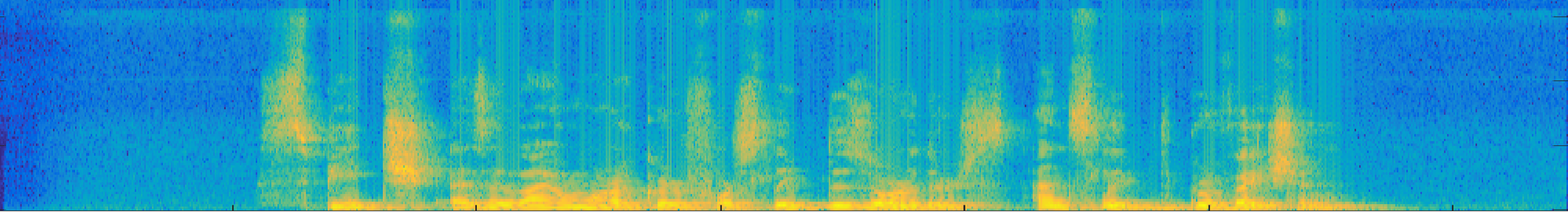

Speech as a Biomarker for Obstructive Sleep Apnea Detection

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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

- Insomnia
- **Obstructive Sleep Apnea**

→ Sleep Deprivation →

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

Obstructive Sleep Apnea →

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

Obstructive Sleep Apnea → Gold standard diagnosis tool: PSG study

Expensive and uncomfortable

Motivation: Facts and Figures

By 2020, **230000 – 345000** people are expected to be **killed** in traffic accidents due to fatigue[1]

$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]

1/3 adults suffers of **inadequate sleep** [2]

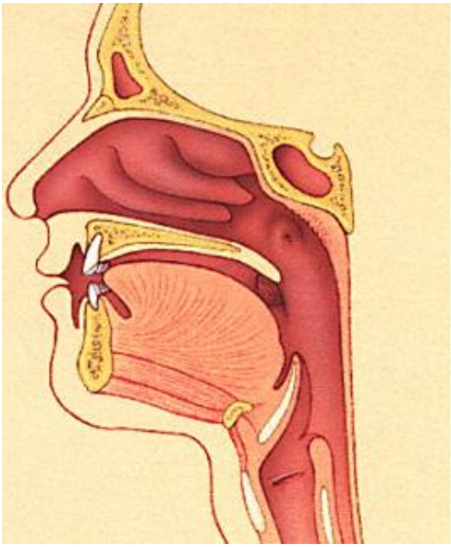
46% of OSA couples sleep in separate rooms [5]

[1] J. E. Ferrie et al. Sleep epidemiology—a rapidly growing field, 2011
[2] D. Hillman et al. The economic cost of inadequate sleep. Sleep, 2018.
[3] C. V. Senaratna et al. Prevalence of obstructive sleep apnea in the general population: a systematic review. Sleep Medicine Reviews, 2017
[4] A. I. Pack et al. Characteristics of crashes attributed to the driver having fallen asleep. Accident Analysis & Prevention, 1995
[5] A. Kales et al. Severe obstructive sleep apnea—i: onset, clinical course, and characteristics. Journal of Chronic Diseases, 1985

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=3xc0t77kEIU



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

→

- Articulatory anomalies
- Phonation anomalies
- Resonance anomalies

Related Work

A. Fox et al., “Speech dysfunction of obstructive sleep apnea: A discriminant analysis of its descrip-tors”, 1989.

R. Pozo et al., “Assessment of severe apnoea through voice analysis, automatic speech, and speaker recognition techniques”, 2009.

J. Solé-Casals et al., “Detection of severe obstructive sleep apnea through voice analysis”, 2014.

Benavides et al., “Analysis of voice features related to obstructive sleep apnoea and their ap-plication in diagnosis support”, 2014.

