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The predictive values of BOAH and No-apnea score for screening obstructive sleep apnea in rotating shift worker drivers

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ABSTRACT

Objective: To evaluate the BOAH (Body mass index, Observed apnea, Age, and Hypertension) and No-apnea score's diagnostic values for detecting obstructive sleep apnea (OSA) risk in shift workers.
Methods: Cross-sectional study with male rotating shift workers and drivers of heavy off-road machinery. The BOAH score is based on body mass index, witnessed apneas during sleep, age, and hypertension. The No-apnea score is based on neck circumference and age. Based on the apnea-hypopnea index (AHI), the severity of OSA was categorized as least mild OSA (AHI ≥5/h), moderate to severe OSA (AHI ≥15/h), and severe OSA (AHI ≥30/h). Sensitivity, specificity, positive predictive value, negative predictive value, and areas under the curve (AUC) were calculated.
Results: Among 119 workers evaluated, 84.0% had AHI ≥5, 46.2% had AHI ≥15, and 14.3% had AHI ≥30. BOAH score with 2 points for AHI ≥5, the AUC was 0.679, and sensitivity and specificity were 41.0% and 94.7%, respectively. No-apnea score with 3 points AHI ≥5, the AUC was 0.692, and sensitivity and specificity were 70.0% and 68.4%, respectively. Furthermore, using at least one of the positive scores, the AUC was higher when compared to the single tests for AHI ≥5 (AUC = 0.727). And when both scores were positive, the AUC was higher for AHI ≥30 (AUC = 0.706).
Conclusion: In rotating shift workers and drivers of heavy off-road machinery, BOAH, and No-apnea scores can be helpful tools in identifying individuals at risk for sleep apnea. In addition, matching the scores may increase the prediction of OSA.

1. Introduction

Obstructive sleep apnea (OSA) is a common sleep disorder characterized by recurrent episodes of cessation or reduction of airflow due to the collapse of the upper airway during sleep. These events cause intermittent hypoxemia, hypercapnia, sympathetic activation and sleep fragmentation, which can lead to adverse health consequences [1,2]. In the United States, about one-third of men have OSA, which increased by 30% between 1990 and 2010 [3]. OSA can increase the risk of heart problems such as hypertension, arrhythmias, heart attacks, and heart failure. It can also affect the brain, kidneys, bones, teeth, and hearing. In addition, OSA can cause excessive daytime sleepiness, which may result in traffic or work accidents [1].

Several factors may predispose to the development of OSA, one of them is shift work [4]. This type of work alters the circadian rhythm, the 24-h biological cycle that regulates living beings' physiological and behavioral functions [5]. Previous studies in this population have shown a high prevalence of sleep disorders, such as OSA [4,5]. Besides, among shift workers, a group of particular interest is professional drivers, who are exposed to long working hours and adverse traffic conditions. OSA in this population may compromise traffic safety and increase the risk of fatal accidents.

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Despite the relevance of OSA to health, it is still underdiagnosed, mainly due to its detection tools [6]. The gold standard method for diagnosing OSA is overnight polysomnography (PSG), and it can be impractical, considering that few places have this equipment available or even professionals trained to perform it [7]. Thus, many screening tools based on well-known risk factors for OSA have been developed, and several methods are available. Therefore, there is a need for alternative tools that can assist in the screening and diagnosis of sleep apnea [8]. Questionnaires are simple, quick, and inexpensive instruments that can assess the risk of sleep apnea in different populations. They are based on questions about symptoms, risk factors, and the impact of sleep apnea on patients' lives. Some examples of questionnaires are the Berlin Questionnaire (BQ), the STOP-Bang Questionnaire (SBQ), the STOP Questionnaire (SQ), and the Epworth Sleepiness Scale (ESS). However, some methods could be more extensive and better used in clinical practice. Thus, using tools that assess simple and easily obtainable measures such as body mass index (BMI), neck circumference (NC), and age becomes essential. These anthropometric measures can be used massively in health services because they are readily available metrics that do not require sophisticated equipment. In this regard, the BOAH (Body mass index, Observed apnea, Age, and Hypertension) and No-apnea scores are beneficial, given their practicality and ease of application.

