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LACK OF DEGRADATION IN VISUOSPATIAL PERCEPTION OF LINE ORIENTATION AFTER ONE NIGHT OF SLEEP LOSS [1, 2]

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Summary.—Sleep deprivation impairs a variety of cognitive abilities including vigilance, attention, and executive function. Although sleep loss has been shown to impair tasks requiring visual attention and spatial perception, it is not clear whether these deficits are exclusively a function of reduced attention and vigilance or if there are also alterations in visuospatial perception. Visuospatial perception and sustained vigilance performance were therefore examined in 54 healthy volunteers at rested baseline and again after one night of sleep deprivation using the Judgment of Line Orientation Test and a computerized test of psychomotor vigilance. Whereas psychomotor vigilance declined significantly from baseline to sleep-deprived testing, scores on the Judgment of Line Orientation did not change significantly. Results suggest that documented performance deficits associated with sleep loss are unlikely to be the result of dysfunction within systems of the brain responsible for simple visuospatial perception and processing of line angles.

Studies of sleep deprivation have generally focused on either of two major cognitive domains, (1) the degrading effects of sleep loss on simple alertness and vigilance performance or (2) the effects of sleep deprivation on complex higher-order executive functions such as problem-solving, decision-making, language, or planning (13). Sleep loss extending beyond the normal period of wakefulness consistently leads to impairments of basic cognitive processes including alertness and vigilance (14) but also adversely affects many complex higher-order cognitive processes such as problem-solving, decision-making, language processing, and flexible thinking (12, 13, 20). Less clear, however, is the extent to which impairments in higher order executive capacities may be due to sleep loss-induced errors occurring at the stage of sensory or perceptual processing of stimuli. For instance, it is possible that some errors attributed to poor judgment or errors in decision-making may actually occur because information that was acted upon was initially misperceived. Recent evidence suggests that sleep loss can impair some aspects of

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simple chemosensory perception systems such as olfaction (22) and can lead to alterations in the threshold of sensitivity to pain (25). At present, however, little is known about how sleep deprivation affects other forms of perception, including the perception of visuospatial information.

Visuospatial perception is a complex cognitive process heavily dependent upon the functioning of regions of the parietal cortex that are involved in integrating complex spatial relationships, especially those within the right cerebral hemisphere (35). Relative to the left side of the brain, the right hemisphere is generally dominant for simple visuospatial judgments (4, 9) and for selectively directing attention to visuospatial stimuli (11, 30, 35). The dominant role of the right hemisphere for attentional processing has also been suggested by several functional neuroimaging studies that show greater activity in this half of the brain during performance of tasks involving the allocation of spatial attention (10, 28). Damage to the right parietal region is often associated with deficits in a variety of visuospatial abilities including left-hemispatial attention, face recognition, mental rotation, and judgment of line orientation (8).

According to one long-standing theory of attentional processing, the two hemispheres of the brain operate together in a dynamic balance of relative activation, and even subtle shifts in this balance can cause changes in the allocation of attentional resources as they are distributed across the individual's perceptual field (24). Consequently, lesions to the right hemisphere are more likely to be associated with a general decrease in global attention capacities as well as a high frequency of hemi-inattention deficits to the left side of perceptual space (1). Interestingly, some recent evidence suggests that sleep loss may differentially reduce the relative activation of the right hemisphere, leading to shifts in lateral visuospatial attention that resemble, although at a much reduced magnitude, the deficits often observed in patients with actual tissue lesions to the right parietal regions (29). Specifically, Manly and colleagues (29) studied the effects of one night of sleep deprivation on a visual perception task involving estimation of the relative length of line segments falling to the left or right of a pericentrally placed mark. When participants were well rested, they showed the normal bias to over-estimate visuospatial information presented within the left visual field, suggesting a dominance of the right hemisphere for visuospatial attention. However, when the same participants were then deprived of sleep, there was significant rightward shift in their visuospatial judgments regarding the relative lengths of the line segments, suggesting a possible change in the balance of activation between the two hemispheres (29). Similarly, sleep deprivation has been associated with deficits in the ability to perceive and process facial expression stimuli presented tachistoscopically to the left visual hemifield, again suggesting a relatively greater impairment of the right hemisphere during sleep loss (34). Recent neuropsychological studies have shown significant deficits on tasks specifically assessing the functional integrity of the right hemisphere during sleep deprivation (17, 23). Furthermore, functional neuroimaging data suggest that, when an individual is sleep-deprived, there is often a compensatory increase in brain activity to maintain performance on attentionally demanding tasks, and this compensatory response is greatest within the frontal and parietal regions of the right hemisphere (7).

