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HEAD AND NECK

Utility of the psychomotor vigilance task in screening for obstructive sleep apnoea

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Abstract

Purpose The study aimed to assess the performance of the PVT in patients with suspected OSA, evaluate its role in population screening for OSA.

Methods The NoSAS, STOP-Bang, ESS scores and PVT tests were performed after suspected OSA patients' admission, followed by PSG. Then we compared the PVT results, calculated the sensitivity, specificity and ROC curve of PVT, and analyzed the accuracy of STOP-Bang and NoSAS questionnaire combined with PVT in predicting OSA.

Results A total of 308 patients were divided into four groups based on AHI: primary snoring (2.74 ± 1.4 events/h, $n = 37$); mild OSA (9.96 ± 3.25 events/h, $n = 65$); moderate OSA (22.41 ± 4.48 events/h, $n = 76$); and, severe OSA (59.42 ± 18.37 events/h, $n = 130$). There were significant differences in PVT lapses ($p < 0.001$) and reaction time (RT, $p = 0.03$) among the four groups. The PVT lapses and RT were positively correlated with AHI ($p < 0.001$) and ODI ($p < 0.001$), and negatively correlated with $LSpO_2$ ($p < 0.001$). When diagnosing OSA (AHI ≥ 5 events/h), the AUCs of PVT, ESS, STOP-Bang, and NoSAS were 0.679, 0.579, 0.727, and 0.653, respectively; the AUCs of STOP-Bang and NoSAS combined with PVT increased. After combined PVT, the diagnostic specificity of STOP-Bang and NoSAS at nodes with AHI $\geq 5, \geq 15$ and ≥ 30 events/h increased to varying degrees.

Conclusion Patients with OSA exhibited impairment in the PVT, and the combination of the PVT and STOP-Bang or NoSAS scores can improve the diagnostic efficacy and specificity for OSA.

Keywords Obstructive sleep apnea · Psychomotor vigilance task · Diagnostic efficacy · STOP-Bang questionnaire · NoSAS questionnaire

Introduction

Obstructive sleep apnoea (OSA) is a sleep disorder characterised by repeated episodes of partial or complete obstruction of the upper airways, resulting in intermittent hypoxia, sleep fragmentation and daytime sleepiness [1]. The most common symptoms of OSA include loud snoring, excessive daytime sleepiness, morning headaches, dry mouth, sore throat upon awakening, and restless sleep. Individuals with OSA may also experience irritability, difficulty concentrating, and depression. OSA can be caused by various factors, including obesity, large neck circumference (NC), nasal congestion, and abnormalities in the structure of the upper airway. It can lead to serious health problems, including high blood pressure, heart disease, stroke, and diabetes. The prevalence of OSA is approximately 1%-5% in children, 9% in adult females, and 24% in adult males [2, 3]; unfortunately,

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a large proportion of OSA in the general population is undiagnosed [4].

Polysomnography (PSG) is the most comprehensive method used to diagnose OSA; however, it is expensive, time-consuming, and uncomfortable. As a result, alternative screening methods have been developed, such as the STOP-Bang questionnaire, the NoSAS (NC, Obesity, Snoring, Age and Sex) score, and the Epworth Sleepiness Scale (ESS). The NoSAS and STOP-Bang are relatively simple and can be administered by healthcare providers in clinical settings. A meta-analysis confirmed the high performance of the STOP-Bang questionnaire for screening OSA in sleep clinics and surgical populations; more specifically, the higher the STOP-Bang score, the greater the likelihood of moderate-to-severe OSA [5]. Similarly, the NoSAS score has demonstrated high sensitivity and positive predictive value for OSA, with a steady increase in specificity and diagnostic accuracy steadily increasing with higher scores [6]. Unlike the NoSAS and STOP-Bang, the ESS, a self-administered questionnaire used to assess an individual's level of daytime sleepiness, exhibits lower sensitivity and higher specificity for OSA [7]. When combined with the ESS, however, both the STOP-Bang questionnaire and the NoSAS score have improved specificity for screening OSA [8, 9]. The Multiple Sleep Latency Test (MSLT) is an objective, and diagnostic test used to evaluate excessive daytime sleepiness and has been reported to be more strongly associated with apnoea-hypopnoea index (AHI) than the ESS [10]. However, the MSLT has disadvantages in terms of time and cost.

The psychomotor vigilance task (PVT) is a simple and noninvasive test to assess vigilant attention [11]. Vigilance, a component of cognition, is most consistently and significantly affected in sleep-deprived individuals [12]. The PVT records reaction time to visual stimuli presented at random intervals of 2–10 s inter-stimulus over 10 min, has virtually no learning curve, and is independent of aptitude [13]. Sleep deprivation induces reliable changes in PVT performance, making it sensitive to sleep disruption; therefore, the PVT is considered to be an objective indicator of cognitive impairment in sleepiness [14]. A cross-sectional study concluded that the PVT can be used to assess sleepiness risk and may be particularly useful in populations in which subjective reports are unreliable [15]. Although primary studies have found no correlation between PVT performance and AHI [15, 16], it has been reported that impaired performance on the PVT may be due to chronic sleep deprivation and insufficient sleep duration in patients with OSA [17].

