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Original Article

Daytime sleepiness associated with poor sustained attention in middle and late adulthood

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ABSTRACT

Objective: We aimed to determine the association between psychomotor vigilance task (PVT) performance and sleep-related factors including sleep duration, daytime sleepiness, poor sleep quality, insomnia, and habitual snoring in a population-based sample.
Methods: This was a cross-sectional analysis from the ongoing prospective cohort study, the Korean Genome and Epidemiology Study. We measured PVT performance and documented demographics, sleep-related factors, life style, and medical conditions in community dwelling adults (N = 2499; mean age 57.1 ± 7.3; male 1259). Associations between PVT parameters and sleep-related factors were tested, adjusting for age, gender, smoking, alcohol use, education, body mass index, hypertension, diabetes, depression, and the interval between mid-sleep time and PVT test.
Results: High Epworth Sleepiness Scale (ESS, ≥8) was associated with slower mean reciprocal response speed (mean RRT) (3.69 ± 0.02 vs. 3.77 ± 0.01, $p < 0.001$), higher probability for increased lapses (≥4) (OR 1.48, CI 1.12–1.88, $p = 0.001$), and more negative RRT slope (–0.036 ± 0.002 vs. –0.030 ± 0.001, $p = 0.02$). Older age, female gender, low education level, depressive mood, and the interval between mid-sleep and PVT test were also associated with poor performance. Sleep duration, habitual snoring, insomnia, or poor sleep quality (the Pittsburgh Sleep Quality Index score > 5) was not related to PVT parameters.
Conclusions: At the population level, our results revealed important modifiers of PVT performance, which included subjective reports of daytime sleepiness.

1. Introduction

An adequate amount sleep and good quality sleep are essential in maintaining sufficient attention and cognitive performance during wakefulness. However, in modern society, a significant number of people suffer from insufficient sleep or sleep disorders such as insomnia and obstructive sleep apnea [1–4]. Sleep disorders, as well as insufficient sleep, are known to impair daytime functioning in both experimental and clinical settings [5,6]. Recently, several epidemiologic or community-based studies have explored the association between short sleep duration and sleep-related complaints such as daytime sleepiness, snoring, insomnia and poor sleep, with impaired cognitive performance [7–12]. One previous study has measured psychomotor speed with response time in simple and multiple-choice tests [7]. A U-shaped association between self-reported sleep duration and psychomotor speed was reported; however, the relationship between sleep complaints and psychomotor slowing was not reported [7].

Whereas simple and multiple-choice tests are mainly used in cognitive epidemiology studies [13,14], the 10-min psychomotor vigilance task (PVT) is the most extensively studied measure of sustained attention in sleep research [15–17]. The PVT protocol is simple to perform with hand-held portable devices and, thus, has a

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potential to be easily administered as a repeated measure of psychomotor functioning in any prospective epidemiologic cohort study. The PVT measures responses to randomly presented stimuli of sufficient test load, up to 100 stimuli per trial [15–17]. The PVT has several advantages over other cognitive tests: it is highly sensitive to sleep loss, demonstrates high intra-class coefficient on repeated testing, and is less likely to be confounded by the learning effects [5,16–18]. It is also known to be sensitive to alterations of sustained attention caused by common sleep disorders [19,20]. The PVT can quantify the level of sustained attention as well as the influence of state instability and time-on task effect [16,17,21,22]. According to the state instability theory, sleep deprivation leads to a fluctuation of sustained attention through the interaction of involuntary sleep initiating and counteracting wake-maintaining systems, and eventually increases the likelihood of lapses (failures in timely response, errors of omission) and false starts (errors of commission) [16,21]. The slope of response time in PVT measures indicates a time-on-task effect, which refers to the systematic deterioration in performance as a function of increasing task duration, and synonymously reflects the capability to maintain attention [16,22–24].

In the present study, the aim was to explore the impact of sleep duration and sleep-related complaints on sustained attention during the waking period at the population level. The PVT was adopted as a measure of sustained attention, which can be regarded as a surrogate marker of daytime functioning. To the best of the authors' knowledge, this is the first study to apply PVT and relate PVT performance to sleep indices in the general population. It was hypothesized that short sleep duration and sleep-related complaints would be related to psychomotor slowing, a higher level of state instability, and a lower level of capacity to maintain attention.

2. Methods

2.1. Study population

The present study is a sub-study to the "Korean Genome and Epidemiology Study" (KoGES), an on-going prospective community-based study, which was established in 2001 [25]. The original cohort consisted of 5020 (2523 males) adults, aged 40–69 years, from the Ansan province of South Korea. All information was collected by trained interviewers. Of specific relevance to the present study were subjects who participated in 2010–2011 ($N = 3144$; male 1600; mean age 57.3 ± 7.4 years). The PVT testing was performed in 3130 (99.6%; mean age 57.3 ± 7.4; male 1597, 51.0%) of 3144 participants. Because PVT performance is affected by sleep deprivation, the circadian phase and possibly by medical conditions, subjects with the following conditions were excluded: (1) shift workers ($N = 136$); (2) a history of stroke ($N = 82$), dementia ($N = 2$), psychiatric illness ($N = 26$), head trauma ($N = 9$), brain operation ($N = 19$), or cancer ($N = 54$); (3) any missing information relevant to this analysis ($N = 32$); (4) acute partial sleep deprivation on the night preceding the PVT test ($N = 335$). Acute partial sleep deprivation was defined as nocturnal sleep on the night before PVT testing that was shorter than habitual sleep duration by at least 1 h. While 2500 subjects qualified, one subject was additionally excluded, whose PVT responses were all errors (102 total stimuli with no valid response: nine false starts and 93 wrong keys). A total of 2499 participants (mean age 57.1 ± 7.3; male 1259) were included in the final analyses. The characteristics and PVT performances of the participants are presented in Table 1.

The institutional review board of the Korea University Ansan Hospital approved the study procedures, and written informed consent was obtained from all study participants.

