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ARCH ARTICLE

Visual attention, reaction time, and self-reported alertness upon awakening from sleep bouts of varying lengths

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Abstract The aim of the present study was to examine visual attention, especially the executive control functions that deal with conflict, when participants were in a low arousal state shortly after a nighttime awakening. Fifteen participants spent four consecutive nights at a laboratory and performed a flankers task using two levels of target-distractor spacing (0.75° and 1.50°) and three trial types (compatible, incompatible, and neutral). The first night was a habituation night. For the next three nights, participants went to sleep at 2300 hours and were then awakened at either 2400 hours (1-h sleep bout), 0300 hours (4-h sleep bout), or 0600 hours (7-h sleep bout) and were administered a flankers task and a self-report questionnaire that measured arousal level. These testing times were counter-balanced across participants, and a 2100 hours (pre-sleep) flankers task was also randomly assigned to be completed on one of the testing nights. Response time on neutral-flanker trials was increased if participants were awakened from a sleep bout and was slowest at 0300 hours, appearing to parallel circadian body temperature. In contrast, failures of selective attention, as indexed by the difference between compatible and incompatible trials, increased linearly as a function of the length of the sleep bout. Compared to the 2100 hours pre-sleep condition, self-reported energy was lower and Tiredness was higher after awakening from a sleep bout. Taken together, the current data suggest a dissociation between the processes that perform a non-conflict task and the executive control of attention. Specifically, longer sleep bouts seem to be associated with greater difficulty in inhibiting task-irrelevant information, perhaps due to a sleep inertia effect affecting the anterior cingulate cortex.

Keywords Arousal · Circadian · Flankers task · Selective attention · Sleep inertia

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Introduction

Within the basic literature, attention has been described as a multi-faceted process comprised of three components: (1) alertness, (2) orienting, and (3) executive control (Posner and Petersen 1990; Fan et al. 2002). Recent research has attempted to verify the independence of these components by using cognitive tasks such as the Attentional Network Test (ANT: Fan et al. 2002) or modifications of it (e.g., Callejas et al. 2004, 2005) and to determine regional brain specialization for these components. For example, the alerting system has been associated with frontal and parietal areas of the right hemisphere (Coull et al. 1996; Fan et al. 2005) and extrastriate cortex (Thiel et al. 2004). The orienting system has been associated with the superior parietal lobes (Corbetta et al. 2000) and the anterior cingulate cortex (ACC) (Thiel et al. 2004). The executive control system, which has been implicated in the processing of conflict, has been linked to

the ACC and the prefrontal cortex (Bush et al. 2000). Double-dissociations, although rare, have also been found. MacDonald et al. (2000) used fMRI and the Stroop task and found that the left dorsolateral prefrontal cortex was more active during congruent trials and that the ACC was more active during incongruent trials, suggesting roles for implementation of control and conflict monitoring, respectively. The ACC is also the source of the "Nogo-N2" (Nieuwenhuis et al. 2003), a negative event-related potential elicited by inhibition and conflict in Go/Nogo tasks (Falkenstein et al. 1995; Nieuwenhuis et al. 2003) and in incompatible conditions of the Stroop task (Kopp et al. 1996) and the Eriksen flanker task (Heil et al. 2000).

Activational states of the organism such as arousal, vigilance, or alertness can also have a modulating effect on these components of attention. Although these terms are frequently used, there is not always agreement on how to measure them and what the underlying physiological correlates are. Typically, vigilance refers to sustained attention to a task for a given period of time (e.g., Davies and Parasuraman 1982; see Oken et al. 2006 for review). Arousal refers to global activation of the cerebral cortex, usually in relation to sleep/wake cycles (Oken et al. 2006), and alertness is related to arousal but implies more cognitive processing (Oken et al. 2006). Factors such as circadian rhythms, sleep deprivation, and sleep inertia can affect these activational states and, thus, have effects on attention.

It has been known for some time that many aspects of information processing show circadian rhythmicities that parallel the circadian rhythm of body temperature (e.g., Carrier and Monk 2000; Casagrande et al. 1997; Colquhoun, 1971; Folkard and Monk 1980; Gillooly et al. 1990; Kleitman 1963; Maury and Queinnec 1992), including self-reported alertness (Wright et al. 2002). However, circadian variations that are specifically linked with selective attention are fewer, and a variety of operational definitions of, and methods for measuring, selective attention have been used. Zuber and Ekehammar (1988) found increases in performance from morning to evening using a task that required attending to a specific aspect of a complex color shape. Circadian drops in selective attention in a 30-h constant routine using a numerical continuous performance task have also been reported (Valdez et al. 2005), as well as slower response times (RT) on spatial-configuration and conjunction-search tasks (Horowitz et al. 2003). Intons-Peterson et al. (1998) found negative priming of word pairs in older subjects if they were tested at their preferred time (morning) when their alertness was highest, but not when tested at nonoptimal times (i.e., later in the day). This finding matches the observation that older adults tend to be more "morning" chronotypes with peak arousal early in the day, while younger adults tend to be more "evening" chronotypes with peak arousal later in the day (Yoon et al. 1998). A similar impairment has been found when reading passages containing distractors in unpredictable locations (Carlson et al. 1995), inhibiting no-longer relevant thoughts (May and Hasher 1998), and performance on a release from proactive interference paradigm (Hasher et al. 2002). Of relevance is that increased bodily arousal has been argued to narrow attention or reduce the range of peripheral cues utilized (e.g., Easterbrook 1959; Kahneman 1973).