However, the predictive value of these tools for screening and diagnosis of OSA has yet to be evaluated in drivers on rotating shifts, a population at high risk for OSA, and associated comorbidities [4]. Therefore, this study aimed to assess the predictive value of BOAH and No-apnea scores for screening obstructive sleep apnea in drivers on rotating shifts using PSG as the gold standard.

2. Methodology

2.1. Design and participants

This cross-sectional study of workers on rotating shifts at an iron ore extraction company in the Iron Quadrangle, Minas Gerais, Brazil, in 2012. These workers operated off-highway trucks in rotating shifts of 6 h, followed by 12 h of rest, in the periods 7 p.m. to 1 a.m., 1 p.m.–7 p.m., 7 a.m. to 1 p.m., and 1 a.m.–7 a.m., with one day off after completing four shifts. Participants were previously evaluated in a screening study entitled "Metabolic syndrome in mining workers in the state of Minas Gerais, Brazil," which identified the prevalence of cardiovascular risk factors in the population [9,10]. The PSG is expensive and *access* is often *difficult* [7]. Therefore, we selected workers with at least one cardiovascular risk factor. We chose these workers because they have a high risk of sleep apnea and cardiovascular disease. Moreover, our sample was representative of this population, as most workers on rotating shifts had cardiovascular risk factors [11]. The methodology and participant flowchart are detailed in a previous study [9] and the supplemental material (Fig. S1). This study followed the guidelines for diagnostic accuracy studies (STARD).

2.2. Cardiovascular risk factors

The cardiovascular risk factors evaluated were hypertension, hyperglycemia, dyslipidemia, abdominal obesity, current smoking, low level of physical activity, and alcohol consumption. Hypertension was assessed by a digital sphygmomanometer in triplicate and classified as systolic blood pressure ≥130 mmHg or diastolic blood pressure ≥85 mmHg [12]. Hyperglycemia was evaluated by a commercial colorimetric fasting kit and classified as blood glucose ≥100 mg/dL [13]. Lipid profile was assessed by a colorimetric biochemical analyzer and classified as total cholesterol ≥200 mg/dL, triglycerides ≥150 mg/dL, low-density lipoprotein ≥160 mg/dL, and high-density lipoprotein <40 mg/dL, respectively [14]. Abdominal obesity was assessed by a tape measure at the height of the navel and classified as waist circumference ≥90 cm [12]. Current smoking was assessed by a questionnaire and classified as using any tobacco product in the past 30 days. A low level of physical activity was assessed by the International Physical Activity Questionnaire (IPAQ) and classified as <600 total energy measure (MET), min/week [15]. Alcohol consumption was assessed by the Test for Identification of Problems Related to Alcohol Use (AUDIT) and classified as medium- and high-risk alcohol consumption [16].

2.3. Anthropometric data

Previously trained teams performed Data collection at the company's outpatient clinic. Weight was measured using a portable TANITA® model BC558 body composition monitor, with a maximum capacity of 150 kg and an accuracy of 0.1 kg (Tanita Corporation of America, Inc., Arlington Heights, Illinois, USA), and the height of the AlturExata portable stadiometer with cm-scale and 1-mm accuracy (AlturaExata, Belo Horizonte, Minas Gerais, Brazil). The participants were assessed in both procedures according to standard reference [17]. Body mass index (BMI) was calculated using the formula: weight (kg)/height [2] (m) [18]. Neck circumference (NC) was measured at the level of the thyroid cartilage, just above the laryngeal prominence, according to the standard reference [19].

2.4. BOAH score

The BOAH score is a shorter version of STOP-BANG based on four variables: body mass index (BMI), obstruction nasal (O), age (A), and hypertension (H). Therefore, the BOAH score was calculated based on the following scoring criteria: BMI (≥30 kg/m^2–1 point; or ≥ 35 kg/m^2–2 points), witnessed apneas during sleep, by self-report (1 point), age (≥50–1 point), and arterial hypertension (1 point). The BOAH score ranges from 0 (low risk for OSA) to 5 points (high risk for OSA) [20].

