

Age-Related Changes in the Time Course of Vigilant Attention During 40 Hours Without Sleep in Men

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Study Objectives: To examine whether vigilant attention and sleepiness develop differently during prolonged wakefulness in young and older men.

Design, Setting, and Participants: Psychomotor vigilance task (PVT) performance and subjective sleepiness were determined in 14 sessions at 3-hour intervals in healthy young ($n = 12$, mean age: 25.2 years, range: 21-31 years) and older ($n = 11$, mean age: 66.4 years, range: 61-70 years) men who were kept awake for 40 hours under continuous supervision in a sleep laboratory and on the morning after the recovery night.

Measurements and Results: PVT speed, response lapses and performance variability, and subjective sleepiness were analyzed. Sleep deprivation led to reversal of an age-related difference in PVT speed at the circadian trough of performance on the morning of the second day of

prolonged wakefulness (Session \times Age interaction: $P < .0006$). Beginning after 22 hours of wakefulness, the young men also produced more lapses ($P < .004$), showed higher performance instability ($P < .0001$), and felt sleepier ($P < .03$) than older men, especially during the morning after the night without sleep.

Conclusions: Vigilant attention is more impaired after 1 night without sleep in young men than in older men, which has important implications for the prevention of accidents associated with the loss of sleep.

Keywords: Sleep deprivation, cognitive function, performance, driving

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INTRODUCTION

THE LEVEL OF NEUROBEHAVIORAL PERFORMANCE AND ALERTNESS IS DETERMINED BY THE COMBINED EFFECTS OF THE ENDOGENOUS CIRCADIAN clock, the prior duration of waking and sleep (sleep homeostasis, i.e., the need for sleep), individual differences, and environmental influences (see reference 1 for recent overview). It is assumed that under normal entrained conditions, the circadian clock and sleep homeostasis interact in humans to ensure stable high performance and alertness during an approximately 16-hour day and consolidated sleep during an approximately 8-hour night.² When wakefulness in young adults is sustained for longer than 16 hours, reaction time and lapses increase and performance on a psychomotor vigilance task (PVT) becomes unstable.¹ If PVT testing occurs at a time of day of minimal endogenous promotion of alertness, such as in the early morning, performance is impaired to a degree similar to that of legal alcohol intoxication.³ Thus, the coincidence of elevated sleep need due to prolonged waking and adverse circadian time might underlie the high incidence of morning vehicle crashes and industrial accidents.^{1,4} Because the homeostatic and circadian facets of sleep-wake regulation,⁵ as well as the impairment in reaction-time tasks induced by sleep loss,⁶ appear to change with increasing age, we investigated age-related differences in the evolution of PVT performance during sleep deprivation.

METHODS

Twelve young (range: 21-31 years, mean: 25.2 ± 2.9 [SD] years) and 11 older (range: 61-70 years, mean: 66.4 ± 3.2 years) healthy men with no sleep complaints were studied. Low sleep efficiency ($< 80\%$), sleep apnea (apnea-hypopnea index > 5), and nocturnal myoclonus (> 5 periodic limb movements per hour of sleep) were excluded by polysomnography in the sleep laboratory. No subject had a history of neurologic or psychiatric disease. All were nonsmokers and denied taking any medication or consuming illicit drugs. Good health was verified in the older men by physical examination. All participants refrained from all sources of caffeine for 2 weeks prior to the study. They were also requested to abstain from ethanol and to maintain regular 8-hour sleep 16-hour wake cycles for 5 days before the experiment. Sleep was scheduled from 11:00 PM to 7:00 AM (4 young men, all older men) or from midnight to 8:00 AM (8 young men) according to the subjects' habitual sleep times. Deviation of more than 1 hour from these bedtimes was not allowed. Compliance with the prestudy instructions was verified by determining the level of caffeine in saliva and breath ethanol concentration upon arrival in the sleep laboratory and by inspecting the records from activity monitors worn on the wrist of the nondominant arm.

The present data were collected as part of a larger research project studying age-related changes in sleep regulation and the effects of caffeine during sleep deprivation. The study protocols were approved by the local ethics committee for research on human subjects and carried out in accordance with the Declaration of Helsinki. All volunteers participated in 2 blocks of 4 consecutive nights separated by 1 week. The first and second nights of each block served as 8-hour adaptation and baseline nights, respectively. The subjects then stayed awake for 40 hours until bedtime of the 10.5-hour recovery night. Two doses of 200 mg of caffeine and placebo were administered to all subjects after 11 and 23 hours of extended waking according to a randomized, double-blind, cross-over design; only the placebo condition is reported

Disclosure Statement

This was not an industry supported study. Drs. Landolt, Adam, Rétey, and Khatami have indicated no financial conflicts of interest.

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here. To ensure wakefulness, the subjects remained under continuous supervision of a member of the research team. They were allowed to read, study, play games, watch films, and occasionally take a walk outside the laboratory.