Sleep-deprived subjects, who are known to have lower levels of arousal (Hoddes et al. 1973), have a decreased ability to focus or maintain attention (Kjellberg 1974; Sanders and Reitsma 1982). Sleep-deprived subjects perform poorly on centrally-displayed pursuit-tracking tasks when they also have to monitor an array of peripheral light sources for occasional signals (Hockey 1970) or on a card-sorting task (Norton 1970). Using a cued reaction-time task (CRTT), Casagrande et al. (2005) found that sleep-deprived subjects experienced a decrease in vigilance or alertness but not in attention-orienting mechanisms (i.e., RT increased after sleep deprivation but did not differentially affect performance on valid, invalid, and neutral trials). In contrast, Versace et al. (2006) used a CRTT in sleep-deprived subjects and found that RTs significantly increased on invalidly cued trials but not on validly cued trials. These results suggest deficits in selective orienting. That is, in the valid and neutral conditions, there is no need to re-orient attention; however, the invalid trials require a disengagement of attention from a previously cued location. This interaction between mechanisms that mediate attention and alertness have also been observed in brain damaged patients (Posner et al. 1987; Robertson et al. 1998).

The executive functions of attention are sensitive to the effect of sleep deprivation as well. Decision making (see Harrison and Horne 2000 for review), word fluency (Harrison and Horne 1997), and performance on the Stroop task (McCarthy and Waters 1997) are all affected, although other studies have found no effect of sleep deprivation on certain executive functions (Binks et al. 1999; Sagaspe et al. 2003). Recently, Sagaspe et al. (2006) found that 36-h of sleep deprivation increased simple reaction time and self-reported sleepiness, but executive control, as measured by interference on the Stroop task, was not affected.

The general objective of the present study was to examine visual selective attention, especially the executive control function of attention, when participants

were in a low arousal state shortly after a nighttime awakening when the effects of sleep inertia would be most prominent. Sleep inertia is a transient period immediately following awakening from sleep characterized by confusion, disorientation, low arousal, and deficits in various types of cognitive and motor performance (Ferrara and De Gennaro 2000). Sleep inertia has been termed "process W" and is contrasted with homeostatic mechanisms that exponentially affect performance as a function of prior waking time ("process S") and an endogenous sleep-independent circadian component ("process C") (Borbely 1982; Folkard and Akerstedt 1992). As stated by Oken et al. (2006) ... "sleep inertia is paradoxical because people immediately arising from sleep (when they should be most refreshed) consistently perform more poorly than they did hours earlier, just before going to bed (when they should have been most fatigued." (p. 6). Tassi et al. (2003) have suggested that sleep inertia (without prior sleep deprivation) is a period of low arousal but normal vigilance, whereas sleep deprivation is characterized by low arousal *and* lapses in vigilance. Accordingly, sleep-deprived participants should show deficits in speed and accuracy upon awakening, but non sleep deprived participants should show deficits in only speed upon awakening. Using a complex Descending Subtraction Test, they found that sleep-deprived participants had more errors than non-sleep-deprived participants upon awakening, suggesting a difference between arousal and vigilance.

Myriad factors appear to modulate the severity of sleep inertia. For example, sleep stage prior to awakening, especially slow wave sleep (SWS), is associated with more sleeep inertia (Bonnet 1983). Time-of-day (process C) influences on sleep inertia have also been documented, but the data are less consistent; more severe sleep inertia has been reported later in the night corresponding to the circadian trough in body temperature (Dinges et al. 1985), early in the night (Gil et al. 1995), as well as no circadian effects on sleep inertia (Naitoh et al. 1993). Prior sleep deprivation also increases sleep inertia (Dinges et al. 1985; Ferrara et al. 2000), probably by increasing the percentage of SWS in the sleep bout. Estimates of the duration of sleep inertia are around 30 min (Dinges et al. 1987; Ferrara and De Gennara 2000), although sleep-inertia effects lasting several hours have been reported (Haslam 1985; Jewett et al. 1999; Naitoh 1981).

