

# Sleep-Disordered Breathing and Psychomotor Vigilance in a Community-Based Sample

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**Study Objective:** Sleep-disordered breathing (SDB) has been associated with impaired psychomotor vigilance performance in patients with sleep apnea patients. A bias toward greater referral of sleep apnea patients with severely impaired performance could explain these findings. Furthermore, no studies on the association between SDB and vigilance performance in a large community-based sample have been reported that encompasses the full spectrum of SDB severity. This study investigated the association between SDB and psychomotor vigilance with cross-sectional data from the Wisconsin Sleep Cohort Study.

**Setting and Participants:** Community-based sample of 265 women and 346 men, mean age of  $53.0 \pm 7.9$  (age range: 35-74) years was used. Within 6 months of completing an overnight polysomnography protocol for SDB assessment, participants completed a 10-minute psychomotor vigilance task (PVT) during a daytime protocol.

**Measurements:** Sleep-disordered breathing was indicated by the number of apneas and hypopneas; psychomotor vigilance task variables included

(1) mean of 1/reaction time (RT), (2) number of lapses, (3) mean reciprocal of fastest 10% RTs, (4) mean reciprocal of slowest 10% RTs, (5) slope of linear regression line across the 10 minutes of the task fit to 1/RTs, and (5) number of false responses.

**Results:** Multiple regression analysis showed a significant negative association between the logarithmically transformed apnea-hypopnea index (LogAHI) and number of lapses, mean of the slowest 10%, and number of false responses from the psychomotor vigilance task, independent of sex and body mass index in participants aged 65 years and older.

**Conclusion:** SDB in the community population is associated with impaired psychomotor vigilance in older men and women.

**Keywords:** Vigilance, sleep apnea, respiration, reaction times, epidemiology  
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SLEEP-DISORDERED BREATHING (SDB) IS A CONDITION CHARACTERIZED BY REPEATED BREATHING PAUSES AND REDUCED AIRFLOW DURING SLEEP, LEADING TO nocturnal arousals, unrefreshing sleep, and daytime sleepiness. SDB has been shown to be a contributing factor in diminished neurocognitive functioning.<sup>1-4</sup> Specifically, within the spectrum of neurocognitive deficits, vigilance impairment or inability to sustain attention is a frequent complaint of patients with SDB. Vigilance lapses have been shown to be associated with sleepiness—regardless of the cause—as well as with fatigue and alcohol impairment,<sup>5-7</sup> and the lapses have been found to be tightly coupled to slow eyelid closures,<sup>8</sup> which increase in frequency with drowsy driving<sup>9</sup> and contribute to motor vehicle crashes and occupation-related accidents.<sup>10</sup>

Significant associations between SDB and impaired vigilance have been shown in patient-based studies.<sup>3,11-13</sup> Because these studies were based on patients who may have been more likely to be referred to a sleep clinic if they experienced impaired vigilance, the association between SDB and impaired vigilance

may be overstated and may not be applicable to SDB in the community-based population.

In contrast with the results from patient-based studies, no significant relationships between SDB and vigilance impairment have been reported in samples of older community-dwelling adults selected independently of sleep complaints.<sup>14,15</sup> Although the data suggest that SDB in older people may not be associated with impairment, it is possible that methodologic differences, restricted age range, selection bias, or small sample size may explain the discrepancies in the findings between these and the findings from the patient-based studies.

SDB is common and the range of SDB severity is wide, but no studies on the association between SDB and vigilance in the community population based on a large sample have been reported that span the full range of SDB severity and age range in adults.

In a large community-based sample of middle-aged and older adults, we assessed the independent association between SDB and vigilance impairment as assessed by the psychomotor vigilance task (PVT), an instrument that is widely used in assessing the maintenance of alertness related to sleep deprivation and sleep disorders.<sup>7</sup> In addition, data on self-reported and polysomnographically determined sleepiness provided the opportunity to assess whether sleepiness mediates the associations of SDB with vigilance impairments and the impact of sleepiness on vigilance performance in a nonclinical population.

## METHODS

### Sample

A subset of the Wisconsin Sleep Cohort Study was analyzed for this investigation. The sample for the Wisconsin Sleep Cohort

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This was not an industry supported study. Dr. Dinges has received research support from Cephalon; has participated in speaking engagements for Cephalon, and Jazz Pharmaceuticals; and has consulted for Cephalon, Merck, Pfizer, GlaxoSmithKline, and Mars Masterfoods. Drs. Kim and Young have reported no financial conflicts of interest.

