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VOCAL AND SPEECH BIOMARKERS OF SLEEPINESS

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December 1, 2022

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université
de **BORDEAUX**

 **SANPSY**
BORDEAUX
neurocampus

EXCESSIVE SLEEPINESS A PERSONAL AND PUBLIC HEALTH PROBLEM

Personal health



- ▶ Disorders:
 - ◆ Metabolic
 - ◆ Cardiovascular
 - ◆ Neurological
 - ◆ Psychiatric

Prevalence = **1/3** of general population

Public health



- ▶ **1/4** des accidents mortels sur autoroute en France
- ▶ **43%** des pilotes (n=500, 2013) s'endorment par inadvertance
- ▶ **31%** : copilote endormi



SLEEPINESS: A PUBLIC HEALTH PROBLEM

Specialized centers

- ▶ Interviews
- ▶ Sleep tests (PSG, MSLT)

PSG : Polysomnography
MSLT : Multiple Sleep Latency
Test

Needs :

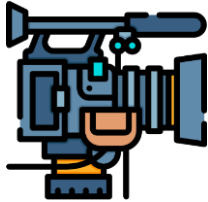
- ▶ **High prevalence** in general population
 - ▶ **Follow-up** between interviews
 - ▶ Symptoms expression in hospital
- **Ecological* Momentary Assessment (EMA)**
- ▶ **Regular** and **ecological** measurement of symptoms

**Ecological* = in the patient's usual living environment



KANOPÉE

SPEECH A PROMISING MEASUREMENT TOOL



- ▶ “Physiological” measurement
- ▶ Non invasive / passive
- ▶ Few calibration / computational resources
- ▶ Already implemented in smartphones
 - ▶ **80%** of worldwide pop.

→ Usefull for EMA

*Is it possible to use **voice/speech** as a measuring tool of **excessive sleepiness** for the follow-up of sleep disorders **patients**?*

1.

What is sleepiness and how to measure it?

Databases

WHAT DOES 'BEING SLEEPY' MEAN? AND HOW TO MEASURE IT

- ▶ Sleepiness =
 - ❌ Fatigue?
 - ❌ Performances?



- ▶ **Subjective** sleepiness
 - ✅ Long-term, e.g. measured by the **Epworth Sleepiness Scale**

Table 1

Examples of some words used to describe fatigue, sleepiness, or both

Fatigued	Sleepy	Either or Both
Beat	Crashing	Exhausted
Languor	Drowsy	Burned out
Lassitude	Fading	Bushed
Lethargic	Groggy	Gassed
Listless	Narcotized	Pooped
Knackered	Heavy-headed	Played-out
Sluggish	Punchy	Tired
Weariness	Gorked	Tuckered-out
Whipped	Yawny	Wiped
Zoned	Slap happy	Zonked

Hirshkowitz 2013



TABLE 1. *The Epworth sleepiness scale***THE EPWORTH SLEEPINESS SCALE**

Name: _____

Today's date: _____ Your age (years): _____

Your sex (male = M; female = F): _____

How likely are you to doze off or fall asleep in the following situations, in contrast to feeling just tired? This refers to your usual way of life in recent times. Even if you have not done some of these things recently try to work out how they would have affected you. Use the following scale to choose the *most appropriate number* for each situation:

0 = would *never* doze1 = *slight* chance of dozing2 = *moderate* change of dozing3 = *high* chance of dozing

Situation	Chance of dozing
Sitting and reading	_____
Watching TV	_____
Sitting, inactive in a public place (e.g. a theater or a meeting)	_____
As a passenger in a car for an hour without a break	_____
Lying down to rest in the afternoon when circumstances permit	_____
Sitting and talking to someone	_____
Sitting quietly after a lunch without alcohol	_____
In a car, while stopped for a few minutes in the traffic	_____

Thank you for your cooperation

WHAT DOES 'BEING SLEEPY' MEAN? AND HOW TO MEASURE IT

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Hirshkowitz 2013

- ▶ **Subjective** sleepiness
 - ✓ Long-term, e.g. measured by the **Epworth Sleepiness Scale**
 - ✓ Short-term, e.g. measured by the **Karolinska Sleepiness Scale**



	Français	Anglais
1	Parfaitement éveillé(e)	Extremely alert
2	Très éveillé(e)	Very alert
3	Éveillé(e)	Alert
4	Assez éveillé(e)	Rather alert
5	Ni éveillé(e) ni somnolent(e)	Neither alert nor sleepy
6	Un peu somnolent(e)	Some signs of sleepiness
7	Somnolent(e), mais sans effort pour rester éveillé(e)	Sleepy, but no effort to keep awake
8	Somnolent(e), mais avec des efforts pour rester éveillé(e)	Sleepy, but great effort to keep awake, fighting sleep
9	Très somnolent(e), luttant contre le sommeil	Extremely sleepy, can't keep awake
10	Extrêmement somnolent, ne peut rester éveillé	Extremely sleepy, can't keep awake

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 - ❌ Fatigue?
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Hirshkowitz 2013

- ▶ **Subjective** sleepiness
 - ✔ Long-term, e.g. measured by the **Epworth Sleepiness Scale**
 - ✔ Short-term, e.g. measured by the **Karolinska Sleepiness Scale**
- ▶ **Objective** sleepiness
 - ✔ EEG (Multiple Sleep Latency Test)



STATE OF THE ART CORPORA

¹[Schuller et al. 2011] ²[Schuller et al. 2019]
³[Huang et al. 2014] ⁴[Gosztolya et al. 2019]

