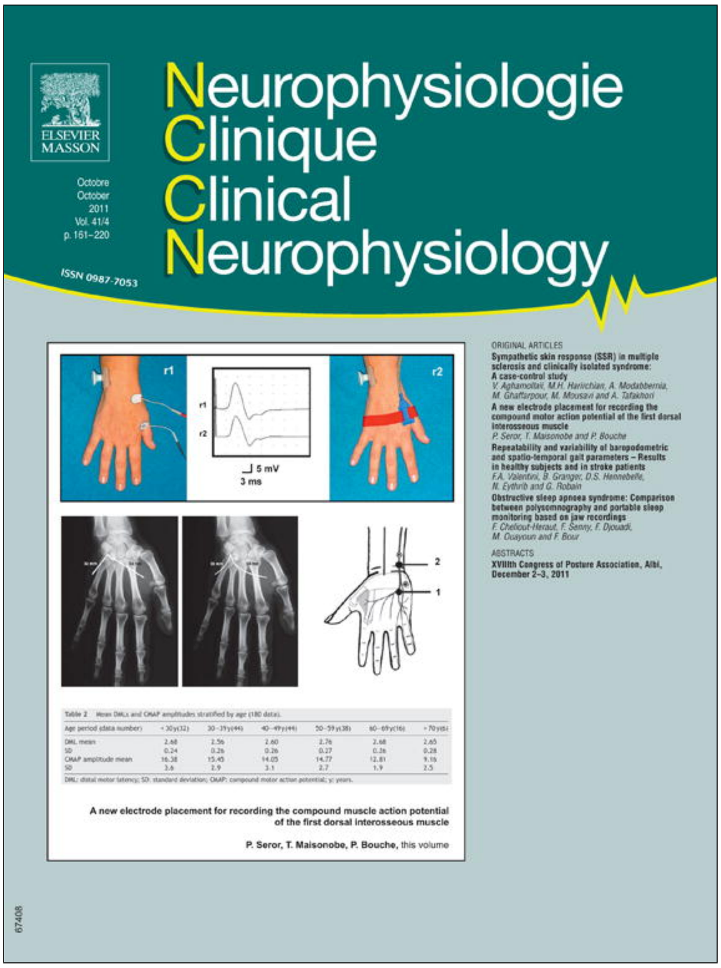
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ORIGINAL ARTICLE

Obstructive sleep apnoea syndrome: Comparison between polysomnography and portable sleep monitoring based on jaw recordings

Apnée obstructive du sommeil : comparaison polysomnographie et système portable avec enregistrement de mouvements mandibulaires

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KEYWORDS
Sleep disorders;
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Polysomnography;
Polygraphic recordings

Summary
Introduction. — Obstructive sleep apnoea syndrome (OSAS) constitutes a new major public health problem because of its several pathophysiologic consequences such as cognitive disorders, excessive daytime sleepiness with risks of traffic accidents, cardiovascular implications, and decrease of quality of life. The necessity of a gold-standard polysomnography to ensure an accurate diagnosis implies an expensive, technical and time-consuming examination. Thus, it seems logical to develop new systems so as to diagnose SAS and to make it possible to detect apnoeas/hypopnoeas easily during sleep even at home.
Aim of the study. — To assess a novel type-3 portable monitoring (PM) device, the Somnolter, and dedicated automatic analysis of several signals, one of which is the mandibular movement signal.
Method. — We studied patients suffering from OSAS. For all the patients, a nocturnal diagnosis polysomnography (PSG) was recorded in hospital settings, based on six EEG channels, two EOG channels, chin EMG channel, EKG, and respiratory parameters. At the same time, the Somnolter PM device recorded the physiological parameters from its own nasal prongs, thoracic belt, pulse oxymeter, body position, and jaw movement sensors. A visual analysis of PSG recordings was made leading to the detection of apnoea/hypopnoea index (AHI-PSG) and an automatic

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analysis of the Somnolter traces was performed to get automatic apnoea/hypopnoea index (AHI-A). The added value of the mandible movement signals was the particular jaw movements related to arousals, to respiratory efforts and to sleep/wake state. A comparison was made between the automatic and gold AHIs standard and the correlation was calculated between them.
Results. — Ninety patients, aged between 47 and 70 years (mean age: 55.4 ± 8.7) took part in the study. The linear regression and the correlation coefficient between AHI-PSG and AHI-A showed the good reliability of the automatic method. The Bland Altman analysis shows a correlation of 0.95 with a sensitivity of 83.6 and specificity of 81.8.
Conclusion. — The dedicated automatic analysis based on mandibular movements presents a good potential for the diagnosis of OSAS. The AHI computed by the automatic method is correlated with the AHI-PSG and the Somnolter could easily be used both in hospital, and in ambulatory settings.