2.5. No-apnea score

The No-apnea is calculated from neck circumference (<37 cm–0 points; 37–39.9 cm – 1 point; 40-42.9 – 3 points; ≥43 cm–6 points) and age (<35 years-0 points; 35–44 years – 1 point; 45–54 years – 2 points; ≥55 years–3 points). The No-apnea score ranges from 0 (low risk for OSA) to 9 points (high risk for OSA) [21].

2.6. Polysomnography

All workers underwent a PSG examination at night and were recorded on the Alice 5 PSG system (Philips Respironics, Inc., Murrysville, PA, USA) in accordance with the American Academy of Sleep Medicine (AASM). The PSG examination included the following measurements: electroencephalogram (EEG), electrooculogram (EOG), electromyogram (EMG), electrocardiogram (ECG), nasal pressure, oral thermistor, thoracic and abdominal respiratory inductance plethysmography, snoring, body position and pulse oximetry. Sleep stages and respiratory events were scored according to the American Academy of Sleep Medicine (AASM) Manual for the Scoring of Sleep and Associated Events [22]. The AASM manual is a document that establishes the rules and criteria for the classification and quantification of physiological events that occur during sleep, as well as the determination of sleep stages and the sleep quality index. The apnea-hypopnea index (AHI) classification was based on the AASM definition, which considers apnea to be a reduction of at least 90% in airflow compared to baseline, lasting at least 10 s, and hypopnea to be a reduction of at least 30% in airflow compared to baseline, lasting at least 10 s, and associated with a drop in oxygen saturation of at least 3% or an awakening [22]. The AHI represents the average number of apneas and hypopneas per hour of sleep, and was calculated by dividing the total number of respiratory events by the total sleep time. According to the AASM, the severity of OSA was categorized as no apnea (AHI <5/h), at least mild apnea (AHI >5/h), moderate to

severe (AHI >15/h) and severe (AHI >30/h) [22].

2.7. Statistical analysis

Statistical analyses were performed using Stata (version 15.0) with a significance level of 5%. Shapiro-Wilk test was performed to assess the data distribution, and data are presented as medians and interquartile ranges (p25–p75) or numbers and percentages. The data were compared using the Mann-Whitney and Chi-square analyses with Bonferroni correction [23].

Sensitivity (S), specificity (E), positive predictive value (PPV), negative predictive value (NPV), Youden index, and area under the curve (AUC) were calculated to assess the accuracy of BOAH e No-apnea score for each OSA severity category. McNemar's test with Yates' correction was used to determine the presence of an association between the proposed screening tests and OSA.

The tests were initially evaluated separately to verify the best cut-off point for determining the high risk of apnea. Subsequently, two methods were used to assess the combination of both tests using the cut-off points with the best results. The first method was a parallel test, where an individual was considered positive for high-risk OSA if they tested positive on at least one of the two tests. The second method was a serial test, in which an individual was considered positive for high-risk OSA only if they tested positive on both tests.

Sampling power (a posteriori) was performed using the G*Power program version 3.1.9.2 and data on similar studies' proportions and sample sizes. This was performed for the whole sample, with an estimated power of 0.98.

3. Results

Characteristics of the shift workers evaluated, including BOAH and No-apnea scores, are shown in Table 1. The prevalence of mild to severe OSA was 84.0%, moderate to severe at 46.2%, and severe at 14.3%. These individuals had a median age of 35.3 years (31.3–43.1). The average time worked in rotating shifts was seven years (5.0–13.0). Most participants self-declared as non-white (70.6%) and had a middle school education (81.5%).

Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and area under the curve (AUC) for each BOAH and No-apnea score are shown in Table 2. BOAH score of 2 had a higher AUC for all OSA severities, with 0.679 for AHI ≥5, 0.664 for AHI ≥15, and 0.672 for AHI ≥30. Evaluating the PPV for a BOAH score of 2, we observed that workers have 97.6% odds of having mild to severe OSA, 57.1% of having severe OSA, and 26.2% for severe OSA (see Table 3).