Sleepy Language Corpus (SLC) ¹	SLEEP ²	
State of the art ³ : UAR = 71.7% ✓	State of the art ⁴ : $\rho = 0.387$ ✓	→ Good performances
German + English	✗	→ French speakers
General population	✗	→ Patients
8.2s (sd: 15.3s) ✗	3.9s (sd: 0.6s) / 5s max ✗	→ minimum = 20 s.
Avg. of three KSS (instantaneous subjective sleepiness)		✗ → No medical validity

WHAT DOES 'BEING SLEEPY' MEAN? AND HOW TO MEASURE IT

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Hirshkowitz 2013

- ▶ **Subjective** sleepiness
 - ✔ Long-term, e.g. measured by the **Epworth Sleepiness Scale**
 - ✔ Short-term, e.g. measured by the **Karolinska Sleepiness Scale**

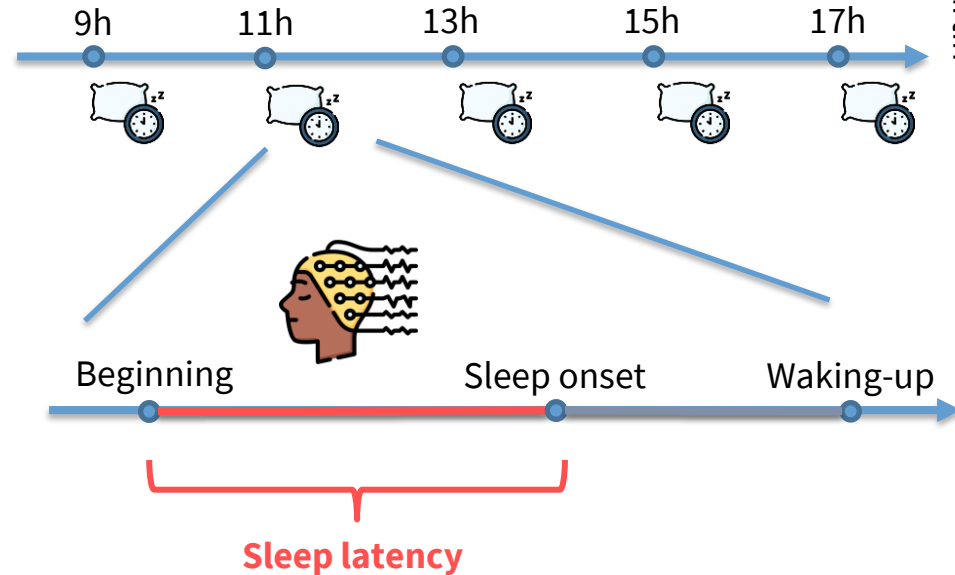
- ▶ **Objective** sleepiness
 - ✔ EEG (Multiple Sleep Latency Test)



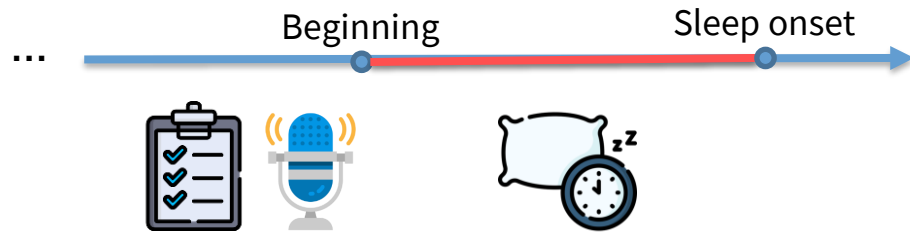
What is the MSLT ?

Multiple Sleep Latency Test

- ▶ 5 nap opportunity
- ▶ **Polysomnographic** recordings
(PSG = EEG + EKG + EMG)
- ▶ Sleep Latency
0 min. → 20 min.
→ Main label of the MSLTc
- ▶ Pathological threshold :
avg. Sleep latency \leq 8min.



MSLT CORPUS METHOD



Voice recordings

- ▶ Sleep Clinic of Bordeaux
- ▶ Few interferences with MSLT
- ▶ **Reading** texts from *Le Petit Prince* (250 words / 1min 30s)
- ▶ 106 subjects, 5 samples/subjects
≈ 11h 30min
- ▶ Inclusion/Exclusion criteria based on reading level

Label and metadata

- ▶ **Sleep latency (Objective sleepiness)**
- ▶ Age, Sex, BMI, Neck circumference, Edu.
- ▶ Fatigue, Anxiety, Depression, ...
- ▶ **Short-** and **long-**term subj. sleepiness

2.

Vocal and speech features

Hypothesis, definition and validation

VOCAL AND SPEECH FEATURES CONSTRAINTS & METHOD

Explainability

- ▶ State of the art : [openSMILE IS11](#) (#4368)
- ▶ “4th coefficient of the linear prediction of the derivative of the 25th coefficient RASTA”