Table 1
General characteristics and psychomotor vigilance task (PVT) performance.

Parameters	Values
Demographic factors and lifestyle	
Age (years)	57.1 ± 7.3
Male gender	1259 (50.4)
Right-handedness	2480 (99.2)
Current smoking	347 (13.9)
Current alcohol drinking	1327 (53.1)
Regular exercise[a]	1223 (48.9)
Education level	
<High school	790 (31.6)
≥High school	1709 (68.4)
Medical conditions and mood	
Overweight[a]	1086 (43.5)
Hypertension	839 (33.6)
Diabetes	496 (19.8)
Depressive mood[a]	357 (14.3)
Sleep-related factors	
ESS	5.3 ± 3.3
Subjective daytime sleepiness[a]	538 (21.5)
Reported sleep duration (h)	6.9 ± 1.2
<6	368 (14.7)
≥6 and <7	662 (26.5)
≥7 and <8	846 (33.9)
≥8 and <9	481 (19.2)
≥9	142 (5.7)
PSQI	4.6 ± 2.9
Poor sleep quality[a]	752 (30.1)
Habitual snoring[a]	475 (19.0)
Insomnia[a]	555 (22.2)
PVT performance	
Mean RRT (1/s)	3.76 ± 0.48
RRT slope (Δ1/s/min)	−0.031 ± 0.047
Lapses[b]	2.9 ± 5.9
<4	1941 (77.7)
≥4	558 (22.3)
False start[b]	2.2 ± 6.9
<3	1974 (79.0)
≥3	525 (21.0)
MST–PVT (h)	7.7 ± 1.5

Data presented as mean ± SD or number (%).
BMI refers to body mass index; ESS, Epworth Sleepiness Scale; MST-PVT, the interval between mid-sleep and PVT testing time; PSQI, Pittsburgh Sleep Quality index; PVT, psychomotor vigilance test; RRT, reciprocal response time.
[a] Each parameter defined as follows: regular physical exercise defined when subjects performed sweat-inducing exercise at least three times a week with each episode lasting at least 30 min; overweight as body mass index ≥25.0 kg/m^2; depressed mood as the Beck Depression Inventory score ≥16; subjective daytime sleepiness as the Epworth Sleepiness Scale score ≥8; poor sleep quality as the PSQI score >5; habitual snoring as subject reported snoring at least 4 nights a week; insomnia defined when subject had relevant symptoms at least 3 nights a week for more than a month.
[b] Lapses were defined as response time ≥500 ms; false starts as responses without a stimulus or response time <100 ms.

2.2. Measurements

2.2.1. Demographics, lifestyle, and health status

Demographic factors, including age and gender, were collected. Body mass index (kg/m^2) was calculated from height (cm) and body weight (kg) measured after overnight fasting. Overweight was a body mass index ≥25.0 [25]. Alcohol drinking and smoking status were categorized into two groups: current and never or former. Regular physical exercise was defined when subjects reported participating in sweat-inducing exercise at least three times a week for more than 30 mins for each activity. Education level was categorized into a low (<12-years of education) or high (≥12-years of education) group. Hypertension was diagnosed when systolic or diastolic blood pressure was ≥140 or 90 mmHg, respectively, or when participants took antihypertensive medications. Diabetes mellitus was considered to be present when there was use of oral hypoglycemic agent or insulin, or with fasting blood glucose ≥126 mg/dL

[26]. Depressive symptoms were evaluated with the Beck Depression Inventory (BDI) [27], and a score ≥16 was used to define depressive mood [28].

2.2.2. Psychomotor vigilance task

The PVT was performed with hand-held portable devices (PVT-192®, Ambulatory Monitoring Inc., Ardsley, NY). The standard 10-min protocol using random visual stimuli [15,17] was adopted. The range of inter-stimulus intervals was 2–10 s. The test was administered between 08:00 and 13:00, and the clock time of the PVT trial for each subject was recorded. Before testing, handedness was determined based on the hand used for writing. Subjects were instructed to press a response button as soon as a visual stimulus appeared on the machine screen with the thumb of the dominant hand. A 1-min practice session was provided to each subject and was followed by a formal test.

The PVT device stored response times (RTs) measured in milliseconds (ms) for all the stimuli in each trial and parameters were presented using software (REACT version 1.1.03, Ambulatory Monitoring Inc., USA). Four PVT parameters were chosen as the primary outcomes: mean reciprocal response time (RRT, 1/s), number of lapses, number of false starts, and the linear regression slope of RRT on trial minute (RRT slope, Δ1/s/min). The RRTs were derived from RTs of valid responses. Responses were valid when RT to the presented stimulus was ≥100 ms. The RRTs were obtained by dividing each RT by 1000 and then reciprocally transforming these values. The average of the RRTs was calculated and defined as mean RRT. Lapses were counted as RTs ≥500 ms. False starts were defined as RTs <100 ms or responses without a stimulus. False starts, as well as lapses, are the markers of a state of instability, as described in the introduction [16,21]. The RRT slope was extracted over the 10-min trial as the index of time-on-task effect [16,22–24].

2.2.3. Sleep-related factors

Perceived subjective daytime sleepiness was measured with the Epworth Sleepiness Scale (ESS), which was administered on the morning of the comprehensive evaluation, including PVT [29]. Participants reported to the question: "How many hours of sleep did you usually get a night for the past month?" Their answer was designated as self-reported sleep duration. Habitual snoring was defined as a participant reporting snoring during at least four nights a week. The presence of insomnia was established when participants had any of four insomnia symptoms (difficulties in sleep initiation or maintenance, early morning awakening or non-refreshing sleep) for at least three days a week during the past month. Overall sleep quality was measured with the Pittsburgh Sleep Quality Index (PSQI) [30].