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

E. Goldshtein et al., “Automatic detection of obstructive sleep apnea using speech signals”, 2011.

O. Elisha et al., “Automatic detection of obstructive sleep apnea using speech signal analysis”, 2012.

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

M. Kriboy et al., “A novel method for obstructive sleep apnea severity estimation using speech signals”, 2014.

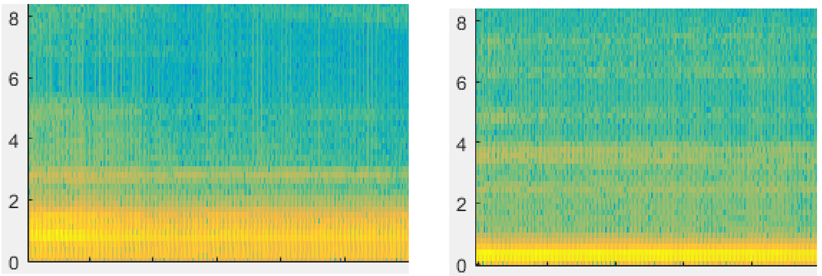
Portuguese Sleep Disorders (PSD) Corpus

Task 1: "The North Wind and the Sun"

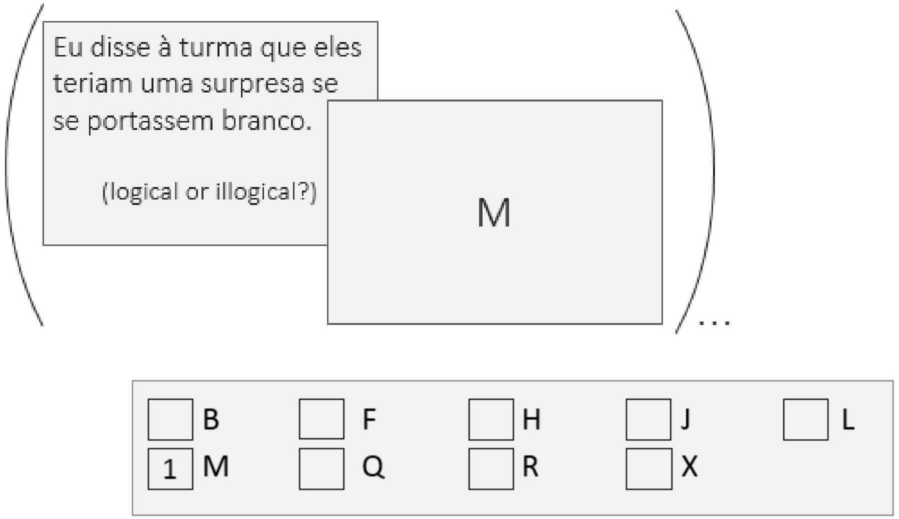
Source: https://en.wikipedia.org/wiki/The_North_Wind_and_the_Sun

Task 2: Elongated vowels

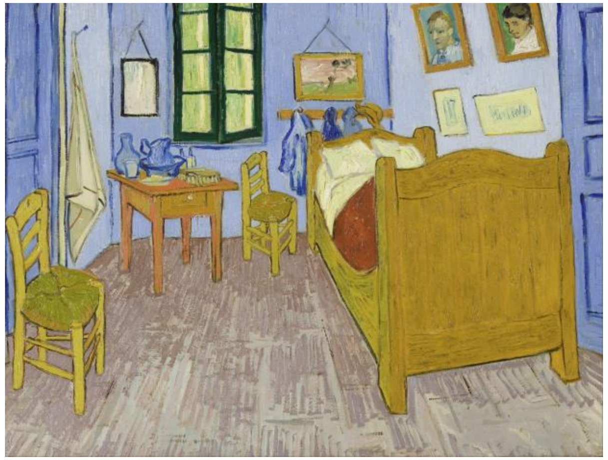
/a/ /i/



Task 3: Reading span task



Task 4: Describing the image



Source: http://time.com/4551131/Vincent-van-gogh-bedroom-bed-boxmeer/

Portuguese Sleep Disorders (PSD) Corpus

Table 2. PSD Corpus.

