Speech as a Biomarker for Obstructive Sleep Apnea Detection

Catarina Tavares Botelho, Isabel Trancoso, Alberto Abad, Teresa Paiva

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Presentation Overview

1. Introduction
2. Corpora
3. Feature Set
4. Results
5. Sleep Disorder’s Impact on Working Memory
6. Conclusions
Motivation

Sleep Disorders

- Insomnia
- Obstructive Sleep Apnea

Sleep Deprivation

- Fatigue
- Mood alterations
- ↓ Work performance
- Traffic accidents
- Work accidents
Motivation

Sleep Disorders

- Obstructive Sleep Apnea
- Insomnia

- Fatigue
- Mood alterations
- ↓ Work performance
- Traffic accidents
- Work accidents

↓ Life quality
- Diabetes
- ↑ Mortality and morbidity by cardiovascular diseases

Gold standard diagnosis tool: PSG study

Expensive and uncomfortable

 PSG study

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2. Corpora
3. Feature Set
4. Results
5. Working Memory
6. Conclusions
Motivation: Facts and Figures

By 2020, 230,000 – 345,000 people are expected to be killed in traffic accidents due to fatigue[1]

1/3 adults suffer from inadequate sleep[2]

$45,210,000,000[2]

9% - 38% of the adult population suffers from OSA[3]

Sleep-related traffic accidents have an injury severity level similar to alcohol intoxication-related traffic accidents[4]

46% of OSA couples sleep in separate rooms[5]

OSA Pathophysiology and Speech

- Decrease in the muscle tone of the upper airway dilator muscle
- Excessive compliance of the pharyngeal wall
- Anatomical alterations of the respiratory tract

Source: TMJ & Sleep Therapy Centre.
https://www.youtube.com/watch?v=3xc0t77kElU

Source: http://www.newmanmd.org/anatomy_lung_upper.php?menu=2&subMenu=1
OSA Pathophysiology and Speech

- Decrease in the muscle tone of the upper airway dilator muscle
- Excessive compliance of the pharyngeal wall
- Anatomical alterations of the respiratory tract
Related Work


F. Espinoza-Cuadros et al., “Reviewing the connection between speech and obstructive sleep apnea”, 2016.


M. Kriboy et al., “Detection of obstructive sleep apnea in awake subjects by exploiting body posture effects on the speech signal”, 2014.

Portuguese Sleep Disorders (PSD) Corpus

**Task 1:** “The North Wind and the Sun”

![The North Wind and the Sun](https://en.wikipedia.org/wiki/The_North_Wind_and_the_Sun)

**Task 2:** Elongated vowels

/\a/  /i/

**Task 3:** Reading span task

Eu disse à turma que eles teriam uma surpresa se se portassem branco.

(Logical or illogical?)

**Task 4:** Describing the image

![Vincent van Gogh's Bedroom in Arles](http://time.com/4551131/Vincent-van-gogh-bedroom-bed-boxmeer/)
### Table 2. PSD Corpus.

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>OSA</th>
</tr>
</thead>
<tbody>
<tr>
<td>#F</td>
<td>12</td>
<td>6</td>
</tr>
<tr>
<td>#M</td>
<td>8</td>
<td>19</td>
</tr>
<tr>
<td>Age – F</td>
<td>33 ± 11</td>
<td>55 ± 9</td>
</tr>
<tr>
<td>Age – M</td>
<td>36 ± 10</td>
<td>53 ± 10</td>
</tr>
</tbody>
</table>

### Table 3. PSD-b Corpus.

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>OSA</th>
</tr>
</thead>
<tbody>
<tr>
<td>#F</td>
<td>11</td>
<td>9</td>
</tr>
<tr>
<td>#M</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>Age – F</td>
<td>50 ± 8</td>
<td>61 ± 14</td>
</tr>
<tr>
<td>Age – M</td>
<td>43 ± 10</td>
<td>55 ± 10</td>
</tr>
</tbody>
</table>

- Control subjects in PSD-b include subjects suffering from insomnia.
### In-the-Wild Obstructive Sleep Apnea (WOSA) Corpus

Table 4. In-the-Wild Obstructive Sleep Apnea Corpus.

