"Added value of mandible movement assessment in the management of adult sleep disordered breathing"

Maury, Gisèle

ABSTRACT

Obstructive sleep apnoea syndrome (OSAS) is a frequently occurring disease with multiple co-morbidities. Left untreated, OSAS has important health and socioeconomic consequences but effective therapies are available. Consequently, its diagnosis is important. The usual pathway for a reliable diagnosis includes detailed sleep history, clinical examination followed by attended full polysomnography (PSG) which is the reference standard for the diagnosis of respiratory sleep disorders. This approach is a time and resource consuming process given its increasing demand. Therefore, several less elaborate sleep portable monitoring (PM) devices have been developed for the diagnosis of OSAS. Up to now however, no single device has been widely accepted as an alternative to PSG because of important limitations such as the lack of sleep/wake status assessment, the lack of detection of arousals during sleep (an important contribution in the calculation of the respiratory arousal index, an index of ...

CITE THIS VERSION

Maury, Gisèle. Added value of mandible movement assessment in the management of adult sleep disordered breathing. Prom. : Marchand, Eric http://hdl.handle.net/2078.1/154224

DIAL is an institutional repository for the deposit and dissemination of scientific documents from UCLouvain members. Usage of this document for profit or commercial purposes is strictly prohibited. User agrees to respect copyright about this document, mainly text integrity and source mention. Full content of copyright policy is available at Copyright policy
Chapter 3
The sleep/wake state scoring from mandible movement signal

Expanded from Sleep Breath 2012;16(2) : 535-542

SUMMARY

Estimating the total sleep time in home recording devices is necessary to avoid underestimation of the indices reflecting sleep apnoea and hypopnoea syndrome severity, e.g. the apnoea-hypopnoea index (AHI). A new method to distinguish sleep from wake using jaw movement signal processing is assessed. In this prospective study, jaw movement signal was recorded using the Somnolter® portable monitoring device simultaneously with polysomnography (PSG) in consecutive patients complaining about a lack of recovery sleep. The automated sleep/wake scoring method is based on frequency and complexity analysis of the jaw movement signal. This computed scoring was compared with the PSG hypnogram, the two total sleep times (TST\textsubscript{PSG} and TST\textsubscript{SMN}) as well. The mean and standard deviation (in minutes) of TST\textsubscript{PSG} on the whole dataset (n = 124) were 407 ± 95.6, while these statistics were 394.2 ± 99.3 for the TST\textsubscript{SMN}. The Bland and Altman analysis of the difference between the two TST was 12.8 ± 57.3 minutes. The sensitivity and specificity (in %) were 85.3 and 65.5 globally. The efficiency decreased slightly when AHI lies between 15 and 30, but remained similar for lower or greater AHI. In the 24 patients with insomnia/depression diagnosis, a mean difference in TST of -3.3 minutes, a standard deviation of 58.2 minutes, a sensitivity of 86.3% and a specificity of 66.2% were found.
Sleep/wake state automated analysis based on mandible movement study provides interesting total sleep time assessment, with a global mean underestimation. This is at least partly explained by the difficulty to detect and distinguish quiet sleep /quiet wakefulness at the beginning of the night. Total sleep time assessment is indispensable in home screening devices.
INTRODUCTION

