutral |
|---|---|---|---|
| *Pre-sleep* | | | |
| No-cue | 570.33 (60.37) | 646.28 (72.84) | 541.20 (52.73) |
| Center | 528.76 (56.50) | 612.99 (82.99) | 477.68 (50.25) |
| Double | 512.39 (49.51) | 614.74 (81.01) | 464.41 (48.74) |
| Spatial | 485.17 (56.73) | 550.99 (72.33) | 441.14 (43.37) |
| *3-h post-sleep* | | | |
| No-cue | 626.88 (82.87) | 694.88 (109.32) | 575.37 (71.87) |
| Center | 588.62 (99.71) | 692.32 (121.33) | 524.54 (95.28) |
| Double | 573.26 (107.35) | 661.67 (98.83) | 509.17 (52.79) |
| Spatial | 539.56 (101.53) | 625.59 (106.41) | 488.79 (87.09) |
| *6-h post-sleep* | | | |
| No-cue | 587.32 (69.90) | 676.37 (110.40) | 559.34 (71.83) |
| Center | 547.49 (72.34) | 654.40 (105.71) | 503.46 (72.99) |
| Double | 545.29 (74.46) | 644.29 (102.76) | 484.13 (55.14) |
| Spatial | 506.95 (67.13) | 592.89 (124.21) | 454.73 (58.17) |

**Table 2** Sleep efficiency, sleep stage upon awakening, and percentage of stages 1, 2, 3, and REM for 3- and 6-h sleep episodes

| | Sex | %N1 | %N2 | %N3 | %REM | SE | Stage |
|---|---|---|---|---|---|---|---|
| *3-h sleep episode* | | | | | | | |
| P1 | M | 12.0 | 46.70 | 2.60 | 38.70 | 97.00 | REM |
| P2 | F | 2.0 | 44.90 | 37.50 | 15.60 | 97.20 | 3 |
| P3 | F | 3.8 | 60.80 | 0.50 | 34.90 | 99.10 | 2 |
| P4 | M | 5.8 | 49.30 | 28.90 | 16.00 | 94.90 | REM |
| P5 | F | 7.9 | 58.20 | 9.50 | 24.30 | 83.50 | REM |
| P6 | M | 6.8 | 71.50 | 7.30 | 14.40 | 94.80 | 2 |
| P7 | F | 3.2 | 34.70 | 51.20 | 11.00 | 96.60 | REM |
| P8 | F | 3.3 | 57.50 | 16.70 | 22.40 | 83.10 | REM |
| P9 | F | 2.6 | 37.80 | 59.60 | 0.0 | 65.40 | 3 |
| P10 | M | 2.0 | 25.40 | 57.60 | 14.90 | 95.00 | 2 |
| P11 | F | 0.0 | 50.80 | 26.60 | 22.60 | 99.00 | 2 |
| P12 | M | 6.9 | 53.30 | 25.40 | 14.40 | 96.10 | 2 |
| P13 | M | 0.0 | 54.10 | 37.70 | 8.20 | 97.50 | REM |
| P14 | F | 11.8 | 40.20 | 25.00 | 23.00 | 96.70 | 2 |
| Mean | | 5.67 | 48.94 | 27.58 | 20.03 | 92.56 | |
| *6-h sleep episode* | | | | | | | |
| P1 | | 5.50 | 56.50 | 11.20 | 26.70 | 97.50 | 2 |
| P2 | | 3.00 | 52.60 | 23.70 | 20.70 | 92.20 | REM |
| P3 | | 4.20 | 62.50 | 4.10 | 29.20 | 97.40 | 2 |
| P4 | | 12.20 | 56.60 | 15.90 | 15.90 | 94.40 | 1 |
| P5 | | 3.90 | 64.80 | 2.20 | 29.10 | 87.20 | 2 |
| P6 | | 3.70 | 50.50 | 21.50 | 24.30 | 90.00 | REM |
| P7 | | 4.20 | 46.80 | 19.60 | 29.40 | 89.90 | 2 |
| P8 | | 16.10 | 46.60 | 11.40 | 25.90 | 92.70 | REM |
| P9 | | 7.60 | 46.70 | 22.10 | 23.70 | 95.30 | 2 |
| P10 | | 1.60 | 37.60 | 39.30 | 21.60 | 97.60 | REM |
| P11 | | 0.40 | 52.10 | 23.90 | 23.50 | 97.80 | REM |
| P12 | | 8.30 | 47.70 | 20.70 | 23.30 | 95.60 | 2 |
| P13 | | 1.70 | 47.10 | 22.50 | 28.70 | 97.70 | 2 |
| P14 | | 0.80 | 48.20 | 30.10 | 20.80 | 98.70 | REM |
| Mean | | 5.23 | 51.12 | 19.16 | 24.49 | 94.54 | |