Previous work on the components of attention has mostly employed tasks involving spatial cuing and shifts of visual attention (e.g., the Attentional Network Task) or situations under which visual attention is not the key mechanism (e.g., card sorting). To obtain some converging measures of selective visual attention in our awakened participants, the current study used the flankers task (Eriksen and Eriksen 1974). The flankers task requires a forced-choice response to a visual stimulus at a known location in a linear display. Typically, subjects are presented with a row of three, five, or seven letters and are asked to respond only to the middle target letter (i.e., the task-relevant or attended stimuli) and to ignore the flanker letters or distractors (i.e., the task-irrelevant or unattended stimuli). Target letters are assigned different response keys. Flankers associated with the same response as the target are called *compatible* (or *congruent* in more recent articles), and flankers associated with the opposite response of the target are called *incompatible* (or *incongruent*). Flankers not associated with either response are *neutral*. This paradigm avoids the involvement of different search strategies, since no visual search is ever required, but still emphasizes selective visual attention, since the flankers are often associated with the incorrect response. Co-activation of competing motor responses during incompatible trials results in response conflict (see, e.g., Coles et al. 1985), often slowing responses by about ten percent of overall mean RT. The difference in RT between compatible and incompatible trials is referred to as the *flanker effect*.

In general, the finding of a flanker effect demonstrates that subjects are not able to selectively process the target (only), even when the location of the target is known in advance. The flanker effect typically occurs in instances under which the flankers are spatially close to the target; that is, within 1° of the target (Eriksen and Eriksen 1974). Flankers at eccentricities beyond 1° typically have little effect on performance. Thus, visual selective attention is sometimes conceptualized as a "spotlight" (LaBerge 1993) or variable "zoom-lens" (Eriksen and St James 1986; Eriksen and Yeh 1985) with a certain minimum size. With regard to the hypothesized three component of attention, the flankers task has been shown to activate brain areas associated with executive control, such as the ACC and the dorsolateral prefrontal cortex (Fan et al. 2003; Fassbender et al. 2006; Botvinick et al. 1999, 2004; Bunge et al. 2002; Casey et al. 2000; Hazeltine et al. 2003).

With regard to the potential role of arousal, Broadbent et al. (1989) found that the flanker effect was dependent upon time-of-day; spatially close, incompatible flankers impaired RT in the morning, but not in the afternoon. Given increases in body temperature and arousal during the afternoon (Wright et al. 2002), these results are consistent with earlier studies finding that arousal narrows attention (Easterbrook 1959; Kahneman 1973). To date, few studies have attempted to replicate this time-of-day effect for attention with

the flankers task (but see Smith 1991). The current study examined selective visual attention when participants were in an underaroused state shortly after a nighttime awakening. This change in method from sleep deprivation to early waking was motivated, in part, by a concern that the situations could well be different and that early waking occurs at least as often in everyday life. The present study's design does not fully distinguish between all factors that may modify attention after awakening [e.g., circadian (Dinges et al. 1985; Wright et al. 2002), sleep stage upon awakening (Bonnet 1983), sleep inertia itself (Tassi and Muzet 2000), and even possible stress induced by awakening during the night (Hancock and Warm 2003)]. However, we were interested in manipulating arousal in general by a nighttime awakening when the effects of sleep inertia would be most prominent. This activational state, with its cornucopia of contributing factors, is similar to what is frequently experienced in the general population, occasionally with deleterious consequences when certain tasks have to be performed.

The specific purpose of the current study was to examine the performance of non-conflict and response-conflict tasks when participants were in an underaroused state shortly after awakening. We hypothesized that longer bouts of sleep would be associated with increased RTs, especially on incompatible trials that elicited response conflict and required inhibiting an inappropriate response. Few neuroimaging studies related to sleep inertia have been conducted. However, Balkin et al. (2002) measured the re-establishment of cerebral blood flow for the first 20 min after awakening and found that blood flow first increased in the brain stem and thalamus within the first 5 min after awakening. Further increases in cerebral blood flow gradually occurred in the prefrontal cortical regions 20 min later. If the prefrontal cortex is involved with conflict monitoring and the flankers task activates areas of the brain associated with executive control such as the dorsolateral frontal cortex and ACC as has been suggested (Fan et al. 2003; Botvinick et al. 1999, 2004; Bunge et al. 2002; Casey et al. 2000; Hazeltine et al. 2003), a prediction is that performance on incompatible trials should be most affected by an abrupt awakening.

In addition, we previously presented preliminary data suggesting that participants had difficulty inhibiting incompatible flankers at wide eccentricities when awakened from sleep (Matchock and Mordkoff 2005). However, because these data were from a larger program examining the effects of long-wavelengths of light on melatonin, photic stimulation was administered to participants after awakening in the three sleep conditions and not in a pre-sleep condition. Thus, the current study more systematically attempts to confirm these findings and is an improvement over the preliminary report by including a habituation night, employing both male and female participants, and eliminating the confounding effects of light.