For No-apnea, the score of 3 had the highest AUC values, with 0.692 for AHI ≥5, 0.633 for AHI ≥15, and 0.676 for AHI ≥30. Evaluating the PPV for this cut-off point, workers have a 92.1% chance of having mild to severe OSA, 56.6% of having severe OSA, and 22.9% for severe OSA.

Furthermore, we evaluated the predictive values for parallel and series combination tests for scores, demonstrated in Table 4. We found that when the parallel test (at least one of the positive scores, No-apnea and BOAH) was evaluated, the AUC for OSA (AHI ≥5) was higher when compared to the single tests (AUC: 0.727). And for series testing (both positive scores, No-apnea and BOAH), the best results were for severe OSA (AHI ≥30) (AUC: 0.706) (Table 4).

4. Discussion

This is the first study to examine the performance of BOAH and No-apnea scores to predict the risk of OSA diagnosed by polysomnography in rotating shift drivers of heavy off-road machinery. We found that the BOAH and No-apnea scores showed satisfactory results in predicting high risk for OSA in all severities of apnea, with slightly higher results for No-apnea. Furthermore, when the two tests were used combined, we observed that the use of the BOAH and No-apnea score in parallel

Table 1
Characteristics of total shift workers according to obstructive sleep apnea (AHI ≥5) measured by polysomnography.

Characteristics	Total (n = 119)	No OSA (n = 19)	OSA (n = 100)	p-valor
Sociodemographic				
Age, years[c]	35.3 (31.3–43.1)	33.6 (29.9–43.7)	35.7 (31.3–42.5)	0.423
Shift work time, years[c]	7.0 (5.0–13.0)	8.0 (5.0–22.0)	7.0 (5.0–11.5)	0.461
Skin color				
White, n (%)	35 (29.4)	5 (26.3)	31 (31.0)	0.684
Not white, n (%)	84 (70.6)	14 (73.4)	69 (69.0)	
Education				
Up to 1st degree complete, n (%)	8 (6.7)	3 (15.8)	5 (5.0)	0.088[b]
2nd degree complete, n (%)	100 (84.0)	16 (84.2)	84 (84.0)	
University education, n (%)	11 (9.2)	0 (0.0)	11 (11.0)	
Anthropometric				
BMI, kg/m^2[c]	28.1 (25.3–30.6)	24.1 (22.3–27.4)	28.5 (26.3–31.2)	< **0.001**
Waist circumference, cm[c]	95.0 (89.5–101.5)	85.5 (79.0–95.3)	96.2 (91.2–103.8)	< **0.001**
Neck circumference, cm[c]	40.0 (38.5–42.0)	37.8 (36.0–40.8)	40.8 (39.0–42.5)	< **0.001**
Cardiovascular risk factors[a]				
Abdominal obesity, n (%)	88 (73.9%)	8 (42.1)	80 (80.0)	**0.001**
Hyperglycemia, n (%)	11 (9.2%)	3 (15.8)	8 (8.0)	0.284
Dyslipidemia, n (%)	87 (73.1%)	11 (57.9)	76 (76.0)	0.212
Hypertension, n (%)	85 (71.4%)	12 (63.2)	73 (73.0)	0.386
Physical inactivity, n (%)	33 (27.3%)	4 (21.1)	29 (29.0)	0.479
Current smoking, n (%)	26 (21.8%)	3 (15.8)	23 (23.0)	0.487
Alcohol consumption, n (%)	81 (68.1%)	13 (68.4)	68 (68.0)	0.971
High risk for OSA				
BOAH score, n (%)				
≥ 1	99 (83.2)	12 (63.2)	87 (87.0)	**0.011**
≥ 2	42 (35.3)	1 (5.3)	41 (41.0)	**0.003**
≥ 3	10 (8.4)	0 (0.0)	10 (10.0)	0.150
No-apnea score, n (%)				
≥ 1	111 (93.3)	14 (73.7)	97 (97.0)	< **0.001**
≥ 2	91 (76.5)	9 (47.4)	82 (82.0)	**0.001**
≥ 3	76 (63.9)	6 (31.6)	70 (70.0)	**0.001**
≥ 4	48 (40.3)	2 (10.5)	46 (46.0)	**0.004**
≥ 5	26 (21.8)	1 (5.3)	25 (25.0)	0.056
≥ 6	22 (18.5)	1 (5.3)	21 (21.0)	0.105
≥ 7	11 (9.2)	0 (0.0)	11 (11.0)	0.129