The first actigraphs were developed in the early 1970’s for the assessment of sleep. Actigraphy is increasingly used in sleep disorders assessment, in sleep research and clinical care. The use of a portable device that records movement over extended periods of time is applied in the study of insomnia and circadian rhythms. Movement is sampled several times per second and stored for later analysis. Despite the lack of sleep staging and microstructure analysis, the movement detectors have been used in patients with a variety of sleep disorders to distinguish sleep from wake periods. In the Update for 2007 performed by the AASM, the level of recommendation for the use of actigraphy in patients with obstructive sleep apnoea was high (standard) meaning a generally accepted patient-care strategy, if combined with validated way of monitoring respiratory events. Actigraphy provides an assessment of the total sleep time (TST). One of the severity indices of the OSAS is the apnoea-hypopnoea index (AHI), the ratio between the number of apnoeas and hypopnoeas, scored in respiration signals, and TST, computed from EEG, EMG and EOG traces. Types 3 and 4 portable monitoring (PM) devices include one to four cardio-respiratory bio-signals which are recorded for the detection of sleep apnoeas and hypopnoeas but neither an expert is available at home nor EEG traces are recorded. The apnoea-hypopnoea index is computed over the total recording time and this leads obviously to underestimation of the index compared with the gold standard PSG. To overcome the index underestimation problem and to allow an accurate diagnosis among the wider family of sleep disorders, sleep periods should be recognized from available data recorded by a type 3 or 4 PM by a dedicated method. The mandible movements is recorded by a
type 3 PM, of which features have been highlighted in. At the moment of the publication of this article, the results of the second chapter were known (the article was in construction for submission). Arousals that often follow up sleep events, appear in the mandible movement signal as the discontinuous and ample movements (the SMM) and are depicted in chapter 2. Differences in the mandible movement behaviour have been observed between wake, normal sleep and disturbed sleep (by apnoeas, hypopnoeas, snoring and respiratory effort related arousal events – RERA) : the mandible movements are quicker, less structured and aperiodic (like speech compared with snoring), moreover the mouth is less opened in wake than during respiratory events. These characteristics are depicted in chapter 5. Nevertheless, it does not mean that the mandible always moves or that periodic patterns do not occur in wake state : periodic patterns are assumed to be characterized by movements faster in wake (e.g. mastication) than in sleep (e.g. snoring), while quiet wake characterized by very few mandible movements is clearly difficult to distinguish from quiet sleep. An automated analysis of the mandible movement signal to distinguish sleep from wake gave sensitivity and specificity of respectively 85.1 % and 76.4 % which were similar to other published data about the actigraphy method. The purpose of this paper is the evaluation of the sleep/wake automated scoring computed from the mandible movement trace recorded by the Somnorler® device (NOMICS, Belgium) which records nasal airflow, blood oxygen saturation and body position signals in addition to the mandible movement signal.
MATERIAL AND METHODS

1. Subjects and recordings

Between 2009 and 2010, all the patients who underwent a polysomnography in the Sleep Laboratory of the University Hospital of Liège, Belgium, and who slept in the same conditions (room, devices and technical staff presence), were considered in the study. All these patients were suspected of any kind of sleep disorders; only those coming for CPAP titration were excluded. This study followed the principles of the Declaration of Helsinki; the patients were informed of the aim of the study and gave oral agreement.

The PSG (S7000 or N7000 polysomnographs, EMBLA Medcare, Denver, US) included neurophysiology signals: a three-channel electroencephalography (EEG, C3-A2, C4-A1, FZ-CZ), left and right electrooculography (EOG), submental electromyography (chin EMG) for sleep staging and arousal scoring, two (left and right) tibial EMG for periodic leg movement evaluation. Cardiorespiratory signals comprised ECG, nasal cannula/pressure transducer (NAF) (Protech, Mukilteo, US), chest and abdominal inductance plethysmography belts, a plethypulse, a blood oxygen oximeter (SaO2, Nonin, Plymouth, US), a snoring sound detection (piezoelectric sensor from EMBLA), and a body position marker (body position sensor Protech).

2. Jaw movements and the portable monitoring device

The Somnolter® device (NOMICS, Liège, Belgium) was placed the same night than PSG. The recording of this mandible movement signal was
performed by a distance-meter as described in chapter 1. This distance meter is the Jawsens® which is also included in the Somnolter®.

2.1. **Manual scoring rules**

Each PSG recording was manually scored by one of the authors (Laurent Cambron and Robert Poirrier).