Given that the PVT can serve as an objective indicator of sleepiness in patients with OSA, we performed the PVT in patients with suspected OSA, and then analyzed their PSG data to assess PVT performance in those patients, evaluate its diagnostic effect on OSA, and further explore its utility in combination with STOP-Bang or NoSAS in the screening of suspected OSA population.

Methods

Study Design and Setting

A case–control study was conducted to investigate the association between PVT and OSA in patients with suspected OSA who visited our hospital between August 2022 and March 2023 and underwent inpatient PSG. All participants were admitted to the Sleep Medical Centre overnight, and clinical data, including demographic information (gender, age, occupation), anthropometric parameters (height, weight, NC, waist circumference [WC]), and medical history (hypertension, diabetes, cardiovascular and cerebrovascular diseases, smoking and drinking history) were collected. All patients were required to complete the NoSAS, STOP-Bang, ESS and PVT 4 h before the PSG examination. The research staff was not involved in the interpretation or completion of the questionnaires.

Study population

This study focused on patients with suspected OSA who received inpatient PSG. Patients with suspected OSA were defined as those who visited our sleep center with the chief complaint of snoring with or without daytime sleepiness. And they were selected based on the following inclusion criteria: ≥ 18 years of age; autonomous behavior and cognitive ability; and able to complete procedures including PSG, questionnaire, and PVT. Individuals with a history of medical, neurological or psychiatric disorders (except OSA), which may affect excessive daytime sleepiness; those with long-term or current use of medications known to affect sleep and daytime vigilance, a history of mental and psychological disease(s), those undergoing OSA treatment, individuals experiencing sleep events that are predominantly central or mixed, those with physical mobility disorders and/or audio-visual impairments unable to complete tests such as PVT, and pregnant women, were excluded. All patients were selected according to the inclusion and exclusion criteria listed herein and they signed the informed consent form.

PSG

One-night standard PSG (Embla Systems N7000 or S4500, Natus Medical Incorporated, Pleasanton, CA, USA) was performed during the patients' usual bedtime. Data regarding continuous sleep architecture were collected, including electroencephalograms, electrooculograms, electrocardiograms, and submental and lower limb electromyograms. In addition, other information, including thoracoabdominal respiratory effort, snoring, body position, oronasal airflow, and oxygen

saturation was collected. After overnight PSG, the software first provided a preliminary analysis; next, a certified PSG technician, with > 10 years' experience, manually reviewed and scored the PSG recordings; finally, a sleep physician reviewed again and approved the final report. Both the sleep physicians and technicians were blinded to the results of all other reports, including clinical information, questionnaires, and PVT. According to the recommendations of the American Academy of Sleep Medicine [18], OSA is defined as obstructive apnoea/hypopnea dominated by respiratory events, with apnoea/hypopnea index (AHI) not less than five events/h. Based on AHI categories, OSA severity was ranked as mild (AHI ≥ 5 and < 15 events/h), moderate (AHI ≥ 15 and < 30 events/h), and severe (AHI ≥ 30 events/h).

Questionnaires

After admission, a researcher distributed the questionnaires to the patient and collected them upon completion. The researcher was blinded to know the questionnaire results, which were summarized and analyzed by the specialized sleep physician and a statistician. The STOP-Bang questionnaire comprises eight questions on S (snoring), T (tiredness), O (observed apnoea), P (hypertension), B (body mass index [BMI] > 35 kg/m^2), A (age > 50 years), N (NC > 40 cm), and G (male), the responses for which are "yes" (1 point) or "no" (0 point). The total score ranges from 0 to 4. A total score of ≥ 3 indicates a high risk of OSA. The NoSAS questionnaire developed by Marti-Soler et al. [19] assesses NC (> 40 cm: 4 points), BMI (25–30 kg/m^2: 3 points; ≥ 30 kg/m^2: 5 points), snoring ("yes": 2 points), age (> 55 years: 4 points), and sex (male: 2 points). Total scores range from 0 to 17 points, with ≥ 8 points indicating a high risk of OSA. The ESS, which includes eight questions, asks respondents to rate their sleepiness on a scale of 0—3 in eight daily situations. For each question, a score of 0 indicates no lethargy, and 1, 2, and 3 indicate light, moderate, and heavy lethargy, respectively. The total score ranges from 0 to 24, with ≥ 10 indicating daytime sleepiness. The research staff was not involved in questionnaire interpretation or completion.

PVT

The PVT (edited by E-PRIMEQ) measures the speed and accuracy of the visual reaction time (RT) in response to a visual stimulus. The PVT is conducted at 10:00 am or 2:00 pm. No significant difference was observed in PVT performance performed at 10:00 am and 2:00 pm for 201 patients who had PVT twice on the same day, and the results of the PVT in the afternoon were analyzed. The remaining patients who had only one PVT were also included in the analysis. The task was performed in a closed and quiet room, without auditory or visual distractions. A trained technician instructed the participants on how to conduct the task. Each test lasted 10 min, and a single 1-min habituation test was provided for each participant before the test. During the test, the participants were instructed to press a button as quickly as possible when the red dots appeared on the screen, and the RT between the appearance of the dots and the button press was recorded. The dots appeared in a random pattern at intervals of 2–10 s. After the test, the program automatically extracted and analyzed the following PVT performance results: 1) mean RT, 2) fastest 10% of RT, 3) slowest 10% of RT, 4) slowest 10% 1/RT, 5) mean 1/RT, 6) number of lapses, defined as an RT > 500 ms, and 7) false start, defined as RT < 100 ms. On the basis of the number of PVT lapses (RT > 500 ms), we defined PVT lapses ≥ 2 as sleepiness and < 2 as nonsleepy [20].