BMI, body mass index; OSA, obstructive sleep apnea. OSA is defined by apnea and hypopnea index ≥5 in polysomnography.
Categorical variables are presented with absolute (n) and relative (%) frequency, compared with Pearson's chi-square test.
[c] Continuous variables are presented as median (interquartile range - IQR), and compared with the Mann-Whitney test, and Bonferroni correction.
[b] Categorical variables with a cell count less than 5 were tested by Fisher's exact test.
[a] Hypertension (systolic blood pressure ≥130 mmHg or diastolic blood pressure ≥85 mmHg), hyperglycemia (fasting blood glucose ≥100 mg/dL) [14], dyslipidemia (total cholesterol ≥200 mg/dl or triglycerides 150 ≥ mg/dL or LDL-c > 160 mg/dL or HDL-c < 40 mg/dL), abdominal obesity (waist circumference ≥90 cm), current smoking (any tobacco product in the past 30 days), low level of physical activity (<600 MET, min/week), alcohol drinking (consumption of medium and high-risk alcohol by AUDIT).

Table 2
Predictive values for all BOAH scores in detecting risk for obstructive sleep apnea in rotating shift workers.

OSA severity	BOAH score	S	E	PPV	NPV	AUC	Youden index	p[b]
At least mild (AHI ≥5)	≥1	87.0	36.8	87.9	35.0	0.619	0.238	0.841
	≥ **2**[a]	**41.0**	**94.7**	**97.6**	**23.4**	**0.679**	**0.357**	**< 0.001**
	≥3	10.0	100.0	100.0	17.4	0.550	0.100	<0.001
At least moderate (AHI ≥15)	≥1	94.5	26.6	52.5	85.0	0.606	0.155	0.063
	≥ **2**[a]	**43.6**	**71.9**	**57.1**	**59.7**	**0.664**	**0.211**	**< 0.001**
	≥3	9.1	92.2	50.0	54.1	0.506	0.013	<0.001
Severe (AHI ≥30)	≥1	94.1	18.6	16.2	95.0	0.564	0.127	<0.001
	≥ **2**[a]	**64.7**	**69.6**	**26.2**	**92.2**	**0.672**	**0.343**	**< 0.001**
	≥3	11.8	92.2	20.0	86.2	0.520	0.039	0.144

OSA obstructive sleep apnea, AHI apnea-hypopnea index, S sensitivity, E specificity, PPV positive predictive value, NPV negative predictive value, AUC area under the curve.
[a] Values in bold represent the cut-off value that maximizes both sensitivity and specificity.
[b] McNemar test with Yates' correction - significant results at $p \leq 0.05$.

Table 3
Predictive values for all No-apnea scores in detecting risk for obstructive sleep apnea in rotating shift workers.