Explainability to
clinicians

→ Interdisciplinary translation



Psychophysio.
mechanisms

→ Integrative model

VOCAL AND SPEECH FEATURES

ACOUSTIC FEATURES

Acoustic quality of voice

A

READING ERRORS

Mistakes during the reading of a text out loud

E

Number, Duration and Location of pauses during reading out loud

READING PAUSES

P

Errors made by an Automatic Speech Recognition System

ASR ERRORS

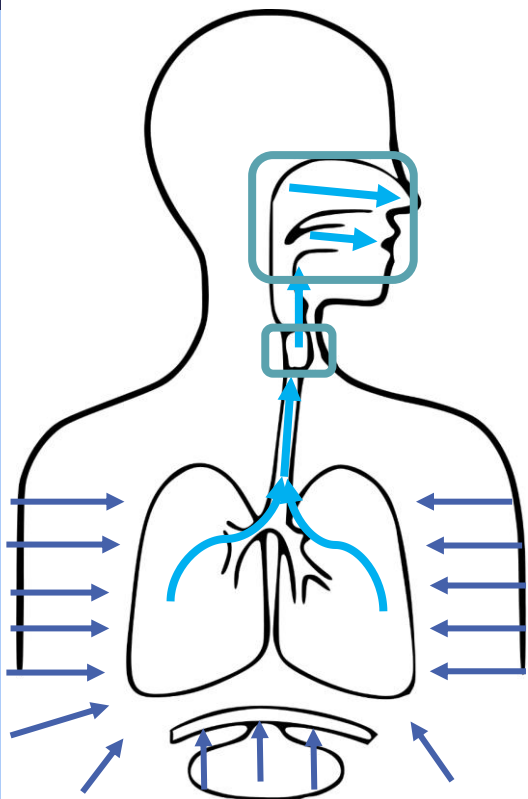
A

ACOUSTIC FEATURES HYPOTHESIS AND METHOD

Is it possible to estimate **sleep latency**
using **acoustic quality descriptors**?

Acoustic features (voiced parts)

- ▶ F0/NRJ mean, std, max, min, bdw, slope
- ▶ Harmonics: H1, H2, H4
- ▶ Formants: (amplitude, bandwidth, amplitude)
- ▶ diff. Harmonics/Formants
- ▶ HNR
- ▶ CPP



MSLT
1 min



MSLT
20 min

→ **44 acoustic features**

VOCAL AND SPEECH FEATURES

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ASR ERRORS

A



MSLT
18.6 min.

KSS
3

Avg. MSLT.
8.3 min

READING MISTAKES HYPOTHESIS

Is it possible to estimate **sleep latency**
using **reading mistakes**?

Quand le mystère est trop impressionnant, on n'ose pas
« il »
désobéir. Aussi absurde que cela me semblât à mille milles
« semblais »
de tous les endroits habités et en danger de mort, je sortis
<ach>
de ma poche une feuille de papier et un stylographe.

READING MISTAKES METHOD

Manual annotation of **530**
samples of the MSLTc

- ▶ **Stumblings** : « hesitation, breaks in the speech rythm »
Dictionnaire d'orthophonie, Brin (2018)
- ▶ **Deletions**
- ▶ **Additions**
- ▶ **Paralexia** : « identification error of written words consisting in the production of a word instead of another »
Dictionnaire d'orthophonie, Brin (2018)
- ▶ **Words inversion**

VOCAL AND SPEECH FEATURES

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READING PAUSES

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Errors made by an Automatic Speech Recognition System

ASR ERRORS

A

Is it possible to automatize reading mistakes annotations ?

RÉFÉRENCE

erreurs STA

HYPOTHÈSE DU STA

VERSION LUE

... n' oubliez pas que je me trouvais **à mille** milles de **toute** région habitée. Or **mon** petit bonhomme ...

DEL + SUB

SUB

SUB

... n' oubliez pas que je me trouvais **amis** mille de **tous** régions habités. Or **un** petit bonhomme ...

... n' oubliez pas que je me trouvais **[ami]** mille de **[tou]** région habitée. Or **mon** petit bonhomme ...

MSLT
18.6 min

KSS
3

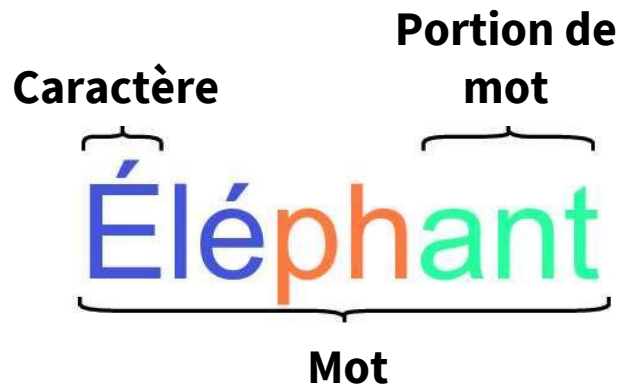
Avg. MSLT
8.3 min



ASR ERRORS METHOD

- ▶ End-to-end (PhD Thesis of F. Boyer)¹
- ▶ 3 different units (word, char, BPE)
- ▶ 7 configurations
- ▶ 4 errors : insertions, deletions, substitutions, nb of correct
- ▶ Word or char errors, nb or %

→ **112 features**



¹[Boyer 2021]