The sleep stages were defined every successive 30s epochs, according to the Rechtschaffen and Kale scoring rules. The manual hypnogram was called PSG hypnogram. The arousals were reported, as recommended by the ASDA: an acceleration of the EEG frequencies in NREM sleep, associated with an increase of chin EMG amplitude in REM sleep, occurring at least during 3 seconds. Breathing events were scored according to the AASM Task Force proposals. Apnoea and hypopnoea were scored as related in Annex 1.

Recordings were classified according to the AHI as mild if AHI < 15, moderate if 15 ≤ AHI < 30 and severe in case of AHI ≥ 30. OSAS was diagnosed if an AHI ≥ 5 was associated to excessive daytime sleepiness or 2 or more symptoms. The jaw activity was blinded for the 2 scorers.

2.2. **Jaw movement processing**

The jaw movement signal processing especially focuses on separating high jaw activity awake from healthy sleep (no jaw movement most likely) and respiratory events, characterized by oscillating jaw movements and a more open mouth. It uses a wavelet-based complexity measure to compute local and contextual features computed on a 1024 sample sliding window without overlap (i.e. 102.4 seconds) and multi-layer perceptrons to take the final decision. The Somnolter® analysis software has the same analysis basis but some post-processing were added: 1) small sleep regions were deleted (less than 3 windows, i.e.
204.8 seconds), 2) if periodic jaw movements (period within 10 and 60 seconds) were found from the Fast Fourier Transform (a 3096-sample Kaiser sliding window was used such that 1024 samples were overlapped by the next sliding window), the central part of the Kaiser window was scored as sleep and 3) the sleep/wake scoring was finally scaled to fit the standard 30s-epoch. This latter sleep/wake scoring is called SMN hypnogram. The figure 1 sketches the jaw movement behaviour at the sleep onset where high jaw activity (wake is the grey part in the chin EMG trace) vanishes and lets place to low jaw activity (sleep is the white part in the chin EMG trace).

Figure 1: At the sleep onset, the jaw activity (provided by the Jawsens®) lowered, thus separating two main behaviours of the signal: high and chaotic jaw movement during (active) wake, highlighted as the grey parts in the chin EMG signal, compared with low and stable jaw movement during (quiet) sleep, the white part in the chin EMG.
3. **Statistical data analysis**

Data from PSG and Somnolter® were converted into European Data Format (EDF) files\(^{27}\) for synchronisation and statistical analysis under the MATLAB environment.\(^{28}\) Since both PSG hypnogram and SMN hypnogram had the same time base but did not exactly began at the same moment, a time START (lights out) and a time STOP (lights on) were defined for all patients and the results were computed only within this range. Intraclass correlation (ICC) was computed under the R software\(^{29}\) to measure the strength of the relation between two measurements (TST\(_{PSG}\) and TST\(_{SMN}\)). This relation was completed by Bland and Altman plot. Sensitivity (Se; the proportion of sleep on PSG identified as sleep by the automated analysis of the Somnolter®), specificity (Sp; the proportion of wake - “non-sleep” - state on PSG recognized as wakefulness by the automated analysis of the Somnolter®), positive and negative likelihood ratios (LR+ and LR-) of the epoch-by-epoch comparison were also computed. All these tests were applied to several sets of recordings based on two criteria : final diagnosis made afterwards (i.e. sleep disorders breathing, insomnia, etc...) and the AHI only.

The sleep latency from both methods was also compared. Two definitions of sleep latency were used : sleep latency was the time in minutes between the START time and the first sleep period (including sleep stage 1) lasting one sleep 30-second epoch or 15 consecutive minutes of sleep (noted SL and SL\(_{15}\) respectively). The first definition comes from the standard AASM rules. The second takes into account the wider analysis window of the automatic method and a more relevant duration of the first sleep period leading to a value arbitrarily set at 15 minutes. The sleep latencies coming from PSG data are noted subsequently SL\(_{PSG}\) and SL\(_{15PSG}\), while the sleep latencies from SMN data are noted SL\(_{SMN}\) and SL\(_{15SMN}\).
RESULTS