OSA severity	No-apnea score	S	E	PPV	NPV	AUC	Younden index	p[b]
At least mild (AHI ≥5)	≥1	97.0	26.3	87.4	62.5	0.617	0.233	0.007
	≥2	82.0	52.6	90.1	35.7	0.673	0.346	0.083
	≥ **3**[a]	**70.0**	**68.4**	**92.1**	**30.2**	**0.692**	**0.384**	**0.001**
	≥4	46.0	89.5	95.8	23.9	0.677	0.355	<0.001
	≥5	25.0	94.7	96.2	19.4	0.599	0.197	<0.001
	≥6	21.0	94.7	95.5	18.6	0.579	0.157	<0.001
	≥7	11.0	100.0	100.0	17.6	0.555	0.110	<0.001
At least moderate (AHI ≥15)	≥1	96.4	9.4	47.7	75.0	0.529	0.057	<0.001
	≥2	89.1	34.4	53.8	78.6	0.617	0.235	<0.001
	≥ **3**[a]	**78.2**	**48.4**	**56.6**	**72.1**	**0.633**	**0.266**	**0.002**
	≥4	50.9	68.7	58.3	62.0	0.598	0.197	0.307
	≥5	30.9	85.9	65.4	59.1	0.584	0.168	<0.001
	≥6	25.4	87.5	63.6	57.7	0.564	0.130	<0.001
	≥7	14.5	95.3	72.7	56.5	0.549	0.099	<0.001
Severe (AHI ≥30)	≥1	100.0	7.8	15.3	100.0	0.539	0.078	<0.001
	≥2	100.0	27.4	18.7	100.0	0.637	0.275	<0.001
	≥ **3**[a]	**94.1**	**41.2**	**22.9**	**91.5**	**0.676**	**0.353**	**< 0.001**
	≥4	64.7	63.7	22.9	91.5	0.642	0.284	<0.001
	≥5	29.4	79.4	19.2	87.1	0.544	0.088	0.117
	≥6	23.5	82.3	18.2	86.6	0.529	0.059	0.369
	≥7	11.8	91.2	18.2	86.1	0.515	0.029	0.221

OSA obstructive sleep apnea, AHI apnea-hypopnea index, S sensitivity, E specificity, PPV positive predictive value, NPV negative predictive value, AUC area under the curve.
[a] The values in bold represent the cut-off value that maximizes sensitivity and specificity.
[b] McNemar test with Yates' correction - significant results at $p \leq 0.05$.

Table 4
Predictive values for parallel and series combination tests for scores in detecting risk for obstructive sleep apnea in rotating shift workers.

OSA severity	Combination tests	S	E	PPV	NPV	AUC	Youden index	p[c]
At least mild (AHI ≥5)	Parallel[a]	77.0	68.4	92.8	36.1	0.727	0.454	0.001
	Series[b]	34.0	94.7	97.1	21.4	0.644	0.287	<0.001
At least moderate (AHI ≥15)	Parallel[a]	83.6	42.2	55.4	75.0	0.629	0.258	<0.001
	Series[b]	38.2	78.1	60.0	59.5	0.582	0.163	0.004
Severe (AHI ≥30)	Parallel[a]	94.1	34.3	19.3	97.2	0.642	0.284	<0.001
	Series[b]	64.7	76.5	31.4	92.9	0.706	0.412	0.001

OSA obstructive sleep apnea, AHI apnea-hypopnea index, S sensitivity, E specificity, PPV positive predictive value, NPV negative predictive value, AUC area under the curve.
[a] Combined tests in parallel: BOAH ≥2 points OR No-apnea ≥3 points. Frequency: 83 (69.8%).
[b] Combined tests in series: BOAH ≥2 points AND No-apnea ≥3 points. Frequency: 35 (29.4%).
[c] McNemar test with Yates' correction - significant results at $p \leq 0.05$.

(increased risk of OSA in at least one of the tests) was more effective for mild to severe OSA (AHI ≥5) when compared to the individual tests. And also, when using the tests in series (high risk of OSA in both tests), better results were obtained for severe OSA (AHI ≥30) when compared to the single trials.

The BOAH and the No-Apnea score differ from questionnaires in that they are not based on subjective questions about symptoms or the impact of sleep apnea on patients' lives but on objectively measured parameters such as weight and height, neck circumference, and blood pressure. This is important because scores that assess sleep apnea shortly

and objectively may minimize the possible underreporting of the patient, which can lead to underdiagnosis and undertreatment of this condition.