VOCAL AND SPEECH FEATURES

ACOUSTIC FEATURES

Acoustic quality of voice

A

READING ERRORS

Mistakes during the reading of a text out loud

E

Number, Duration and Location of pauses during reading out loud

READING PAUSES

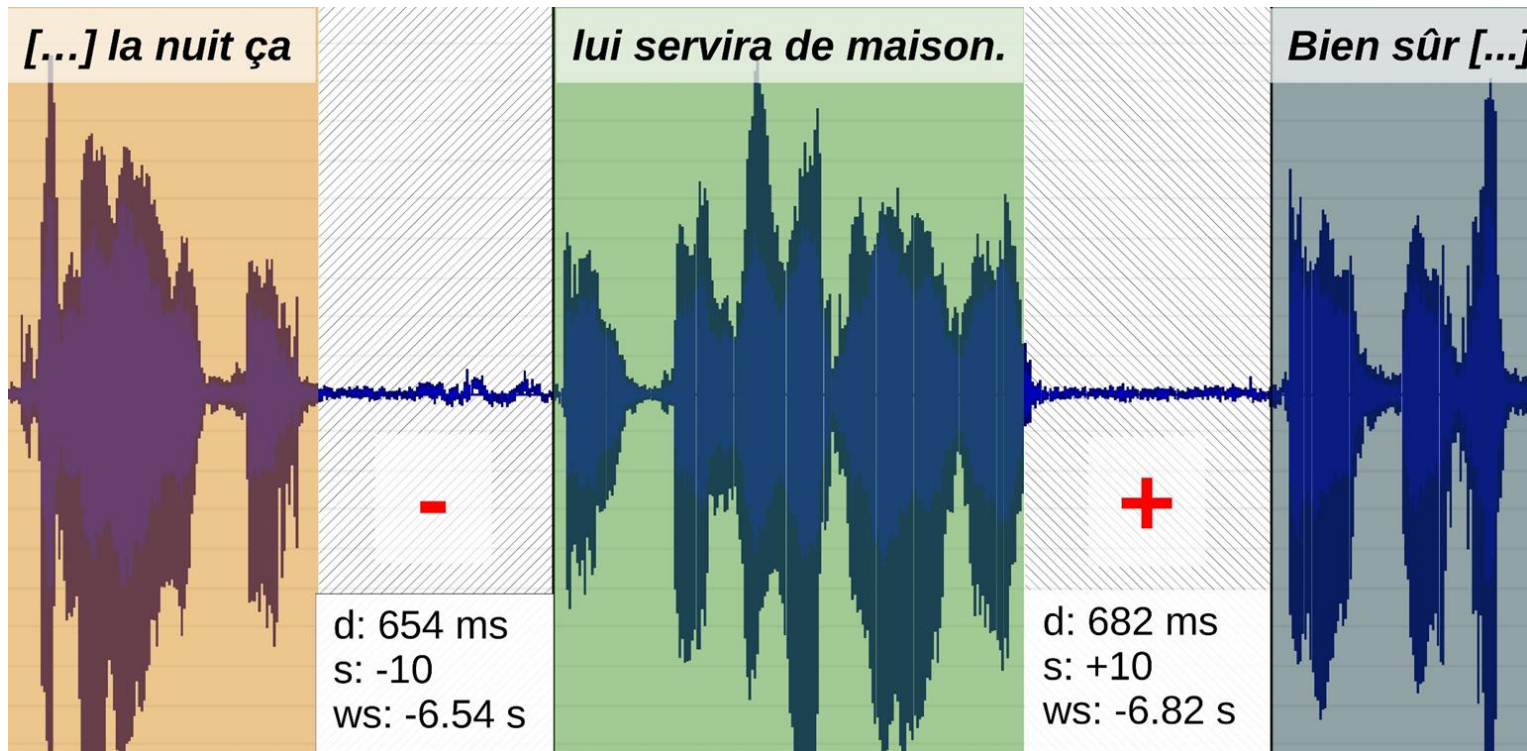
P

Errors made by an Automatic Speech Recognition System

ASR ERRORS

READING PAUSES HYPOTHESIS

Are **reading pause locations** linked to **sleep propensity** ?