Method

Subjects

Fifteen undergraduate students (nine women and six men, mean age = 21.6 years) volunteered to participate based on advertisements at the first author's university. All participants were in good physical and mental health with no chronic medical conditions, and all reported having normal or corrected-to-normal visual acuity. None of the participants reported any excessive daytime sleepiness and had stable sleep-wake cycles with no daytime napping and no prior sleep deprivation. Because of the relatively early to-be-imposed sleeping schedule (2300–0700 hours), all participants' self-reported chronotypes were estimated to be morning or intermediate chronotypes with no evening chronotypes. Participants were also naïve as to the purpose of the experiment and were paid for participating. The protocol for the present study was approved in advance by the local Institutional Review Board and has, therefore, been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki. Each participant provided written informed consent before participating.

Materials and procedure

Participants spent four consecutive nights at the Nursing Laboratory at the Sheetz Health and Wellness Center at Pennsylvania State University, Altoona. Arrival time at the laboratory was 2000 hours and participants left at 0730 hours the next day; lights were out from 2300 to 0700 hours. The first night served as a habituation night; participants read and signed informed consent forms and were shown their sleeping room. On the first night, 192 practice trials were completed at approximately 2000 hours to familiarize participants with the flankers task. Because of the habituation night and experience with the same types of trials, exogenous stimuli at the time of testing were unlikely to have affected sustained attention as has been reported for novelty (Rockstroh et al. 1987) and stress (Hancock and Warm 2003). At this time, participants were randomly assigned to complete one 2100 hours (pre-sleep) testing flankers task on one of the three subsequent testing nights. Data from the pre-sleep flankers task at

2100 hours was used to compare with the post-sleep testing times of 2400 (1 h sleep bout), 0300 (4 h sleep bout), and 0600 hours (7 h sleep bout). The three post-sleep testing times were counterbalanced across participants. In this manner, each participant was tested only once for each of the testing conditions (i.e., 2100, 2400, 0300, and 0600 hours).

On the testing nights, all participants were instructed to sleep with lights out at 2300 hours and were then awakened at the appointed testing time (i.e., 2400, 0300, or 0600 hours) to complete the flankers task. Participants were quietly awakened by a research assistant and then escorted to the adjacent testing room. The flankers task was administered within three minutes after awakening and all participants reported that they were asleep at the time that the experimenter came to their room. Thus, the flankers task was administered to all participants in a repeated-measures design at 2100 hours before sleeping and at different points of subjective night (i.e., 2400, 0300, and 0600 hours) after sleeping approximately 1, 4, and 7 h, respectively. Before administration of the flankers task at each testing session, self-report measures of arousal were obtained using Thayer's Activation–Deactivation Check List (AD-ACL) that used a visual analog scale (VAS) presented on paper (Thayer 1967, 1978). For each of Thayer's adjectives, a 100 mm line was presented. Participants indicated their current feelings at that moment on the 100 mm bipolar VAS by making a slash mark perpendicular through the VAS line. Responses ranged from "definitely feel" to "definitely do not feel" going from extreme left to extreme right. The location of the slash mark was later measured in millimeters and assigned a score from 1 to 100. Items were reverse scored so that larger numbers indicated more of the construct. Completion of the AD-ACL took less than one minute. The Thayer AD-ACL is comprised of four different components: General Activation (GA; "energy"), General Deactivation (GD; "calmness"), Deactivation-Sleep (DS; "tiredness"), and High Activation (HA; "tension"; Thayer 1978, 1986). Each of these components was measured by responses to five different adjectives on a 100 mm VAS; thus, final scores for each component could range from 0 to 500.

The AD-ACL is thought to be a valid index of overall arousal and a useful adjunct to more direct physiological measures. GA and HA refer to two different types of arousal. GA refers to subjective sensations of energy, vigor, or peppiness and is an overall type of bodily arousal associated with gross motor activity and the incorporation of many diverse physiological processes. HA is also characterized by arousal, but this arousal includes subjective feelings of tension, anxiety, or fearfulness. Taken together, Thayer's four factors may represent two bipolar dimensions. GA and DS represent "energetic arousal" and are negatively correlated, while HA and GD represent "tense arousal" and are also negatively correlated (Thayer 1986).

Flankers task

For the flankers task, subjects were seated approximately 60 cm away from a standard PC computer monitor. There were eight blocks of 48 randomly-ordered trials for a total of 384 trials (64 trials in each Flanker condition × Spacing condition); each block of trials was separated by a 7 s break. On each trial, a small black cross first appeared for 500 ms, serving as the fixation point. A 350 ms blank screen followed, and then the presentation of the final display until a response was made. The intertrial interval was 1.5 s. Stimulus letters were in upper case, subtended 0.38 degrees of visual angle in width and 0.51° in height, and always appeared in the same location as the fixation point. Participants were instructed to ignore the irrelevant flankers that appeared to the left or right of the center location. If the center (target) letter was an *S*, they were instructed to press a computer key with their left index finger and, if an *H*, to press the opposite key with their right index finger. Three flankers were included on each side of the target and three types of flanker trials were employed: 1. flankers same as target/compatible (i.e., H H H H H H H or S S S S S S S), 2. flankers different from target/incompatible (i.e., H H H S H H H or S S S H S S S), and 3. a neutral condition (i.e., O O O H O O O or O O O S O O O). The two different spacings between the centers of adjacent letters were 0.75° and 1.5° (near and far conditions). The main dependent measure was RT in ms, as subjects were asked to be a fast as possible while making very few errors. The completion of all 384 flanker trials took approximately 20 min. Upon completion of the flankers task, participants were escorted back to their sleeping rooms. After completing the final session, all participants were thoroughly debriefed and paid for participating.