To adjust for circadian influences on PVT, the interval (MST-PVT) was defined as between mid-sleep time (MST) and the time of PVT testing. The MST is the mid-point between sleep onset and offset [31,32]. Time of sleep onset and offset was based on responses to two questions: "When did you usually get into bed to sleep during the past month?" and "When did you usually get up during the past month?" The MST is known to correlate with the chronotype measured by the Horne-Ostberg Morningness-Eveningness score [33].

2.3. Statistical analysis

The primary aim of the analysis was to explore the relationship between PVT parameters and sleep-related factors independent from the socio-demographic factors and medical conditions. Mean RRT (1/s) and RRT slope (Δ1/s/min) were analyzed as continuous variables. Distributions of the count of lapses and false starts were extremely skewed in the population. They were dichotomized at the value of 25th percentile (≥4 vs. <4 for lapses and ≥3 vs. <3 for false starts). The presence of subjective daytime sleepiness was defined when the ESS score was ≥8. The distribution of ESS scores was also skewed and the threshold matched with the 25th percentile score. In the previous study, an ESS of ≥8 reliably predicted sleep latency of less than 10 min on the multiple sleep latency test [34]. Sleep duration was categorized into five groups (<6, 6–7, 7–8, 8–9, and ≥9 h). The group sleeping was designated as a reference of 7–8 h, according to previous research demonstrating the effect of sleep duration on neurocognitive function [7,8,35]. The presence of habitual snoring and insomnia was classified into two groups: yes or no. Poor sleep quality was defined when the PSQI score was >5 [30].

Covariates for statistical adjustment were age, gender, current smoking and alcohol drinking status, exercise, education level, body mass index, hypertension, diabetes, depressive mood, and MST-PVT. The MST-PVT was categorized into seven groups: <5 h (3.2%); 5–6 (8.8%); 6–7 (18.8%); 7–8 (26.5%); 8–9 (23.2%); 9–10 (12.7%); ≥10 (6.8%). For group comparisons, a two-tailed Student's *t*-test or analysis of variance and Pearson's Chi-squared test were used. Multivariate analysis was performed with mean RRT, RRT slope, lapses, and false starts as dependent variables, and sleep-related factors as independent variables. A general linear model was applied for mean RRT and RRT slope, and binary logistic regression analysis for lapses and false starts. Data storage and statistical analysis were performed with IBM SPSS Statistics software (version 19.0, SPSS, Inc., an IBM company, Chicago, IL, USA). The null hypothesis was rejected at p-value <0.05.

3. Results

3.1. Association between sleep-related factors and PVT performance

Subjective daytime sleepiness was significantly associated with poor PVT performance. Presence of daytime sleepiness was an indicator of slower response (lower mean RRT; $p < 0.001$), and more failure in timely response (more lapses; $p = 0.001$). Response speed also decreased more profoundly in subjects with daytime sleepiness ($p = 0.02$). This association was independent from age, gender, education level, MST-PVT, mood and cardiovascular risk. False start was not correlated with daytime sleepiness. The detailed results can be found in Tables 2 and 3 (results from univariate analysis) and Table 4 (results from multivariate analysis).

PVT performance was not associated with reported sleep duration (Tables 2, 3, 5). The adjusted mean RRT was highest in the group with short nocturnal sleep (<6 h). However, the difference across the whole range of sleep duration was not significant ($p = 0.92$). An interaction between the presence of subjective daytime sleepiness and reported sleep duration for mean RRT was not significant ($p = 0.84$) (Table 6). The presence of daytime sleepiness was significantly associated with lower mean RRT ($p = 0.001$), but reported sleep duration was not ($p = 0.97$) (Table 6). In subjects with daytime sleepiness, adjusted mean RRT was the highest in the group sleeping 7–8 hrs, and was lower in the groups sleeping <7 and >8 h (Table 6). However, mean RRT was similar among the groups of different sleep durations in subjects with lower ESS score. The RRT slope was negative in all sleep duration groups, being the least negative in the group sleeping 8–9 h. But neither the overall difference nor the quadratic trend was significant ($p = 0.56$ and $p = 0.26$, respectively) (Table 5). There was no association between sleep duration and lapses or false starts. Poor sleep quality tended to be associated with slower response speed and more lapses (Tables 2 and 3); however, the relationship was not significant after adjusting for covariates (Table 4). Neither the presence of habitual snoring nor insomnia was related to PVT performance (Tables 2–4).

Table 2
Relationship between psychomotor vigilance task performance and various parameters including sleep-related factors: mean reciprocal response time (RRT) and RRT slope.