<table>
<thead>
<tr>
<th>Class</th>
<th># Female subjects</th>
<th># Male subjects</th>
<th># Subjects under CPAP treatment</th>
<th># Subjects using oral appliances</th>
<th># Subjects not under treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>4</td>
<td>4</td>
<td>-</td>
<td>-</td>
<td>8</td>
</tr>
<tr>
<td>OSA</td>
<td>4</td>
<td>4</td>
<td>6</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
Feature Set

Original Feature Set

- Formant Frequency (F1, F2, F3)
- Formant Bandwidth (F1, F2, F3)
- Harmonics-to-Noise ratio
- Jitter
- Spectral Flux
- F0
- 12 MFCC, 12 Δ, 12 ΔΔ
- 48 LPCC
Feature Set

Original Feature Set
- Formant Frequency (F1, F2, F3)
- Formant Bandwidth (F1, F2, F3)
- Harmonics-to-Noise ratio
- Jitter
- Spectral Flux
- F0
- 12 MFCC, 12 Δ, 12 ΔΔ
- 48 LPCC

Random Forest Feature Selection
- 5 features.
  - ΔΔMFCC, ΔMFCC, F0.

Mann-Whitney U Test Feature Selection
- 18 features.
  - MFCC, ΔMFCC, ΔΔMFCC, F0, HNR, formant frequency, jitter.
Experimental Results

- PSD Corpus
  - Comparison: SVM, kNN, LDA, Naïve Bayes, Random Forest
  - Ensemble classifiers

- PSD-b
- WOSA Corpus
- PSD+WOSA Corpus
### Experimental Results

Table 4. Best performing classifiers and feature sets for OSA detection, using PSD and WOSA corpus.

<table>
<thead>
<tr>
<th>Feature Set</th>
<th>RF features; SVM</th>
<th>OFS features; SVM</th>
<th>OFS features; SVM+LDA+kNN</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TPR (%)</td>
<td>TNR (%)</td>
<td>WA (%)</td>
</tr>
<tr>
<td>PSD</td>
<td>92.0</td>
<td>65.0</td>
<td>80.0</td>
</tr>
<tr>
<td>PSD-b</td>
<td>85.0</td>
<td>68.2</td>
<td>76.2</td>
</tr>
<tr>
<td>WOSA</td>
<td>12.2</td>
<td>37.5</td>
<td>25.0</td>
</tr>
<tr>
<td>PSD+WOSA</td>
<td>50.0</td>
<td>25.0</td>
<td>37.5</td>
</tr>
</tbody>
</table>
Recall: PSD Corpus

**Task 1:** “The North Wind and the Sun”

![Images of the North Wind and the Sun](https://en.wikipedia.org/wiki/The_North_Wind_and_the_Sun)

**Task 3:** Reading span task

Eu disse à turma que eles teriam uma surpresa se se portassem branco. (logical or illogical?)

M

... B F H J L

1 M Q R X

X 10 sentences

Source: https://en.wikipedia.org/wiki/The_North_Wind_and_the_Sun

**Task 4:** Describing the image

![Image of Van Gogh's Bedroom](http://time.com/4551131/Vincent-van-gogh-bedroom-bed-boxmeer/)

Source: http://time.com/4551131/Vincent-van-gogh-bedroom-bed-boxmeer/
Table 5. Comparison of the performance achieved per task and the relative frequency of nasal phonemes and diphthongs.