The BOAH score is a simple and practical tool for the clinic because it is based on data such as body mass index (BMI), apneas experienced during sleep, age, and hypertension. Gabryelska et al. (2021) applied this score to 273 patients in a sleep clinic in Scotland and found that the best cut-off point for mild to severe OSA (AHI ≥5) was 2 points, with an AUC of 0.749 and a Youden index of 0.41. Our study used the same cutoff point, the AUC was 0.679, and the Youden index was 0.36. A possible explanation for the lower AUC in our research is the difference in the mean age of the evaluated subjects: 35 years in our study and 49.4 years in the study by Gabryelska et al. (2021) [20].

The BOAH score has a good predictive score and is based on simple data but depends on the presence of another person who can report the apneas witnessed during sleep. This may underestimate the risk of OSA in individuals who are not married or who live alone. Therefore, the No-apnea score may be a good alternative because it uses only age and neck circumference to assess the risk of OSA. This score has had good predictive results, especially for mild to severe OSA. The best cut-off point for all OSA severities was 3 points, the same as suggested by the study that developed indicator [24]. Similar studies confirm our findings, such as a study by Duarte et al. (2020) in Brazil with 6606 adults of both sexes with suspected sleep disorders. Among the 3054 men evaluated, 88.5% had mild to severe OSA, and the PPV and NPV of the No-apnea score were 92.0 and 37.3 (+2.1 and + 7.1% higher than in our study. Furthermore, as in our research, Duarte et al. (2020) also found that the No-apnea score had better predictive results across all OSA severities than other methods, such as STOP, NoSAS, and ESS. It only fell below STOP-Bang, which had similar results [24].

To evaluate the accuracy of a diagnostic test, it is essential to understand the relationship between sensitivity and specificity. In our study, the BOAH score had better specificity results (>70% across all OSA severities), whereas the No-apnea score had better sensitivity results (>70% across all OSA severities). These two tests have opposite results regarding sensitivity and specificity, but their combination may increase diagnostic accuracy [25]. Since polysomnography (PSG), the gold standard test for diagnosing OSA, is expensive and scarce, combining different tests may be a more viable option to improve diagnostic ability. We have found this: in the parallel test, the AUC for mild to severe OSA (AHI ≥5) was higher than in the single trials, and in the serial test, the best results were for severe OSA (AHI ≥30). Other studies show similar results, such as the study by Chung et al. (2014) in Australia of 424 participants with OSA symptoms revealed that the combination of STOP-Bang with ESS can be used to confirm but not rule out the presence of clinically relevant OSA. This combination increased the specificity of STOP-Bang from 31% to 94% but reduced its sensitivity from 87% to 51% [26]. Another study conducted in Canada with 516 preoperative patients found that combining different alternative STOP-Bang scoring models with other variables (age, BMI, sex, and blood pressure.) improved the specificity and PPV of the screening tool for obstructive sleep apnea in surgical patients. The specificity for any two positive items from the 4 STOP questions plus BMI >35 kg/m^2, male sex, or neck circumference >40 cm for identifying moderate-severe OSA was 85%, 77%, and 79%, respectively. The authors conclude that specific combinations of predictive factors improved the specificity of the STOP-Bang questionnaire [27]. And this combined analysis is also demonstrated with other instruments, such as the pulse oximeter. A study conducted in Germany with 132 participants undergoing surgery evaluated the impact of combining the STOB-Bang with the pulse oximeter in detecting OSA. For all severities of OSA, ODI alone displayed a larger AUC than SBQ and a similar AUC to their combination [28]. Therefore, the studies indicate that combining questionnaires and instruments to assess the risk of OSA may be a suitable strategy to improve diagnostic accuracy and reduce the number of false positives and negatives. However, the choice of the ideal questionnaires and how to combine them may vary depending on the study population's clinical characteristics and the screening test's purpose.