Factors	Mean RRT (1/s)	*p*-Value	RRT slope (Δ1/s/min)	*p*-Value
Demographic factors and lifestyle				
Age (years)	–0.37	<0.001	–0.03	0.11
Gender				
Male	3.86 ± 0.44	<0.001	–0.031 ± 0.045	0.94
Female	3.65 ± 0.50		–0.031 ± 0.050	
Current smoking				
Yes	3.81 ± 0.42	0.03	–0.035 ± 0.049	0.10
No	3.75 ± 0.49		–0.031 ± 0.047	
Current drinking				
Yes	3.83 ± 0.44	<0.001	–0.030 ± 0.047	0.17
No	3.69 ± 0.51		–0.032 ± 0.048	
Regular exercise[a]				
Yes	3.74 ± 0.48	0.49	–0.031 ± 0.047	0.57
No	3.77 ± 0.49		–0.032 ± 0.048	
Education level				
<High school	3.55 ± 0.55	<0.001	–0.031 ± 0.049	0.76
≥High school	3.85 ± 0.42		–0.031 ± 0.047	
Medical conditions and mood				
Overweight[a]				
Yes	3.72 ± 0.49	0.001	–0.031 ± 0.047	0.89
No	3.78 ± 0.48		–0.031 ± 0.048	
Hypertension				
Yes	3.69 ± 0.51	<0.001	–0.032 ± 0.049	0.50
No	3.79 ± 0.47		–0.031 ± 0.046	
Diabetes				
Yes	3.68 ± 0.51	<0.001	–0.032 ± 0.049	0.50
No	3.77 ± 0.48		–0.031 ± 0.046	
Depressive mood[a]				
Yes	3.59 ± 0.54	<0.001	–0.031 ± 0.049	0.90
No	3.78 ± 0.47		–0.031 ± 0.047	
Sleep-related factors				
Subjective daytime sleepiness[a]				
Yes	3.70 ± 0.51	0.01	–0.036 ± 0.047	0.02
No	3.77 ± 0.48		–0.030 ± 0.048	
Sleep duration (h)				
<6	3.77 ± 0.47	0.19	–0.035 ± 0.044	0.53
≥6 and <7	3.77 ± 0.53		–0.032 ± 0.049	
≥7 and <8	3.76 ± 0.46		–0.031 ± 0.046	
≥8 and <9	3.74 ± 0.47		–0.029 ± 0.050	
≥9	3.67 ± 0.52		–0.032 ± 0.046	
Poor sleep quality[a]				
Yes	3.69 ± 0.53	<0.001	–0.029 ± 0.048	0.08
No	3.78 ± 0.46		–0.034 ± 0.047	
Habitual snoring[a]				
Yes	3.72 ± 0.52	0.12	–0.034 ± 0.046	0.12
No	3.76 ± 0.48		–0.031 ± 0.048	
Insomnia[a]				
Yes	3.70 ± 0.51	<0.001	–0.032 ± 0.047	0.55
No	3.77 ± 0.47		–0.031 ± 0.048	

p-Values from Pearson's correlation analysis, Student *t*-test, or ANOVA.
Data presented as values of correlation coefficient, or mean ± SD of mean RRT or RRT slope.
RRT refers to reciprocal response time.
[a] Each parameter defined as in Table 1.

3.2. Circadian influence and effects of age, gender, education, and other factors on PVT performance

The PVT performance was modified by MST-PVT, a circadian phase marker of this analysis. The adjusted average response speed (mean RRT) was highest when measured at 5–6 h after MST, and the overall difference across the testing times was marginally significant ($p = 0.06$) (Table 7). The relationship between mean RRT and MST-PVT was in a cubic trend ($p = 0.05$) (Fig. 1A). The chance for lapses was lowest at the 5–6 h point (Table 1). The predicted probability for a greater number of lapses had a U-shaped relationship with MST-PVT in the analyzed segments, although it was not substantial (p for trend = 0.72) (Fig. 1C). The probability for lapses was negatively correlated with mean RRT (Fig. 1A and C, Table 6). The RRT slope linearly decreased as MST-PVT increased (p for trend = 0.001, Fig. 1B) and its difference was evident across the MST-PVT categories ($p = 0.01$) (Table 6). The probability of greater false starts was not associated with MST-PVT (Table 6 and Fig. 1D).

Independent of sleep-related factors and other covariates, older age, female gender, low education level, and current smoking were associated with poor PVT performance. Aging was related to slowing in response speed (β –0.020, CI –0.023 to –0.018, $p < 0.001$), more lapses (OR 1.08, CI 1.07–1.10, $p < 0.001$) and false start (OR 1.02, CI 1.00–1.03, $p < 0.001$), but not with RRT slope ($p = 0.25$). Males responded faster than females (mean RRT, 3.84 ± 0.01 vs. 3.66 ± 0.01, $p < 0.001$) and had a lower probability for lapses (OR 0.77, CI 0.60–0.99, $p = 0.04$). Female gender was associated with more false starts (OR 1.49, CI 1.17–1.90, $p = 0.001$), but not with RRT slope ($p = 0.83$). The education level positively correlated with the response speed (β 0.139, CI 0.100–0.179, $p < 0.001$) and negatively associated with a great number of lapses (OR 1.61, CI 1.29–2.01, $p < 0.001$). Neither RRT slope nor false start was different depending on the education level. Current smoking was significantly associated with poor PVT performance; mean RRT (β –0.134, CI –0.179 to –0.08, $p < 0.001$), lapses (OR 2.83, CI 2.09–3.83, $p < 0.001$), RRT slope (β –0.008, CI –0.013 to –0.002, $p = 0.01$), and false start (OR 1.39, CI 1.02–1.88, $p = 0.04$). The presence of depressive mood was related to a slow response (β –0.086, CI –0.135 to –0.037, $p = 0.001$) and more lapses (OR 1.41, CI 1.08–1.86, $p = 0.01$), but not false start and RRT slope. Being overweight was related to lower mean RRT (3.73 ± 0.01 vs. 3.77 ± 0.01, $p = 0.02$), and hypertension to more lapses (OR 1.26, CI 1.01–1.57, $p = 0.04$).

4. Discussion

The PVT, as a standard measure of sustained attention, has been used to evaluate the changes or effects related to specific conditions such as sleep deprivation, circadian phase or sleep apnea [16,19,20,31,32,36,37]. In this context, fluctuations of PVT performance in each individual reflect "state"-dependent changes according to the given condition. On the other hand, the inter-individual difference in PVT performance is a robust and stable phenomenon over repeated testing [38,39]. Some subjects are vulnerable to sleep loss but some are quite resilient. This suggests that the difference in PVT performance between individuals could be a "trait-like" stable characteristic. The aim of the present study was to explore whether the difference in PVT performance between individuals as a "trait-like" phenotype is associated with various sleep-related factors in the community-dwelling middle-to-old aged subjects. For this purpose, the present study was restricted to samples, as described in the exclusion criteria, and adjusted the influence of circadian "state".

Of the sleep-related factors, subjective daytime sleepiness, as expected, was significantly associated with PVT performance. More-sleepy subjects were slower in responses (lower mean RRT), with a larger decrement in response speed over the trial (more negative RRT slope) and higher chance for more lapses (Table 4). Based on these results, it can be contended that subjective sleepiness is related to psychomotor slowing, higher levels of state instability, and lower capability to maintain attention. To the authors' knowledge, this is the first study to demonstrate the association of daytime sleepiness with PVT parameters at the level of the general population. If sleepiness is a counterpart of alertness or sustained attention, it is intuitively acceptable that sleepier subjects will show poor PVT performances.