Results

Mean RTs from correct-response trials were subjected to two, separate ANOVAs, both having four levels of Time (2100, 2400, 0300, and 0600 hours) and two levels of Spacing (far and near). The first ANOVA only concerned the trials with neutral flankers (see Fig. 1) and served to provide a measure of any changes in perfor-

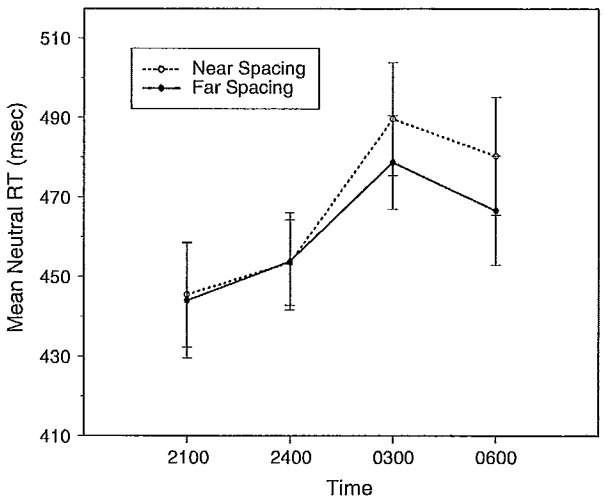

Fig. 1 Mean RT and SEM (*vertical bars*) for neutral flankers at near and far flanker spacing at 2100, 2400, 0300, and 0600 hours

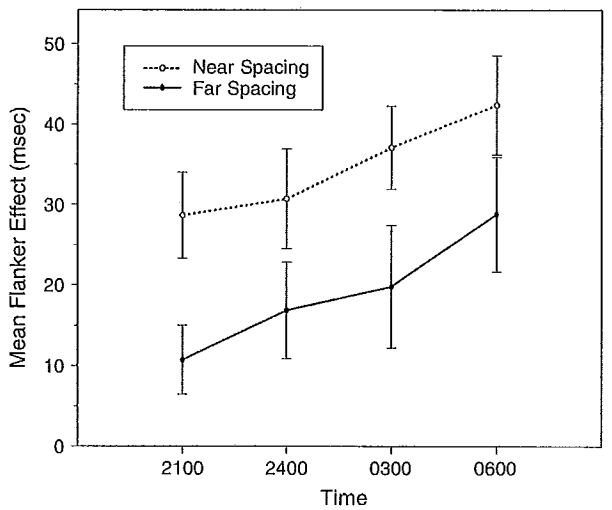

Fig. 2 Mean flanker effect scores for far and near spacing conditions at 2100, 2400, 0300, and 0600 hours

mance that are not due to selective attention (since failures of selective attention will have little effect on these trials). The main effect of Time was significant, $F(3, 42) = 8.31$, $P < 0.001$. Bonferroni-corrected pairwise comparisons indicated that the peak in RT at 0300 hours was different from 2100 hours ($P = 0.013$) and 2400 hours ($P = 0.039$). The 0600 hours condition was only significantly different from the 2100 hours condition ($P = 0.046$). Within-subject contrasts also indicated a cubic trend (i.e., two inflection points) for Time, $F(1, 14) = 5.07$, $P = 0.041$. The effect of Spacing was also significant, $F(1, 14) = 6.84$, $P = 0.020$, with near spacing trials being slower than far spacing trials. The suggestion of an interaction between Time and Spacing was not significant.

The second ANOVA concerned the flanker effect—i.e., the difference in RT between compatible and incompatible trials—and provided evidence concerning changes in selective attention (since any overall effects not due to failures of selective attention are cancelled). It should be noted first that the overall flanker effect was highly significant (as tested using the intercept from the ANOVA model), $F(1, 14) = 55.79$, $P < 0.001$. With regard to changes in the size of the flanker effect as a function of Time and Spacing (see Fig. 2), the main effect of Time was significant, $F(3, 42) = 3.81$, $P = 0.017$. While no (corrected) pairwise comparisons were reliable, the apparent linear trend across time was significant, $F(1, 14) = 6.34$, $P = 0.025$. The main effect of Spacing was also significant, $F(1, 14) = 13.04$, $P = 0.003$, with flanker effects being larger in the near condition ($M = 34.72$ ms) than in the far condition ($M = 19.06$ ms). The interaction between time and spacing was not significant.