While some evidence suggests that sleep deprivation may negatively affect the functioning of the right hemisphere to a relatively greater extent than the left, it is not clear whether this effect extends beyond findings of mild perceptual changes within one or another visual hemifield to also include impairment of visuospatial judgments such as visual line-angle orientation. Therefore, in the present study, the effects of sleep deprivation were evaluated on performance of the Judgment of Line Orientation Test (2), a clinical measure sensitive to right-hemisphere dysfunction in patients with brain lesions (37). It was hypothesized that one night of sleep loss would impair visuospatial performance on the Judgment of Line Orientation Task.

Method

Participants

Healthy volunteers (29 men, 25 women) remained awake for a total of 66 hr. as part of a larger study in which the effects of stimulant intake on cognitive function during sleep deprivation were examined. Other data from this same sample have been reported elsewhere (18, 19, 21, 22), although the present findings have never been published. The average age of participants was 23.5 yr. ($SD = 4.0$). Participants were predominantly right-handed as assessed on the Edinburgh Handedness Inventory (33), a 10-item form ($M = 53.6$, $SD = 49.3$), and by self-report (48 right-handed, 6 left-handed). All volunteers were thoroughly screened by a physician and were excluded from participation if there was any history of medical, psychological or neurological problems. All volunteers were moderate to low users of caffeine (i.e., less than 400 mg/day) and were free from nicotine use for at least three years. Prior to participation, volunteers were instructed to abstain from alcohol, stimulants (e.g., caffeine, cola, tea, and chocolate) and any psychoactive substances 48 hr. prior to arriving at the laboratory. All participants were screened by urinalysis for illicit substance use, nicotine, and presence of other stimulants at intake and every 24 hr. throughout the duration of the study. Participants who wore corrective lenses were asked to wear them throughout all testing sessions. Monetary compensation was provided at the completion of the study, and all participants were offered a cash "performance bonus" as an incentive to put forth their best effort. Thirty-five minutes before each administration of the Judgment of Line Orientation Test, standard scripts were read to all participants reminding them that their performance on all of the cognitive tests would contribute to a final performance bonus at the end of the study. All research was conducted in accordance with the Human Use Review Committee at Walter Reed Army Institute of Research and the U.S. Army Human Subjects Research Review Board.

Materials

Visuospatial performance was assessed using the standard commercially available version of the Judgment of Line Orientation Test (2), a task requiring examinees to make judgments about the orientation of line pairs presented at different angles. The test booklet was placed flat on a table directly in front of the subject, approximately 50 cm from the skull nasion. For each item, volunteers were required to compare the angled lines to a template consisting of 11 reference angles arranged within a 180° viewing plane at 18° intervals. Examinees selected the two reference lines that they believed matched each pair of stimulus lines. Both stimulus lines had to be identified correctly for an item to be scored as correct. Lighting within the testing rooms was maintained at approximately 500 lx from a single source located on the ceiling directly above the testing table. Participants were not limited in the amount of time they had to complete each item, although all easily finished the entire task in less than 10 minutes. Volunteers were initially presented with five practice items followed by 30 test items during each test session. When calculating the total score, a correct response required both angles in a pair to be judged accurately. The test was scored by summing the number of correct item pairs, with possible scores ranging from 0 to 30. In addition, each individual item pair was assessed for difficulty according to the criteria established by Kupke (26). According to those criteria, items were classified as "easy" or "hard," and the percent of correct answers for each type of item was calculated. Two alternate versions of the test, differing only in the order of item presentation, were used (Form H and Form V), with each version counterbalanced across baseline and sleep deprived sessions.

Psychomotor vigilance performance was assessed using a variation of the Psychomotor Vigilance Test (36). This version was exactly 5 min. in duration and was administered on a hand-held palm computer. The task required the participant to monitor the screen continuously for periodic appearances of a "bulls-eye" target. Every time the target appeared, the examinee was required to press a response key as quickly as possible using the dominant hand. The Psychomotor Vigilance Test was administered at 2-hr. intervals throughout the study, but only the data for the administration most proximal to each administration of the Judgment of Line Orientation Test were analyzed for the present study. Performance on the Psychomotor Vigilance Test was analyzed in terms of Performance Speed [i.e., (1/Average Reaction Time) × 1000].