P1 = participant 1; SE = sleep efficiency; Stage = sleep stage upon awakening

effect of sleep condition was significant, $F(2,26) = 5.49$, $p = .010$, $\eta^2 = 0.297$ (left side of Fig. 2), and an LSD test showed that the pre-sleep condition was significantly different from both post-sleep 3 ($p = .012$) and post-sleep 6 ($p = .034$), while the two post-sleep conditions did not significantly differ from each other ($p = .147$). In short, when participants are tested shortly after awakening from sleep, responses are significantly slowed.

In the second analysis, the three separate components of the ANT were each subjected to the same, one-way analysis. The effect of sleep condition was not reliable for any measure (right side of Fig. 2): Alerting, $F(2,26) = 0.38$, $p = .690$, $\eta^2 = 0.028$; Orienting, $F(2,26) = 0.11$, $p = .899$, $\eta^2 = 0.008$; Conflict, $F(2,26) = 1.33$, $p = .283$, $\eta^2 = 0.093$. To assess tonic alertness (see Posner 2008), a one-way repeated-measures ANOVA compared no-cue

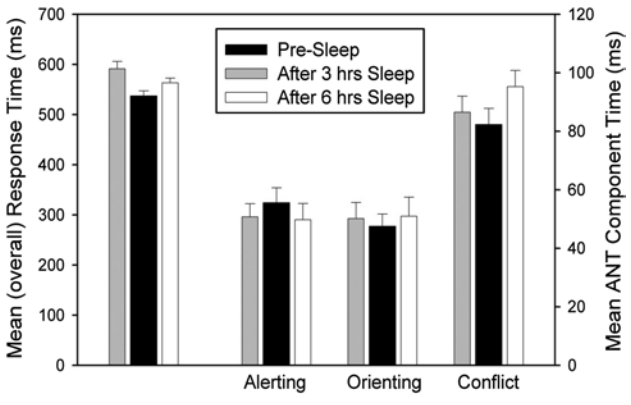


**Fig. 2** Mean response time and mean size of each of the ANT components as a function of sleep condition. *Errors bars* calculated using the within-subject residuals

RT data across the three testing conditions. This was found to be significant, $F(2, 26) = 4.21$, $p = .026$, such that tonic alertness in the pre-sleep condition ($M = 586.05$, $SD = 59.30$) was significantly better than after 3 h of sleep ($M = 632.09$, $SD = 84.54$, $p = .018$) and marginally better than after 6 h of sleep ($M = 607.77$, $SD = 81.03$, $p = .164$).

For all of the subsequent analyses, the three-condition data were converted to "post-sleep decrement" measures (hereafter: PSD values) for each of the two post-sleep conditions. This was accomplished by calculating the difference from the pre-sleep value. For both Alerting and Orienting, the post-sleep value was subtracted from the pre-sleep value since both are desirable attributes in that becoming ready to respond and attending to the cued location are useful. For overall mean RT and Conflict, the pre-sleep value was subtracted from the post-sleep value since both are undesirable attributes in that being slow or being affected by irrelevant items is not useful. This produced positive values whenever performance was worse after sleep than before, such that these are all (positive) measures of the detrimental effects associated with early morning testing.

The first set of covariance analyses concerned the same four measures as above: mean RT and the three ANT components. To be clear: the difference between these analyses and those already reported are (1) these only concern the difference between the post-sleep 3 and post-sleep 6 conditions (with higher scores implying more negative effects) and (2) these analyses control for differences in the amount of sleep during the night prior to coming to the laboratory. In all four analyses, the effect of sleep length condition was unreliable (which matches what was found without the covariate): all $F(1,12) \leq 1.10$, $p \geq .316$. It is worth noting, however, that this non-change in the pattern of results is not unexpected, given that the amount of sleep on the night prior to testing was not correlated with any of the PSD values: all $r$ between $-0.169$ and 0.247, all $p \geq .204$.

