VOCAL AND SPEECH BIOMARKERS OF SLEEPINESS

Vincent P. MARTIN

LaBRI

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)

Needs :

▷ **High prevalence** in general population

▷ **Follow-up** between interviews

▷ Symptoms expression in hospital

→ **Ecological* Momentary Assessment (EMA)**
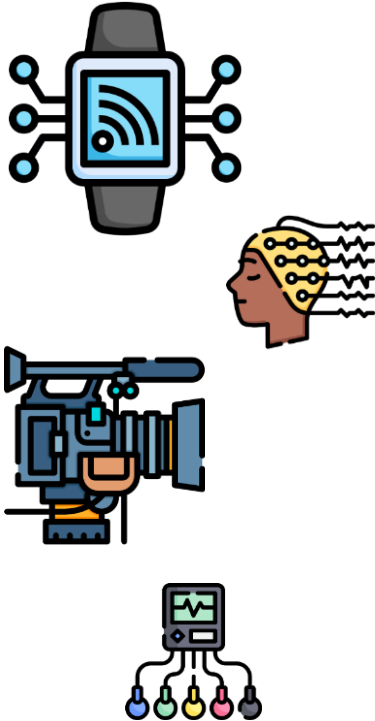
▷ **Regular** and **ecological** measurement of symptoms

> **PSG** : Polysomnography
> **MSLT** : Multiple Sleep Latency Test

*Ecological = in the patient's usual living environment

Avez-vous des difficultés d'endormissement ?

Aucune	Légère
Moyenne	Très
Extrêmement	

KANOPÉE

SPEECH
A PROMISING MEASUREMENT TOOL

- ▷ "Physiological" measurement
- ▷ Non invasive / passive
- ▷ Few calibration / computational ressources
- ▷ 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

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

▷ Sleepiness =
  ❌ Fatigue?
  ❌ Performances?

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

ESS
Epworth Sleepiness Scale

8

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* doze
1 = *slight* chance of dozing
2 = *moderate* change of dozing
3 = *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

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

▷ Sleepiness =
   ❌ Fatigue?
   ❌ Performances?

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

KSS
Karolinska Sleepiness Scale

	Français	Anglais
1	Parfaitement éveillé(e)	Extremely alert
2	Très éveillé(e)	Very alter
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

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

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

▷ Sleepiness =
  ❌ Fatigue?
  ❌ Performances?

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

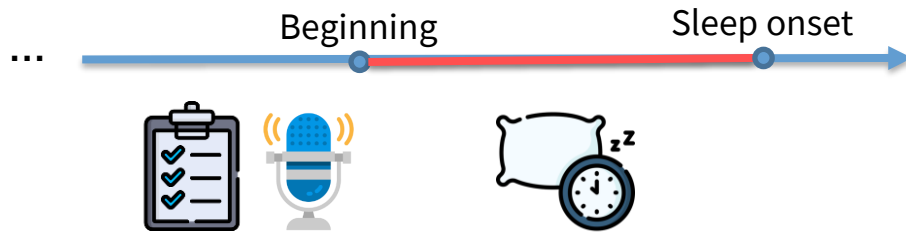▷ **Objective** sleepiness
  ✅ EEG (Multiple Sleep Latency Test)

STATE OF THE ART
CORPORA

UAR : Unweighted Average Recall

Sleepy Language Corpus (SLC)[1]	SLEEP[2]	
State of the art[3] : UAR = 71.7% ✓	State of the art[4] : ρ = 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

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

▷ Sleepiness =
   ❌ Fatigue?
   ❌ Performances?

▷ **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)

MSLT
METHOD

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 ≤ 8min.