MOTS CLÉS
Troubles du sommeil ;
Troubles respiratoires du sommeil ;
Syndrome d'apnée obstructive du sommeil ;
Mouvements mandibulaires ;
Somnolter ;
Polysomnographie ;
Polygraphie

Résumé
Introduction. — Le syndrome d'apnées obstructives du sommeil (SAOS) avec toutes ses conséquences physiopathologiques : troubles attentionnels, somnolence, impact cardiovasculaire, constitue un important facteur de risque d'accidents de circulation et/ou de travail et devient un sérieux problème de santé publique. L'augmentation régulière de cette pathologie incite à développer des systèmes d'enregistrement simplifiés au domicile du patient permettant un dépistage précoce et une prise en charge rapide du SAOS.
Objectifs. — Nous avons utilisé un nouveau système portable ambulatoire de type 3 (Somnolter) de détection des apnées/hypopnées sur la base de l'enregistrement de mouvements mandibulaires avec analyse automatique associant la mesure des mouvements mandibulaires à celle des paramètres respiratoires : capteur nasal, ceintures thoracoabdominales et oxymétrie du pouls. Nous avons comparé les résultats obtenus par ce système à ceux de la polysomnographie.
Méthode. — Nous avons étudié les patients présentant des signes cliniques de syndrome d'apnée obstructive du sommeil. Tous ont eu de façon systématique une polysomnographie (PSG) nocturne comportant l'enregistrement des voies EEG, EOG, EMG, ECG et des paramètres respiratoires avec simultanément un enregistrement Somnolter permettant l'acquisition de signaux respiratoires propres et des mouvements de fermeture-ouverture de la bouche par capteur mandibulaire. L'index d'apnées/hypopnées par heure de sommeil a été calculé chez chaque patient à partir de la polysomnographie (IAH-PSG) et comparé à celui obtenu par le système Somnolter (IAH-A).
Resultats. — Nonante patients âgés de 47 à 70 ans (âge moyen : 55,4 ± 8,7) sont entrés dans cette étude. L'index d'apnées/hypopnées est comparable dans les deux systèmes et le calcul de la corrélation indique un coefficient significatif. L'analyse par Bland-Altman montre une corrélation de 0,95, avec seuil de sensibilité à 83,6 et de spécificité à 81,8.
Conclusion. — La corrélation entre IAH-A et IAH-PSG (*gold standard*) est significative. L'analyse automatique par Somnolter basée sur les mouvements mandibulaires constitue une méthode utile dans le diagnostic du syndrome d'apnée obstructif du sommeil aussi bien en milieu hospitalier qu'en ambulatoire.

Introduction

Polysomnography is considered the gold standard for the diagnosis of obstructive sleep apnoea syndrome (OSAS), both in adults and children. However, access to polysomnography is restricted due to its cost and limited availability [2,30]. Although the diagnosis of OSAS is first suspected on clinical grounds, such as excessive daytime sleepiness and snoring, confirmation of the diagnosis requires overnight studies and the use of techniques to assess sleep and wakefulness.

Sleep apnoea syndrome is constantly increasing and affects a very large population but the possibility to diagnose it is often small. Thus, in the Wisconsin Sleep Cohort Study, the prevalence of an apnoea/hypopnoea index (AHI) ≥ 5 was 24% in men and 9% in women aged 30—60 [31], while 93% of women and 82% of men with moderate-to-severe sleep apnoea did not receive any diagnosis [32]. OSAS now constitutes a major public health problem because of its frequency and numerous pathophysiological consequences such as excessive daytime sleepiness with risks of traffic accidents [8], cardiovascular disorders [16,22], cognitive disorders, decrease in work performance, impairment of executive functions and attention, and decreased quality of life [9]. Therefore, it seems important to develop new systems to diagnose OSAS and to make it possible to detect easily apnoeas/hypopnoeas during sleep, even at home.