The database was made of 133 recordings. Nine of them were excluded due to a partial loss of data on the computer (n = 1), poor quality of PSG data (n = 3), a fault in jaw movement recording (n = 4) and a battery problem (n = 1). It means that 4% (5 out of 133) of the recordings were excluded due to a technical problem about the portable monitoring which is acceptable. From the remaining 124 recordings, there were 32 women and 92 men, with a mean age of 50.8 ± 12.4 years and BMI 29.5 ± 5.4 kg/m². As mentioned in Table 1, an OSAS was diagnosed in 68 of them (54.8%; mean AHI: 27.7 ± 25.6/h), insomnia/depression/anxiety was diagnosed in 27 of them (21.7%) while the 29 others (23.5%) had other sleep disorders (e.g. periodic limb movement, circadian rhythm disorder, etc…).

| Table 1 – Anthropometric information and main diagnosis about the patients |
|--------------------------|--------------------------|--------------------------|--------------------------|
| Recordings               | Anthropometric data      | Diagnosis                |
|                          | men | women | age   | BMI   | OSAS | Insomnia/depression | Other pathologies |
| 124                      | 92  | 32    | 50.8  ± 12.4 | 29.5  ± 5.4 | 68   | 27                | 29            |

The TST_{PSG} in the whole dataset was 407 ± 95.6 minutes, the TST_{SMN} from the algorithm was 394.2 ± 99.3 minutes (see figure 3 for the comparison of both TST scatter plot graph). The Table 2 sums up the bias and standard deviation in minutes from the Bland and Altman analysis of the TST (PSG versus Somnolter®; figure 2): on the whole dataset, the difference in TST was 12.8 with a standard deviation of 57.3 minutes, and did not differ in OSAS patients (12.6 ± 6.7 minutes). As far as insomnia and “other pathologies” are concerned, the mean differences were respectively -3.3 and 25.3 while the standard deviations were 56.0
and 59.7 minutes. When the AHI only criterion is considered, for mild AHI (AHI < 15), the bias was 6.8 and increased with the severity (13.4 and 12.4 in case of moderate and severe AHI, i.e. AHI ≥ 15 and ≥30).

![Figure 2: Bland and Altman (µ = mean of the difference or the "bias"; dashed lines are limits of agreement: µ ± 2s) comparing the manual TST$_{PSG}$ and automatic TST$_{SMN}$ (n = 124).](image)

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>n</th>
<th>Bland and Altman TST$<em>{PSG}$ and TST$</em>{SMN}$ (min)</th>
<th>ICC</th>
<th>Sensitivity/specificity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Bias [CI 95%]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall</td>
<td>124</td>
<td>12.8* [-11.6, 37.2]</td>
<td>57.3</td>
<td>0.82 85.3 65.5</td>
</tr>
<tr>
<td>OSAS</td>
<td>68</td>
<td>12.6 [-17.9, 43.0]</td>
<td>56.7</td>
<td>0.81 85.8 64.3</td>
</tr>
<tr>
<td>Insomnia</td>
<td>27</td>
<td>-3.3 [-59.4, 53.0]</td>
<td>58.2</td>
<td>0.85 86.3 66.2</td>
</tr>
<tr>
<td>Other pathologies</td>
<td>29</td>
<td>25.3* [-30.4, 81.0]</td>
<td>59.7</td>
<td>0.80 83.8 70.1</td>
</tr>
<tr>
<td>AHI &lt;15</td>
<td>49</td>
<td>6.8 [-33.8, 47.4]</td>
<td>48.3</td>
<td>0.89 86.8 67.9</td>
</tr>
<tr>
<td>15&lt; AHI&lt;30</td>
<td>32</td>
<td>13.4 [-35.0, 61.8]</td>
<td>64.0</td>
<td>0.77 83.1 63.3</td>
</tr>
<tr>
<td>AHI≥30</td>
<td>43</td>
<td>12.4 [-24.3, 49.1]</td>
<td>56.0</td>
<td>0.78 85.8 63.5</td>
</tr>
</tbody>
</table>