## Sleep stage analyses

The first set of analyses concerning the stages of sleep examined the decrements in performance following sleep (i.e., PSD scores) for the same four measures—viz., mRT, alerting, orienting, and conflict—but as a function of sleep stage at the time of awakening for both the 3- and 6-h episodes together: light sleep (Stages 1 and 2 combined; see Methods) versus REM sleep. In preliminary analyses, none of the effects reported below depended on whether the sleep bout was 3 or 6 h in length; all $F < 1$. Therefore, these effects are reported only in terms of sleep stage at time of awakening and/or the time spent in each of the stages of sleep. These analyses were conducted using hierarchical multiple regression, because sleep stage at time of awakening was observed, instead of being manipulated (but shall be discussed in terms of the "effect of sleep stage" on each measure because the causal relationship cannot operate in the opposite direction). There was a large effect of light versus REM sleep at the time of awakening on the PSD values for overall mRT, $t(11) = 2.25$, $p = .046$, $sr = 0.327$. After removing the effects of the previous night's sleep, responses were $43.9 \pm 19.51$ ms slower when the participants were awakened from REM sleep. For the Alerting measure, there was no effect of sleep stage, $t(11) = 1.55$, $p = .149$, $sr = 0.209$. Nor were there effects of sleep stage at awakening on either Orienting or Conflict, both $t(11) < 1$, $p \geq .576$, $sr \leq 0.067$.

Finally, we turn to the analysis of the effects of the details of the entire sleep bout on this early morning impairment in attention. This was done by regressing each of the PSD values onto the amounts of time that the participant spent in each of the four stages of sleep (after removing the effects of previous night's sleep, as above). The durations of the four stages of sleep were entered into the regression simultaneously, such that none were credited with any shared variance. The complete results from all four of these multiple regressions would be rather lengthy, so the beta-weights are provided in a figure (see Fig. 3 below) and the statistical tests and semi-partials are provided in a table (see Table 3 below).

As can be seen, while none of the sleep stage durations could predict either Alerting or Orienting components from the ANT, the value of PSD for overall mRT was reliably predicted by the duration of SWS, and the value of PSD for Conflict was predicted by the duration of REM. In both

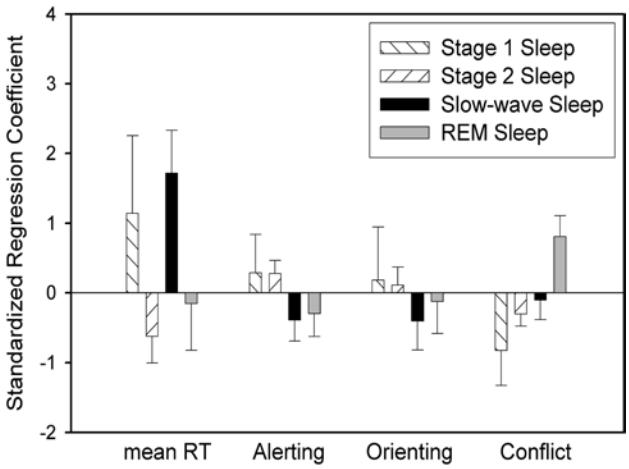


**Fig. 3** Standardized regression coefficients for predicting mean response time and mean size of each of the ANT components using the durations of each sleep stage. Positive values indicate larger post-sleep decrement values for longer stage durations; *errors bars* calculated using the residuals

**Table 3** Regressions of post-sleep decrement (PSD) values onto the durations of each stage of sleep

| | PSD mean RT | PSD alerting | PSD orienting | PSD conflict |
|---|---|---|---|---|
| Stage | | | | |
| 1 | $t(9) = 1.03$ | $t(9) = 0.52$ | $t(9) = 0.24$ | $t(9) = 1.63$ |
| | $p = .331$ | $p = .615$ | $p = .815$ | $p = .137$ |
| | $sr = 0.134$ | $sr = 0.074$ | $sr = 0.049$ | $sr = -0.178$ |
| 2 | $t(9) = 1.62$ | $t(9) = 1.45$ | $t(9) = 0.42$ | $t(9) = 1.74$ |
| | $p = .139$ | $p = .180$ | $p = .683$ | $p = .116$ |
| | $sr = -0.211$ | $sr = 0.205$ | $sr = 0.086$ | $sr = -0.190$ |
| SWS | $t(9) = 2.81$ | $t(9) = 1.27$ | $t(9) = 0.95$ | $t(9) = 0.37$ |
| | $p = .020$ | $p = .235$ | $p = .365$ | $p = .719$ |
| | $sr = 0.366$ | $sr = -0.179$ | $sr = -0.194$ | $sr = -0.040$ |
| REM | $t(9) = 0.24$ | $t(9) = 0.89$ | $t(9) = 0.28$ | $t(9) = 2.69$ |
| | $p = .819$ | $p = .395$ | $p = .789$ | $p = .025$ |
| | $sr = -0.031$ | $sr = -0.126$ | $sr = -0.056$ | $sr = 0.293$ |