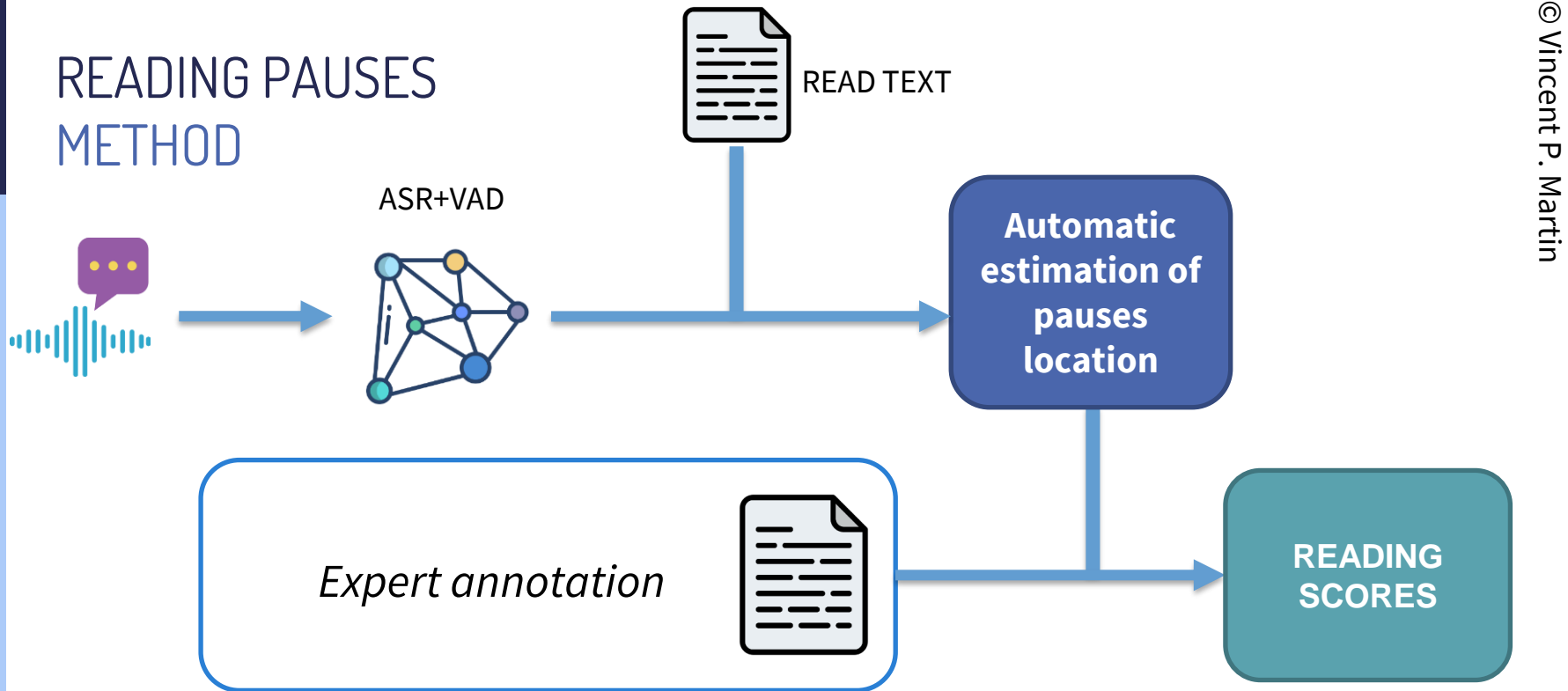


MSLT
14.5

KSS
7

Avg. MSLT
17.5

READING PAUSES METHOD

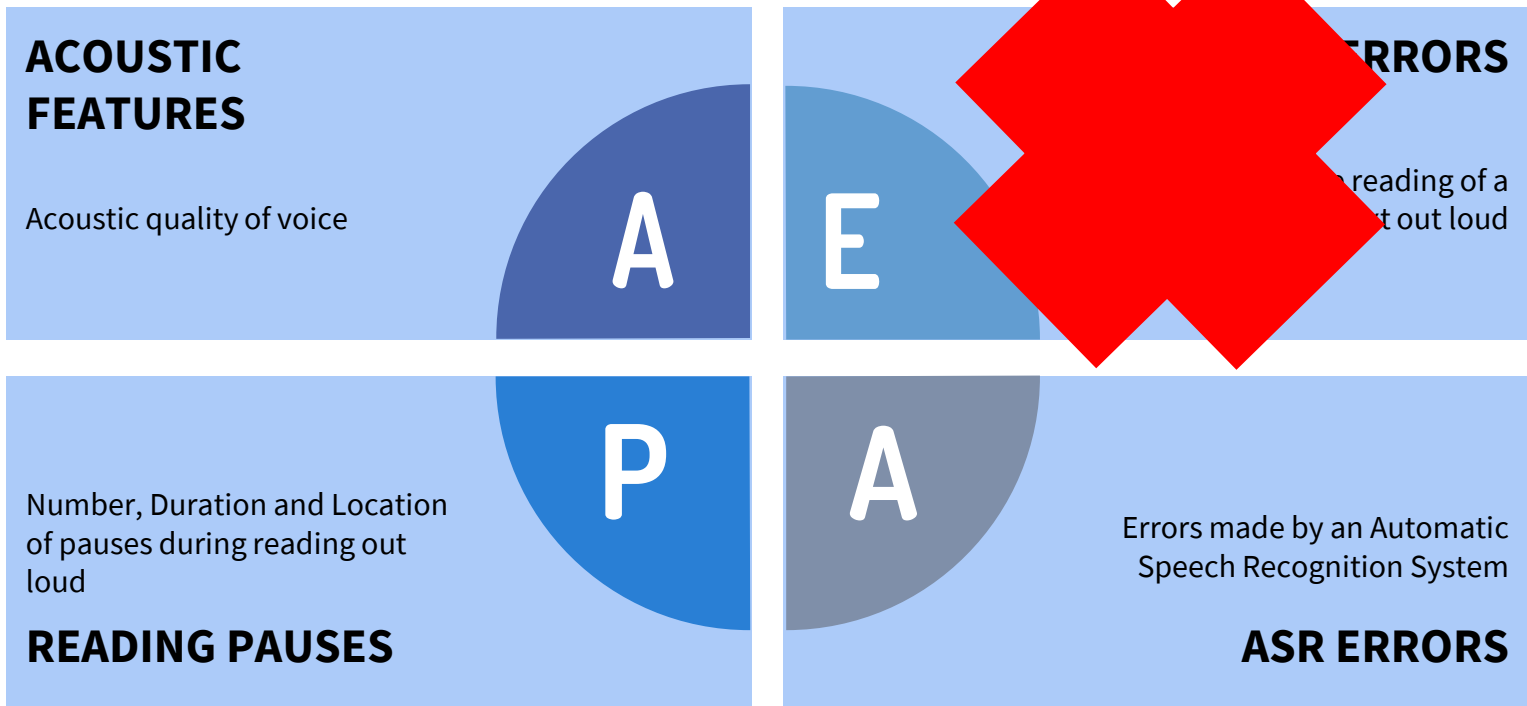


Annotated text

J' -10 ai -10 beaucoup -10 vécu -8 chez -10 les -10 grandes -10 personnes. +10

Intraclass correlation coefficient = 0,97

Features: conclusion



3. Classification & interpretation

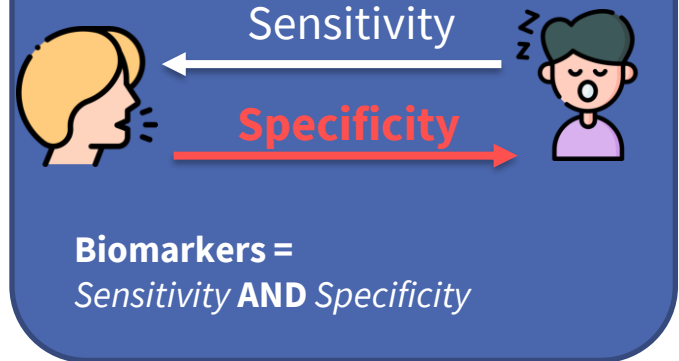
AUTOMATIC CLASSIFICATION CONSTRAINTS



Explainability

Ability to explain the decision to clinicians

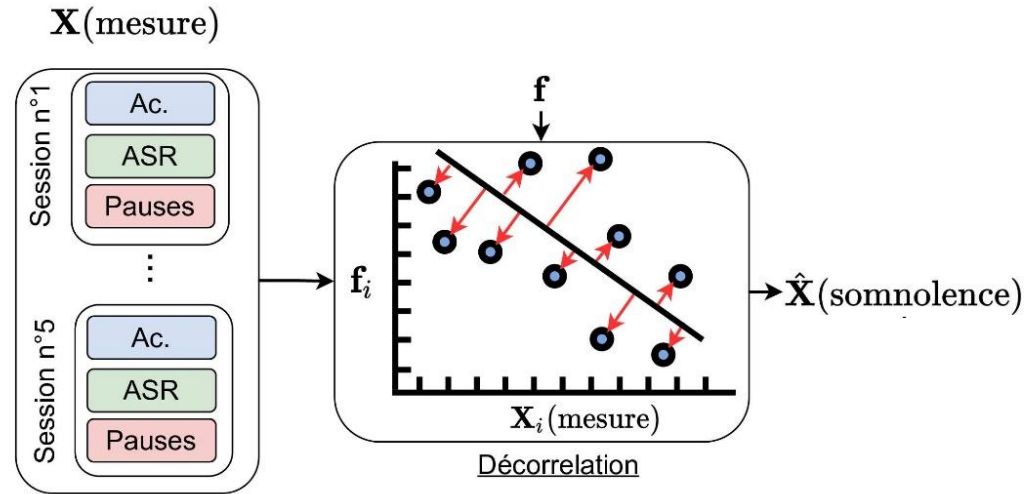
How to detect **sleep propensity** using the previous features?



Biomarkers =

Sensitivity AND Specificity

AUTOMATIC CLASSIFICATION METHOD

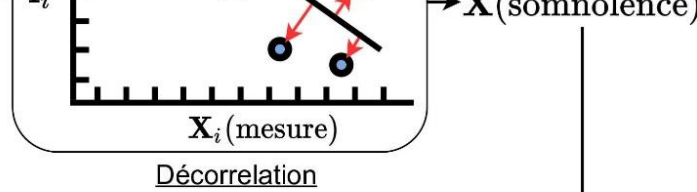


- Âge
- Sexe