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Study was constructed as follows: All employees, aged 30 to 60 years, of 4 state agencies in south central Wisconsin were initially surveyed from 1989 to 2001 to create a defined sampling frame. A weighted sampling scheme, with oversampling of habitual snorers, was used to select invitees from the survey respondents to increase the variability in SDB for the Wisconsin Sleep Cohort. A complete description of the recruitment and sampling method are provided elsewhere.<sup>16</sup> These invitees were then recruited to undergo an extensive laboratory protocol that included an overnight polysomnogram and a daytime nap study conducted at 4-year intervals. The protocol for nighttime and daytime studies began in 1989, and the PVT data collection was included in the daytime study in 1996. Our data analysis utilizes the initial PVT from each subject.

The sample for this study comprised 265 women and 346 men who underwent a daytime study protocol consisting of the PVT conducted at least 3 days after the overnight study to allow assessment of usual performance. Mean time between the nighttime and the daytime evaluation was 1.2 ( $\pm 1.3$ ) months. Participants receiving treatment for SDB were excluded from analyses. Study protocol and informed consent were approved by the institutional review board of the University of Wisconsin-Madison Medical School.

## Measures

### Sleep-Disordered Breathing

SDB was assessed by standard nocturnal polysomnography. The nocturnal polysomnogram consisted of continuous polygraphic recording of electrooculography, electroencephalography, electrocardiography (single lead), tracheal sounds (microphone), nasal and oral airflow (dual-channel thermocouples; Pro-tech, Mukilteo, Wash), nasal pressure (pressure inducer; Validyne Engineering Corp., Northridge, Calif), thoracic and abdominal respiratory effort (inductance plethysmography; Respitrace, Ambulatory Monitoring, Ardsley, NY), and oxyhemoglobin saturation (finger-pulse oximeter, Ohmeda 3740, Englewood, Colo). All monitoring allowed normal positional changes during sleep.

All recordings were scored for sleep, respiration, oxyhemoglobin changes, and movement in 30-second epochs. Sleep stage was scored by standard criteria of Rechtschaffen and Kales.<sup>17</sup> Respiration was evaluated for apnea (cessation of airflow for 10 seconds or more) and hypopnea (reduction in respiratory effort accompanied by a 4% drop in oxyhemoglobin saturation). An apnea-hypopnea index (AHI) was defined as the number of apneas and hypopneas per hour of total sleep time. Minimum requirements for acceptable quality of sleep polysomnography were adequate signals throughout the night, at least 240 minutes of objectively measured sleep, and at least 1 rapid eye movement period.

### Psychomotor Vigilance Task

Vigilance performance was assessed using the PVT, which has been tested under a number of conditions recognized to induce neurocognitive deficits due to sleep loss, including total sleep deprivation, chronic partial sleep deprivation, sleep fragmentation, and disorders of excessive sleepiness, including untreated SDB.<sup>5,7</sup> Irrespective of the mode of sleep loss, results of extensive experiments on PVT performance have demonstrated that the task is capable of capturing the effects of sleep loss on the stability of

**Table 1**—Characteristics of the Sample (n=611)

Variable	
AHI, median (range)	2.79 (0-120.8)
AHI, mean (SD)	7.6 (12.8)
AHI category, n (%)	
< 5	394 (64.5)
5-15	127 (20.8)
> 15	90 (14.7)
Age in years, mean (SD)	53.0 (7.94)
Men, n (%)	346 (56.6)
BMI, kg/m <sup>2</sup> , mean (SD)	31.3 (6.8)
Caffeine consumption	
Units <sup>a</sup> /day, mean (SD)	3.1 (2.5)
Alcohol consumption	
Units <sup>b</sup> /week, mean (SD)	3.5 (4.8)
Smoking status, n (%)	
Never and past	517 (84.6)
Current	94 (15.4)
Caffeine or stimulant use prior to PVT testing <sup>c</sup>	
Yes	341 (56.0)
No	268 (44.0)
MSLT, mean (SD)	10.2 (5.0)
MSLT, n (%)	
< 5	108 (17.7)
5-10	217 (35.5)
> 10	286 (46.8)
ESS <sup>d</sup> , median (range)	9.0 (1-23)
ESS <sup>d</sup> , n (%)	
< 11	366 (63.2)
≥ 11	213 (36.8)

AHI refers to apnea-hypopnea index; BMI, body mass index; PVT, Psychomotor Vigilance Task; MSLT, Multiple Sleep Latency Test; ESS, Epworth Sleepiness Scale.

<sup>a</sup>Number of caffeinated coffee, tea, and soft drinks.

<sup>b</sup>Number of beers, glasses of wine, and shots of hard liquor.

<sup>c</sup>Data available for 609 subjects.

<sup>d</sup>Data available for 579 subjects.

sustained attention and the benefits of interventions for sleepiness.<sup>7</sup> The PVT was designed to be easy to perform when alert, and, unlike most other cognitive tests, it is not affected by aptitude and learning.