Sustained attention is a scaffold for a wide range of neurocognitive processes. Previous studies have reported that reaction times were correlated with psychometric intelligence test scores from

Table 3
Relationship between psychomotor vigilance task performance and various parameters including sleep-related factors: lapse and false start.

	Lapse		*p*-Value	False start		*p*-Value
	<4 (*N* = 1941)	≥4 (*N* = 558)		<3 (*N* = 1974)	≥3 (*N* = 525)	
Demographic factors and life style						
Age (years)	56.1 ± 6.5	60.8 ± 8.4	<0.001	57.0 ± 7.1	57.7 ± 7.7	0.05
Gender (male)	999 (51.5)	260 (46.6)	0.04	1020 (51.7)	239 (45.5)	0.01
Current smoking	245 (12.6)	102 (18.3)	0.001	268 (13.6)	79 (15.0)	0.39
Current drinking	930 (47.9)	242 (43.4)	0.06	933 (47.3)	239 (45.5)	0.49
Regular exercise[a]	940 (48.4)	283 (50.7)	0.36	969 (49.1)	254 (48.4)	0.81
Education level (≥high school)	1409 (72.6)	300 (53.8)	<0.001	1359 (68.8)	350 (66.7)	0.34
Medical conditions and mood						
Overweight[a]	818 (42.1)	268 (48.0)	0.01	859 (43.5)	227 (43.2)	0.97
Hypertension	598 (30.8)	241 (43.2)	<0.001	652 (33.0)	187 (35.6)	0.92
Diabetes	353 (18.2)	143 (25.6)	<0.001	385 (19.5)	111 (21.1)	0.42
Depressive mood[a]	241 (12.4)	116 (20.8)	<0.001	282 (14.3)	75 (14.3)	1.00
Sleep-related factors						
Subjective daytime sleepiness[a]	397 (20.5)	141 (25.3)	0.02	430 (21.8)	108 (20.6)	0.59
Sleep duration (h)						
<6	248 (14.6)	84 (15.1)	0.32	287 (14.5)	81 (15.4)	0.63
≥6 and <7	521 (26.8)	141 (25.3)		526 (26.6)	136 (25.9)	
≥7 and <8	667 (34.4)	179 (32.1)		679 (34.4)	167 (31.8)	
≥8 and <9	363 (18.7)	118 (21.1)		375 (19.0)	106 (20.2)	
≥9	106 (5.5)	36 (6.5)		107 (5.4)	35 (6.7)	
Poor sleep quality[a]	555 (28.6)	197 (35.3)	0.003	599 (30.3)	153 (29.1)	0.63
Habitual snoring[a]	365 (18.3)	119 (21.3)	0.13	373 (18.9)	102 (19.4)	0.80
Insomnia[a]	415 (21.4)	140 (25.1)	0.08	435 (22.0)	120 (22.9)	0.68

p-Values from Student's *t*-test or Chi-squared test.
Data presented as mean ± SD or value (%).
[a] Each parameter defined as in Table 1.

Table 4
Association of psychomotor vigilance task performance with subjective daytime sleepiness, poor sleep quality, habitual snoring and insomnia.

		Mean RRT		RRT slope		More lapses		More false starts	
		Mean ± SE	*p*-Value	Mean ± SE	*p*-Value	OR (95% CI)	*p*-Value	OR (95% CI)	*p*-Value
Subjective daytime sleepiness[a]	Yes	3.69 ± 0.02	<0.001	−0.036 ± 0.002	0.02	1.48 (1.12, 1.88)	0.001	0.95 (0.74, 1.21)	0.68
	No	3.77 ± 0.01		−0.030 ± 0.001		REF		REF	
Poor sleep quality[a]	Yes	3.77 ± 0.02	0.31	−0.029 ± 0.002	0.09	1.04 (0.83, 1.30)	0.76	0.87 (0.70, 1.01)	0.22
	No	3.75 ± 0.01		−0.032 ± 0.001		REF		REF	
Habitual snoring	Yes	3.74 ± 0.02	0.34	−0.034 ± 0.002	0.15	1.08 (0.84, 1.39)	0.57	1.02 (0.79, 1.31)	0.72
	No	3.76 ± 0.01		−0.031 ± 0.001		REF		REF	
Insomnia	Yes	3.76 ± 0.02	0.86	−0.032 ± 0.002	0.54	0.96 (0.75, 1.22)	0.74	1.06 (0.82, 1.36)	0.68
	No	3.75 ± 0.01		−0.031 ± 0.001		REF		REF	

p-Values from general linear model with mean RRT (1/s) and RRT slope (Δ1/s/min) as dependent variables, and from logistic regression analysis for lapses (more ≥4 vs. less <4) and false start (more ≥3 vs. less <3) as dependent. Each sleep-related factor (subjective daytime sleepiness, poor sleep quality, habitual snoring and insomnia) was designated as independent variables, adjusted for age, gender, current smoking and alcohol drinking status, education level, overweight, hypertension, diabetes, depressive mood, and MST-PVT (the interval between mid-sleep time and time to test psychomotor vigilance task).
Data presented as estimated marginal mean ± standard errors for mean RRT and RRT slope, and as adjusted odds ratio (95% CI) for more lapses and false starts.
CI refers to 95% confidence interval; mean, estimated marginal mean; OR, adjusted odds ratio; REF, reference; RRT, reciprocal response time; SE, standard errors.
[a] Each parameter defined as in Table 1.

Table 5
Profiles of psychomotor vigilance task performance across the reported sleep durations.