Many authors developed ambulatory systems to detect apnoeas/hypopnoeas without EEG recording [7]. Since polysomnography is expensive and not readily available, respiratory polygraphy is now widely used in the diagnosis of OSAS [5,13,28]. The severity of OSAS is appreciated through the apnoea/hypopnoea index (AHI: number of apnoeas/hypopnoeas per hour of sleep) with distinction of severe OSAS (AHI > 30/h), moderate OSAS ($15 \geq$ AHI ≤ 30), and mild OSAS ($5 \geq$ AHI < 15). A minutely detailed diagnosis of OSAS must be appreciated not only by the AHI, but also by oxygen desaturation events, duration of apnoeic events, and number of arousals associated with apnoea/hypopnoea. Respiratory polygraphy through portable monitoring (PM) allows accurate and simple diagnosis of OSAS in selected patients with clinically suspected sleep apnoea and could improve access to care and reduce costs [5,28]. In respiratory polygraphy, one to four cardiorespiratory biosignals are recorded for the detection of sleep apnoeas/hypopnoeas, but the AHI is automatically computed over the total recording time. This leads to underestimate the AHI, compared with the gold standard PSG. In a large review of literature, Flemons et al. [10] established recommendations when using PM according to the American Sleep Disorders Association (ASDA) classification, which divides the diagnostic systems into four levels [3]. These authors consider that Level-3 studies (using at least four channels) are potentially appropriate in patients with a high pretest probability of sleep apnoea. More recently, some authors have also used automatic analysis of ambulatory polygraphy to detect sleep disordered breathing [6,25].

In our study, we used a new Type-3 PM device that records several physiological signals, i.e., nasal flow, SpO_2, body position, thoracic movements, and jaw movements. The automatic analysis of the traces is based on a multisignal approach to detect sleep apnoeas/hypopnoeas and sleep/wake states. Dedicated signal processing of the jaw movements was shown to be efficient both in sleep apnoea and hypopnoea detection [26] and in sleep/wake discrimination [27]. In short, recording the jaw movement signals allows the distinction between high jaw activity in wakefulness, from no jaw movement in healthy sleep. Respiratory events when they exist are characterized by oscillating jaw movements, more opened mouth and a salient mouth closure movement occurring after the event.

The rationale of the jaw movements is that when the upper airway collapses and when, in the meantime, the pressure in the lungs becomes more and more sub-atmospheric, the inferior jaw is passively lowered by thoracic attraction [12]. The consequent opening of the mouth means, during sleep, a stronger effort to breath.

We focused our work on patients suffering from excessive daytime sleepiness and snoring and compared the AHI computed with the automatic analysis of the Somnolter traces to the AHI obtained from the visual analysis of PSG traces.

Methods

Patients and polysomnographic recordings

We studied patients with suspected obstructive sleep apnoea syndrome based on excessive daytime sleepiness and snoring. Patients were selected only on clinical investigations. We excluded all patients suffering from neurological disorders or nocturnal parasomnias, restless leg syndrome and periodic limb movements. All patients were first examined by a pneumologist who excluded severe respiratory disorders. For at least 3 weeks prior to the investigation, the subjects did not take any specific medication (dopamine agonists, benzodiazepines, opioids or substances of abuse such as alcohol, which can be a risk factor of OSAS). Body mass index (BMI) was calculated for all patients. Daytime sleepiness was assessed with the Epworth Sleepiness Scale (ESS) [20]. In the sleep laboratory, all patients underwent a 10-hour diagnosis overnight polysomnography (PSG) using Resmed system (Embla). This system recorded six EEG channels (symmetrical frontal, temporal and occipital), two EOG channels, chin EMG, bilateral tibial EMG, EKG, and the respiratory parameters: nasal flow, thoracic and abdominal efforts (thoracic and abdominal piezo bands), oxyhemoglobin saturation (digital pulse oximetry), body position, and snoring.

Ethical considerations

All patients gave informed consent to the investigations and this work has been approved by the ethic committee of our institution. We did not cause any physical or emotional harm to our subjects and the results of our research are totally anonymous. The patients were not financially interested in the device.