A portable PVT device (Model PVT-192, CWE, Inc, Ardmore, PA), based on the original test described by Dinges and Powell (1985),<sup>18</sup> was used to electronically measure the ability to sustain attention to a variable visual stimulus by responding in a timely manner over a 10-minute period (resulting in 60-90 reaction times [RTs], depending on RT latency). The task consisted of responding by button press to a small, bright red-light stimulus (light-emitting diode digital counter) as soon as the stimulus appeared. This stopped the counter and displayed the RT in milliseconds for a 1-second period. Consecutive stimuli appeared randomly in the range of 2 to 10 seconds. The subject was instructed to press the button as soon as possible to keep the RT number as low as possible, but not to press the button too soon (which yielded a false-start warning on the display). The task was performed at 10:00 and at 14:00 during the daytime nap study. The PVT was administered by a trained technician, and each subject was instructed on how to perform the task. A single 1-minute acclimation practice was given before the first trial.

**Table 2**—Psychomotor Vigilance Task Scores by Apnea-Hypopnea Index Category

	AHI Category		
	< 5	5-15	> 15
No.	394	145	90
1/RT	3.96 (0.46)	3.87 (0.43)	3.97 (0.54)
LAPSES	2.22 (1.19)	2.32 (1.15)	2.54 (1.71)
FALSE RT	2.07 (1.37)	2.46 (1.50)	2.59 (1.59)
FASTEST 10%	4.92 (0.50)	4.84 (0.50)	4.97 (0.59)
SLOWEST 10%	2.68 (0.45)	2.59 (0.42)	2.61 (0.60)
SLOPE	0.002 (0.04)	-0.001 (0.04)	-0.004 (0.04)

Data are expressed as mean (SD). AHI refers to apnea-hypopnea index; 1/RT, mean reciprocal reaction time (RT) in seconds<sup>-1</sup>; LAPSES, number of responses  $\geq$  500 milliseconds (transformed:  $\sqrt{x} + \sqrt{x+1}$ ); FALSE RT, number of false responses (transformed:  $\sqrt{x} + \sqrt{x+1}$ ); FASTEST 10%, mean of the reciprocal of the fastest 10% RTs (seconds<sup>-1</sup>); SLOWEST 10%, mean of the reciprocal of the fastest 10% RTs (seconds<sup>-1</sup>); SLOPE, slope of the linear regression line fit to the 1/RTs. Higher scores on 1/RT, FASTEST 10%, SLOWEST 10%, and SLOPE indicate better performance; higher scores on LAPSES and FALSE RT indicate worse performance.

The following 6 PVT performance outcomes were extracted from each 10-minute test bout and analyzed: (1) response speed defined as mean 1/RT (seconds<sup>-1</sup>) during the 10 minute testing period, labeled 1/RT; (2) total number of lapses (RTs  $\geq$  500 ms) subjected to Tukey transform ( $\sqrt{x} + \sqrt{x+1}$ ), labeled LAPSES; (3) total number of response errors (responses when no stimulus was present) subjected to Tukey transform, labeled FALSE RT; (4) the mean of the reciprocal of the fastest 10% RTs (seconds<sup>-1</sup>), labeled FASTEST 10%; (5) the mean of the reciprocal of the slowest 10% RTs (seconds<sup>-1</sup>), labeled SLOWEST 10%; and (6) slope of linear regression line across the 10 minutes of the task fit to the transformed 1/RTs (seconds<sup>-1</sup>), labeled SLOPE. Reciprocal and Tukey transformation ( $\sqrt{x} + \sqrt{x+1}$ ) were used to provide normal distribution of the variables. Higher scores on the 1/RT, FASTEST 10%, SLOWEST 10%, and SLOPE indicate better performance; higher scores on LAPSES and FALSE RT indicate poorer performance.

### Covariates

Data on sex, age, body mass index (BMI), usual caffeine consumption (number of drinks containing caffeine consumed per day), smoking status (current vs never and past user), alcohol consumption (number of beers, glasses of wine, and shots of liquor per week), and the Epworth Sleepiness Scale (ESS)<sup>19</sup> from the overnight protocol were used to evaluate potential confounding or interactions. In addition to usual caffeine consumption, we evaluated the effect of caffeine or stimulant intake the day of PVT testing. Participants were asked, "Did you have any coffee or other stimulants this morning?" Answers were coded as *yes* or *no*. In addition, objective sleepiness was measured by the Multiple Sleep Latency Test (MSLT).<sup>20</sup> Briefly, the MSLT consisted of 4-