	Control	OSA
#F	12	6
#M	8	19
Age – F	33 ± 11	55 ± 9
Age – M	36 ± 10	53 ± 10

Table 3. PSD-b Corpus.

	Control	OSA
#F	11	9
#M	11	11
Age – F	50 ± 8	61 ± 14
Age – M	43 ± 10	55 ± 10

- 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.

Class	# Female subjects	# Male subjects	# Subjects under CPAP treatment	# Subjects using oral appliances	# Subjects not under treatment
Control	4	4	-	-	8
OSA	4	4	6	1	1

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

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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

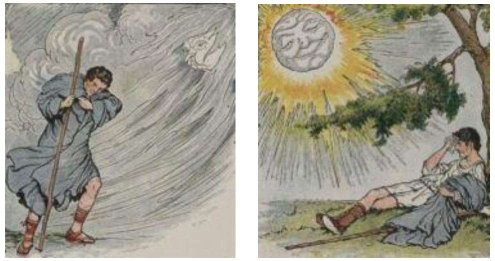
Experimental Results

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

	RF features; SVM			OFS features; SVM			OFS features; SVM+LDA+kNN		
	TPR (%)	TNR (%)	WA (%)	TPR (%)	TNR (%)	WA (%)	TPR (%)	TNR (%)	WA (%)
PSD	92.0	65.0	80.0	88.0	75.0	82.2	88.0	80.0	84.0
PSD-b	85.0	68.2	76.2	70.0	77.3	73.8	80.0	72.7	76.2
WOSA	12.2	37.5	25.0	75.0	87.5	81.3	75.0	87.5	81.2
PSD+WOSA	50.0	25.0	37.5	75.0	62.5	68.8	75.0	62.5	68.8

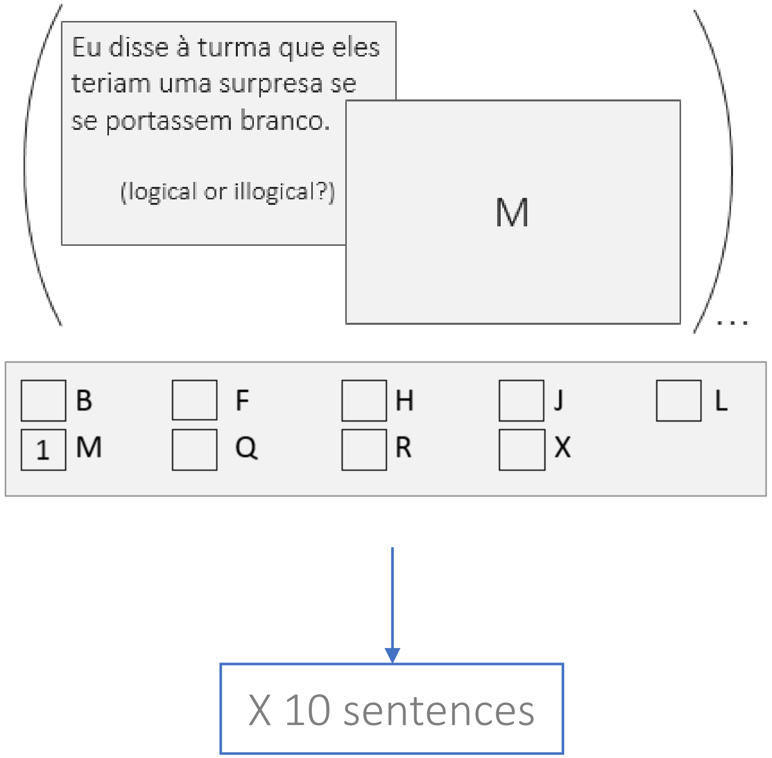
Recall: PSD Corpus

Task 1: "The North Wind and the Sun"