Manual scoring

The same experienced neurophysiologist, who was not aware of the portable monitoring device data, manually scored the sleep stages and respiratory events from all PSG recordings. Sleep was staged according to the standard criteria [24]. Arousals were defined according to the American Sleep Disorders Association (ASDA) guidelines [3]. Apnoeas/hypopnoeas were scored according to the American Academy of Sleep Medicine (AASM) Guidelines for measurement in clinical research [1]. Apnoea was defined as a complete cessation of nasal flow ≥ 10 seconds. Hypopnoea was defined either as $\geq 50\%$ reduction in respiratory airflow for ≥ 10 seconds or as $\geq 30\%$ reduction in respiratory airflow for ≥ 10 seconds and accompanied by a decrease of $\geq 3\%$ from the baseline in SaO_2 or by an arousal. An apnoea/hypopnoea index (AHI) was calculated based on the number of apnoeas plus hypopnoeas per hour of sleep. The recordings were studied within a ''start-analysis'' (9 p.m.) and ''stop-analysis'' (7 a.m.) time period. The 10 hours were also recorded on a video.

Portable monitoring device

Jaw movements and other respiratory parameters, i.e., nasal flow (Protek canula), thoracic movements (plethysmography inductance), SpO_2 (Nonin pulse oxymetry), and body position (built-in sensor), were recorded simultaneously with PSG using the Somnolter device (Nomics, Liege, Belgium). The principle of the measure of the jaw movements is based on the mutual electromagnetic induction of two electromagnets (the sensors). The probes were placed on the vertical midline of the face, parallel to each other,

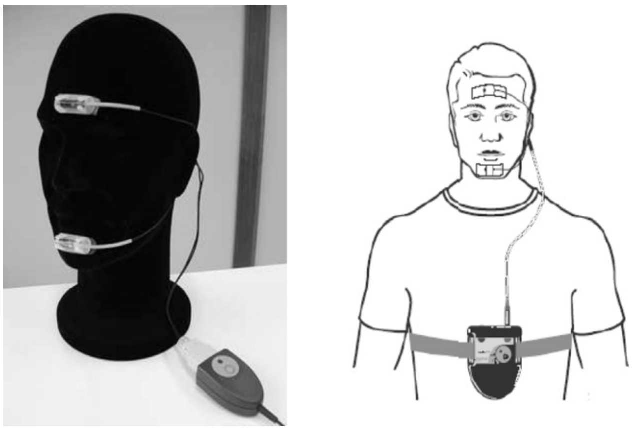

Figure 1 Left: placement of the sensors measuring the mid-sagittal jaw movement. Right: the ambulatory portable Somnolter device, which records the mid-sagittal jaw movement, the nasal airflow, the arterial oxygen saturation.

one on the forehead and one below the lower lip (Fig. 1). The output voltage is a monotonic cubic function of the distance between the two probes [4]. The voltage is sampled at 10 Hz, digitally linearized and the corresponding mouth opening is stored on the computer synchronously with the other PSG channels in an EDF file along with the other parameters recorded by the device. Jaw movement data can be expressed in absolute values (millimeter) or in normalized value (percentage of mouth opening), the reference value (zero) being the fully closed mouth level [12,26] (Fig. 2); we chose to analyze the signals in absolute values.

Portable sleep apnoea automated analysis

The automatic scoring was based on standard rules applied on nasal airflow to delineate respiratory events of at least 10 seconds. Apnoeas occurred if an airflow reduction of more than 80% appeared within 10 seconds. Hypopnoeas were scored if an airflow reduction of more than 30% occurred in association with a desaturation $\geq$ 4% or with a salient jaw