Statistical analysis

We used Python 3.8 for data preprocessing and statistical modelling, and the specific toolkits and versions were as follows: numpy version 1.18.5, pandas version 1.3.4, matplotlib version 3.5.0, seaborn version 0.11.0, sklearn version 1.1.3, scipy version 1.9.0, and statsmodels version 0.13.5.. Two PVT measurements were collected from each individual in the morning and afternoon, along with PSG data from the patients. We performed data preprocessing before the statistical analysis: outliers in each column, such as oxygen desaturation index (ODI) and the lowest pulse oxygen saturation ($LSpO_2$), were handled by removing samples that fell outside of 3σ to eliminate the influence of extreme data. Second, missing values were filled out using linear regression estimation.

During the statistical process, we first analyzed the differences between the morning and afternoon PVT data using t-tests. At a significance level of 5%, no significant differences were found for any individual, so the data were merged. Next, we divided the PVT-related variables, sleep-related indicators, and questionnaire indicators into four groups based on the severity of OSAHS. We analyzed whether the severity had an impact on these indicators. ANOVA revealed that at a significance level of 1%, severity had an impact on Lapses, ODI, $LSpO_2$, STOP-Bang, and NoSAS. Second, the correlation between PVT and PSG data was calculated using the Pearson correlation analysis. Finally, we divided the data into two categories based on AHI equal to 5, 15, and 30, respectively, and used logistic regression to model the data. During the modelling process, we performed Z-score standardization on the variables; split the data into training and testing sets at a ratio of 7:3; selected parameters using grid search; used L2 regularization to prevent overfitting; selected the best parameters using cross-validation; and finally calculated sensitivity, specificity, positive predictive value (PPV), negative predictive

value (NPV), and area under the curve (AUC) on the test set. The 95% confidence interval of AUC was calculated using hypothesis testing.

Results

A total of 921 patients came to the sleep center of our hospital with snoring as the main complaint from August 2022 to March 2023. According to the search strategy, there were 308 (252 males, 56 females) patients were finally enrolled in the present study (Fig. 1). The study cohort had a mean (± SD) age of 40.48 ± 11.36 years, BMI of