The PVT is a simple visual reaction time task, which has no learning curve and is virtually independent of aptitude.¹ Subjects are instructed to press a button as quickly as possible to stop a digital millisecond counter, which starts to scroll at variable intervals (interstimuli intervals: 2-10 seconds). The task requires continuous attention to detect the randomly occurring stimuli. PVT performance sensitively reflects circadian rhythmicity and sleep need, as well as individual vulnerability to the effects of these processes on the ability to sustain vigilant attention, which is necessary for traffic and industrial safety. Ten-minute PVT sessions and self-ratings of sleepiness (German translation of the Stanford Sleepiness Scale) were administered in 14 sessions at 3-hour intervals during the 40-hour waking period, as well as in the morning after the recovery night. The testing after baseline and recovery sleep started approximately 45 minutes after lights on. During the 45 minutes before each PVT session, all subjects stayed in the nonsocial environment of their bedroom and were engaged in waking electroencephalographic recordings, filling in questionnaires, and performing cognitive tasks. The effects of caffeine on subjective sleepiness and the electroencephalogram during wakefulness and sleep in the young men were published previously.⁷

The data were analyzed with 1- and 3-way mixed-model analyses of variance (ANOVA) with the within-subject factor Session (1-14) and Week (1,2), the between-subject factor Age (young, older) and their interactions (SAS PROC MIXED; SAS® 8.2 software, SAS Institute, Cary, NC). An AR(1) covariance structure was used. No significant main effects or interactions of Week were observed. Two-tailed t tests were used to localize significant differences between the groups.

RESULTS

Both young and older men maintained stable and almost lapse-free PVT performance across the first 16 hours waking (Figure 1). As expected, the young men responded faster to the stimuli than the older men. After 19 hours of wakefulness, reaction speed (1/reaction time) started to decrease (factor Session: $F_{13,135} = 11.1$, $P < .0001$). The impairment, however, was much more pronounced in the young (Session \times Age interaction: $F_{13,135} = 3.1$, $P < .0006$), leading to reversal of the age-related difference at 25 and 28 hours waking. Moreover, the young men missed more stimuli (reaction time > 500 milliseconds; Age: $F_{1,19} = 11.7$, $P < .003$; Session \times Age: $F_{13,137} = 2.6$, $P < .004$) and felt sleepier than the older men (Age: $F_{1,19} = 11.7$, $P < .003$; Session \times Age: $F_{13,137} = 2.0$, $P < .03$), especially in the morning after the night without sleep.

Elevated sleep propensity was recently associated with “wake-state instability” reflected in increased variability in PVT performance.¹ To quantify response variability, we analyzed over the 14 sessions the difference between tenth (fastest) and 90th (slowest) percentiles of reaction time. Performance variability increased exclusively in the young men (Session: $F_{13,75} = 7.2$, $P < .0001$; Session \times Age: $F_{13,130} = 4.6$, $P < .0001$), whereas the older men showed stable performance throughout sleep deprivation (Session: $F_{13,75} = 1.5$, $P > .15$).