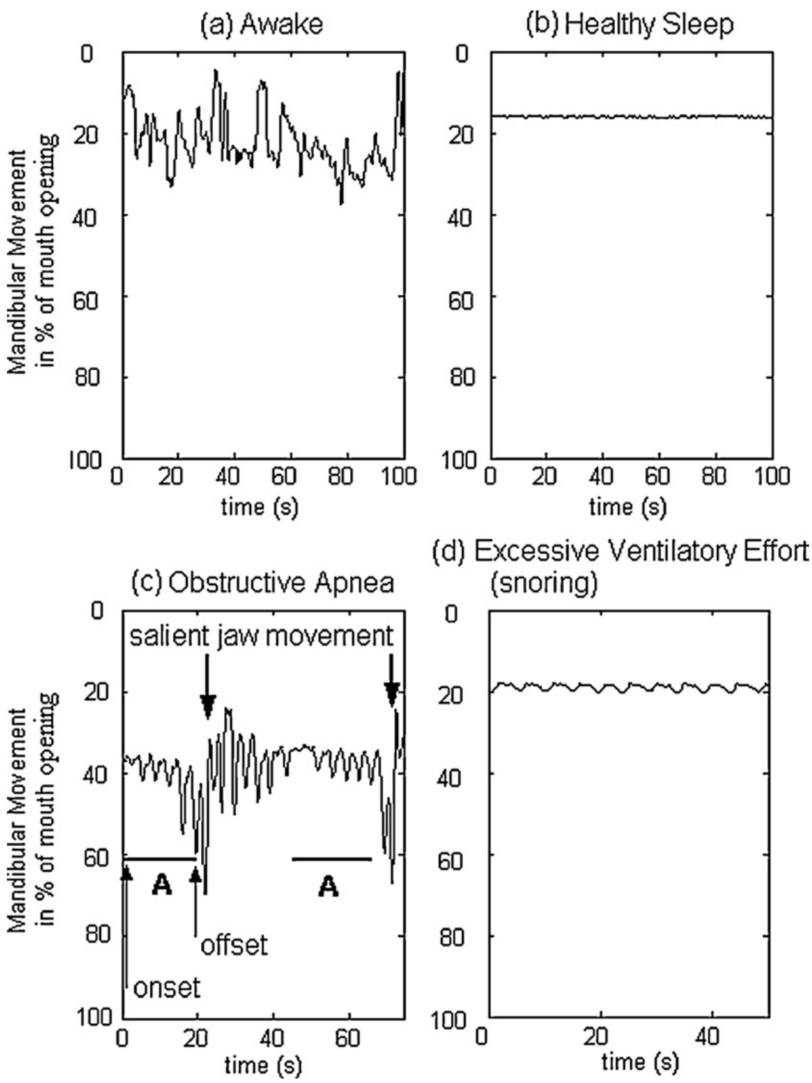

Figure 2 Jaw movement patterns in (a) wake state, (b) healthy sleep, (c) obstructive apnoea and (d) snoring. The signal is expressed in % of mouth opening, i.e., 0% is the fully closed mouth level while 100% corresponds to a fully opened mouth.