**Table 3**—Age- and Sex-Stratified Psychomotor Vigilance Task Variables

	Age, y			
	35-44	45-54	55-64	65-74
<b>Men</b>				
n	44	145	114	43
1/RT	4.23 (0.45)	4.08 (0.49)	3.95 (0.50)	3.88 (0.52)
LAPSES	1.95 (0.93)	2.12 (1.44)	2.42 (1.29)	2.45 (1.75)
FALSE RT	2.26 (1.33)	2.14 (1.36)	2.19 (1.64)	2.75 (1.56)
FASTEST 10%	5.21 (0.55)	5.03 (0.51)	4.92 (0.52)	4.84 (0.61)
SLOWEST 10%	2.87 (0.47)	2.78 (0.50)	2.62 (0.51)	2.56 (0.57)
SLOPE	0.0036 (0.03)	0.0026 (0.04)	0.0038 (0.04)	-0.0051 (0.03)
<b>Women</b>				
n	37	115	90	23
1/RT	3.98 (0.67)	3.84 (0.54)	3.77 (0.45)	3.76 (0.53)
LAPSES	1.97 (1.42)	2.22 (1.46)	2.54 (1.25)	2.52 (1.70)
FALSE RT	1.93 (1.49)	1.93 (1.30)	2.19 (1.39)	2.02 (0.77)
FASTEST 10%	4.94 (0.78)	4.81 (0.58)	4.77 (0.51)	4.66 (0.55)
SLOWEST 10%	2.76 (0.57)	2.61 (0.58)	2.49 (0.42)	2.51 (0.58)
SLOPE	-0.0085 (0.04)	-0.0070 (0.05)	-0.0006 (0.04)	0.0066 (0.03)

Data are expressed as mean (SD). 1/RT refers to mean reciprocal reaction time (RT) in seconds<sup>-1</sup>; LAPSES, number of responses  $\geq$  500 milliseconds (transformed:  $\sqrt{x} + \sqrt{x+1}$ ); FALSE RT, number of false responses (transformed:  $\sqrt{x} + \sqrt{x+1}$ ); FASTEST 10%, mean of the reciprocal of the fastest 10% RTs (seconds<sup>-1</sup>); SLOWEST 10%, mean of the reciprocal of the fastest 10% RTs (seconds<sup>-1</sup>); SLOPE, slope of the linear regression line fit to the 1/RTs. Higher scores on 1/RT, FASTEST 10%, SLOWEST 10%, and SLOPE indicate better performance; higher scores on LAPSES and FALSE RT indicate worse performance.

nap trials at 2-hour intervals while the subject was lying down in a darkened bedroom. The trial was terminated by onset of electroencephalographically determined sleep or 20 minutes if sleep did not occur. An average of the 4-nap trials' time to sleep onset was used for analysis.

### Statistical analyses

All analyses were performed by using SAS (SAS Institute, Inc., Cary, NC) and SUDAAN software (Research Triangle Institute, Research Triangle Park, NC). SUDAAN was used to provide unbiased, population estimates of sex- and age-stratified means and variances of the PVT variables. SUDAAN procedures use appropriate statistical techniques and sample weights to account for the study design (oversampling of habitual snorers) when estimating population means and prevalences. For regression analyses, SAS software was used. In linear modeling, adjustment for factors that were affected by the sampling scheme (age and sex) takes into

**Table 4**—Multiple Linear Regression Model for Psychomotor Vigilance Task Variables Fitted by LogAHI, Age, Sex, and Body Mass Index (n=611)

Independent Variables	Dependent Variables <sup>a</sup>					
	1/RT	LAPSES	FALSE RT	FASTEST 10%	SLOWEST 10%	SLOPE
	$\beta^b$ (SE) <sup>c</sup>	$\beta$ (SE)	$\beta$ (SE)	$\beta$ (SE)	$\beta$ (SE)	$\beta$ (SE)
Intercept	5.1263 (0.1551)	-0.1639 (0.4420)	1.7686 (0.5125)	6.0268 (0.1754)	3.8872 (0.1592)	0.0132 (0.0139)
LogAHI	0.0003 (0.0196)	0.0600 (0.0559)	0.1362 <sup>d</sup> (0.0648)	0.0168 (0.0222)	-0.0103 (0.0201)	-0.0017 (0.0018)
Age	-0.0718 <sup>d</sup> (0.0023)	0.1360 <sup>d</sup> (0.0066)	0.0150 (0.0076)	-0.0745 <sup>d</sup> (0.0026)	-0.0735 <sup>d</sup> (0.0024)	0.0005 (0.0002)
Sex (1 = women)	-0.2040 <sup>d</sup> (0.0384)	0.1635 (0.1093)	-0.1390 (0.1268)	-0.1772 <sup>d</sup> (0.0434)	-0.1343 <sup>d</sup> (0.0394)	-0.0051 (0.0034)
BMI	-0.0214 <sup>d</sup> (0.0030)	0.0542 <sup>d</sup> (0.0086)	0.0100 (0.0100)	-0.0174 <sup>d</sup> (0.0034)	-0.0246 <sup>d</sup> (0.0031)	-0.0008 (0.0003)