Table 2: performance of the automated sleep/wake scoring according to the diagnosis and the AHI assessed by the Bland and Altman, the correlation ICC (TST$_{PSG}$ and TST$_{SMN}$) and the sensitivity/specificity (epoch-by-epoch comparison) methods. * statistically significant difference with p<0.05.
Table 2 provides also the ICC between $TST_{PSG}$ and $TST_{SMN}$. The worst correlation was found for moderate AHI ($15 \leq AHI < 30$), ICC = 0.77, while the best correlation was achieved for mild AHI with ICC equal to 0.89. The method correlated better when AHI was greater than 30 (ICC = 0.78) than in patients having a moderate AHI. By comparing epoch by epoch from the two hypnograms (PSG and Somnolter®), the sensitivity and specificity were computed over all the recordings and according to the diagnosis (see Table 2). The overall sensitivity was 85.3%, the corresponding specificity was 65.5%. The Table 3 details the 95% confidence intervals for the sensitivity, the specificity, positive and negative likelihood ratios for the $TST_{PSG}$ and $TST_{SMN}$.

Figure 3: Scatter plot of the data points ($n=124$), the automatic total sleep time ($TST_{SMN}$) versus the manual total sleep time ($TST_{PSG}$). The identity line is drawn.
The sleep latencies computed from the two methods (SL_SMN and SL_15SMN) were compared with the sleep latency from PSG (SL_PSG and SL_15PSG). The sleep latency provided by the automated analysis of the Somnolter® differed from PSG latency. Nevertheless, the means of SL_15SMN and SL_15PSG were not significantly different (mean difference of 4.2 minutes) despite a very large discrepancy in some cases (standard deviation of the difference was 59.6 minutes), see figure 4. Table 4 provides the mean and standard deviation of the difference between the sleep latency from PSG and Somnolter® for the two definitions considered (one 30-second epoch and 15 minutes of sleep).
Figure 4: The Bland and Altman plot of the Sleep Latency (defined as the time between the START analysis and the first 15 consecutive minutes of sleep). The mean (µ) and limits of agreement (µ ± 2σ) are also shown.

Table 4: Mean and standard deviation (in minutes) of the difference between the sleep latency from PSG and Somnolter® for the two definitions considered (mean difference [CI 95%] ± standard deviation).

* Statistically significant difference with p < 0.05

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>Sleep latency (30-s epoch)</th>
<th>Sleep latency (15 min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>33.1* [14.7, 51.7] ± 77.4</td>
<td>4.2 [-20.4, 28.8] ± 59.6</td>
</tr>
<tr>
<td>OSAS</td>
<td>36.1* [6.6, 65.4] ± 88.7</td>
<td>-1.4 [-32.4, 34.8] ± 59.6</td>
</tr>
<tr>
<td>Insomnia</td>
<td>29.7* [-4.7, 64.1] ± 68.2</td>
<td>8.8 [-44.5, 62.1] ± 65.7</td>
</tr>
<tr>
<td>Other pathologies</td>
<td>33.3* [-6.0, 72.0] ± 59.5</td>
<td>11 [-33.3, 55.1] ± 33.9</td>
</tr>
<tr>
<td>AHI&lt;15</td>
<td>29.9* [2.9, 56.7] ± 64.0</td>
<td>9.8 [-24.1, 43.7] ± 51.8</td>
</tr>
<tr>
<td>15 ≤ AHI &lt;30</td>
<td>35.0* [6.6, 63.4] ± 62.7</td>
<td>2.7 [-41, 46.4] ± 63.0</td>
</tr>
<tr>
<td>AHI ≥ 30</td>
<td>36.3* [-2.7, 75.3] ± 99.9</td>
<td>-1.3 [-53.1, 50.3] ± 66.4</td>
</tr>
</tbody>
</table>
Finally, from the whole dataset (n = 124), we considered for the AHI computation the sleep periods and TST computed from the two methods: automatically from the mandible movement signal and the manually scored sleep periods from PSG. The respiratory events were still those manually scored, but only those occurring in sleep periods were involved in the corresponding AHI computation. The \( \text{AHI}_{\text{SMN}} \) (\( = \) number of PSG events in SMN sleep periods / TST\(_{\text{SMN}}\)) was slightly lower than the AHI (\( = \) number of PSG events in PSG sleep periods / TST\(_{\text{PSG}}\)) but remained close to the latter: ICC was equal to 0.95, linear regression equation of 0.9*x-1.6 and the mean and standard deviation of the difference were 4.9 ± 5.8 (CI 95% of the bias was [-1.2, 11.0]).