cases, the beta-weight (and semi-partial correlation) was positive, implying that more time spent in SWS was associated with more slowing of overall mRT, and more time spent in REM sleep was associated with greater amounts of Conflict (i.e., larger Flanker Effects). Corrections for multiple tests did not alter this pattern of results. The effects of the duration of Stage 1 sleep on overall mRT and Conflict, although large in absolute size, were too inconsistent across participants to be reliable (see Table 3).

## Discussion

The present results indicate that participants have slower overall RTs after awakening from a sleep episode, at least compared to performance in the two pre-sleep conditions at 2100 h. This general slowing of neuronal activity shortly after awakening is consistent with a growing body of literature (Ferrara et al. 1999; Horne and Moseley 2011). Although these cognitive deficits could stem from sleep inertia or circadian processes, the pre-sleep overall RT was significantly faster than both post-sleep conditions, while the two post-sleep conditions did not differ from each other.

In contrast, Posner's orienting, alerting, and conflict measures (Fan et al. 2002) did not differ from pre- to post-sleep. To our knowledge, no study has administered the ANT to participants shortly after awakening, making a direct comparison of our results to other literature (i.e., construct validity) difficult. Given the relatively short sleep episodes in the present study, it is plausible that there could be an effect associated with SD since our participants were at least partially sleep deprived. While it is well accepted that SD negatively affects overall vigilance and performance (Carskadon and Dement 1979; Sagaspe et al. 2006), the extent to which SD affects the alerting, orienting, and executive control components of attention has only recently received attention (Cain et al. 2011; Casagrande et al. 2006; Harrison and Horne 1997; Jugovac and Cavallero 2011; Martella et al. 2011; Muto et al. 2012; Roca et al. 2012; Tsai et al. 2005; Tucker et al. 2010; Versace et al. 2006).

With regard to the roles played by the stages of sleep, one finding of the present study is that greater overall slowing is observed when participants are awakened from REM sleep as opposed to a lighter (stages 1 and 2) sleep; orienting, alerting, and the executive functioning components of attention did not vary according to sleep stage. Surprisingly, few studies have specifically examined how sleep stage upon awakening affects later cognitive performance and this process is not well understood. Awakening from SWS is typically associated with more profound cognitive impairments (Bruck and Pisani 1999; Dinges et al. 1985; Splaingard et al. 2007; Tassi and Muzet 2000). The current study had few SWS awakenings because of the standard 0600 h awakening time, so we were only able to compare REM to light sleep but our results are not consistent with several studies (Cavallero and Versace 2003; Silva and Duffy 2008). It is known that awakening from REM can give the right hemisphere an advantage on tasks that normally (i.e., in an awake state or upon awakening from NREM) the left hemisphere outperforms such as a consonant recognition task (Casagrande et al. 1995). The right hemisphere also appears to be the last hemisphere to fall asleep (Casagrande and Bertini 2008a) and is involved with maintaining vigilance (Casagrande and Bertini 2008b). The right hemisphere undergoes an increase in activation during REM (Casagrande et al. 1995), but it is unclear how this might correlate with a decrease in overall RT as observed in the current study. Also of relevance is that conflict adaptation in face-word Stroop tasks has recently been correlated with activity in the right inferior frontal gyrus (Egner 2011). Of course, the presentation of stimuli in our ANT testing was not restricted to one visual field or the other, precluding a comparison of performance between the two hemispheres.