<sup>a</sup>1/RT refers to mean reciprocal reaction time (seconds<sup>-1</sup>); LAPSES, number of responses  $\geq 500$  milliseconds (transformed:  $\sqrt{x + \sqrt{x+1}}$ ); FALSE RT, number of false responses (transformed:  $\sqrt{x + \sqrt{x+1}}$ ); FASTEST 10%, mean of the reciprocal of the fastest 10% RTs (seconds<sup>-1</sup>); SLOWEST 10%, mean of the reciprocal of the fastest 10% RTs (seconds<sup>-1</sup>); SLOPE, slope of the linear regression line fit to the 1/RTs. Higher scores on 1/RT, FASTEST 10%, SLOWEST 10%, and SLOPE indicate better performance; higher scores on LAPSES and FALSE RT indicate worse performance. LogAHI refers to the ln (apnea-hypopnea index +1); age, 5-y change in age; BMI, 2-unit change in body mass index.

<sup>b</sup> $\beta$  is the regression coefficient of the variable.

<sup>c</sup>SE is the standard error of  $\beta$ .

<sup>d</sup>p-value < 0.05

**Table 5**—Association Between Sleep-Disordered Breathing, and Psychomotor Vigilance Task Stratified by Age (n=611)

Age group, y	n	Dependent Variables <sup>a</sup>					
		1/RT	LAPSES	FALSE RT	FASTEST 10%	SLOWEST 10%	SLOPE
		$\beta^b$ (SE) <sup>c</sup>	$\beta$ (SE)	$\beta$ (SE)	$\beta$ (SE)	$\beta$ (SE)	$\beta$ (SE)
35-44	81	-0.0280 (0.0782)	0.0127 (0.1785)	-0.0424 (0.2808)	-0.0602 (0.0914)	0.0162 (0.0752)	0.0029 (0.0064)
45-54	260	-0.0243 (0.0278)	0.0711 (0.0826)	0.1160 (0.0907)	-0.0175 (0.0315)	-0.0075 (0.0300)	-0.0043 (0.0027)
55-64	204	0.0379 (0.0349)	-0.1263 (0.0933)	0.0902 (0.1173)	0.0633 (0.0386)	0.0279 (0.0339)	0.0023 (0.0030)
65-74	66	0.0057 (0.0579)	0.4935 <sup>d</sup> (0.1904)	0.4022 <sup>d</sup> (0.1560)	0.0688 (0.0650)	-0.1326 <sup>d</sup> (0.0610)	-0.0051 (0.0043)

<sup>a</sup>RT refers to mean reciprocal reaction time (RT) in seconds<sup>-1</sup>; LAPSES, number of responses  $\geq 500$  milliseconds (transformed:  $\sqrt{x + \sqrt{x+1}}$ ); FALSE RT, number of false responses (transformed:  $\sqrt{x + \sqrt{x+1}}$ ); FASTEST 10%, mean of the reciprocal of the fastest 10% RTs (seconds<sup>-1</sup>); SLOWEST 10%, mean of the reciprocal of the fastest 10% RTs (seconds<sup>-1</sup>); SLOPE, slope of the linear regression line fit to the 1/RTs. Higher scores on 1/RT, FASTEST 10%, SLOWEST 10%, and SLOPE indicate better performance; higher scores on LAPSES and FALSE RT indicate worse performance.

<sup>b</sup> $\beta$  is the regression coefficient of LogAHI ln((apnea-hypopnea index +1)), adjusting for sex and body mass index.

<sup>c</sup>SE is the standard error of  $\beta$ .

<sup>d</sup>p-value < 0.05

account effects of the oversampling. In addition, our variable of interest, AHI, is the primary sampling factor, and, because we are looking for relationships between AHI and other variables, rather than population means and prevalences, standard linear modeling is appropriate.

For regression analysis, AHI was transformed to natural logarithm of AHI + 1 (LogAHI) to meet the assumption of linearity and homoscedacity between AHI and the PVT variables. Multiple regression analysis was used to estimate the relationship between LogAHI and PVT variables. In addition, multiple regression anal-

ysis was used to estimate the association between SDB and PVT variables using SDB as a categorical variable (AHI: <5, 5-15, >15). Age, sex, and BMI were included in all models. Additional potential confounding variables (usual caffeine and alcohol consumption, smoking status, and use of caffeine or stimulants before PVT testing) were added singly to the model with LogAHI, age, sex, and BMI to determine if adjusting for those variables changed the relationships between LogAHI and PVT variables. A variable was considered to be confounder when its inclusion in the regression changed the coefficient of LogAHI by more than