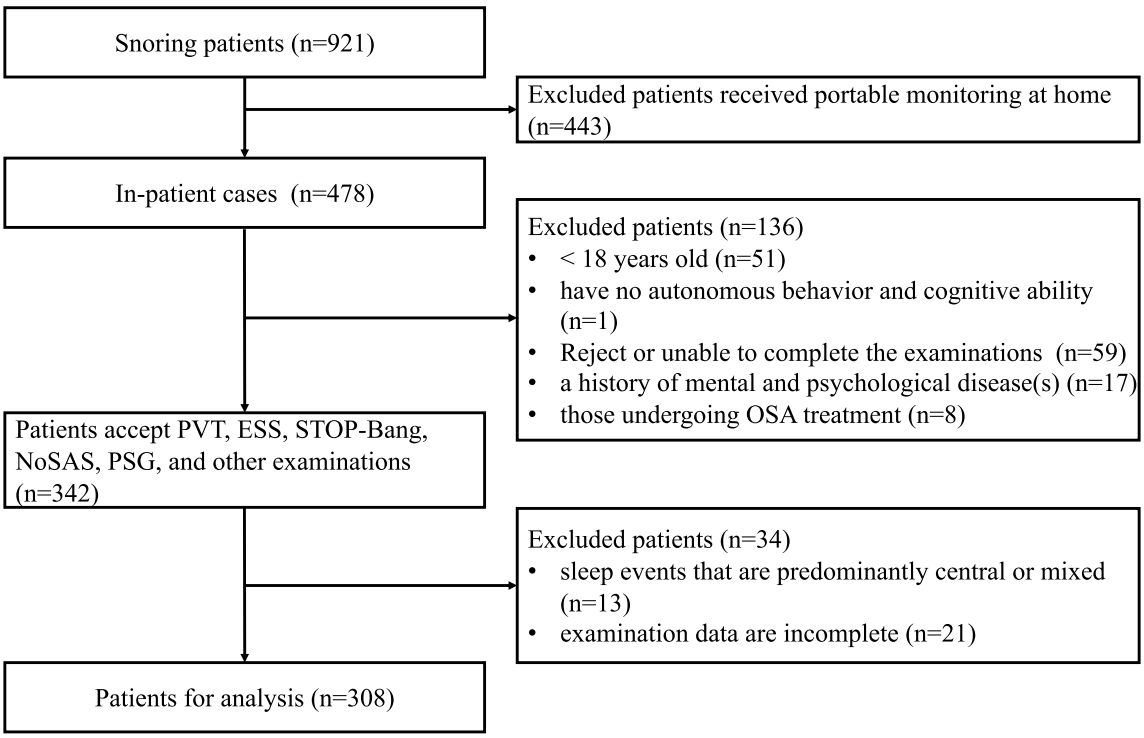

Fig. 1 Flow diagram of data distribution

Table 1 Demographics and polysomnographic information of all subjects

	All	AHI < 5	5 ≤ AHI < 15	15 ≤ AHI < 30	AHI ≥ 30	F/χ2	P
n	308	37	65	76	130		
Male (*n*, %)	252,81.8%	26, 70.3%	48, 73.8%	60, 78.9%	118, 90.8%	13.52	< 0.001
Age (years)	40.48 ± 11.36	35.27 ± 10.39	41.55 ± 13.31	42.55 ± 11.8	40.12 ± 9.85	3.77	0.01
BMI (kg/m^2)	26.61 ± 4.09	23.87 ± 3.83	25.41 ± 3.7	26.36 ± 3.71	28.14 ± 3.98	15.44	< 0.001
NC (cm)	38.57 ± 3.71	36.07 ± 3.73	36.83 ± 3.35	38.32 ± 3.57	40.32 ± 3.08	24.83	< 0.001
WC (cm)	92.05 ± 11.77	84.3 ± 10.11	88.82 ± 8.24	91.95 ± 10.0	95.96 ± 13.13	13.13	< 0.001
AHI (events/h)	33.04 ± 26.37	2.74 ± 1.4	9.96 ± 3.25	22.41 ± 4.48	59.42 ± 18.37	371.17	< 0.001
ODI (events/h)	31.0 ± 25.62	4.05 ± 11.21	12.94 ± 14.54	22.0 ± 13.21	53.33 ± 19.92	144.86	< 0.001
$LSpO_2$ (%)	79.91 ± 10.64	91.57 ± 2.65	85.6 ± 5.74	82.86 ± 7.11	71.97 ± 9.91	85.90	< 0.001
ESS	6.41 ± 4.18	5.35 ± 3.97	5.23 ± 2.88	5.93 ± 3.92	7.57 ± 4.64	6.52	< 0.001
STOP-Bang	3.35 ± 1.31	2.68 ± 1.25	2.75 ± 1.31	3.39 ± 1.18	3.82 ± 1.22	15.20	< 0.001
NoSAS	7.2 ± 3.58	4.73 ± 2.78	6.0 ± 3.44	6.89 ± 3.24	8.72 ± 3.4	19.12	< 0.001

Values are presented as mean ± standard deviation (M ± SD)

26.61 ± 4.09 kg/m^2, NC of 38.57 ± 3.71 cm, and WC of 92.05 ± 11.77 cm (Table 1). All patients were divided into four groups based on AHI: primary snoring (2.74 ± 1.4 events/h, $n = 37$); mild OSA (9.96 ± 3.25 events/h, $n = 65$); moderate OSA (22.41 ± 4.48 events/h, $n = 76$); and, severe OSA (59.42 ± 18.37 events/h, $n = 130$). As shown in Table 1, there were significant differences in ODI (mean ODI, 53.33 ± 19.92 vs 4.05 ± 11.21 events/h, $p < 0.001$) and $LSpO_2$ (71.97 ± 9.91 vs 91.57 ± 2.65%, $p < 0.001$) between severe OSA and primary snoring group. The ESS, STOP-Bang, NoSAS scores were significantly higher in the severe OSA group compared to the primary snoring group (mean ESS, 7.57 ± 4.64 vs 5.35 ± 3.97, $p < 0.001$; STOP-Bang, 3.82 ± 1.22 vs 2.68 ± 1.25, $p < 0.001$; NoSAS, 8.72 ± 3.4 vs 4.73 ± 2.78, $p < 0.001$).

The PVT variables are listed in Table 2. The mean PVT lapses were significantly higher in the severe OSA group compared to the primary snoring group (46.83 ± 34.73 vs 22.95 ± 14.99, $p < 0.001$). RT demonstrated a similar difference; more specifically, there were statistical differences in RT between severe OSA and primary snoring group (522.29 ± 241.97 vs 455.05 ± 43.62, $p = 0.03$). In addition, 1/RT showed differences among the four groups ($p = 0.01$, Table 2).

Correlation analysis between PVT and OSA variables revealed that PVT lapses were positively correlated with AHI ($r = 0.266$, $p < 0.001$) and ODI ($r = 0.230$, $p < 0.001$), and negatively correlated with $LSpO_2$ ($r = -0.215$, $p < 0.001$). Similarly, RT was positively correlated with AHI ($r = 0.274$, $p < 0.001$) and ODI ($r = 0.212$, $p < 0.001$) and negatively correlated with $LSpO_2$ ($r = -0.224$, $p < 0.001$). Correlation analysis performed among the groups revealed that lapses had no significant correlation with AHI, ODI, or $LSpO_2$ ($p > 0.05$). RT in patients with primary snoring was correlated with $LSpO_2$ ($r = 0.365$, $p = 0.026$) but not with AHI or ODI ($p > 0.05$). RT in patients with mild and moderate OSA had no correlation with AHI, ODI, and $LSpO_2$ ($p > 0.05$). In the severe OSA group, both lapses and RT were associated with AHI (lapses, $r = 0.354$, $p < 0.001$; RT, $r = 0.313$, $p < 0.001$), ODI (lapses, $r = 0.298$, $p < 0.001$;

