Can We Predict Obstructive Sleep Apnea (OSA) during Wakefulness?

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The driver of a commuter train that slammed into a station going double the speed limit, killing a woman and injuring 17, suffered from severe sleep apnea that had gone undiagnosed.

Hoboken train crash, Sept. 29, 2016
Sleep Apnea can kill by causing catastrophic accidents

Associated with: snoring, high blood pressure, daytime symptoms, cardiovascular disease, obesity, etc.
What is Sleep Apnea?

Non-Obstructed Airway

Obstructed Airway
Definition of Sleep Apnea

- Apnea (hypopnea): cessation (reduction > 50%) of air flow for at least 10 sec that is usually associated with a drop > 4% in blood Oxygen Saturation level (SaO2).
  - Central Sleep Apnea – rare ~5%
  - Obstructive sleep Apnea (OSA) – common 85%
  - Mixed apnea ~10%
Causes or Contributing Factors to Sleep Apnea

- Anatomical, e.g. big tongue (falling backward, closing the airway), big tonsils, jaw deformities
- Neurological, e.g., stroke, MS, etc.
- Physiological, e.g., Loss of muscle tone due to aging or obesity, etc.
Can Sleep Apnea cause death?
High blood pressure
37% also with sleep apnea

Drug-resistant high blood pressure
83% also with sleep apnea

Atrial fibrillation
49% also with sleep apnea

Males with congestive heart failure
76% also with sleep apnea
Sleep Apnea Risk Factors

- Over-Weight
- Males
- Medical Conditions
- Increasing Age
- Large Neck Size
- Smoking
- African-Americans
- Post-Menopausal Women
- Family History
- Alcohol Use
How is Sleep Apnea measured?

The severity of sleep apnea is measured by Apnea/hypopnea Index (AHI) per hour of sleep.

- Total AHI per night
- Supine AHI

In adults:

- AHI<5 : non-OSA
- 5< AHI <15: Mild OSA
- 15< AHI < 30: Moderate and in need of treatment
- AHI > 30 : Severe

Is AHI the most accurate measure for sleep apnea?!
Polysomnography (PSG) System for Sleep Apnea Diagnosis

Waiting Time ~ 1-4 years!
Current PM Products for Sleep Study

- SleepStrip
- Respironics stardust
- Watch-Pat 100
- LifeShirt
- ApneaLink
- Sandman Pocket
- SnapLabs
- ARES
Our Acoustic OSA System (ASAD)
Existing Treatments
Existing Treatments

• Medical devices:
  – Dental appliances: help bring the tongue and lower jaw forward during sleep.
  – Nasal strips: keep nasal airway open.
  – CPAP (Continuous Positive Airway Pressure) generates required air pressure to keep the airway open

• Surgery
Our Goal

➢ To screen Obstructive Sleep Apnea (OSA) and its severity by breathing sounds analysis during wakefulness
Diagnosis people with OSA during sleep: easy! Many methods including our acoustic OSA detection detect OSA with high accuracies (>95%)

- Identifying people with OSA during wakefulness: Very challenging!
- Sleep apnea is a multifactorial disorder
- Very heterogeneous population

Obstructive Sleep Apnea Syndrome: From Phenotype to Genetic Basis
M Casale,¹,* M Pappacena,¹ V Rinaldi,¹ F Bressi,² P Baptista,³ and F Salvinelli¹
Identifying OSA during wakefulness:

- Using voice analysis (studies in Spain and Israel)

- Using breathing sounds analysis (our group and two more groups in Israel and Spain)
Rationale

On average, compared to those with normal airway, people with OSA have:

- narrower and more collapsible pharynx

This is compensated by the increased dilator muscle activity during wakefulness.
Velopharyngeal Anatomy in Patients With Obstructive Sleep Apnea Versus Normal Subjects

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Purpose: Obesity can cause disturbed breathing and is one of the most significant risk factors for

\[ PL = TD_1L + TD_2L \]

Narrowing Type 1
BOTTLE SHAPE

\[ PL = TD_1L + TD_2L \]

Narrowing Type 2
HOURGLASS SHAPE

\[ PL = TD_1 \]

Narrowing Type 3
TUBE SHAPE

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Our Hypotheses

- There must be significant differences in breathing sounds between OSA and non-OSA individuals.