9h   11h   13h   15h   17h

Beginning   Sleep onset   Waking-up

Sleep latency
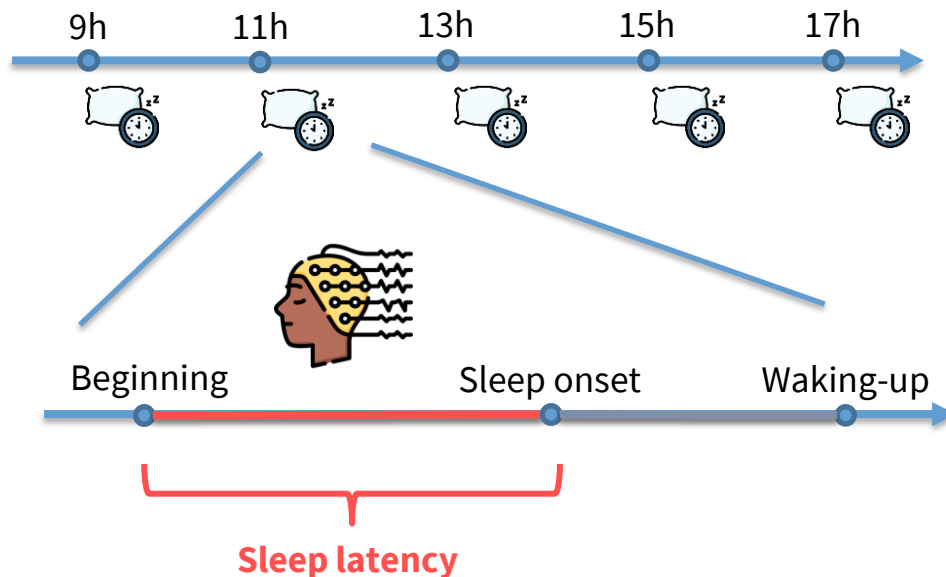
MSLT CORPUS
METHOD

Beginning   Sleep onset

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 circomference, 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"

Explainibility to clinicians

→ Interdisciplinary translation

Psychophysio. mecanisms

→ Integrative model

VOCAL AND SPEECH FEATURES

ACOUSTIC FEATURES

Acoustic quality of voice

A

E

READING ERRORS

Mistakes during the reading of a text out loud

P

Number, Duration and Location of pauses during reading out loud

READING PAUSES

A

Errors made by an Automatic Speech Recognition System

ASR ERRORS

ACOUSTIC FEATURES
HYPOTHESIS AND METHOD

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

MSLT 1 min

MSLT 20 min
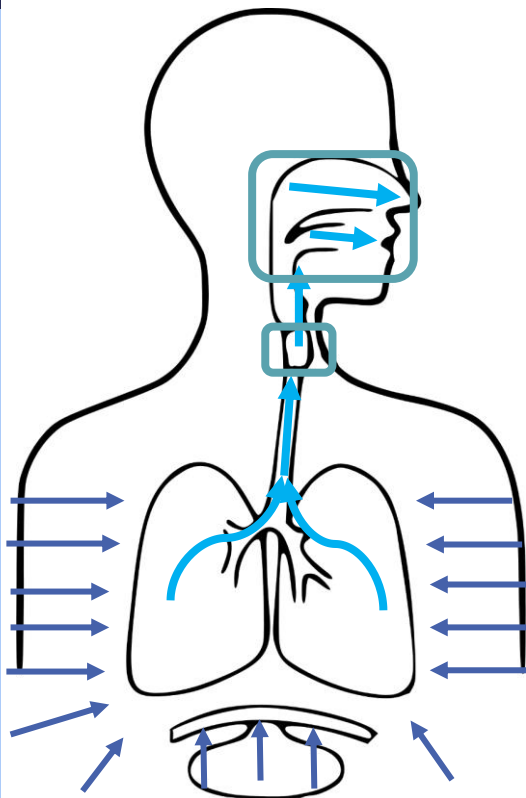
Acoustic features (voiced parts)

▹ F0/NRJ mean, std, max, min, bdw, slope

▹ Harmonics: H1, H2, H4

▹ Formants: (amplitude, bandwidth, amplitude)

▹ diff. Harmonics/Formants

▹ HNR

▹ CPP

→ 44 acoustic features

VOCAL AND SPEECH FEATURES

ACOUSTIC FEATURES

Acoustic quality of voice

A

E

READING ERRORS

Mistakes during the reading of a text out loud

Number, Duration and Location of pauses during reading out loud

READING PAUSES

P

A

Errors made by an Automatic Speech Recognition System

ASR ERRORS

READING MISTAKES HYPOTHESIS

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

MSLT
18.6 min.