- IMC
- Cou
- Édu.
- Anx.
- Dep.



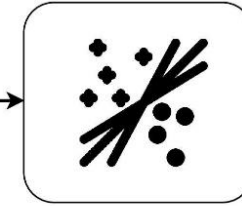
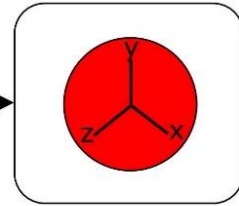
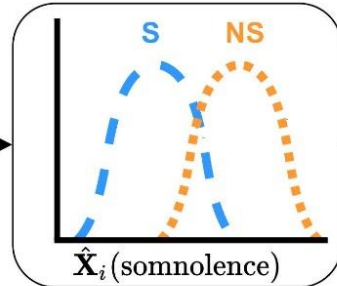
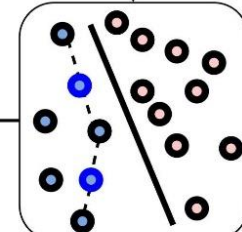
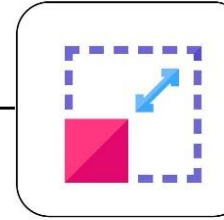
AUTOMATIC CLASSIFICATION

Session n°5

Ac.
ASR
Pauses

[Ins, Del, Sub,
Correct]

Filtrage des
erreurs de STA



LOSOCV



Sensitivity



Specificity

AUTOMATIC CLASSIFICATION RESULTS

Obj. Sleepiness

Avg. MSLT ≤ 8 min

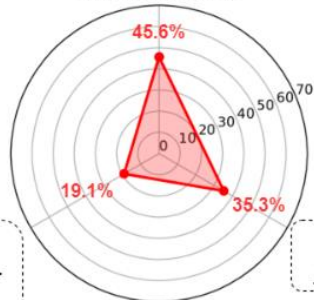
UAR = 84,6%



Acoustique

H1, H1A3

durvowels



Pauses

Ratio +, -
N-
D moy
D é-t

STA

Sub, Ins

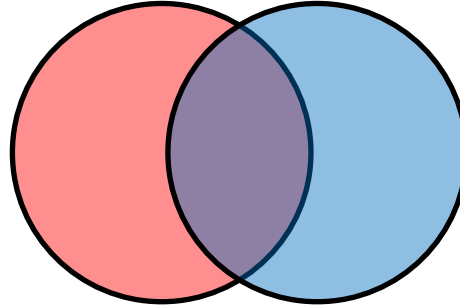
AUTOMATIC CLASSIFICATION OBJECTIVES

Pathological sleep propensity

Avg. MSLT ≤ 8 min.