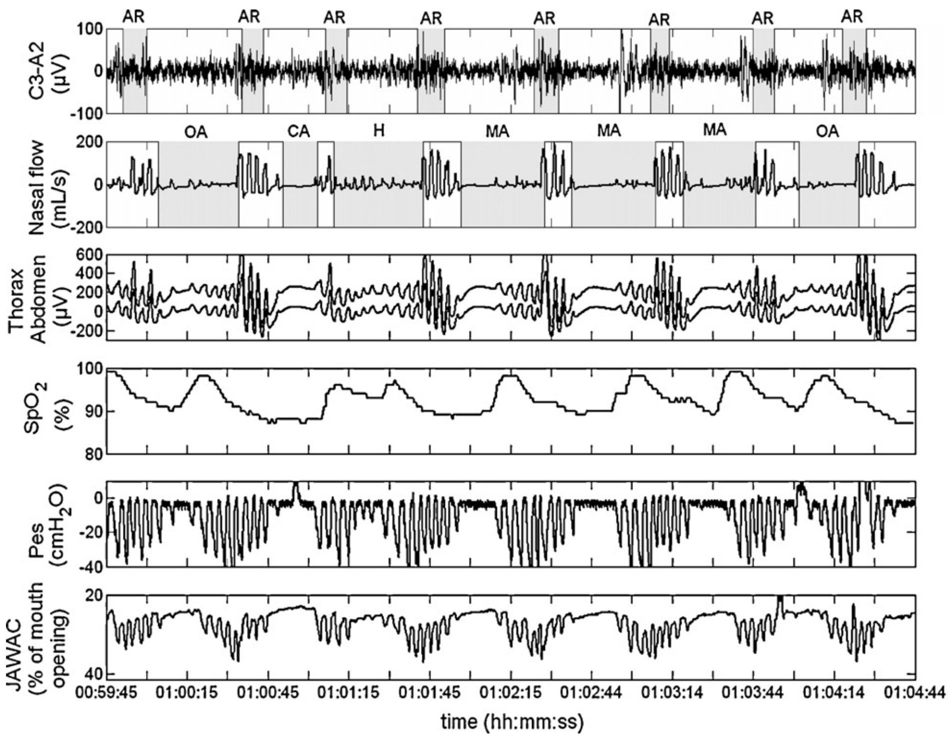

Figure 3 Illustration of the jaw movements (Jawac), Pes (oesophageal pressure), oxygen saturation (SpO_2), thoracic-abdominal movements and nasal flow in case of obstructive apnoea (OA), central apnoea (CA), mixed apnoea (MA) and hypopnoea (H). An EEG channel (C3-A2) and the scored arousals (AR) are also illustrated.
Senny et al., 2007.

movement following the respiratory event, connected with an arousal. A salient jaw movement is characterized by high amplitude or discontinuous movements in the time signal (see Fig. 2c, the salient jaw movements are pointed by an arrow). The sleep/wake state provided by the automated analysis was also based on a multisignal approach in which the wake states are characterized by ''up'' body positions or very high or ''chaotic'' jaw activity (see Fig. 3). The jaw movement signal processing has been described in Senny et al. [26,27] and integrated into the multisignal analysis software provided with the device. Even if the system is able to classify apnoeic events into obstructive, central and mixed apnoeas and hypopnoeas [27], the assessment of the sleep event classification provided by the automatic analysis is out of the scope of this study. The portable recordings were analyzed over the same ''start-analysis'' (9 p.m.) and ''stop-analysis'' (7 a.m.) time period as PSG.

Data analysis and statistics

For each patient, we calculated: the AHI from the PSG index (AHI-PSG) and the AHI from the automated analysis of the PM recorded signals (AHI-A). We considered as severe OSAS patients those whose apnoea index was higher than 30 (group 1); moderate OSAS patients those whose AHI was between 15 and 30 (group 2); mild OSAS patients those whose AHI was equal or higher than five and less than 15 (group 3). Patients with AHI < 5 (group 4) were considered normal. Daytime sleepiness was considered excessive when the ESS was > 10. The statistical analysis of quantitative data was performed by analyzing variances (ANOVAs). A comparison was made between the two methods concerning the AHI index and the correlation was calculated between the automatic method and the gold standard using Bland-Altman analysis.

Results

The database comprised 104 recordings (Tables 1—4). However, seven recordings were excluded due to a total sleep time inferior to 5 hours, and seven of them were rejected because one or several of the respiration signals were lost (two in PSG and five in Somnolter recordings). Ninety patients between 47 and 70 (mean-age: 55.4 ± 8.7; 30 women and 60 men) were finally included in the study. They were grouped according to the value of AHI-PSG: 34 patients with severe OSAS (group 1, eight women and 26 men), 28 patients with moderate OSAS (group 2, 11 women and 17 men) and 21 patients with mild OSAS (group 3, five women and 16 men). Seven patients were considered healthy (group 4, six women and one man).The BMI showed an upper-weight in patients with moderate and severe OSAS but with the Student the difference was not significant ($P < 0.2$). No relation was observed between ESS and OSAS ($P = 3$) and ESS was lower in severe OSAS. A good correlation is obtained between AHI from PSG and AHI from Somnolter device (Fig. 4) with R: 0.95 ($P < 0.0001$). The Bland-Altman analysis (Fig. 5) of AHI-A vs AHI-PSG showed a bias of 6.0 and a standard deviation of 8.3 leading to an underestimation of

Table 1 AHI-PSG/ AHI-A comparison. Mild OSAS (5 ≥ AHI < 15/h).

Patients $n = 21$	Gender	Age (Years)	BMI	ESS	AHI—PSG	AHI—A
Mean	5 females	44.8	26.7	9.8	9.1	13.7
SD	16 males	11.6	7.3	6.5	2.2	10.1

BMI: body mass index; ESS: Epworth Sleepiness Scale; AHI-PSG: polysomnography apnoea/hypopnoea index; AHI-A: automatic apnoea/hypopnoea index.

Table 2 AHI-PSG/ AHI-A comparison. Moderate OSAS (15 ≥ AHI ≤ 30/h).