- This difference should be detectable during wakefulness by spectral (2nd order) and higher order statistics (HOS) characteristics of tracheal breathing sounds.
Our Work!

Abracadabra
Non-OSA
Breathing Sounds

Hocus pocus
OSA
Challenges

- Biological data are often stochastic and non-stationary; more importantly, they have a heterogeneous nature.
- The underlying pathopathology of OSA is multifactorial, and varies considerably between individuals.
- Problems when analyzing breathing sounds of people with sleep apnea:
  - Imbalance groups,
  - Large group overlap caused by high inter-group variability
  - Many confounding variables
Methods: Recording Data
Experimental Procedure

- Record tracheal breath sounds during wakefulness in **Supine position** and **2 breathing manoeuvres**.
- Breathing Manoeuvres: **Nose & Mouth** breathing, each 5 **Deep** breaths at the same flow rate.
- Analyze inspiratory & expiratory phases separately → 8 different signals/subject
Flow-Sound Relationship to Separate respiratory phases
Method: Analysis

- Separating inspiratory/expiratory phases
- Filtering [75-3000 Hz]
- Normalization (by signal’s energy and also its variance envelope)
- Selecting the stationary part of the signal (middle part corresponding to upper 40% of flow)
Method: Signal Analysis

- Estimate power spectral density (PSD) and bispectrum of the signals, using 25ms running window (Hanning, 50% overlap).
- Look at the non-overlapping area between OSA and non-OSA groups in the training set and extracted spectral features.
Methods – Bispectrum Estimation

Used the conventional direct method of bispectrum estimation

AHI=0

AHI=30
The reduced pharyngeal width (reduced area) increases the compliance (more collapsibility), and that will be reflected in lowering the resonant frequencies according to Helmholtz resonance equation for a bottle: 

\[ f_c = \frac{\vartheta}{2\pi} \sqrt{\frac{A}{VL}}, \]

where \( \vartheta, A, V \) and \( L \) are speed of sound in air, cross section area, volume of cavity and length of the bottle neck →

- the formant frequencies in OSA group shifts toward lower frequencies,
- a difference of low frequency sound energy components because more compliant materials absorb sound more low than high frequencies
Obstructive Sleep Apnea Screening and Airway Structure Characterization During Wakefulness Using Tracheal Breathing Sounds

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Associate Editor Meesyn Tawhai oversaw the review of this article.

Abstract—Screening for obstructive sleep apnea (OSA) disorder during wakefulness is challenging. In this paper, we present a set of tracheal breathing sounds characteristics with classification power for separating individuals with apnea/hypopnea index (AHI) ≥ 10 (OSA group) from those with AHI ≤ 5 (non-OSA group) during wakefulness. Tracheal breathing sound signals were recorded during wakefulness in supine position; subjects were instructed to have a few deep breaths through their nose, then through their mouth. Study participants were 147 individuals (80 males) referred to overnight polysomnography (PSG) assessment; their AHI scores were collected after their overnight-PSG study was completed. The signals were normalized; then, their power spectra were estimated. After conducting a multistage process for feature extraction and selection on a subset of training data, two spectral features showing significant differences between the two groups were selected for classification. These features showed a correlation of 0.42 with AHI. A 2-class support vector machine classifier with a linear kernel was used. Following this an exhaustive leave-two-out cross-validation was performed. The overall accuracies were 83.85 and 83.92% for training and testing datasets, respectively, while the overall sensitivity and specificity of the test datasets were 82.61 and 85.22%, respectively. We also applied the same method for anthropometric information (i.e., age, weight, etc.) as features, and they resulted in an overall accuracy of 77.6 and 76.2% for training and testing datasets, respectively. The results of this study show a superior classification power of respiratory sound features compared to anthropometric features for a quick screening of OSA during wakefulness. The relationship of the sound features and known morphological upper airway structure of OSA subjects are also discussed.