Objective evaluation

21 Subjects



Is it possible to detect **other symptoms**?

Excessive Daytime Sleepiness

ESS > 15

Subj. evaluation (1 execution)

39 Subjects



Epworth Sleepiness Scale

TABLE 1. *The Epworth sleepiness scale*

THE EPWORTH SLEEPINESS SCALE

Name: _____

Today's date: _____ Your age (years): _____

Your sex (male = M; female = F): _____

How likely are you to doze off or fall asleep in the following situations, in contrast to feeling just tired? This refers to your usual way of life in recent times. Even if you have not done some of these things recently try to work out how they would have affected you. Use the following scale to choose the *most appropriate number* for each situation:

0 = would *never* doze1 = *slight* chance of dozing2 = *moderate* change of dozing3 = *high* chance of dozing

Situation	Chance of dozing
Sitting and reading	_____
Watching TV	_____
Sitting, inactive in a public place (e.g. a theater or a meeting)	_____
As a passenger in a car for an hour without a break	_____
Lying down to rest in the afternoon when circumstances permit	_____
Sitting and talking to someone	_____
Sitting quietly after a lunch without alcohol	_____
In a car, while stopped for a few minutes in the traffic	_____

Thank you for your cooperation

AUTOMATIC CLASSIFICATION OBJECTIVES

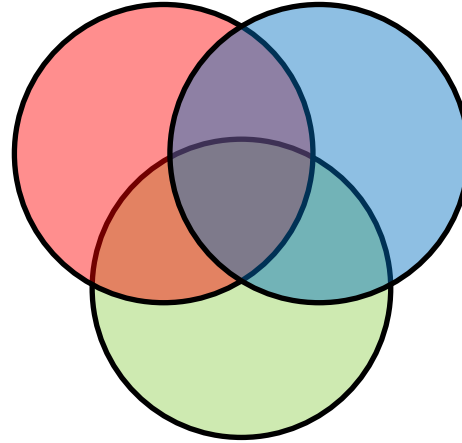
Is it possible to detect **other symptoms**?

Pathological sleep propensity

Avg. MSLT \leq 8min.

Objective evaluation

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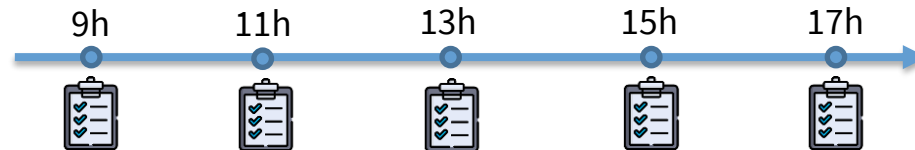


Average daytime sleepiness

Avg. Of 5 KSS > 5

Subj. evaluation (5 executions)

27 Subjects



Français	Anglais
1 Parfaitement éveillé(e)	Extremely alert
2 Très éveillé(e)	Very alter
3 Éveillé(e)	Alert
4 Assez éveillé(e)	Rather alert
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AUTOMATIC CLASSIFICATION OBJECTIVES

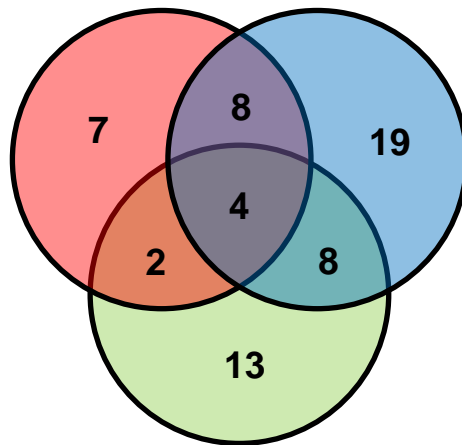
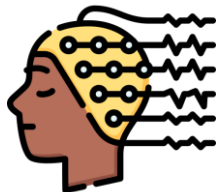
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Pathological sleep propensity

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Objective evaluation

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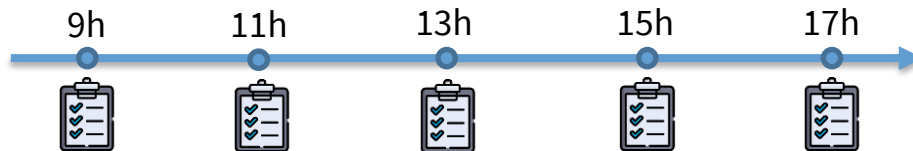


Average daytime sleepiness

Avg. Of 5 KSS > 5

Subj. evaluation (5 executions)