Procedure

Participants completed the study in groups of four. Upon arrival at the sleep laboratory at 1800 hr. (acclimation day), participants were asked to provide urine samples and were fitted with electrodes for ambulatory polysomnographic recording. Participants were then briefed on the schedule of events, were familiarized with and trained to complete several cognitive tests, and were provided with a meal. At 2300 hr. participants were given an enforced 8 hr. time in bed within separate noise- and light-insulated bedrooms. The following morning, participants were awakened at 0700 hr. and remained awake for the next 66 hr. The Psychomotor Vigilance Test was administered every 2 hr. throughout the duration of the study beginning at 0820 hr. Baseline Psychomotor Vigilance Test performance was defined as mean speed of the eight Psychomotor Vigilance Tests administered on the first day. Performance Speed scores for the sessions of interest (i.e., 1220 hr. on Day 1 [5.3 hr awake] and 0620 hr on Day 2 [23.3 hr. awake]) were converted to a percentage of Day 1 mean baseline performance. The Baseline Judgment of Line Orientation Test was administered at 1140 hr. on Day 1 (4.7 hr. awake) and again at 0540 hr. on Day 2 (22.7 hr. awake). Although the present study was conducted as part of a larger investigation into the effects of sleep loss and stimulants on cognitive performance, both Judgment of Line Orientation Test administrations occurred prior to the administration of any stimulant medications. Thus, no stimulant effects were present in the current study.

Data Analysis

First, the total scores from the baseline and sleep-deprived conditions were compared using a paired t test. The percent correct was also calculated for each of the 11 individual line angles separately. To assess whether there was a significant effect of sleep deprivation on total performance or for specific line angles, the percent correct data were subjected to a 2 (baseline versus sleep deprivation) $\times$ 11 (line angle), repeated-measures analysis of variance. Greenhouse-Geisser corrected *df* were used as appropriate when violations of sphericity were present. Pairwise comparisons were conducted using Bonferroni adjustments. In previous research, several of the items of the Judgment of Line Orientation Test have been identified as more difficult than others (26). In general, item pairs that include a vertical or horizontal line in combination with a second line angle that is only a single 18° increment from vertical or horizontal appear to be easier to discriminate than pairs that include two oblique angles. Specifically, Kupke (26) categorized specific Judgment of Line Orientation Test items as "easy" (Form H Item Nos. 2, 4, 6, and Form V Item Nos. 3, 4, 6) or "hard" (Form H Item Nos. 21, 26, 28, and Form V Item Nos. 24, 28, 29). Easy and hard items were compared separately across testing sessions using paired t tests. All statistical tests were conducted with $\alpha = .05$.

Results

Total Judgment of Line Orientation Test Score

Total Judgment of Line Orientation Test scores were compared between baseline and sleep-deprived conditions (maximum score = 30). The total number of correctly identified angle pairs did not differ between baseline ($M = 25.33$, $SD = 3.91$) and sleep-deprived ($M = 25.89$, $SD = 3.68$) conditions ($t_{53} = -1.41$, $p = .16$).

Judgment of Line Orientation Test Individual Line Angles

When error rates for individual lines were compared, there was no significant main effect of session ($F_{1,53} = 1.95$, $p = .17$), indicating that, overall, sleep deprivation did not significantly alter performance on the Judgment of Line Orientation Test (see Fig. 1). In contrast, performance varied significantly as a function of specific line orientation ($F_{4.87,257.84} = 21.82$, $p < .001$), with vertical and horizontal angles (Lines 1, 6, and 11) identified at nearly 100% accuracy, while lines at oblique angles were correctly identified with progressively lower levels of accuracy as they approached 45° or 135° (see Fig. 1). *Post hoc* comparisons indicated that Lines 1, 6, and 11 were signifi-