KSS
3

Avg. MSLT.
8.3 min

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

ACOUSTIC FEATURES

Acoustic quality of voice

A

E

READING ERRORS

Mistakes during the reading of a text out loud

P

Number, Duration and Location of pauses during reading out loud
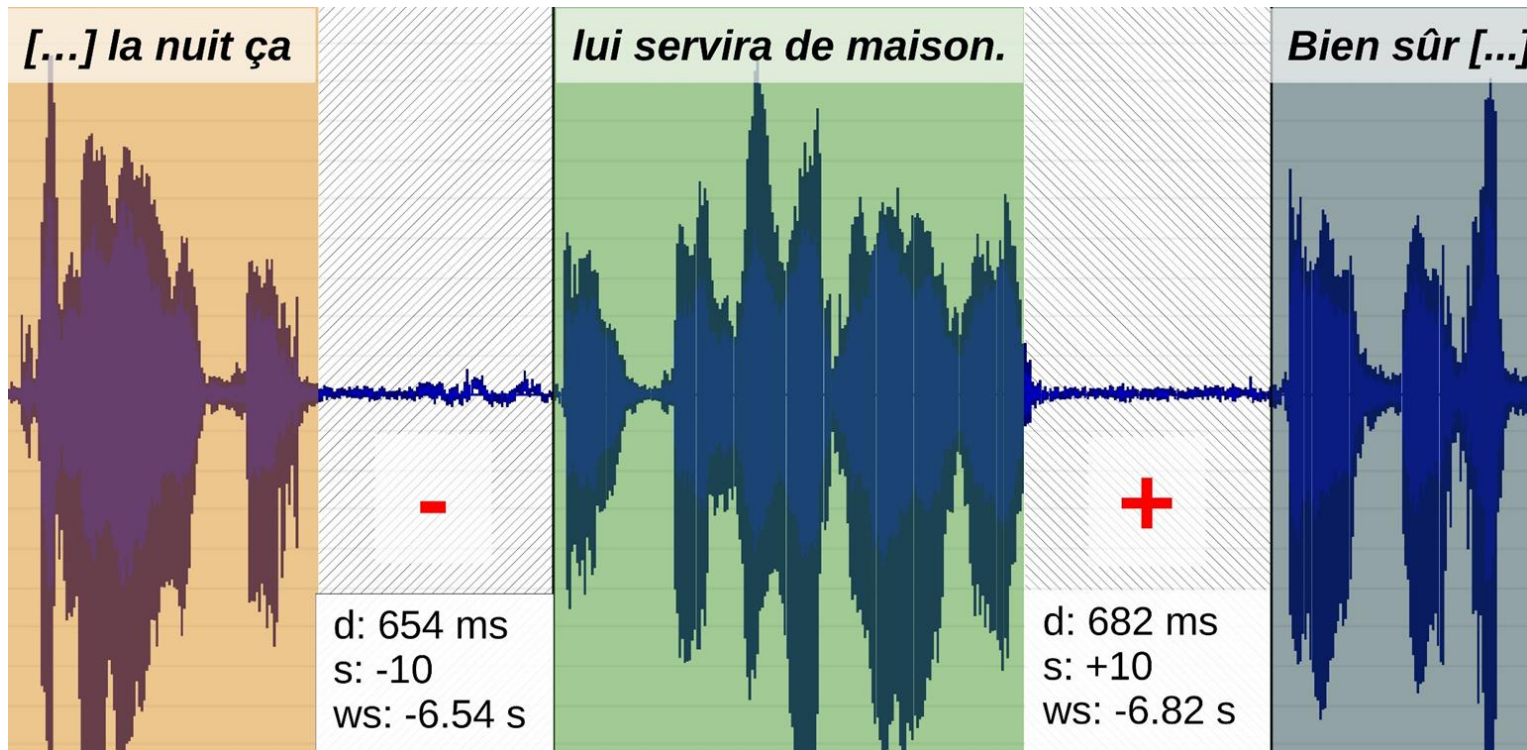
READING PAUSES

A

Errors made by an Automatic Speech Recognition System

ASR ERRORS

ASR ERRORS
HYPOTHESIS

Is it possible to automize reading mistakes annotations ?

MSLT
18.6 min

KSS
3
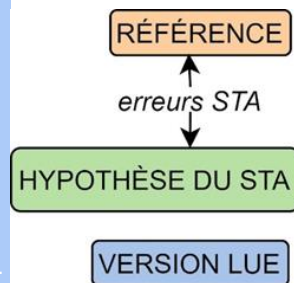
Avg. MSLT
8.3 min

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 %

Caractère

Portion de mot

Éléphant

Mot
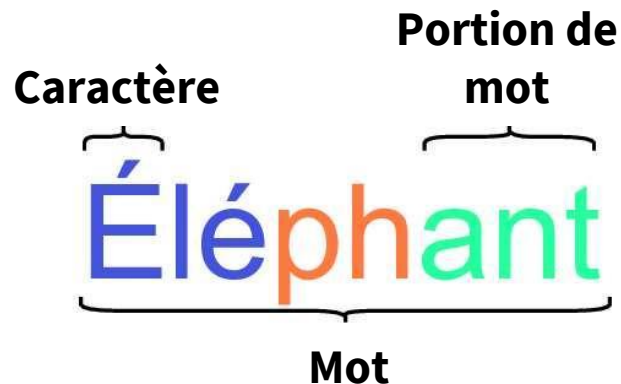
→ 112 features

[1][Boyer 2021]