27 Subjects



AUTOMATIC CLASSIFICATION RESULTS

Obj. Sleepiness

Avg. MSLT ≤ 8 min

UAR = 84,6%



Long-term subj. sleepiness

ESS > 15

UAR = 75,4%



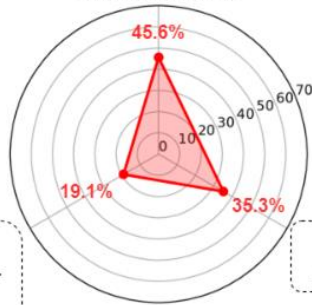
Avg. subj. sleepiness

Avg. KSS > 5

UAR = 67,8%



Acoustique
H1, H1A3
durvowels

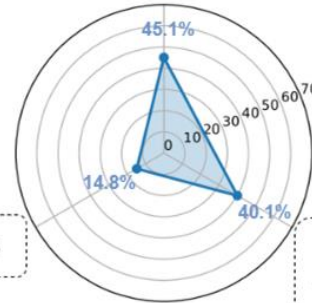


Pauses
Ratio +, -
N-
D moy
D ét

STA
Sub, Ins

HIGH LEVEL

Acoustique
H2H4, A1, H1, H1A3
NRJ moy, max
F0var

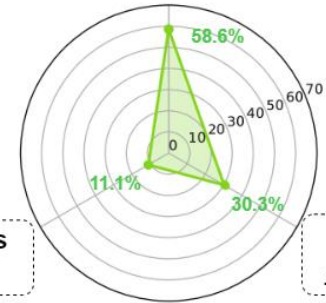


Pauses

STA
Sub, Ins,
Del

LOW LEVEL

Acoustique
F1, H2, H1, B1,
H1A3, A1
NRJ moy



Pauses
D max.

STA
Sub, Ins

Classification: conclusion

- **Simple** pipeline (explainability)
- **Objective** sleepiness → **High-level** features
- **Subjective** sleepiness → **Low-level** features

Perspectives

New databases & Symptom networks

PERSPECTIVES NEW DATABASES

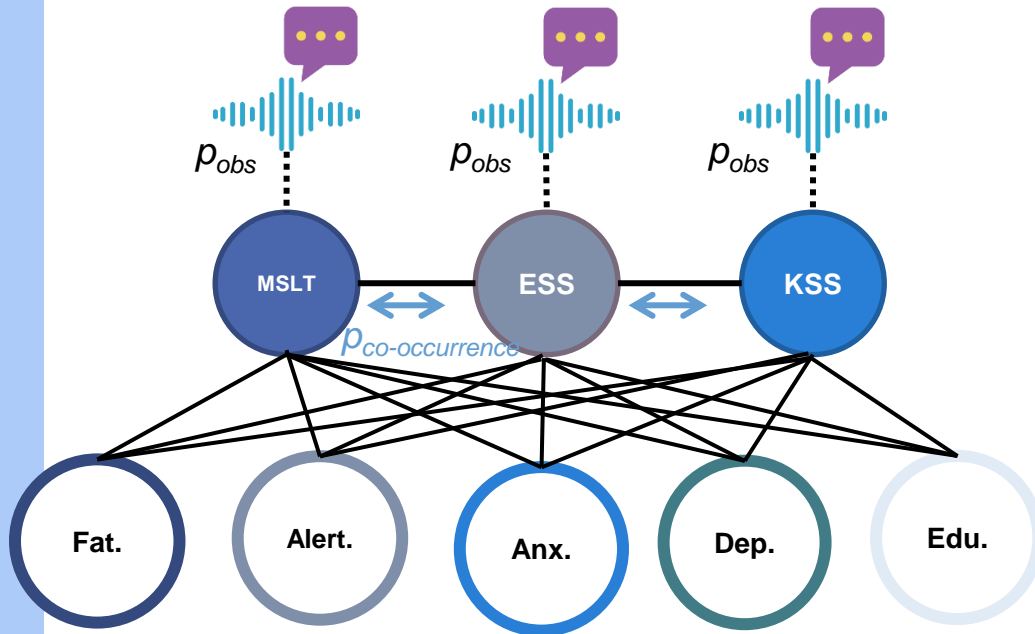
SOMVOICE

- ▶ 32 healthy subjects
- ▶ MSLT after Total Sleep Deprivation / after normal night
- ▶ Under recording

MEDISPEECH

- ▶ **Colleen Baumard** (stay tuned !)
- ▶ **Spontaneous speech** / Smartphone interaction
- ▶ Clinical MSLT / MWT
- ▶ Sleepiness/Fatigue/Depression

PERSPECTIVES SYMPTOM NETWORKS



Symptom Networks

▶ Bayesian networks

→ Data processing perspectives

- ▶ Joint information
 - ▶ *Belief propagation*
 - ▶ What graph?
 - ▶ Transitions?

→ Clinical perspectives

- ▶ Interaction between symptoms
- ▶ Prognostic / therapeutic targeting
- ▶ Inaccessible symptoms
- ▶ Multimodality?

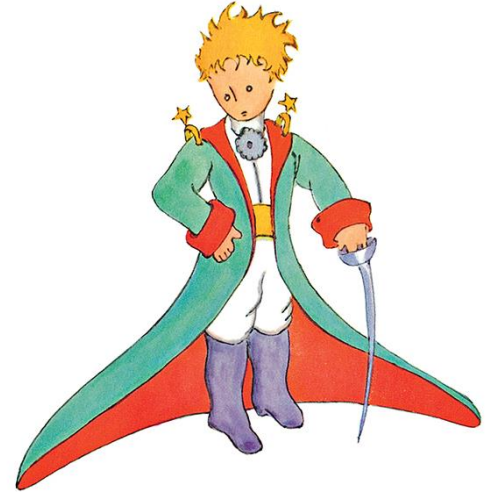
Conclusion

Doggy bag

DOGGY BAG

- ▶ Databases with **obj. and subj.** sleepiness
- ▶ Simple explainable (**to clinicians**) features and pipeline
- ▶ **Biomarkers** = sensibility + **specificity**

Thank you for your attention!



QUESTIONS?



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