**Table 6**—Relationship Between Sleepiness (MSLT and ESS) and Psychomotor Vigilance Task Variables in the 65- to 74-Year Age Group (n=66)

	1/RT		LAPSES		FALSE RT		FASTEST 10%		SLOWEST 10%		SLOPE	
	$\beta^a$ (SE) <sup>b</sup>	P-value	$\beta$ (SE)	P-value	$\beta$ (SE)	P-value	$\beta$ (SE)	P-value	$\beta$ (SE)	P-value	$\beta$ (SE)	P-value
Model												
MSLT <sup>c</sup>	-0.0045 (0.0125)	0.7200	0.0097 (0.0411)	0.8131	-0.0146 (0.0336)	0.6669	0.0041 (0.0140)	0.7687	-0.0063 (0.0132)	0.6331	0.0002 (0.0009)	0.8193
ESS <sup>c</sup>	-0.0389 (0.0129)	0.0039	0.1051 (0.0437)	0.0195	-0.0048 (0.0359)	0.8931	-0.0391 (0.0146)	0.0099	-0.0355 (0.0140)	0.0139	-0.0014 (0.0009)	0.1333

1/RT refers to mean reciprocal reaction time (RT) in seconds<sup>-1</sup>; LAPSES, number of responses  $\geq 500$  milliseconds (transformed:  $\sqrt{x} + \sqrt{x+1}$ ); FALSE RT, number of false responses (transformed:  $\sqrt{x} + \sqrt{x+1}$ ); FASTEST 10%, mean of the reciprocal of the fastest 10% RTs (seconds<sup>-1</sup>); SLOWEST 10%, mean of the reciprocal of the fastest 10% RTs (seconds<sup>-1</sup>); SLOPE, slope of the linear regression line fit to the 1/RTs. Higher scores on 1/RT, FASTEST 10%, SLOWEST 10%, and SLOPE indicate better performance; higher scores on LAPSES and FALSE RT indicate worse performance. MSLT refers to Multiple Sleep Latency Test; ESS, Epworth Sleepiness Scale (based on n = 62).

<sup>a</sup> $\beta$  is the regression coefficient of the sleepiness variable

<sup>b</sup>SE is the standard error of  $\beta$ .

<sup>c</sup>Adjusting for ln(apnea-hypopnea index +1), sex, and body mass index (BMI).

10%. In addition, multiple regression analysis was used to assess the relationship between LogAHI and PVT, stratified by sex and age (10-year intervals: 35-44, 45-54, 55-64, 65-74). Test of significance was set at a P value < 0.05.

## RESULTS

The complete data on the 6 PVT outcome variables were available for 611 subjects. The characteristics of the sample are shown in Table 1. The average of PVT trials completed at 10:00 and 14:00 was used for subsequent analysis, since the results showed no differences between the 2 trials (data not shown). PVT scores by AHI category are shown in Table 2. The sex- and age-stratified means of the PVT variables are shown in Table 3.

### Association Between SDB, Covariates, and PVT Variables

Regression models for PVT variables are given in Table 4. LogAHI was significantly related to only the FALSE RT variable (coefficient of LogAHI ( $\beta$ ) = 0.1362,  $P=0.036$ ), adjusting for age, sex, and BMI. Higher AHI was associated with a greater FALSE RT. No significant associations were seen between LogAHI and other variables of the PVT (1/RT, LAPSES, FASTEST 10%, SLOWEST 10%, and SLOPE). The results did not vary when the analyses were performed using SDB as a categorical variable (AHI: <5, 5-15, >15).

In the same model, older age and higher BMI were significantly related to poorer response speed (1/RT) performance (coefficient of 5-year change in age ( $\beta$ ) = -0.0718,  $P<0.0001$ ; coefficient of 2-unit change in BMI ( $\beta$ ) = -0.0214,  $P = 0.0004$ ); to more frequent LAPSES (coefficient of 5-year change in age ( $\beta$ ) = 0.1360,  $P < 0.0001$ ; coefficient of 2-unit change in BMI ( $\beta$ ) = 0.0542,  $P=0.0017$ ); to slower FASTEST 10% (coefficient of 5-year change in age ( $\beta$ ) = -0.0745,  $P<0.0001$ ; coefficient of 2-unit change in BMI ( $\beta$ ) = -0.0174,  $P = 0.0108$ ); and to slower SLOWEST 10% (coefficient of 5-year change in age ( $\beta$ ) = -0.0735,  $P < 0.0001$ ; coefficient of 2-unit change in BMI ( $\beta$ ) = -0.0246,  $P<0.0001$ ). Women performed significantly slower than men on all PVT RT speed measures: 1/RT (coefficient of sex ( $\beta$ ) = -0.2040,  $P < 0.0001$ );

FASTEST 10% (coefficient of sex ( $\beta$ ) = -0.1772,  $P < 0.0001$ ); SLOWEST 10% (coefficient of sex ( $\beta$ ) = -0.1343,  $P = 0.0007$ ).