Table 2 Outcomes of PVT variables

PVT variables		AHI categories				*T*	*P* value
	All	< 5/h	5–15/h	15–30/h	≥ 30		
RT (ms)	489.47 ± 169.05	455.05 ± 43.62	478.19 ± 82.35	461.12 ± 80.21	522.29 ± 241.97	3.01	0.03
Fastest 10% RT (ms)	343.76 ± 40.7	338.78 ± 28.71	342.14 ± 38.36	340.86 ± 38.3	347.95 ± 45.85	0.80	0.49
Slowest 10% RT (ms)	959.08 ± 1135.01	763.36 ± 194.04	885.77 ± 454.49	785.33 ± 298.87	1156.17 ± 1684.92	2.38	0.07
1/slowest 10% RT	1.32 ± 0.42	1.39 ± 0.32	1.31 ± 0.4	1.41 ± 0.39	1.25 ± 0.46	2.62	0.05
1/RT	2.14 ± 0.35	2.22 ± 0.21	2.14 ± 0.3	2.22 ± 0.32	2.07 ± 0.41	3.86	0.01
Lapses (RT > 500 ms)	39.81 ± 30.79	22.95 ± 14.99	36.8 ± 23.37	38.58 ± 34.69	46.83 ± 34.73	6.1866	< 0.001
False start (RT < 100 ms)	0.06 ± 0.48	0.03 ± 0.16	0.02 ± 0.12	0.04 ± 0.2	0.12 ± 0.71	0.86	0.46

Values are presented as M ± SD

Table 3 Correlation analysis of PVT and OSA variables

	AHI	ODI	$LSpO_2$
All			
Lapses (RT > 500 ms)	0.266 ($p < 0.001$)	0.230 ($p < 0.001$)	− 0.215 ($p < 0.001$)
RT (ms)	0.274 ($p < 0.001$)	0.212 ($p < 0.001$)	− 0.224 ($p < 0.001$)
< 5/h			
Lapses (RT > 500 ms)	0.157 ($p = 0.352$)	− 0.054 ($p = 0.749$)	0.041 ($p = 0.809$)
RT (ms)	0.044 ($p = 0.796$)	− 0.287 ($p = 0.086$)	0.365 ($p = 0.026$)
5–15/h			
Lapses (RT > 500 ms)	− 0.076 ($p = 0.550$)	− 0.026 ($p = 0.838$)	0.101 ($p = 0.423$)
RT (ms)	− 0.041 ($p = 0.743$)	− 0.041 ($p = 0.747$)	0.135 ($p = 0.284$)
15–30/h			
Lapses (RT > 500 ms)	0.161 ($p = 0.171$)	0.005 ($p = 0.966$)	0.083 ($p = 0.480$)
RT (ms)	0.168 ($p = 0.154$)	− 0.003 ($p = 0.978$)	0.089 ($p = 0.453$)
> 30/h			
Lapses (RT > 500 ms)	0.354 ($p < 0.001$)	0.298 ($p < 0.001$)	− 0.276 ($p = 0.002$)
RT (ms)	0.313 ($p < 0.001$)	0.204 ($p = 0.022$)	− 0.234 ($p = 0.008$)

RT, $r = 0.204$, $p = 0.022$), and $LSpO_2$ (lapses, $r = -0.276$, $p = 0.002$; RT, $r = -0.234$, $p = 0.008$) (Table 3).

Using AHI ≥ 5, 15, and 30 events/h as nodes, logistic regression analysis was performed, the receiver operating characteristic (ROC) curve was plotted, and the area under the ROC curve (AUC) for PVT lapses was calculated. When diagnosing OSA (AHI ≥ 5 events/h), the AUCs [percentage (95%CI)] for the PVT, ESS, STOP-Bang and NoSAS were 0.679[0.596,0.762], 0.579[0.421,0.737], 0.727[0.664,0.790], 0.653[0.624,0.682], respectively (Fig. 2a); when AHI ≥ 15 events/h was used as the node, the respective AUCs were 0.535[0.519,0.551], 0.511[0.411,0.620], 0.756[0.722,0.790], 0.814[0.804,0.824] (Fig. 2b); and with AHI ≥ 30 events/h as the node, the respective AUCs were 0.545[0.518,0.572], 0.685[0.515,0.855], 0.856[0.836,0.876], 0.873[0.863,0.883] (Fig. 2c).

Using an AHI cut-off of 5 events/h, the AUCs [percentage (95%CI)] for the STOP-Bang, STOP-Bang combined with PVT, and STOP-Bang combined with ESS were 0.727[0.664,0.790], 0.805[0.772,0.838], and 0.601[0.487,0.715], respectively (Fig. 3a); considering AHI ≥ 15 events/h as the node, the respective AUCs were 0.756[0.722,0.790], 0.814[0.685,0.943], and 0.791[0.719,0.863] (Fig. 3b); and using AHI cut-off of 30 events/h, the respective AUCs were 0.856[0.836,0.876], 0.904[0.885,0.923], and 0.806[0.777,0.835] (Fig. 3c).