**DISCUSSION**

This study focused on an innovative portable monitoring (PM) device, called Somnolter®, which is a type 3 PM using mandible movement signal in addition to nasal airflow, SpO\(_2\) and body position. The main problem with the PM is the underestimation of respiratory events, due to no or bad assessment of sleep periods. A correct TST allows the calculation of an index per hour, defined for respiratory or neurological events. This index is essential to the severity classification of the obstructive sleep apnoea and hypopnoea syndrome.

As suggested previously by Senny et al., the inferior jaw activity signal is another easy-to-use actimeter\(^{24}\). Thus, the basic principle is like the wrist actigraphy signal behaviour analysis: high and unstructured activity is likely related to wake, while the quite and periodic features may occur in sleep. The complex relations existing between the two states “Wake”, “Sleep” and the time behaviour of mandible movement signal were investigated, leading to an automated analysis of the mandible movement signal.\(^{24}\)
In our prospective study, the results came from the data from 124 patients, among them 32 were women (26%), 68 were diagnosed OSAS (55%) and 27 were diagnosed insomnia/depression (26%). An important caveat in this study is the absence of control group with subjects without sleep disturbances. The $T_{\text{PSG}}$ in the whole dataset was $407 \pm 95.6$, the $T_{\text{SMN}}$ from the algorithm was $394.2 \pm 99.3$ with an ICC of 0.82. The Bland and Altman analysis of the difference between the two TST in all patients was $12.8 \pm 57.33$ minutes, with sensitivity and specificity of respectively 85.3% and 65.5%. Globally there is an underestimation of sleep time except for insomnia/depression ($n = 27; 21.7\%$) where mean TST difference is negative ($-3.3 \pm 58.2$ min) corresponding to an overestimation of the TST with the Somnolter®. In other cases, TST was underestimated. In sleep disordered breathing, the main point of interest is the OSAS whose severity come down to the AHI. Considering the AHI criterion exclusively, the search for diagnosis devices easy to use and with excellent accuracy characteristics is growing. With the Somnolter® PM device and compared to PSG, measures of mean agreement for TST in patients having a mild ($\text{AHI} < 15$), moderate ($15 < \text{AHI} < 30$) and severe ($\text{AHI} \geq 30$) AHI were respectively $6.8 \pm 48.3$ minutes, $13.4 \pm 64$ minutes and $12.4 \pm 56$ minutes. Sensitivities were respectively 86.8%, 83.1% and 85.8 % for mild, moderate and severe AHI, while specificities were respectively 67.9%, 63.3% and 63.5%. In the comparison with the PSG, a time-locking of the epochs of the actigraph with those of the PSG would reduce the sleep-wake misclassification. Indeed, the sleep scoring relies on rules defining the sleep-wake state according to the prominent state (>15 sec) on the epoch. Therefore, a partial shift between 30s-epoch of the PSG and the Somnolter® could modify the scoring. To reduce this problem, a time START and STOP and 30s-epochs were considered in both methods.

Beside the TST, other sleep variables could be studied by the actigraph, e.g. the sleep onset latency. In terms of movement assessment, the quiet
wakefulness and quiet sleep will be very similar, being frequently misidentified. Variables such as sleep efficiency and wake time after sleep onset depend upon the sleep onset. In our study, two sleep latencies were considered.