The associations of LogAHI and the PVT variables were not affected by caffeine and alcohol consumption per week, smoking status, or the use of caffeine or stimulants prior to PVT testing. In models with singly added covariates, smoking status was significantly related to poorer performance on the PVT time-on-task SLOPE (coefficient of current vs past and nonsmokers ( $\beta$ ) = -0.0096,  $P = 0.0305$ ), and the use of caffeine or stimulants prior to PVT testing was related to longer RTs from the SLOWEST 10% (coefficient of caffeine or stimulant use ( $\beta$ ) = -0.0906,  $P = 0.0137$ ), independent of LogAHI, age, sex, and BMI.

### Association Between SDB and PVT Variables Stratified By Sex and Age

After stratifying by sex, the multiple regression analysis showed no significant associations between LogAHI and the PVT variables in either men or women. After stratifying by age groups, multiple regression analysis revealed significant relationships between higher LogAHI and poorer PVT performance (Table 5). The frequency of LAPSES (coefficient of Log AHI ( $\beta$ ) = 0.4935,  $P=0.0119$ ) and FALSE RTs (coefficient of Log AHI ( $\beta$ ) = 0.4022,  $P=0.0123$ ) increased as LogAHI increased in the 65- to 74-year age group. The duration of lapses, as measured by SLOWEST 10%, also increased in this age group as LogAHI increased (coefficient of Log AHI ( $\beta$ ) = -0.1326,  $P = 0.0337$ ). No significant relationships between LogAHI and PVT variables were seen in groups aged 35 to 64 years.

To assess whether sleepiness mediates the association between SDB and vigilance impairment in the 65- to 74-year age group, ESS and the MSLT variables were singly added into the models. Neither the ESS nor the MSLT sleepiness variable significantly changed the coefficient of LogAHI. The analyses also showed that higher ESS was significantly related to slower response speed or 1/RT (coefficient of ESS ( $\beta$ ) = -0.0389,  $P = 0.0039$ ), to increased LAPSES (coefficient of ESS ( $\beta$ ) = 0.1051,  $P=0.0195$ ), and to longer duration on FASTEST 10% (coefficient of ESS( $\beta$ ) = -0.0391,  $P=0.0099$ ) and SLOWEST 10% (coefficient of ESS( $\beta$ ) =

= -0.0355,  $P = 0.0139$ ) from the PVT (Table 6). No significant relationships were seen between the MSLT and the PVT variables.

## DISCUSSION

We investigated the association between SDB and impaired vigilance performance in a community-based sample of middle-aged and older adults, aged 30 to 75 years, with a wide range in SDB severity (median AHI 2.79, range 0-120.8). The main findings of this cross-sectional analysis of the WSCS data reveal that SDB is related to diminished vigilant attention performance, as measured by the PVT in men and women in the upper age range (65-74 years). There was no significant association between SDB and PVT performance among those younger than 65 years of age.

Past studies have found no associations between SDB and vigilance-related performance in older, community-dwelling people selected independent of sleep complaints. For example, Knight et al<sup>14</sup> showed no significant relationship between apnea events and the Letter Cancellation Test performance in a sample of adults aged 64 years or older who lived in nursing homes. Also, Ingram et al<sup>15</sup> reported no significant relationship between SDB and performance on the Steer Clear Test in a healthy community-dwelling sample with mean age of 62 years. It is difficult to resolve our findings with previous reports, since study design, including measures of SDB and vigilance, varied between studies. The association between SDB and diminished accuracy in vigilance performance seen in our study may have been attributed to the sensitivity of the PVT relative to other tests of vigilant attention.<sup>21</sup>

Our findings of a significant relationship between reduced PVT performance and older age are expected and consistent with previous research showing the tendency for older subjects to show poorer performance in vigilance-related tasks.<sup>15,22</sup> In addition, the significant poorer vigilance performance in women, compared with men, seen in our results has been shown in prior studies.<sup>23,24</sup> The reasons for the sex differences in PVT response speed are not likely to reflect aptitude differences<sup>24,25</sup> as much as differences between men and women in response bias—men tend to bias toward speed whereas women tend to bias toward accuracy, which is consistent with our finding that men had significantly shorter RTs overall, but they also averaged a higher number of false responses.