Keywords—Obstructive sleep apnea, Respiratory sounds, Upper airway structure, Support vector machine classifier.
Our Previous Work Method & Result

- Used tracheal breathing sounds from 142 individuals to screen OSA (AHI>10) from non-OSA (AHI < 5), and ran exhaustive feature selection search and **machine learning** to maximize accuracy in the training set.

- We achieved ~85% accuracy in training set and ~84% unbiased test accuracy (similar sensitivity and specificity).
Results

Scattered plot of the selected best features
How about using anthropometric info?

- It is used a means for quick screening before the surgery (Stop-Bang Questionnaire)

- Its sensitivity could be quite high (90%) but at the cost of a very low specificity (~20%)!

- How about adding those parameters to the sounds features?
Using Anthropometric Features

• Used the same method of feature selection/reduction for BMI, Mallampati score, gender, age, weight and height.

• Ran support vector machine (SVM) learning for 2-group classification on anthropometric best two features with and without sound features.
Anthropometric features **alone** with SVM achieved about 70% accuracy (similar sensitivity and specificity)

Anthropometric + Sound features increased the sensitivity by 6% but decreased specificity by 4%; thus, overall, it added the accuracy by 1% to when we used sound features only!
The Objectives of our recent Studies

• Investigate to what extend the sounds features are affected by anthropometric info.

• Investigate whether subdivision of the subjects based on their anthropometric info helps with the accuracy.

• For this study, we used AHI=15 as a sharp cut off threshold of grouping.

• Also used only supine AHI as opposed to total AHI.

• Feature selection and SVM routine were similar to those of our previous work.
Results

• BMI, Age, Gender, Mallampati scores were found to affect the sounds the most.

• Sound features with the least dependency on anthropometric info: Fundamental Spectral Frequency and bispectral entropy → resultant test accuracy was ~75%.
Results

• Also found sounds features for each sub-division based on BMI, age, gender, Mallampati score, etc.

• Used individual classifiers for each subgroup.
Our New Acoustic Diagnostic Classifier

Test Sensitivity, Specificity and Accuracy: 81%, 82% and 81.4%

(Training accuracy: 83%)
Our New Acoustic Diagnostic Classifier

A Novel Decision Making Procedure during Wakefulness for Screening Obstructive Sleep Apnea using Anthropometric Information and Tracheal Breathing Sounds

Ahmed Elwali & Zahra Moussavi

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**Abstract**

Obstructive sleep apnea (OSA) is an underdiagnosed common disorder. Undiagnosed OSA,
Summary & Conclusion

• There is a need for quick and cost effective screening for OSA.

• Sleep Apnea screening during wakefulness has great applications:
  – Reducing health care cost by reducing the need for PSG study
  – Capability to be combined with iPhone Stethoscope and being used in people’s homes for self screening and monitoring the improvements
  – Great use for quick screening before any anaesthesia (surgery); it can save lives!
Have a good sleep!
Acknowledgement

• The study was supported by NSERC, TRTech (Winnipeg) and Phillips (Respronics).

[Logos: TRLabs, Philips, NSERC CRNIG]

• Our studies on OSA have resulted 4 patents.

• Dr. Eleni Giannouli, and Dr. Sonia Mezra, M.D. FRCPC, collaborators from Faculty of Medicine.

• Data were recorded all in Misericordia Hospital, Winnipeg.
Current and Former Acoustic Team Members
Any and all questions are welcome especially if this is a noisy crowd with oscillations between pros and cons!

“But before we move on, allow me to belabor the point even further...”