	Reported sleep duration (hours)					*p*-Value
	<6 (*N* = 368)	6≤, <7 (*N* = 662)	7≤, <8 (*N* = 846)	8≤, <9 (*N* = 481)	≥9 (*N* = 142)	
Mean RRT	3.77 ± 0.03	3.75 ± 0.02	3.75 ± 0.02	3.75 ± 0.02	3.76 ± 0.04	0.92
RRT slope	−0.034 ± 0.002	−0.032 ± 0.002	−0.031 ± 0.002	−0.029 ± 0.002	−0.033 ± 0.004	0.56
More lapses	1.09 (0.80, 1.50)	1.02 (0.78, 1.33)	REF	1.09 (0.82, 1.44)	0.86 (0.55, 1.34)	0.90*
More false starts	1.13 (0.83, 1.52)	1.05 (0.82, 1.36)	REF	1.15 (0.9, 1.52)	1.23 (0.83, 1.96)	0.80*

p-Values from general linear model with mean RRT (1/s) and RRT slope (Δ1/s/min) as dependent variables, and from logistic regression analysis of lapses (more ≥4 vs. less <4) and false start (more ≥3 vs. less <3) as dependent, with sleep duration designated as independent variables with 7–8 h sleepers as a reference, adjusted for age, gender, current smoking and alcohol drinking status, education level, overweight, hypertension, diabetes, depressive mood, and MST-PVT (the interval between mid-sleep time and time to test psychomotor vigilance task).
Data presented as estimated marginal mean ± standard errors for mean RRT and RRT slope, and as adjusted odds ratio (95% CI) for more lapses and false starts in relation to sleep duration.
REF refers to reference; RRT, reciprocal response time.
* *p*-Values for quadratic trend.

Table 6
Mean reciprocal reaction time (1/s) across the reported sleep duration, stratified by the presence or absence of subjective daytime sleepiness.

Subjective daytime sleepiness	Reported sleep duration (h)					*p*-Value
	<6 (*N* = 368)	6≤, <7 (*N* = 662)	7≤, <8 (*N* = 846)	8≤, <9 (*N* = 481)	≥9 (*N* = 142)	
Yes	3.66 ± 0.05	3.68 ± 0.03	3.72 ± 0.03	3.67 ± 0.05	3.68 ± 0.09	0.84
No	3.78 ± 0.03	3.78 ± 0.02	3.76 ± 0.02	3.77 ± 0.02	3.78 ± 0.04	

Estimates from general linear model with mean reciprocal reaction time (1/s) as dependent variable, and reported sleep duration and subjective daytime sleepiness as fixed factors, adjusted for age, gender, current smoking and alcohol drinking status, education level, overweight, hypertension, diabetes, depressive mood, and MST-PVT (the interval between mid-sleep time and time to test psychomotor vigilance task).
Subjective daytime sleepiness was defined as the Epworth Sleepiness Scale score ≥8.
Data presented as estimated marginal mean ± standard errors.
p-Value for interaction between reported sleep duration and subjective daytime sleepiness for mean reciprocal reaction time.

a population-based cohort, although reaction times were measured by different methods [40]. Additionally daytime sleepiness was associated with cognitive dysfunction in the elderly [41], which may be postulated as an effect of impaired sustained attention. To confirm any association between sleepiness and cognitive function and to define the contribution of vigilant attention measured by PVT to cognition, a direct evaluation of PVT performance in relation to various cognitive domains is required.

In this study, the presence of subjective daytime sleepiness was designated as an ESS of ≥8. This threshold is lower than the commonly used cut-off value of 11 for defining 'excessive' daytime sleepiness [29]. The finding suggests that daytime sleepiness might impair sustained attention even at the degree of sleepiness below the level of "excessive" sleepiness. An ESS of ≥8 reliably predicted a moderate degree of daytime sleepiness on the multiple sleep latency test [34]. One caveat to interpret the correlation between daytime sleepiness and PVT performance is that daytime sleepiness measured by ESS is determined by multiple factors [42,43]. Age, gender, and depressive mood, as well as several symptoms of sleep disorders, are strongly correlated with ESS. Depressed mood was an indicator of poor PVT performance (slower response speed and more lapses) in the present study, which may be mediated by reduced motivation. The ESS is not always correlated with objectively measured sleep propensity [44]; however, a high ESS (≥8) was significantly associated with PVT parameters after adjustment for age, gender, depressive mood and other covariates (Table 4). Even adding sleep duration, insomnia, snoring, and sleep quality into the multivariate model, the association between high ESS and poor PVT performance remained significant (data not shown).

Counter to the hypothesis, sleep duration was not correlated with PVT parameters. The response speed was not different across the various sleep durations, and the group with shortest sleep duration (<5 h) showed the best performance (ie, highest mean RRT, although it was not statistically significant (Tables 2 and 5). This result is not concordant with the reported dose–response relationship between sleep duration and PVT performance in experimental sleep deprivation studies [18]. One possible explanation is the presence of individually different vulnerability to sleep loss and sleep need (that is, if sleep need is less, a shorter sleep duration is "normal" for that individual). The presence of daytime sleepiness largely determined the response speed on PVT but the subjects without daytime sleepiness showed similar mean RRT, as shown in Table 6. In groups with daytime sleepiness, mean RRT tended to be lower in subjects sleeping less than 7 h. Therefore it may be assumed that the insignificant difference in PVT performance across the whole range of sleep duration is partly explained by individual differences in vulnerability or resiliency to sleep loss [38,39]. Another possible explanation is that as sleep restriction is often chronic, the brain might adapt to the level sufficient to stabilize performance, an allostatic adaptation to chronic sleep restriction [45,46]. However this hypothesis cannot explain why the shortest sleepers showed the fastest responses compared with subjects sleeping longer. Speculatively, hyperarousal (or arousal state) may impact both measures – speeding up PVT and reducing sleep duration. One study documented psychomotor slowing in both short and long sleepers [7]; but the method to measure psychomotor speed was different from the present study, and neither daytime sleepiness nor circadian influence was adjusted in the analysis [7].