Our findings may be limited by incomplete control for confounding factors. We controlled for several possible confounding variables, including age, sex, and BMI, in our analysis. In addition, we investigated the use of stimulants as a potential negative confounder in the association between SDB and vigilance, whereby participants with SDB may have greater use of stimulants and consequently have better performance. However, we found that adding potential confounding variables (usual caffeine and alcohol consumption, smoking status, use of caffeine or stimulants before PVT testing) singly to the model with LogAHI, age, sex, and BMI did not change the findings of no relationships between LogAHI and PVT variables.

Interestingly, we found that neither of the widely used measures of clinical sleepiness—the ESS and the MSLT—explained the relationship between SDB and the PVT variables, suggesting that both objective and subjective sleepiness do not mediate a SDB-vigilance relationship in the community-dwelling elderly population. This suggests that, although the PVT is sensitive to sleepiness resulting from a wide variety of conditions,<sup>7</sup> its relationship to SDB in the community-dwelling elderly may reflect

a neurocognitive deficit associated with non-sleepiness-related pathophysiologic factors.

Psychomotor vigilance performance was related to subjective sleepiness, as measured by the ESS. Higher ESS scores were associated with reduced PVT performance (i.e., more lapses of attention and slower RTs). However, scores on the MSLT were not significantly related to PVT performance variables. Differential relationships between clinical sleepiness measures and the PVT variables are congruent with results from previous studies showing poor agreement between subjective and objective measures of sleepiness.<sup>19,26</sup> These findings support the contention that sleepiness may be multidimensional<sup>27-29</sup> and that more research is needed on the neurobehavioral and neurobiologic bases of different sleepiness measures. It is also important to note that sleepiness measures can be differentially affected by both sleep disorders and lifestyle factors.

Our analysis was restricted to participants who had nighttime polysomnograms and daytime PVT assessments within 6 months (median of 21 days), but not within 3 days. The exclusion of those having polysomnograms and daytime PVT assessments in close proximity was to ensure that PVT performance would not be affected by any sleep disturbances associated with the overnight polysomnogram. Further investigation showed that most (75%) reported sleeping “as usual” or better the night before the PVT testing and that the sleep quality did not affect the relationship between SDB and PVT. In addition, it is possible that the time lag may have resulted in PVT measures that differed from what would have been measured at the time of the SDB data collection. However, SDB is a condition that is considered chronic in nature, and we expect minimal change over a 6-month period. We found a significant association between SDB severity and PVT performance in older individuals despite the variability in timing of the 2 measures. It is unclear whether the failure to find this relationship in other age groups was due to random variability in the temporal separation of the nighttime sleep and daytime vigilance measures. We investigated the influence of time between the polysomnography and PVT assessments by including a variable for time lag (in days) in the analyses. We found no discernable change in the regression coefficients of SDB after adding the time-lag variable in the models.

Although studies have shown the prevalence of SDB to increase with age,<sup>30-32</sup> there is debate as to whether the significance of SDB in older adults is equal to that of SDB in middle-aged adults.<sup>33</sup> Several studies have reported little or no association of SDB with sleepiness, hypertension, or diminished cognitive functioning in older adults.<sup>34-37</sup> Consequently, there has been some controversy regarding the benefit of diagnosis and treatment of mild or moderate sleep apnea in older people. However, our findings of an association of SDB and decreased vigilance performance in older people provide some evidence that SDB does have significant functional consequences in older people. A recent study of older adults found that excessive sleepiness was multifactorial and that severe SDB was but one of a number of contributors to it.<sup>38</sup>

Some studies have shown that treatment of SDB with continuous positive airway pressure (CPAP) improves vigilance in patients with sleep apnea,<sup>39,40</sup> but little is known regarding CPAP efficacy in older people with low to moderate SDB severity. Studies are critically needed to assess vigilance performance-related benefits of SDB treatment specifically in older people.

An important consideration in interpreting our results is measurement validity of the PVT. This test has been extensively validated in laboratory, clinical, and field studies to be sensitive to sleepiness from a wide range of conditions.<sup>7</sup> It has been found to predict sleep attacks and eyelid closures while driving, which has resulted in its use in safety-sensitive operational studies in all transportation modes.<sup>7</sup> However, the extent to which this test, or any other subjective or objective measure of sleepiness, can accurately predict accidents, remains probabilistic at best. Since the PVT reveals the effects of sleepiness on the ability to sustain attention and respond quickly—performance features of driving and other every-day tasks—it has relevance to the functional consequences of sleepiness.

In summary, the present study represents the largest epidemiologic dataset to date on objectively measured SDB and psychomotor vigilance performance, and it provides evidence that SDB is associated with diminished vigilance capability in adults over 65 years of age. Prospective studies are needed to further investigate SDB and aging, including age-related changes in tasks requiring vigilant attention and other neurocognitive functions. A better understanding of both the health significance of SDB and treatment outcomes is critical to ensure equitable health care for SDB in older adults.

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