With regard to errors (see Table 1), two analyses were conducted that paralleled those for RT. For the neutral trials, there was no effect of time ($P = 0.252$), spacing ($P = 0.698$), or a time by spacing interaction ($P = 0.519$). The ANOVA on the flanker effect in errors also found no effect of time ($P = 0.293$), spacing ($P = 0.071$), or the time by spacing interaction ($P = 0.315$). In general, there was no evidence of a speed-accuracy trade-off that would preclude an interpretation based solely upon the RT results.

Separate ANOVAs were also performed for each of Thayer's constructs as a function of time of awakening (see Fig. 3). The effect on Energy (GA) was significant, $F(3, 42) = 36.38$, $P < 0.001$, with Energy at 2100 hours (pre-sleep) being significantly elevated compared to all post-sleep conditions (all $P < 0.001$) while the post-sleep conditions did not significantly differ from each other. The effect on Tiredness (DS) was also significant, $F(3, 42) = 34.67$, $P < 0.001$, and was significantly lower at 2100 hours (pre-sleep) compared to all post-sleep conditions (all $P < 0.001$) which did not differ from each other. The effect on Calmness (DS) was significant, $F(3, 42) = 3.53$, $P = 0.023$, but none of the corrected comparisons were significant. The effect on Tension (HA) was not significant.

Finally, a series of hierarchical regressions were conducted to examine the relationship between Thayer's constructs and performance on the flankers task. In each case, the variance associated with Subjects and Time was first removed and then the four constructs were each given the opportunity to explain the remaining variance in neutral mean RT and flanker effect in both the near- and far-spacing conditions. These analyses showed that

Table 1 Mean reaction time in ms and error rate by time condition, spacing, and Flanker type for the Flankers task

	2100 hours time condition				2400 hours time condition			
	Near		Far		Near		Far	
	M	%*E*	*M*	%*E*	*M*	%*E*	*M*	%*E*
Flanker								
Compatible	444.18	1.98	438.76	1.98	453.16	3.22	450.36	2.81
Incompatible	472.85	4.48	449.51	3.02	483.87	6.77	467.24	5.20
Neutral	445.46	2.40	444.00	3.12	453.53	4.36	453.80	4.06
	0300 hours time condition				0600 hours time condition			
	Near		Far		Near		Far	
	M	%*E*	*M*	%*E*	*M*	%*E*	*M*	%*E*
Flanker								
Compatible	483.48	4.06	478.05	2.81	461.27	3.33	465.91	3.43
Incompatible	520.57	7.39	497.87	2.39	503.70	5.52	494.69	4.06
Neutral	489.69	4.79	478.77	3.64	480.37	3.64	466.64	3.95

Note M mean; %*E* error rate

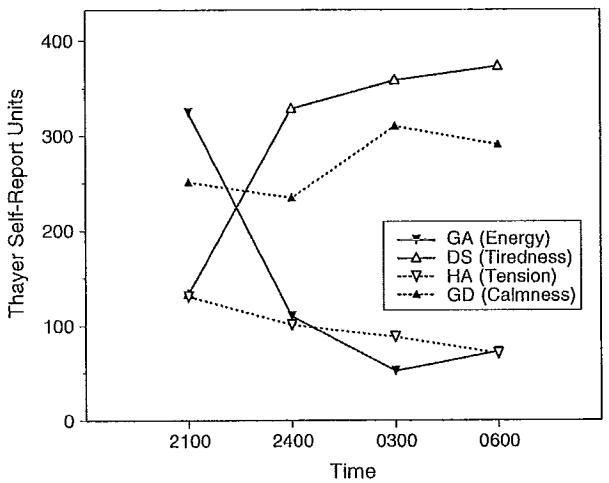

Fig. 3 Mean Thayer scores for energy, tiredness, tension, and calmness at 2100, 2400, 0300, and 0600 hours

energy and tiredness were reliable predictors of performance in the near-spacing condition, with (absolute) partial correlations ranging from .26 to .39, $t(42)$ ranging from 1.73 to 2.68, p ranging from 0.092 to 0.011. In each case, higher levels of energy or lower levels of tiredness were associated with lower neutral mean RT and smaller flanker effects. Neither tension nor calmness was a reliable predictor of any performance measure and none of the predictors could explain a significant proportion of the variance in the far-spacing conditions.