We had specifically hypothesized that greater depth of sleep and/or increasing amounts of SWS during the sleep episode would be associated with greater cognitive deficits. This prediction was partially confirmed by the finding that SWS was a significant predictor of overall mean RT. Dinges et al. (1985) had previously found that prior sleep deprivation increased the amount of SWS in 2 h naps, resulting in greater post-nap deficits. In contrast, Signal et al. (2012) recently found that the percentage of SWS was not related to the severity of early morning performance on a working memory task. However, in a different study by the same group, Mulrine et al. (2012) found that RT was slowed in a psychomotor vigilance test after napping if

little SWS occurred during the nap (<10 min) compared to naps with more SWS (20–30 min); SWS in their naps was also not related to performance on a working memory task.

Contrasting nicely with the relationship between SWS and overall slowing, the current study also found that the duration of REM sleep was a significant predictor of Conflict scores on the ANT. That is, longer REM bouts were associated with greater failures of selective attention. It may be important that REM sleep has been associated with right hemisphere activity (Casagrande et al. 1995) and that conflict adaptation has also been associated with the right hemisphere (Egner 2011). Although our hypothesis that SWS would predict Conflict turned out to be incorrect, the present results on REM and Conflict are compatible with our previous work. As mentioned above, in our previous study (Matchock and Mordkoff 2007), longer sleep episodes were associated with larger flanker effects. Although sleep stage measures were not available in that study, it is well known that the percentage of time in REM increases throughout the length of the sleep episode (e.g., Dement and Kleitman 1957). It is very likely, therefore, that the longer sleep episodes included more REM than the shorter episodes; thus, those results are consistent with the new finding that duration of REM predicts conflict scores. That it was REM, in particular, that predicted conflict is interesting as the cognitions that are associated with REM sleep have long been hypothesized to be different than those in other sleep stages. It is plausible, for example, that the residual effects of the "loose associations" associated with REM sleep make participants more susceptible to irrelevant, flanking stimuli when tested early in the morning (see Stickgold et al. 1999).

The above notwithstanding, it is important to note that the current findings do not imply that obtaining SWS or REM is necessarily a harmful process as it relates to cognitive functioning. On the contrary, REM sleep has been positively associated with the consolidation of certain perceptual memories (Karni et al. 1994), and SWS sleep has shown to be restorative (Van Cauter et al. 2008) and may also be involved in the consolidation of memories (Fowler et al. 1973; Gais and Born 2004). Schabus et al. (2005) found that SWS in a 60-min nap improved declarative memory using a paired associate word list task, and depriving participants of SWS has been found to slow RT performance in morning testings (Ferrara et al. 1999).

Our participants were tested immediately after awakening, but it is likely that these same sleep stages that predicted poor performance would yield more beneficial effects if measured later in the day after any effect of suboptimal circadian testing times or sleep inertia has passed. For example, regarding naps, shorter naps (e.g., 20 min) produce few deficits upon awakening and a somewhat short-lived increase in cognitive functioning right after the nap, while longer naps (e.g., 2 h) cause greater impairments and a delayed, but longer-lasting, improvement in cognitive functioning (see Lovato and Lack 2010). Our findings only imply that the amount of SWS or REM subsumed within the sleep episode each have separate, residual, and harmful effects, but these probably only linger during the time period shortly after awakening. For SWS, this appears as a general, overall slowing of RT, perhaps due to SWS's autonomic and hormonal profile which includes reductions in cerebral blood flow and decreases in brain temperature (McGinty and Szymusiak 1990). For REM, similar (but distinct) biological underpinnings may contribute to poor conflict resolution.

A limitation of the current study is that our early morning deficits in cognitive performance could stem from testing at a suboptimal circadian phase, from sleep inertia, or more likely, both of these factors. Various types of RT appear to be negatively correlated with body temperature (Wright et al. 2002), which is higher in the early evening hours (coinciding with our pre-sleep measure) and lowest during the late night or early morning hours (coinciding with our post-sleep measure). In addition, it is very likely that our RT scores were strongly affected by sleep inertia processes because the testing occurred shortly after awakening. Future studies planned to replicate or extend this work should include larger sample sizes with a no sleep control group, an 8-h sleep group (to control for the effects of SD) and continued testing of participants over a longer period of time after awakening after sleep inertia has fully dissipated. However, to our knowledge, this is the first study that has administered the ANT shortly after awakening while using EEG measures. These preliminary results suggest that different sleep stage mechanisms have effects on different aspects of performance. When tested in a less-than-optimal state shortly after awakening, increases in SWS during the prior sleep episode are associated with a general slowing of responses, while increases in REM are associated with deficits in selective attention and/or conflict resolution.

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