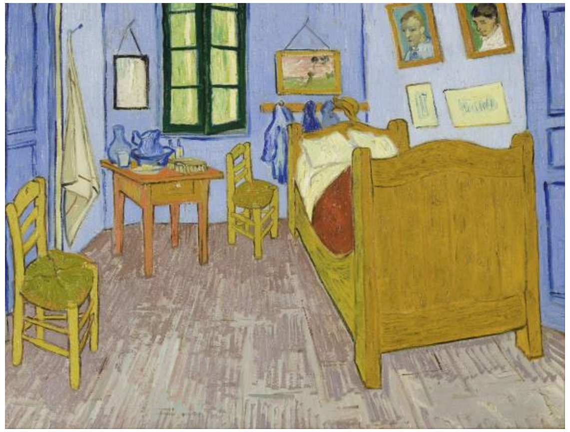


Source: https://en.wikipedia.org/wiki/The_North_Wind_and_the_Sun

Task 3: Reading span task



Task 4: Describing the image



Source: http://time.com/4551131/Vincent- van-gogh-bedroom-bed-boxmeer/

Phoneme Relevance for OSA detection

Table 5. Comparison of the performance achieved per task and the relative frequency of nasal phonemes and diphthongs.

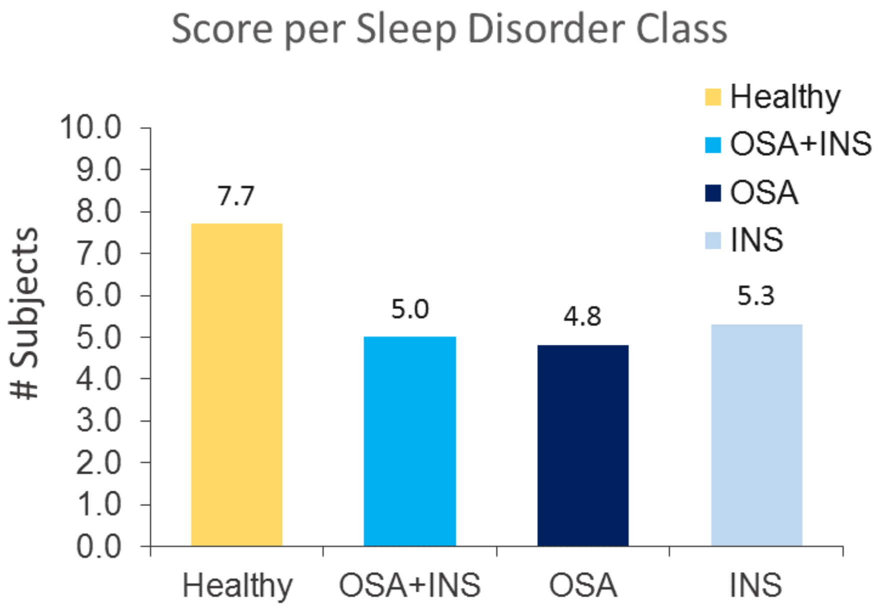
Task	Performance			Nasal Phonemes (%)	Diphthongs (%)
	TPR (%)	TNR (%)	WA (%)		
1	84.0	70.0	78.8	12.6	6.4
3.1	84.0	65.0	75.6	13.5	5.7
3.2	**92.0**	**75.0**	**84.4**	**25.0**	**10.0**
3.3	72.0	65.0	68.9	18.8	6.3
3.4	84.0	70.0	77.8	6.5	6.5
3.5	92.0	65.0	80.0	12.1	5.1
3.6	80.0	85.0	82.0	8.9	4.4
3.7	84.0	75.0	80.0	14.0	7.0
3.8	84.0	75.0	80.0	14.3	7.1
3.9	92.0	65.0	80.0	11.5	1.9
3.10	88.0	60.0	75.6	16.0	4.0
4	92.0	55.0	75.6	-	-