Using an AHI cutoffs of 5 events/h, the AUCs [percentage (95%CI)] for the NoSAS, NoSAS combined with PVT,

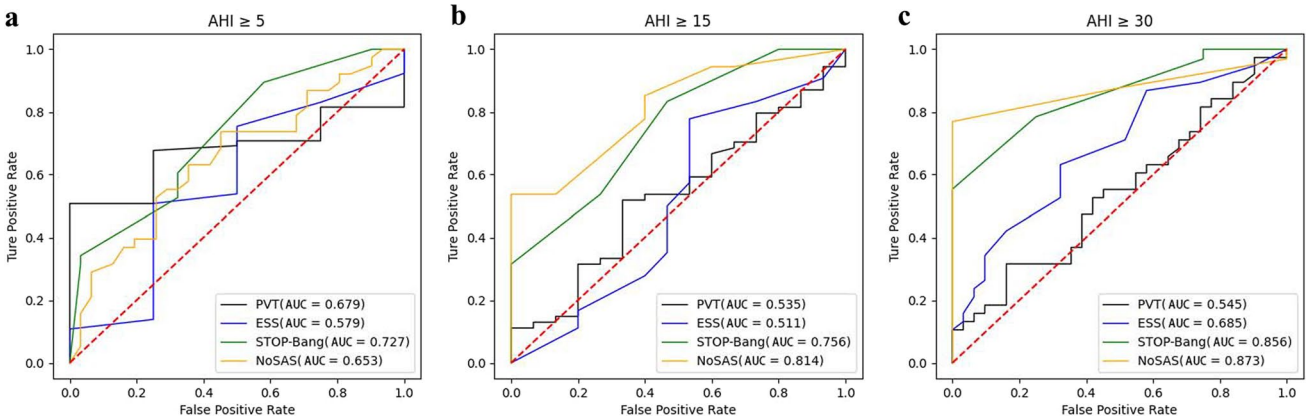

Fig. 2 ROC curve of the PVT, ESS, STOP-Bang and NoSAS. The ROC curve of the PVT (AUC = 0.679) was greater than that of the ESS (AUC = 0.579) when used to diagnose OSA (AHI ≥ 5 events/h). With AHI ≥ 30 events/h as the node, the AUCs of ESS, STOP-Bang and NoSAS increased, while PVT did not change significantly. *AHI* apnoea-hypopnoea index; *PVT* psychomotor vigilance task; *ESS* Epworth Sleepiness Scale; *STOP-Bang* STOP-Bang questionnaire; *NoSAS* Neck circumference, Obesity, Snoring, Age and Sex score; *AUC* area under the ROC curve

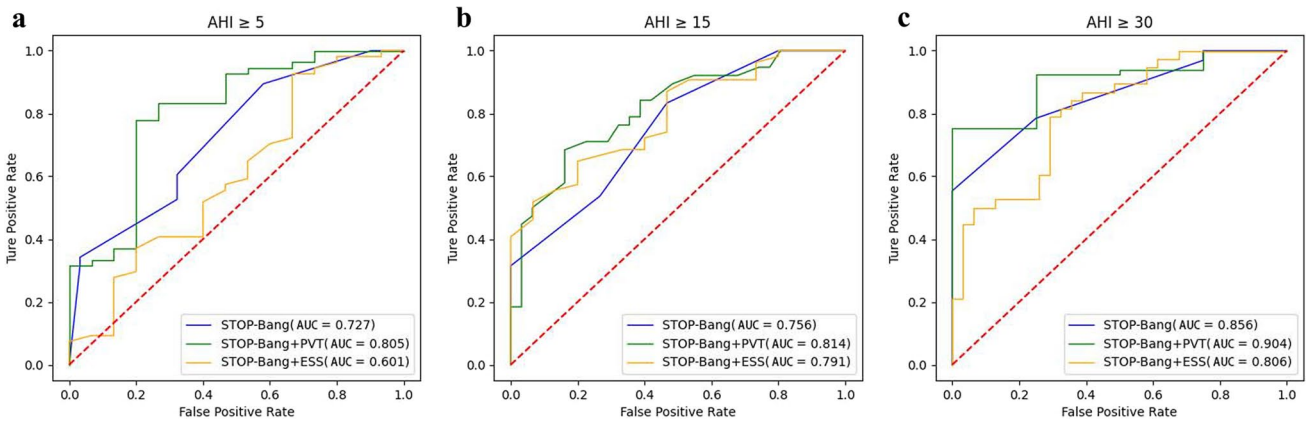

Fig. 3 ROC curve of the STOP-Bang, STOP-Bang combined with PVT, STOP-Bang combined with ESS. When AHI ≥ 5, 15, and 30 events/h as the node, the AUCs of STOP-Bang combined with PVT were greater than STOP-Bang combined with ESS. *AHI* apnoea-hypopnoea index; *PVT* psychomotor vigilance task; *ESS* Epworth Sleepiness Scale; *STOP-Bang* STOP-Bang questionnaire; *AUC* area under the ROC curve