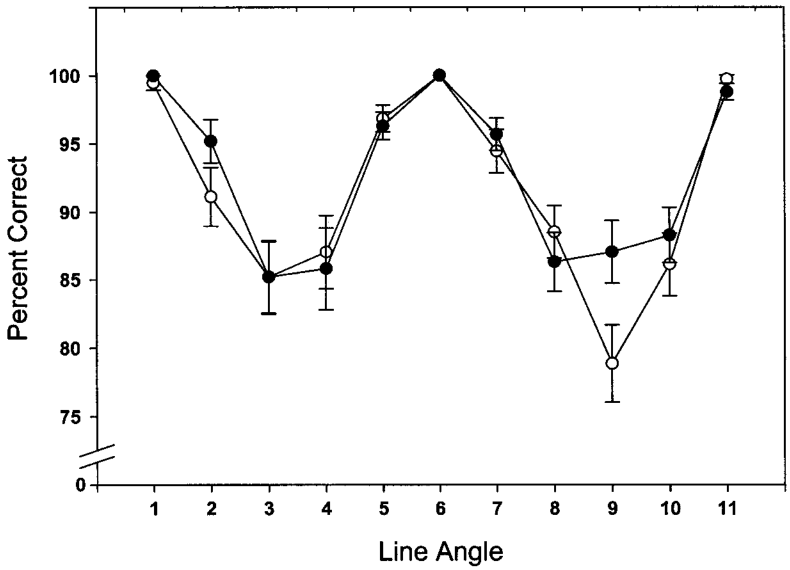

FIG. 1. Lines show the percent correct for individual line angles of the Judgment of Line Orientation Test during the rested baseline (○) and 23-hr. sleep-deprived (●) sessions

cantly different from all other lines ($p < .05$, Bonferroni adjusted) but not from each other (ps $> .05$). The most poorly identified lines included angle No. 3 at 36° (85.2%) and angle No. 9 at 144° (83.0%) across both sessions. There was a significant session by line orientation interaction ($F_{5.08,269.11} = 2.38$, $p = .04$). However, direct Bonferroni adjusted *post hoc* comparisons indicated that, contrary to the hypothesis, scores actually improved after sleep loss for two of the angles, including line angles No. 2 ($p = .05$) and No. 9 ($p = .001$).

Judgment of Line Orientation Test Item Difficulty

Items were also assessed for difficulty (26). Volunteers scored more poorly on items categorized as "hard" ($M = 75.6\%$, $SD = 24.1$) compared to items categorized as "easy" ($M = 99.4\%$, $SD = 4.5$; $F_{1,53} = 105.41$, $p < .001$), regardless of session. There was, however, no main effect of session ($F_{1,53} = .04$, $p = .84$) or interaction between session and error type ($F_{1,53} = .04$, $p = .84$), indicating that sleep loss did not differentially impair the judgment of hard versus easy items.

Psychomotor Vigilance

To assess general psychomotor vigilance, an indicator of alertness and cognitive performance that is known to be sensitive to sleep deprivation, Psychomotor Vigilance Test Performance Speed was also compared between the baseline and sleep-deprived sessions. When compared to baseline performance ($M = 100.3\%$, $SD = 8.1$), sleep deprivation was associated with significantly slower Performance Speed ($M = 81.3\%$, $SD = 20.5$; $t_{53} = 5.97$, $p < .001$).

Discussion

Contrary to our hypothesis, one night of sleep loss was not associated with significant decrements in visuospatial judgment on the Judgment of Line Orientation Test. In fact, accurate judgment of the orientation of line angles was uniformly maintained and even slightly improved for some items following sleep loss, suggesting a possible learning effect. These findings suggest that visuospatial capacities involving judgment of angular relationships are generally resistant to one night of sleep loss, even though testing occurs during the early morning hours when the circadian rhythm of alertness is approaching its nadir. These data are consistent with findings from a number of studies showing that some complex cognitive abilities are often not sensitive to sleep deprivation (3), particularly tasks that are of short duration and sufficiently interesting or motivating (13, 16). In the present study, the Judgment of Line Orientation Test typically required about 8 to 10 min. administration time, which is usually sufficient to elicit time-on-task decrements when participants are sleep-deprived (27). While some cognitive abilities are readily degraded by sleep loss, this did not appear for visuospatial judgment of line angles.