An increased number of PVT responses in the absence of

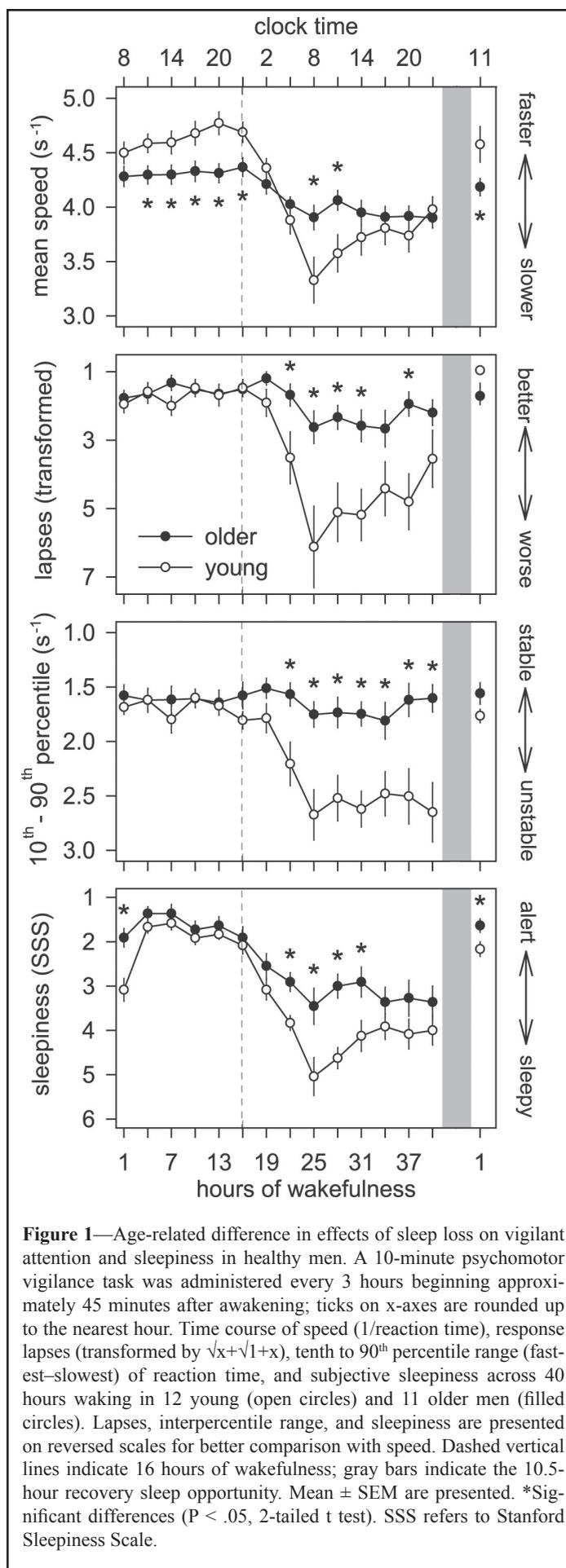


Figure 1—Age-related difference in effects of sleep loss on vigilant attention and sleepiness in healthy men. A 10-minute psychomotor vigilance task was administered every 3 hours beginning approximately 45 minutes after awakening; ticks on x-axes are rounded up to the nearest hour. Time course of speed (1/reaction time), response lapses (transformed by $\sqrt{x+\sqrt{1+x}}$), tenth to 90th percentile range (fastest–slowest) of reaction time, and subjective sleepiness across 40 hours waking in 12 young (open circles) and 11 older men (filled circles). Lapses, interpercentile range, and sleepiness are presented on reversed scales for better comparison with speed. Dashed vertical lines indicate 16 hours of wakefulness; gray bars indicate the 10.5-hour recovery sleep opportunity. Mean \pm SEM are presented. *Significant differences ($P < .05$, 2-tailed t test). SSS refers to Stanford Sleepiness Scale.

stimuli (referred to as errors of commission) was proposed to reflect the attempts of sleep-deprived subjects to compensate for response lapses (errors of omission).¹ The number of errors of commission might, thus, indicate the degree of motivation to perform the task. It did not differ between the ages ($P > .3$ for all sessions), suggesting that loss of motivation in the young subjects was not critical for the age-related differences during prolonged wakefulness. Moreover, baseline differences in PVT performance and sleepiness were re-established after awakening from recovery sleep (Figure 1), indicating that the different evolution during wakefulness indeed reflected the consequences of absent sleep.

DISCUSSION

Male drivers younger than 30 years of age account for more than half of sleep-related vehicle accidents.^{4,8} This fact may indicate that young men are particularly at risk of having sleep-related accidents when compared with other demographic groups. Although the generality of our study is limited because no women were studied, our data may support this conclusion. We demonstrate the presence of prominent age-related changes in the subjects' ability to sustain vigilant attention during prolonged wakefulness. Specifically, 1 night without sleep reversed the age-related difference in PVT speed and led young men to produce significantly more lapses and to feel sleepier than older men during the morning of the second day of extended wakefulness. These findings are consistent with the prolonged sleep latency, indicating reduced homeostatic sleep propensity in older people at the circadian trough of vigilance and performance in the morning.⁵

It has recently been suggested that deficits from high and stable neurocognitive performance occur when wakefulness within a circadian cycle exceeds 15.84 hours.⁹ Our data are consistent with this suggestion. Beginning after approximately 20 hours of wakefulness, we found reduced psychomotor speed, more response lapses, increased performance instability, and higher sleepiness in men in their 20s when compared to men in their 60s. Most intriguingly, response variability increased in the young group, yet remained stable throughout the sleep-deprivation period in the older group. Highly variable PVT performance reflecting long-lasting lapses because of sleep-initiating processes and fast responses due to compensatory mechanisms may be a sign of "wake-state instability" associated with reduced alertness.¹ Our data demonstrate that, in contrast to young men, older men are able to maintain virtually stable performance in 10-minute PVT sessions, which are regularly spaced during 40 hours without sleep.

While the neurobiologic mechanisms underlying degraded and unstable performance after sleep loss still await elucidation, we suggest that the risk of failures of vigilant attention after more than 16 hours waking is particularly high in young adults, especially in the morning after a night without sleep. This conclusion is consistent with recent epidemiologic studies, which have revealed that young age together with disturbed sleep, shift work, and other factors predicts an elevated risk of falling asleep while driving and at work.^{8,10} Road-safety education and shift-work schedules should take this into account, to minimize the risk of sleep-related accidents, which cause mortality in young people⁸ and enormous costs for society.¹

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