Therefore, combining BOAH and No-apnea scores can provide complementary information and improve the accuracy of sleep apnea diagnosis in rotating shift workers, reducing false positives and negatives. There are two basic ways to combine tests: in parallel and series. The combined result is positive with parallel testing if one of the two tests is positive. This increases the sensitivity and decreases the specificity of the test. If one of the two tests is negative, the combined result is negative with serial testing. This form increases the specificity and decreases the sensitivity of test [25]. The choice of the combination form depends on the severity of the apnea and the tests' availability. For example, for mild to severe OSA (AHI ≥5), parallel testing can detect as many cases as possible and refer them for appropriate diagnosis. For severe OSA (AHI ≥30), serial testing can be used to confirm the diagnosis with greater certainty and facilitate the initiation of treatment. Combining BOAH and No-apnea scores in a series setting can exclude cases of severe OSA (AHI ≥30/h) with an NPV of 92.9%, avoiding unnecessary PSGs. Positive cases can be referred for PSG to confirm the diagnosis. This approach reduces PSGs, optimizes resources, and improves care quality. However, the BOAH and No-apnea scores do not replace PSG as the definitive diagnostic method for OSA. They are screening tools that can identify individuals at risk for OSA and indicate PSG when necessary. Further studies are needed to assess their generalizability and validity across different patient groups and settings.

The study has several strengths, such as the evaluation of workers at risk for sleep apnea and occupational accidents; the comparison of two simple and easy questionnaires with polysomnography, the gold standard method for the diagnosis of sleep apnea; the analysis of the combination of the questionnaires in parallel and in series to increase the accuracy and reliability of the diagnosis; and the use of objective and standardized criteria to define the study outcomes. However, the study also has some limitations, such as the sample size for polysomnography, which may be due to the procedures for performing the method (sleeping one night in the hospital) on an individual's day off, which may be inconvenient or impractical for personal reasons. Despite this, the post hoc analyses had power above 80%. Selecting individuals with at least one cardiovascular risk factor limits extrapolation to other populations. However, shift work generates metabolic changes with an increased risk of hyperglycemia, dyslipidemia, and hypertension because of the altered circadian cycle. In addition, modified work schedules lead shift workers to have more physical inactivity. Furthermore, another limitation of this study is the non-performance of the full STOP-BANG, which impedes us from comparing the combination of BOAH and No-apnea scores with the full STOP-BANG; however, this was impossible.

5. Conclusion

BOAH score and No-apnea score are valuable tools in screening for OSA in rotating shift workers drivers of heavy off-road machinery. It offers similar predictive values to other available tools while being shorter, easier to use, and without information bias in drivers. In addition, matching the scores may increase the prediction of OSA. Therefore, it should be considered a valuable tool in clinical practice. Moreover, this study may contribute to further research in the field, as these tools are more feasible and practical for population-based surveys.

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Conflicts of interest/Competing interests

This was not an industry-supported study. The authors have indicated no financial conflicts of interest. There is no off-label or investigational use in this study.

Ethics approval

All procedures involving human participants were approved by the Research Ethics Committee of the Federal University of Ouro Preto (CAAE: 39682014.7.0000.5150).

Consent to participate

This study was conducted according to the guidelines laid down in the Declaration of Helsinki, and written informed consent was obtained from all participants.

Consent for publication

Informed consent was obtained from all individual participants included in the study.

Data availability statement

The data supporting this study's findings are not openly available due to reasons of sensitivity and are available from the corresponding author upon reasonable request.

CRediT authorship contribution statement

Luiz Antônio Alves de Menezes-Júnior: Conceptualization, Methodology, Data curation, Writing – original draft. **Virgínia Capistrano Fajardo:** Conceptualization, Methodology, Data curation, Writing – review & editing. **Raimundo Marques do Nascimento Neto:** Conceptualization, Methodology, Data curation, Writing – review & editing. **Silvia Nascimento de Freitas:** Conceptualization, Methodology, Data curation, Writing – review & editing. **Fernando Luiz Pereira de Oliveira:** Conceptualization, Methodology, Data curation, Writing – review & editing. **Fausto Aloísio Pedrosa Pimenta:** Conceptualization, Methodology, Data curation, Writing – review & editing. **George Luiz Lins Machado-Coelho:** Conceptualization, Methodology, Data curation, Writing – review & editing. **Adriana Lúcia Meireles:** Data curation, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.sleepx.2023.100084.

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