Discussion

The present results indicate that if participants are awakened during a sleep bout, they are slower to respond to visually presented stimuli. In fact, the data from the neutral trials seem to parallel the well-known changes that are observed in body temperature, with a trough in the middle of subjective night, and are akin to Posner's alerting effect (Posner and Petersen 1990; Fan et al. 2005). These data are also consistent with the increase in the prevalence of accidents when workers have to perform when internal circadian time is less than optimal (Moore-Ede et al. 2004). In contrast, the size of the flanker effect, which indexes failures of selective attention and parallel Posner's executive attention or conflict resolution (Posner and Petersen 1990), continued to increase linearly across the night. Of particular interest is how the flanker effect in the far-spacing condition, while not as robust as that observed with near spacing, approximately doubled in size across the night. A components analysis (see Grosjean and Mordkoff 2005) found that incompatible flankers exerted an increasing amount of interference across the night (rising from less than 6 ms to more than 28 ms between 2100 and 0600 hours). That is, inhibiting irrelevant information became more and more difficult. Failures of selective attention may be mediated by length of the sleep bout, rather than a circadian factor such as body temperature. This increasing interference across the night may be akin to a quasi-homeostatic factor. Sleep homeostasis typically refers to sleep depth increasing as the length of wakefulness increases. We propose that the current results may be a residual component of sleep inertia that is determined by the total length of the sleep bout (perhaps total amount of SWS in the bout). That is, instead of being a performance deficit associated with time spent awake, these are performance deficits (measured

immediately after awakening) associated with time spent sleeping. Of relevance is the frequent use of naps as a countermeasure of sleepiness in night- and shift-workers (Takeyama et al. 2005). Given these rather pernicious flanker effects at longer sleep bouts, a practical recommendation from this research may be to restrict naps to a relatively short duration if selective attention is required upon awakening.

However, it is also plausible that flanker interference (i.e., failures of selective attention) is phase-delayed with respect to changes in overall performance and that both are still coupled to circadian oscillators. As a result, our testing times may have been insufficient to capture the circadian nature of performance on incompatible trials. Indeed, tasks that require relatively simple processing (i.e., card sorting or letter cancellation) are more closely associated with body temperature (Carrier and Monk 2000; Casagrande et al. 1997) as compared to immediate memory (Folkard and Monk 1980) or dichotic processing of digits (Morton and Kershner 1991), which are still circadian in nature.

Polysomnographic recordings were not taken in the present study, thus making determination of sleep stage upon awakening difficult. However, it is well known that the percentage of REM increases throughout a night of sleep while SWS decreases. SWS awakenings have been associated with significant sleep inertia effects (Bonnet 1983), but it is unlikely that our subjects tested at 0600 hours (7-h sleep bout) had a greater probability of being in SWS than in REM. Concerning REM, the cholinergic system is more active in REM than in non-REM sleep (Oken et al. 2006), and cortical cholinergic innervation may be important for mediating top-down mechanisms of attention (Sarter et al. 2006). Thus, a theoretical prediction is that flanker effects should be less pronounced after a REM awakening, a prediction that our results do not support.

The present results also support a distinction between the cognitive deficits associated with sleep deprivation and those linked with sleep inertia, complementing the findings of Sagaspe et al. (2006). They found that sleep deprivation increased simple RT and increased self-reported sleepiness, but had no effect on Stroop interference. Although our manipulation did increase neutral-trial RT, it had a more systematic effect on flanker interference. Our results are in contrast to a recent sleep inertia study by Tassi et al. (2006) that tested participants with the Stroop test upon awakening at 0700 hours. One group of participants was not sleep-deprived, going to sleep at 2300 hours and tested at 0700 hours (8-h sleep bout); the other group of participants was sleep deprived, going to sleep at 0500 hours and tested at 0700 hours (2-h sleep bout). The participants in the short sleep bout had worse performance on the Stroop than those in the long sleep bout. These results appear incompatible with ours as we found that more interference was associated with longer sleep bouts, demonstrating the need for more research on sleep inertia and attention. If time spent sleeping is important (as our results suggest), length of sleep bout and sleep deprivation are confounded in the Tassi et al. (2006) study.

The AD-ACL was used as a general self-report measure of phenomenological arousal. Participants reported significantly less "energy" and more "tiredness" during the three sleep conditions than the 2100 hours pre-sleep condition. Energy was lowest at 0300 hours (similar to performance on the neutral-flanker trials) and Tiredness was highest at 0600 hours (similar to the flanker-interference effects). However, Tiredness and Energy scores were not statistically different from each other at 0300 and 0600 hours and both were reliable predictors of performance in the hierarchical regressions. It is unclear why tiredness and energy were not predictors of performance in the far spacing condition. In contrast, tension and calmness showed no change over time and neither explained a significant amount of performance variance. Thus, the current data do not suggest a distinction or dissociation between arousal and vigilance as reported by Matchock and Mordkoff (2005). They found that self-reported "tiredness" significantly decreased across time conditions, yet interference on incompatible/far trials significantly increased. Matchock and Mordkoff (2005) measured tiredness after 50 min of light exposure, which increasingly suppressed more melatonin across the nighttime conditions. Without this confound, the present study found increases in tiredness across the nighttime conditions, as would be expected. Moreover, Tassi et al. (2003) suggested that sleep inertia (low arousal) produces deficits in RT, while sleep deprivation (low arousal and low vigilance) should produce deficits in RT and accuracy. We did not specifically manipulate sleep deprivation, but our participants tested at 2100 and 2400 hours (presumably more sleep deprivation because of a longer period of wakefulness) did not have more errors than at 0300 or 0600 hours (less sleep deprivation), although circadian phase is not controlled for. We also believe that the procedure of spending four consecutive nights in the laboratory did not produce any sleep deprivation. Post-hoc interviews with the participants indicated that they reported to sleep well and actually looked forward to their quiet and cool laboratory sleeping environments (some participants did not have air conditioning at home). Furthermore, in our preliminary report (Matchock and Mordkoff 2005), participants'