Patients $n = 28$	Gender	Age (Years)	BMI	ESS	AHI—PSG	AHI—A
Mean	11 females	49.8	28.9	8.6	22.6	18.1
SD	17 males	11.9	5.3	5.3	4.6	9.1

BMI: body mass index; ESS: Epworth Sleepiness Scale; AHI-PSG: polysomnography apnoea/hypopnoea index; AHI-A: automatic apnoea/hypopnoea index.

Table 3 AHI-PSG/AHI-A comparison. Severe OSAS (AHI > 30/h).

Patients $n = 34$	Gender	Age (Years)	BMI	ESS	AHI—PSG	AHI—A
Mean	8 females	57.2	29.7	6.3	55.5	46.9
SD	26 males	10.9	4.1	5.2	17.1	20.7

BMI: body mass index; ESS: Epworth Sleepiness Scale; AHI-PSG: polysomnography apnoea/hypopnoea index; AHI-A: automatic apnoea/hypopnoea index.

the AHI by the Somnolter compared to PSG. Nevertheless, the automatic method had a high sensitivity (83.6) and specificity (81.8) with LR+ (4.59) and LR− (0.0020) (Table 4).

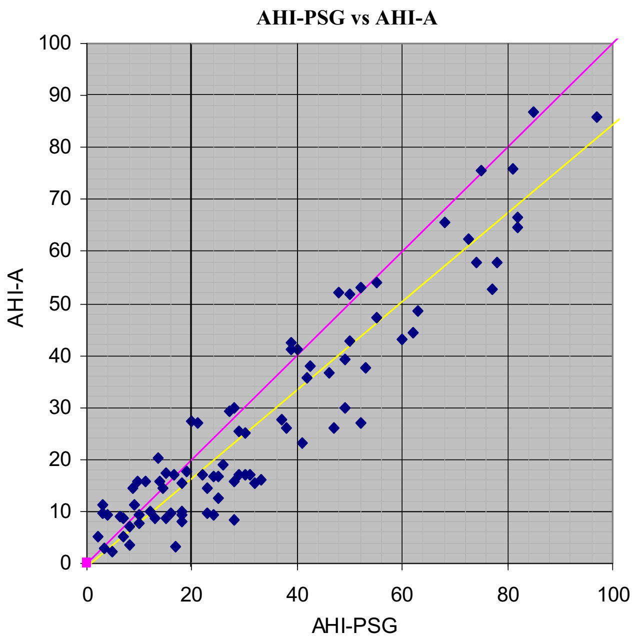

Figure 4 Relationship between polysomnography AHI and automatic AHI. AHI-PSG vs AHI-A.

Discussion

Since polysomnography, which is the classical gold standard, is costly and not readily available, respiratory polygraphy is now widely used in the diagnosis of OSAS [5]. Validation studies of different respiratory systems performed simultaneously with night polysomnography in sleep laboratories have shown the high sensitivity and specificity [13,28] of respiratory polygraphy. Nevertheless, these ambulatory

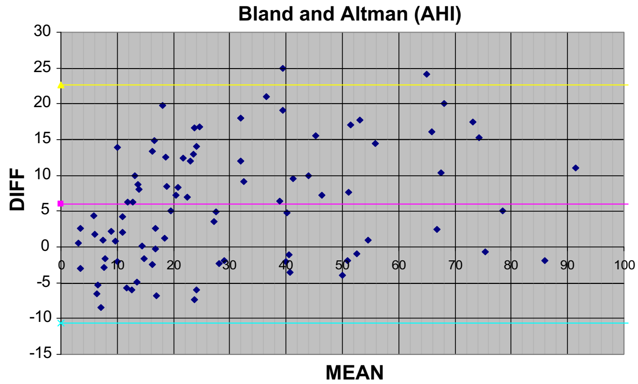

Figure 5 Bland and Altman diagram of apnoea/hypopnoea index. The pink line is the average of the differences; the yellow and blue lines are the average plus and minus two standard deviations.

Table 4 Bland-Altman analysis.

Patients $n = 90$	AHI-A vs AHI-PSG
Correlation	0.95
Bland Altman analysis	
Mean	6
SD	8.3
Sensitivity	83.6
Specificity	81.8
LR+	4.59
LR−	0.0020

systems have to be used with caution because negative results obtained by portable systems do not exclude OSAS.