While participants showed no effect of sleep deprivation on visuospatial judgments, they did show a significant decline on a test of psychomotor vigilance and performance speed, despite the fact that the duration of the Psychomotor Vigilance Test was approximately half as long as the Judgment of Line Orientation Test. The differential sensitivity of these two tasks to sleep loss highlights the different attentional demands required by each. Whereas the Psychomotor Vigilance Test is machine-paced and requires sustained and continuous attention to stimuli that appear at irregular intervals, the Judgment of Line Orientation Test is self-paced and requires only momentary episodes of directed attention toward a predictable and continuously present stimulus. During periods of prolonged sleep deprivation, sustaining attention for several minutes is likely to be considerably more difficult than occasional momentary refocusing of attention to make a series of line-angle judgments. Growing evidence suggests that sleep loss may have particularly adverse effects on the functioning of the prefrontal cortex, a region that appears to be heavily recruited during sleep deprivation to sustain Psychomotor Vigilance Test performance (5, 15). In contrast, the Judgment of Line Orientation Test has been shown to activate primarily posterior parietal regions (32), areas that have shown compensatory activation during sleep-deprived performance of some cognitive tasks (6). Consequently, Judgment of Line Orientation Test performance may be less directly affected by sleep deprivation than other tasks which require sustained vigilance and which draw more heavily upon the resources of the prefrontal cortex. It should be noted, however, that it is uncertain whether the findings may have been influenced by differences in the mode of presentation (i.e., machine-paced versus self-paced). Researchers may attempt to control this by forcing a machine-paced presentation of the Judgment of Line Orientation Test.

Although task performance on the Judgment of Line Orientation Test was not significantly affected by sleep loss, it was significantly affected by the difficulty of the test items regardless of the duration of wakefulness. Performance scores for test items that have been defined by previous research as being "hard" due to their angle configurations (26) were significantly lower than scores for items defined as "easy" for both baseline and sleep-deprived sessions. Overall, performance scores on "easy" items [for lines oriented in the horizontal or vertical plane (Lines 1, 6, and 11 in Fig. 1)] were virtually perfect (greater than 99% correct for both sessions). The more oblique the individual line angles, the more frequently they were judged incorrectly. It is not clear whether this phenomenon reflects a general superiority at identifying line angles in the vertical and horizontal planes or whether it was an artifact of the presentation media used to display the stimuli. For the present study, the Judgment of Line Orientation Test was administered using the standard commercially available test booklet presentation. It is possible that the borders of the booklet may have provided reference cues which permitted easier identification of the vertical and horizontal lines. Further studies may evaluate this by presenting test stimuli in the absence of such reference cues.

Data from this study are limited in several respects. Our design only permitted comparison of Judgment of Line Orientation Test scores at two time points, at baseline and again after 23 hr. of wakefulness. It is possible that with longer durations of sleep deprivation, Judgment of Line Orientation Test performance might show greater change from baseline and might even decline. A further limitation is that a fully rested control condition during which participants were administered the Judgment of Line Orientation Test 23 hr. apart without intervening sleep deprivation was not included. This prevents a full assessment of whether the present findings do, in fact, differ in some way from what would be seen in nonsleep-deprived individuals upon retest. Specifically, it is possible that significant differences were not observed because participants showed a learning effect between the two testing sessions that may have overshadowed any effects of sleep deprivation. Some evidence suggests that the Judgment of Line Orientation Test does not show significant learning effects (38), however, even when administered twice within a short 20-min. period (31), but this possibility cannot be ruled out entirely in the present study and replications should include a nonsleep-deprived control condition. It is also quite possible that the Judgment of Line Orientation Test, a test specifically designed for assessing patients with clinically significant brain injury, may simply lack the sensitivity necessary to detect the effects of sleep deprivation. Finally, the present study could be criticized because the Judgment of Line Orientation Test was not administered at the same time of day for the two administrations. This was done intentionally, however, to maximize possible performance differences if they did exist by studying participants at their most alert and most fatigued points in the day. The baseline administration was given when participants were well rested and near their circadian peak (i.e., 11:40 a.m.), and again when they were sleep-deprived and at the circadian nadir (5:40 a.m.). Despite assessing volunteers at the extremes of wakefulness and circadian rhythmicity, however, no evidence of change was found in Judgment of Line Orientation Test performance.

Overall, the present results suggest that, despite a significant slowing of psychomotor vigilance speed, one night of sleep deprivation did not significantly impair accurate judgment of the orientation of line angles. Given this result, it is still unclear whether other aspects of perceptual processing are also equally insensitive to sleep loss.

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