<table>
<thead>
<tr>
<th>Task</th>
<th>Performance</th>
<th>Nasal Phonemes (%)</th>
<th>Diphthongs (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TPR (%)</td>
<td>TNR (%)</td>
<td>WA (%)</td>
</tr>
<tr>
<td>1</td>
<td>84.0</td>
<td>70.0</td>
<td>78.8</td>
</tr>
<tr>
<td>3.1</td>
<td>84.0</td>
<td>65.0</td>
<td>75.6</td>
</tr>
<tr>
<td>3.2</td>
<td>92.0</td>
<td>75.0</td>
<td>84.4</td>
</tr>
<tr>
<td>3.3</td>
<td>72.0</td>
<td>65.0</td>
<td>68.9</td>
</tr>
<tr>
<td>3.4</td>
<td>84.0</td>
<td>70.0</td>
<td>77.8</td>
</tr>
<tr>
<td>3.5</td>
<td>92.0</td>
<td>65.0</td>
<td>80.0</td>
</tr>
<tr>
<td>3.6</td>
<td>80.0</td>
<td>85.0</td>
<td>82.0</td>
</tr>
<tr>
<td>3.7</td>
<td>84.0</td>
<td>75.0</td>
<td>80.0</td>
</tr>
<tr>
<td>3.8</td>
<td>84.0</td>
<td>75.0</td>
<td>80.0</td>
</tr>
<tr>
<td>3.9</td>
<td>92.0</td>
<td>65.0</td>
<td>80.0</td>
</tr>
<tr>
<td>3.10</td>
<td>88.0</td>
<td>60.0</td>
<td>75.6</td>
</tr>
<tr>
<td>4</td>
<td>92.0</td>
<td>55.0</td>
<td>75.6</td>
</tr>
</tbody>
</table>
Sleep Disorders’ impact on Working Memory

- **Working Memory**
  - Temporary storage
  - Information processing

- **Cognitive Load**
  - Effort of performing a task

Source: https://www.opendooreducation.in/others/cognitive-load-theory/
Working Memory Impairment: Task 3 analysis

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Score per Sleep Disorder Class

- Healthy: 7.7
- OSA+INS: 5.0
- OSA: 4.8
- INS: 5.3

Score per Age and Class

<table>
<thead>
<tr>
<th>Age</th>
<th>Healthy</th>
<th>OSA+INS</th>
<th>OSA</th>
<th>INS</th>
</tr>
</thead>
<tbody>
<tr>
<td>[20-30]</td>
<td>6.0</td>
<td>4.0</td>
<td>3.5</td>
<td>4.5</td>
</tr>
<tr>
<td>[30-40]</td>
<td>8.0</td>
<td>6.0</td>
<td>5.0</td>
<td>6.0</td>
</tr>
<tr>
<td>[40-50]</td>
<td>9.0</td>
<td>7.0</td>
<td>6.0</td>
<td>7.0</td>
</tr>
<tr>
<td>[50-60]</td>
<td>9.0</td>
<td>7.0</td>
<td>8.0</td>
<td>8.0</td>
</tr>
<tr>
<td>[60-70]</td>
<td>7.0</td>
<td>6.0</td>
<td>6.0</td>
<td>7.0</td>
</tr>
<tr>
<td>[70-80]</td>
<td>6.0</td>
<td>5.0</td>
<td>5.0</td>
<td>6.0</td>
</tr>
<tr>
<td>&gt; 80</td>
<td>5.0</td>
<td>4.0</td>
<td>4.0</td>
<td>5.0</td>
</tr>
</tbody>
</table>

# Control

| Age | 8 | 7 | 2 | 2 | 1 | 0 | 0 |

# OSA

| Age | 0 | 3 | 6 | 12 | 5 | 1 | 0 |

# Insomnia

| Age | 1 | 9 | 16 | 17 | 9 | 3 | 1 |
Conclusions

- The feature set proposed for OSA detection provides satisfactory results;
- Evidence for phonation and resonance anomalies with the PSD corpus;
- Proof-of-concept for OSA detection with in-the-wild data;
- Evidence for the fact that OSA treatment does not alter speech anomalies;
- Evidence for the impairment of working memory caused by sleep disorders;
- Limitation: reduced size of the corpora.
Future Work

- Expand PSD corpus;
- Expand WOSA data set, addressing the automatic classification of the vlog data;
- Further explore the spontaneous speech subset;
- Compare cognitive load levels in sleep disordered and control subjects, in speech recordings.
Thank you for your attention.