The SL_PSG and SL_SMN were significantly different in all cases (overall : 33.1 ± 77.4 minutes; p < 0.05), illustrating the difficulty to identify a first (and possibly isolated) epoch of sleep. The SL_15 mean agreement was not significantly different (overall : 4.2 ± 59.6 minutes; p : NS).

The method used in this paper has comparable results with the ones from wrist actigraphy (WAc) approach, a convenient and accepted way to assess the TST in portable monitoring. The WAc method is considered as useful, cost-effective and non-invasive but has some drawbacks like a loss of performance in the case of some sleep disorders, i.e. periodic limb movements. Good performance has been reported in studies about the assessment of the TST in a normal population, in an OSAS population, in an old population and in an insomniac population.

The mandible movement signal and its analysis suffer from the same drawbacks as WAc, i.e. 1) a lack of sensitivity in wake recognition because quite activity does not necessarily imply sleep-related brain activity, 2) a decrease in performance when sleep is disturbed. For example, in this chapter, the results for patients having an AHI between 15 and 30 were inferior to those from patients with lower or greater AHI (see above) but fortunately the decrease in sensitivity of sleep recognition was a few percents and it remained greater than 80% (lower boundary of the 95% CI). One reason of such loss in efficiency could be the smaller number of moderate AHI patients (n = 32) compared with the mild and severe populations (n = 49 and n = 43). Another reason could be that such patients have a more complex mandible movement signal behaviour, the periodic feature could be unclear, at least less straight
forward than in mild or severe cases. Furthermore, short and repeated respiratory events are mostly accompanied by respiratory arousals which are high activity on mandible movement.\textsuperscript{21-22} Sleep fragmentation, in particular macro-fragmentation could lead to TST underestimation. Most, chosen sample windows are bread (102.4 seconds) and few quiet sleep epochs (30 seconds) could be considered as sleep in our analysis. Lastly, we have no knowledge about bruxist’s mandible behavior and results from the automated signal analysis in such a case.

Improvement of the automated method is desired, maybe with a multi-signal approach, or by the inclusion of a criterion (a post-processing) about effort. The periodicity test could be more versatile, much more pattern oriented (i.e. time behaviour) than frequency tracking. To reduce the source of error, \textsc{START} and \textsc{STOP} times were defined for all patients and the results were computed only within this range. This is a focus on acquiring time between lights out and when there is light. Despite these improvements in methodology, breathing arrhythmia could occur in wakefulness (like Cheyne Stokes breathing) which could lead to overestimation of the sleep period.

Mandible movement signal has two promising features over \textsc{WAc}: the detection of arousals and the delineation/classification of sleep apnoeas and hypopnoeas.\textsuperscript{24} Advantages and disadvantages of both \textsc{MM} and \textsc{WAc} (included in the \textsc{Watch-PAT 100\textsuperscript{®}}) are elaborated in chapter 7. Further studies will focus on 1) the assessment of the sleep/wake mandible method on a healthy population, 2) a multi-signal approach, of which the mandible movements, to identify the respiratory events and 3) the evaluation of a full automated analysis based on mandible movements that computes an AHI. The study of the mandible movement signal is original but quite complex, has the advantage to provide much information based on one signal, which could also be a disadvantage in case of artefacts or loss of the signal. The combination of the \textsc{Jawse\textsuperscript{®}}, \textsc{SpO\textsubscript{2}} and \textsc{NAF} provided by the \textsc{Somnolter\textsuperscript{®}} has the advantage to provide
this associated valid test for the presence and type of breathing abnormalities (NAF). In the future, this multisignal approach of sleep and sleep disorders will be assessed.

CONCLUSION

Sleep/wake state automated analysis based on mandible movement study provides interesting total sleep time assessment, with a global mean underestimation. This is partly explained by the difficulty to detect and distinguish quiet sleep /quiet wakefulness at the beginning of the night. Total sleep time is indispensable in home screening methods.

ACKNOWLEDGEMENT

The authors would like to thank the students from the University of Liège who helped us in this study.
REFERENCES