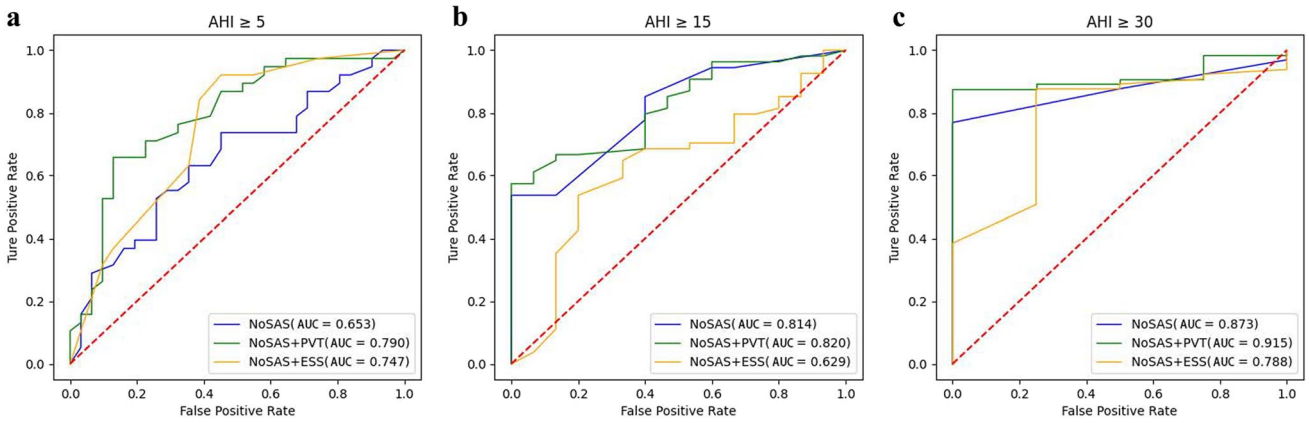

Fig. 4 ROC curve of the NoSAS, NoSAS combined with PVT, NoSAS combined with ESS. When AHI ≥ 5, 15, and 30 events/h as the node, the AUCs of NoSAS combined with PVT were greater than NoSAS combined with ESS. *AHI* apnoea-hypopnoea index; *PVT* psychomotor vigilance task; *ESS* Epworth Sleepiness Scale; *NoSAS* Neck circumference, Obesity, Snoring, Age and Sex score; *AUC* area under the ROC curve

Table 4 The scale predictors of OSA patients

Scale	Sensitivity	Specificity	PPV	NPV
AHI ≥ 5 events/h				
PVT	0.419	0.4	0.857	0.074
STOP-Bang	0.538	0.500	0.946	0.063
STOP-Bang combine PVT	0.554	0.513	0.947	0.065
NoSAS	0.586	0.613	0.676	0.594
NoSAS combine PVT	0.655	0.613	0.684	0.613
AHI ≥ 15 events/h				
PVT	0.571	0.231	0.667	0.167
STOP-Bang	0.684	0.516	0.743	0.647
STOP-Bang combine PVT	0.702	0.613	0.750	0.670
NoSAS	0.749	0.516	0.880	0.424
NoSAS combine PVT	0.857	0.667	0.688	0.762
AHI ≥ 30 events/h				
PVT	0.417	0.667	0.556	0.533
STOP-Bang	0.708	0.600	0.981	0.176
STOP-Bang combine PVT	0.785	0.750	0.979	0.136
NoSAS	0.778	0.724	0.654	0.765
NoSAS combine PVT	0.895	0.733	0.875	0.849

and NoSAS combined with ESS were 0.653[0.624,0.682], 0.790[0.784,0.796], and 0.747[0.710,0.784], respectively (Fig. 4a); using AHI ≥ 15 events/h as the node, the respective AUCs were 0.814[0.804,0.824], 0.820[0.750,0.870], and 0.629[0.479,0.779] (Fig. 4b); using an AHI cut-off of 30 events/h, the respective AUCs were 0.873[0.863,0.883], 0.915[0.885,0.945], and 0.788[0.653,0.923] (Fig. 4c).

When STOP-Bang score ≥ 3 was used as the cut-off, the specificity of the STOP-Bang for AHI ≥ 5, ≥ 15, and ≥ 30 events/h was 0.500, 0.516, and 0.600, respectively. After combination with PVT, the specificity of the STOP-Bang was 0.513, 0.613 and 0.750, respectively (Table 4).

With NoSAS score ≥ 8 as the cut-off, the specificity of the NoSAS for AHI ≥ 5, ≥ 15, and ≥ 30 was 0.613, 0.516, and 0.724, respectively. In combination with PVT, the specificity of the NoSAS was 0.613, 0.667, and 0.733, respectively (Table 4).

Discussions

We investigated PVT performance in patients with suspected OSA and evaluated the usefulness of the PVT in OSA screening. PVT indicators were different among patients with different OSA severity, and the PVT demonstrated diagnostic efficiency (AUC = 0.679). When used in combination with NoSAS or STOP-Bang, PVT improved the diagnostic efficacy and specificity of these questionnaires.