In our study, we used a new type-3 portable monitoring, the Somnolter device (Nomics, Liege, Belgium). This device records jaw movements in association with classical parameters by nasal prongs, thoracic belt, and pulse oxymeter. The automatic analysis of the signals provided in the software package relies on a multisignal approach for respiratory event detection and sleep/wake discrimination. In this paper, a PSG and the PM device were simultaneously recorded in patients suffering from excessive daytime sleepiness and snoring. Then, we compared the automatic Apnoea/Hypopnoea Index (AHI-A) computed from the Somnolter recordings with the gold standard AHI-PSG. The recommendations of the American Sleep Disorders Association (ASDA) established that type-3 studies are potentially appropriate in patients with high probability of sleep apnoea.

Our results showed a good correlation between the gold standard PSG analysis and automatic analysis ($R = 0.95$), the average and standard deviation of the difference between these two indices were 6 ± 8.3. The sensitivity and specificity for SAS diagnosis using the automatic method were 83.6 and 81.8%, respectively. The averaged AHI calculated by the Somnolter is a bit underestimated compared with the gold standard PSG. This could come from the difference in total sleep time calculated from EEG signals in PSG and estimated from a multisignal approach involving jaw activity in Somnolter. False negative events came mainly from isolated respiratory events missed by the analysis, while respiratory effort related arousal (RERA) and sleep events close to hypopnoea mainly contributed to false positive events. The performance of the automatic method was nevertheless good. Moreover, thanks to its multisignal approach, the analysis is robust especially in hypopnoea detection because its definition (case of automatic analysis) relies on the presence of a SaO_2 or a salient jaw movement. Thus, even if SaO_2 recording fails, hypopnoeas are expected to be scored if a salient jaw movement occurs. Finally, in the worst case where both SaO_2 and nasal flow are not available, sleep apnoeas and hypopnoeas may still be correctly detected from jaw signal processing [26].

The fact that jaw movements observed in wakefulness are different from those in sleep, and the fact that both jaw movements and other respiratory parameters are analyzed together, seems to make automatic analysis more performing in OSAS diagnosis. In healthy subjects during wake state, jaw movements are expected to be chaotic. During healthy sleep, no or very little jaw movements occur but during respiratory effort, jaw activity becomes oscillatory, with breathing frequency. These behaviours might be related to the genioglossal activity, which varies with the intrapharyngeal negative pressure during wakefulness [12,18,26]. Fogel et al. [11] suggest that during wakefulness, genioglossal muscle activation is directly proportional to intrapharyngeal pressure. As there is a relationship between jaw movements, masseter activation and genioglossal muscle activity [15,19], we suppose that the analysis of jaw movements can score respiratory events and may be a good tool for OSAS diagnosis. In our study, we carried out our observation by using jaw movement sensors monitoring and we observed when the upper airway collapses that jaw is passively lowered by thoracic attraction. This result has been described in an initial study by Van de Graf [29]. The consequent opening of the mouth during sleep reflects a stronger effort to breathe and for Meurice et al. [17], mouth opening contributes to the occurrence of sleep-related respiratory disorders. Some authors [14,23] have described a correlation between jaw movements with frequency breathing (0.15—0.33 Hz) and oesophageal pressure (Pes) during obstructive sleep apnoeas. This correlation confirmed that the jaw movements could reflect the effort to breathe, meaning that the jaw motion sensor is an effort sensor and not a respiration sensor (like cannula). Other authors have noted that apnoeas tend to be followed by large mouth breaths and that patients with OSAS show increased sleep-time breathing orally in comparison with snorers. These results indicate that vertical mandibular position is more open during sleep in OSAS patients than in healthy subjects. Even if significant jaw openings are more important in OSAS patients during NREM sleep than during REM sleep because of the muscle atonia attenuation [21], a ''salient jaw movement'' as a smooth or sharp closing jaw movement always appears during the breathing recovery. The arousals following apnoeas or hypopnoeas appear clearly on the jaw movements when discontinuities of the masseter signal happen.

Conclusion

The dedicated automatic analysis based on mandibular movements presents a good potential for the diagnosis of OSAS. The AHI computed by the automatic method is in correlation with the AHI-PSG and the Somnolter could easily be used in hospitals, as well as in ambulatory settings.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

Acknowledgments

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