nights in the laboratory were not consecutive and separated by at least a week, with remarkably consistent results for neutral-trial RT and flanker effects.

The current study extends the time-of-day analysis of Broadbent et al. (1989). For their afternoon-tested participants, the flanker effect in the near spacing condition disappeared (because, presumably, this was their optimal time with higher arousal). The present results indicate a significant flanker effect in the near-spacing condition for all four time conditions, none of which would be close to the optimal time. What is unique about the current study is the finding of flanker effects in the far conditions. Although this flanker effect was quite small in the 2100 hours condition (10.75 ms), a moderate effect was found in the three nighttime (post-sleep) conditions ($M = 21.82$ ms). These nighttime flanker effects and high interference scores from the component analysis in the far spacing condition warrant further investigation. Much past research has suggested that the focus of visual selective attention subtends approximately 1° of visual angle when focused completely (e.g., Eriksen and Eriksen 1974; Humphreys 1981) and that flankers beyond this boundary area produce little in the way of response competition. Our data suggest a much broader spotlight of attention, at least when participants are awakened from sleep. They seem to suggest a gradient in which a spotlight of visual processing gradually expands out from the central focus area. Eriksen and St James (1986) found that as incompatible flankers moved from 0.5° to 1.5°, the flanker effect decreased. Here, flanker spacing was manipulated and presumably the size of the spotlight was constant. Traditionally, attempts to measure the spatial extent of selective attention have emphasized manipulations inherent in the attention task itself. For example, presenting a digit target just prior to the letter target (LaBerge et al. 1991), manipulating the size of the distractors (Merikle and Gorewich 1979), and in general, altering perceptual load to identify boundary conditions of the flanker effect (Lavie and Tsal 1994; Miller 1991) will affect RT to incompatible flankers. The current study, however, held task difficulty constant and manipulated general arousal by nighttime awakenings, yielding results just as robust as that of task manipulation. We found that the size of the attended area expanded 2100 to 0600 hours, such that a constant spacing of 1.5° for flankers produced a concomitant slowing of RT. Accordingly, within-spacing comparisons as a function of time did not have the confound of reduced acuity.

Studies on arousal and selective attention possess much variability in the parameters of the selective attention task, but taken together, older results (e.g., Easterbrook 1959; Hoddes et al. 1973; Hockey 1970; Kahneman 1973; Kjellberg 1974; Sanders and Reitsma 1982) are consistent with our data. In another study, attention was measured using a visual search for a target in an array of letters in Alzheimer's disease (AD) patients and age-matched controls (Levy et al. 2000). Results showed that administration of the drug scopolamine for AD patients, but not controls, decreased arousal and broadened spatial attention such that performance suffered, even on precued trials. Participants in our study could arguably be comparable to AD patients in selective attention. Taken together, the extant literature suggests that low arousal may be associated with an inability to inhibit irrelevant information, and that this may be especially prominent in older individuals tested at nonoptimal times (Carlson et al. 1995; May and Hasher 1998), AD patients (Levy et al. 2000), sleep-deprived participants (Kjellberg 1974; Sanders and Reitsma 1982), and in younger adults tested at very nonoptimal times such as after a sleep bout (Matchock and Mordkoff 2005). Testing younger adults at nonoptimal times could be used as a model of age-related changes in selective attention. Of relevance is that older participants show large spotlights of attention accompanied by greater interference by incompatible flankers than younger subjects (Zeef and Kok 1993; Zeef et al. 1996). Presumably, testing older, sleep-deprived participants in our experimental paradigm would produce the largest interference effects.

Although the separate influences of circadian, homeostatic, and sleep inertia factors remain to be determined, we were interested in manipulated arousal in general by a nighttime awakening so as to examine deficits in selective attention. Future forced desynchronization studies are underway to further disentangle the specific underlying processes, but on the surface, the present flanker interference effects seem to stem from a sleep inertia effect. Taken together, the present data suggest a dissociation between non-conflict performance and the executive control function of attention. That is, RT in relatively simple tasks may be more influenced by circadian body temperature, while inhibiting irrelevant stimuli, even at wide eccentricities, may be more difficult after longer sleep bouts. These data urge more confirmatory research using research designs from chronobiology and sensitive computerized measures of attention from cognitive neuroscience.

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