The PVT is sensitive to sleep deprivation and is a good indicator of fatigue and cognitive impairment [21]. Wide variability in the use of PVT outcome metrics has been reported, and lapse, often used as a primary outcome measure of PVT performance, is a marker of a sleep-deprived state and a highly sensitive measure of the effect of sleep deprivation or sleep restriction on attention and vigilance [21, 22]. Furthermore, the number of PVT lapses in patients with OSA is significantly higher than that in patients without OSA, indicating that patients with OSA are less alert [23–25]. We selected six PVT indicators to evaluate the effects of OSA on alertness. No significant differences were observed in the fastest 10% RT, slowest 10% RT, 1/slowest 10% RT, and false start among the four groups of primary snoring, mild, moderate, and severe OSA, whereas a difference was found in lapse, RT, and 1/RT. Therefore, lapse and RT were selected for further correlation analyses.

Although impaired alertness is the most common and persistent cognitive finding in patients with OSA, the relationship between the severity of OSA and PVT manifestations remains controversial. Several studies have reported no relationship between OSA severity and PVT performance [16, 22]; by contrast, others have found an association between AHI and lapses [24, 26]. Our results revealed a significant correlation between PVT performance and PSG outcomes (AHI and ODI, $p < 0.001$), which was evident in patients with severe OSA but not in those with nonsevere OSA. The severity of nocturnal intermittent hypoxaemia may be negatively correlated with PVT performance in patients with OSA. SForza et al. [24] indicated that the number of lapses was moderately correlated with $LSpO_2$. Kainulainen et al. [16] reported that more severe hypoxaemia resulted in longer RTs and more lapses. Similarly, we observed that the lower the blood oxygen saturation, the greater the number of lapses and the longer the RT, indicating that PVT damage is more serious. This study calculated that RT in patients with primary snoring was positively correlated with $LSpO_2$ ($r = 0.365$, $p = 0.026$) which was ignored as an experimental error.

The utility of the PVT is similar to the ESS score as an objective measure of sleepiness, and the number of PVT lapses was chosen as the main analysis index to evaluate the risk of OSA. On the basis of the establishment of the model, we observed that PVT (AUC = 0.679) demonstrated a certain diagnostic value for OSA, and its diagnostic effect was better than that of the ESS (AUC = 0.579), similar to that of the NoSAS (AUC = 0.653), but weaker than that of the STOP-Bang (AUC = 0.727). When used to diagnose severe OSA (AHI ≥ 30 events/h), the AUC for the ESS, NoSAS, and STOP-Bang increased, whereas PVT did not change significantly and was lower than that of the three questionnaires. This may imply that PVT, as a screening tool, does not yield a significant advantage over questionnaires for OSA detection in the general population.

The STOP-Bang and NoSAS can be used as screening tools for OSA [6, 27]. Our data also verified their predictive effect on OSA, with the STOP-Bang demonstrating better diagnostic efficacy. The combination of ESS with the STOP-Bang and NoSAS improved their diagnostic specificity [8, 9]. By contrast, in this study, the AUC for the STOP-Bang and NoSAS decreased to different degrees after combination with the ESS. We speculate that the ESS—a subjective evaluation—may be biased by patients' subjective feelings. We plan to increase the sample size in future studies to validate this conclusion. The PVT was used to objectively evaluate patients' cognition; when combined with the STOP-Bang and NoSAS, the diagnostic specificity of both questionnaires improved. In addition, we found that at different nodes, the AUC of PVT combined with STOP-Bang or NoSAS was greater than that of the questionnaire alone and was greater than that of the ESS combined with the questionnaire. Therefore, we propose that in individuals with suspected OSA, a combination of the PVT with the STOP-Bang or NoSAS can help in the primary screening of OSA, with a better performance than the ESS.

This study has some limitations. First, our ability to objectively observe the relationship between OSA and PVT performance may have been limited by the relatively small sample size, necessitating larger-scale studies to validate our results. Second, because of the inclusion of patients with suspected OSA with snoring and the preponderance of individuals with severe OSA, our conclusions cannot be generalised. Finally, the lack of a (healthy) control group may affect the reliability of the results. We have subsequently collected nearly a thousand cases of data, and further statistical analysis is required to verify these results.

Conclusion

To summarise, patients with OSA exhibited impairment in the PVT, and corresponding PVT lapses and RTs increased. Compared with STOP-Bang or NoSAS, PVT did not demonstrate a significant advantage in screening for OSA in people with suspected OSA; however, the combination of PVT and questionnaires can improve the diagnostic efficacy and specificity for OSA in individuals with suspected OSA.

Author contributions JM made substantial contributions to design the study, and wrote the paper; XQ and YW offerred PVT software; LS analyzed data; NC and CW involved in designing the study. JH collected the specimen and critically revised the paper.

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Data availability Not applicable.

Declarations

Conflict of interest The authors do not have any commercial or associative interest that represents a conflict of interest in connection with the work submitted.

Ethical approval Ethics approval was obtained from the Ethics Committee of the EENT Hospital of Fudan University (No.2022140) and the study was registered in the Chinese Clinical Trial Registry (ChiCTR2300069223). Informed consent was obtained from all patients before the procedure.

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