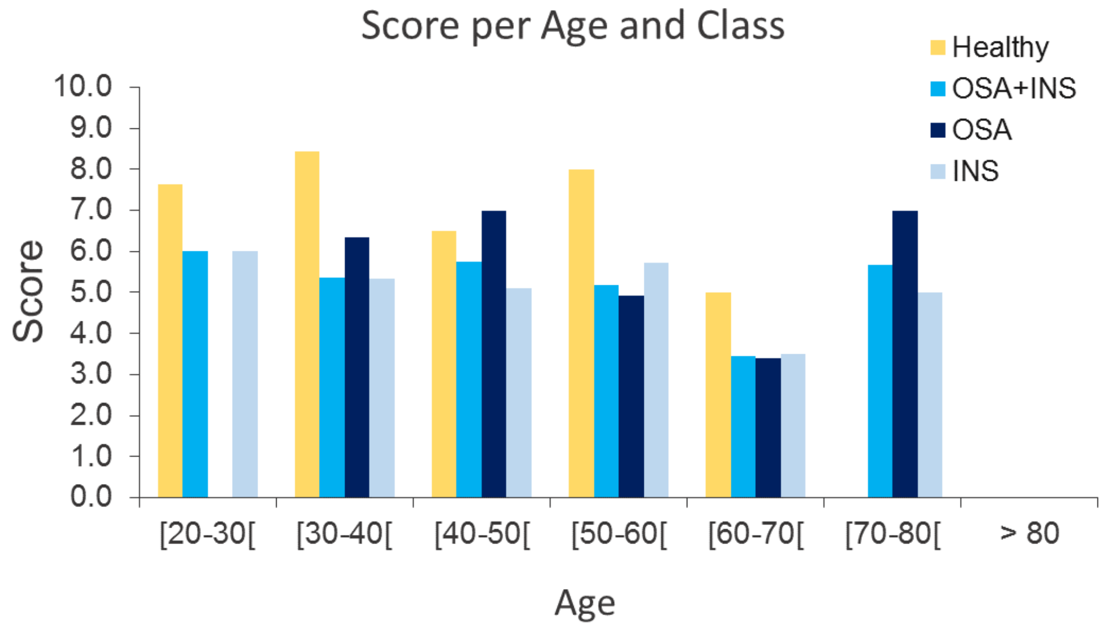
Sleep Disorders' impact on Working Memory

Source: https://www.opendooreducation.in/others/cognitive-load-theory/

- Working Memory
  - Temporary storage
  - Information processing
- Cognitive Load
  - Effort of performing a task

Working Memory Impairment: Task 3 analysis





# Control	8	7	2	2	1	0	0
# OSA	0	3	6	12	5	1	0
# Insomnia	1	9	16	17	9	3	1

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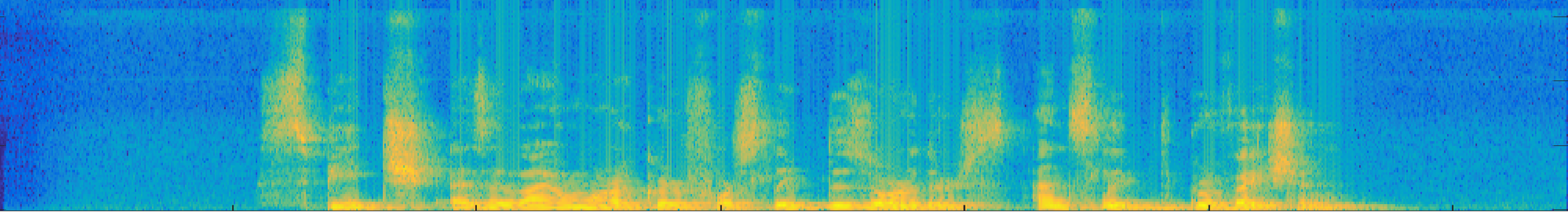
Conclusions

- 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.

May, 2019