Habitual snoring was not associated with PVT performance. This is in contrast to previous studies showing a negative association between sleep apneas and PVT [19,20]. The presence of snoring does not necessarily indicate sleep apnea nor is the absence a sufficient condition to exclude it [4,47]. Neither insomnia nor poor sleep quality

Table 7
Psychomotor vigilance task (PVT) performance stratified by the interval between mid-sleep and PVT test time.

		MST-PVT							*p*-Value
		<5 (*N* = 80)	5≤, <6 (*N* = 219)	6≤, <7 (*N* = 469)	7≤, <8 (*N* = 663)	8≤, <9 (*N* = 580)	≥9 (*N* = 317)	≥10 (*N* = 171)	
Mean RRT	Unadjusted	3.76 ± 0.52	3.86 ± 0.42	3.82 ± 0.43	3.78 ± 0.46	3.74 ± 0.47	3.65 ± 0.59	3.60 ± 0.54	<0.001
	Adjusted	3.70 ± 0.04	3.80 ± 0.03	3.75 ± 0.02	3.78 ± 0.02	3.75 ± 0.02	3.70 ± 0.02	3.72 ± 0.03	0.06
RRT slope	Unadjusted	–0.023 ± 0.042	–0.027 ± 0.046	–0.029 ± 0.047	–0.028 ± 0.047	–0.035 ± 0.047	–0.035 ± 0.049	–0.039 ± 0.049	<0.001
	Adjusted	–0.022 ± 0.005	–0.027 ± 0.003	–0.029 ± 0.002	–0.028 ± 0.002	–0.035 ± 0.002	–0.035 ± 0.003	–0.038 ± 0.004	0.01
More lapses	%	26.3	15.5	16.4	21.1	22.9	31.9	30.4	0.76
	OR (CI)	1.81 (1.03–3.18)	REF	1.06 (0.70–1.60)	1.17 (0.80–1.72)	1.25 (0.84–1.84)	1.75 (1.15–2.66)	1.30 (0.80–2.11)	0.72*
More false starts	%	17.5	24.2	19.6	22.8	21.0	18.6	19.9	<0.001
	OR (CI)	REF	1.18 (0.69–2.04)	0.96 (0.58–1.60)	1.01 (0.61–1.66)	0.95 (0.58–1.58)	0.78 (0.45–1.34)	0.91 (0.50–1.64)	0.48**

p-Values from analysis of variance (unadjusted) or general linear model (adjusted) for mean RRT (1/s) and RRT slope (Δ1/s/min), and from Chi-squared test or logistic regression analysis for lapses (more ≥4 vs. less <4) and false start (more ≥3 vs. less <3).
Multivariate models included age, gender, current smoking and alcohol drinking status, education level, overweight, hypertension, diabetes, depressive mood, and the Epworth Sleepiness Scale score as covariates.
Data presented as mean ± standard deviation (unadjusted) and estimated marginal mean ± standard errors (adjusted) for mean RRT and RRT slope, and as percentage of the designated condition and adjusted odds ratio (95% CI) for more lapses and false starts.
CI refers to 95% confidence interval; MST-PVT, interval between mid-sleep and PVT test time; OR, adjusted odds ratio; REF, reference; RRT, reciprocal response time.
* ,** *p*-Values for quadratic and linear trend, respectively.

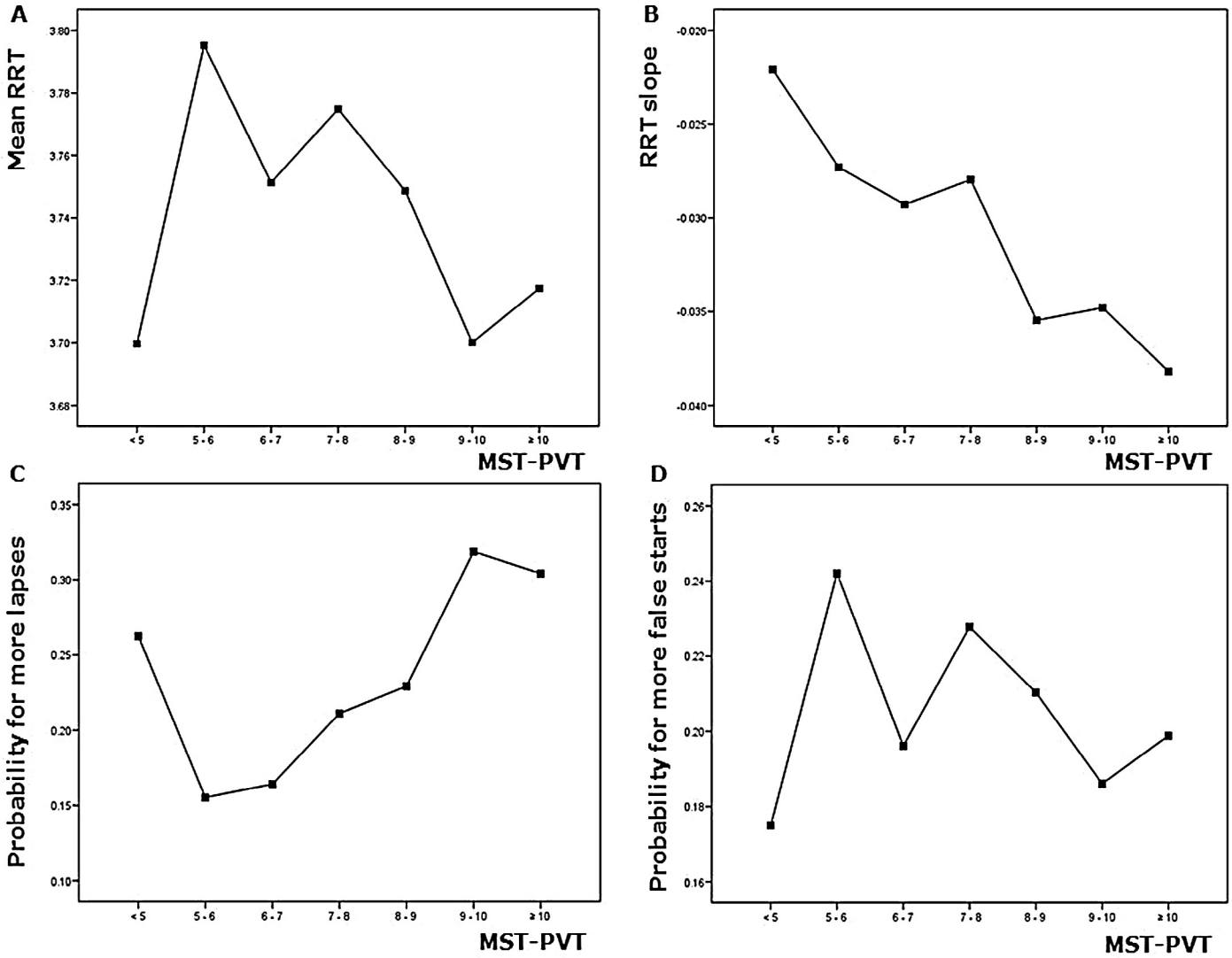

Fig. 1. PVT performance changes according to the interval between mid-sleep and PVT test time. Results shown in panels A, B, C, and D are derived from analysis of covariance for mean RRT (1/s) and RRT slope (Δ1/s/min), and from logistic regression analysis for more lapses (≥4) and false starts (≥3). Data are presented as estimated marginal means of mean RRT (A) and RRT slope (B), and average of predicted probability for more lapses (C) and false starts (D) in each segment of MST-PVT. MST-PVT refers to the interval between mid-sleep and PVT test time; PVT, psychomotor vigilance task; RRT, reciprocal response time.

were related to PVT performance. All these factors are highly likely to disrupt normal sleep. The reason for the absence of any relationship between PVT parameters and sleep-related symptoms, except daytime sleepiness, was elusive. Genetic factors may have a stronger influence on PVT performance than behavioral factors or prevalent sleep disorders at the population level [48–50].

It was demonstrated that PVT performance is dependent on the circadian phase of testing indicated by the MST-PVT, although it was analyzed only in a limited segment of circadian period (Table 6 and Fig. 1). The PVT parameters other than false start were largely under the influence of circadian rhythm, although the exact circadian phase for each MST-PVT segment could not be determined and thus cannot completely preclude homeostatic influences on PVT performance. The response speed and lapses, as well as RRT slope, worsened as the time interval between MST and PVT testing lengthened. Previous studies have shown a linear trend of improvement in PVT performance after the circadian nadir in the segment comparable to morning period [31,32]. Circadian influences on RRT slope had not been reported [31,32].

Finally, age and gender were also related to PVT performance. Female gender and older age were related to poor performance, as in the recent studies on psychomotor vigilance from the general or clinical population [7,19,20]. It is interesting that a higher level of education was positively correlated with PVT variables; the reason is unclear. Based on the assumption that academic achievement might be related to the level of motivation, subjects with a higher education level could show better PVT performance. In the present study, worse performance in subjects with depressive mood was demonstrated. This also may support the role of motivation in the PVT performance.

Although this is the first population-based study to measure psychomotor vigilance with PVT and explore the relationship between sleep-related factors and PVT performance, there are some methodological limitations that must be addressed. Restless legs syndrome (RLS), which is a prevalent condition [51], can lead to sleep disruptions and might affect the PVT performance. Certain portions of sleep-related complaints such as insomnia symptoms or poor sleep quality might result from the presence of RLS in the study

population. As a RLS questionnaire was not administered to the KoGES population during the study period, its effect on PVT performance could not be adjusted for.

Subjects who were taking medications that possibly affect psychomotor vigilance, such as anxiolytics, antidepressants, hypnotics, antihistamines or neuroleptics, were not excluded in the primary analysis. Although subjects with a history of a major neurologic or psychiatric illness were carefully excluded, who were highly likely to take medications that can affect psychomotor vigilance, it is still possible that drug use confounded the results. The number of subjects who were taking medications, as mentioned above, was relatively small (48, 1.9% of included subjects) and the association between subjective daytime sleepiness and PVT performance was significant in the subjects who were free from medication effects ($N = 2451$; mean age 57.0 ± 7.2 years; male 1245, 50.8%; Supplementary Data, Table S1). Poor sleep quality, insomnia symptoms, habitual snoring, and sleep duration were not related to PVT performance (Supplementary Data, Tables S1 and S2) in this medication-free subset.

In summary, population norms for PVT performance were provided, with limitations imposed by age and other characteristics of the KoGES cohort. The present study indicated that subjective daytime sleepiness is significantly related to impaired sustained attention measured by the standard PVT. These findings add evidence for the importance of healthy sleep on neurocognitive function. Further research is required to fully understand the determinants of PVT performance and subjective daytime sleepiness, and the correlation between PVT performance and various domains of neurocognitive function. The rate of change in PVT parameters as a marker of future cognitive dysfunction or dementia is also testable in epidemiological cohorts, and is of obvious importance.

Conflicts of interest

Robert J Thomas is a co-patent holder for an ECG-based analytic technique for phenotyping sleep and sleep apnea; he is also a patent holder for a method to treat central/mixed forms of apnea with adjunctive low concentration carbon dioxide. He consulted for and receives grant support from DeVilbiss Healthcare, in the area of auto-CPAP. He consults for GLG Councils in the general area of sleep disorders.

The ICMJE Uniform Disclosure Form for Potential Conflicts of Interest associated with this article can be viewed by clicking on the following link: http://dx.doi.org/10.1016/j.sleep.2014.07.028.

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Appendix: Supplementary material

Supplementary data to this article can be found online at doi:10.1016/j.sleep.2014.07.028.

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