VOCAL AND SPEECH FEATURES

ACOUSTIC FEATURES

Acoustic quality of voice

A

E

READING ERRORS

Mistakes during the reading of a text out loud

Number, Duration and Location of pauses during reading out loud

READING PAUSES

P

A

Errors made by an Automatic Speech Recognition System

ASR ERRORS

READING PAUSES
HYPOTHESIS

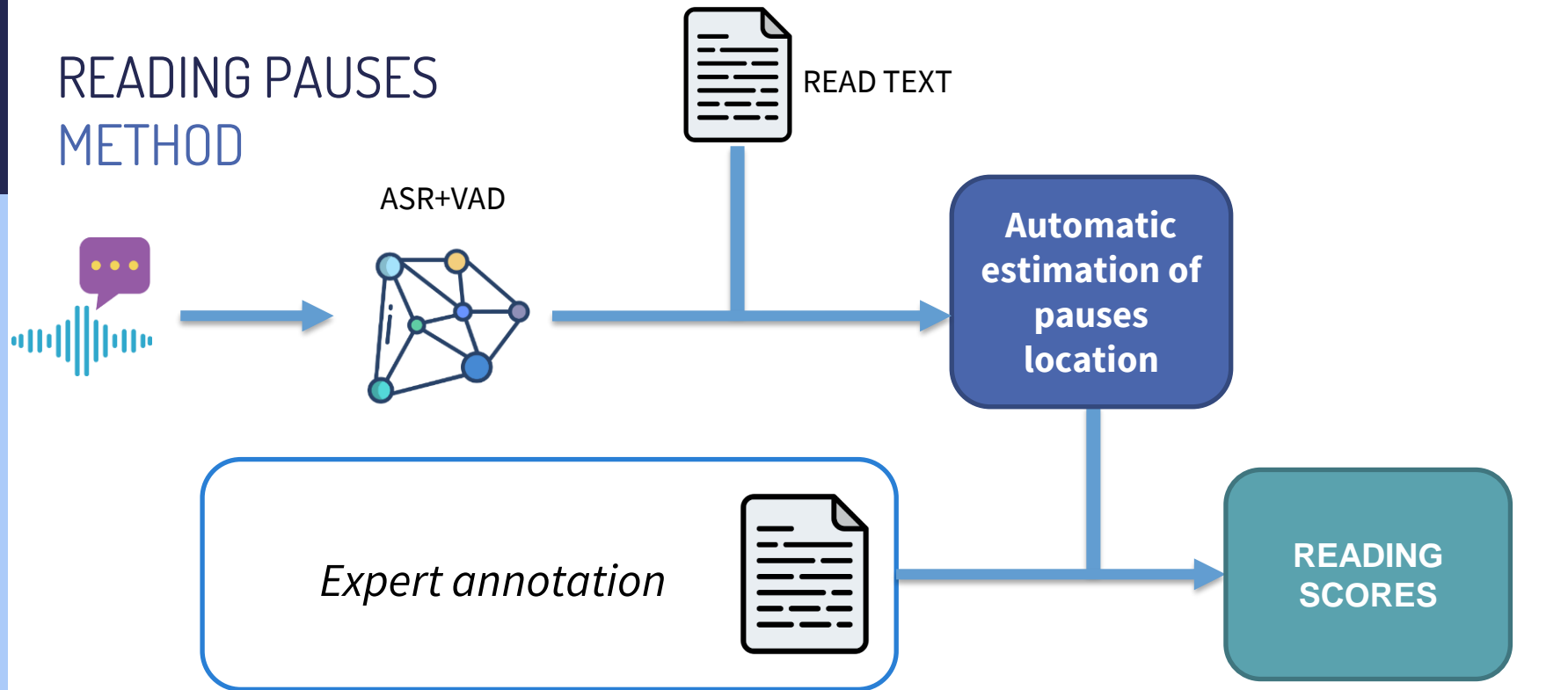Are **reading pause locations** linked to **sleep propensity** ?

MSLT
14.5

KSS
7

Avg. MSLT
17.5

[...] la nuit ça

lui servira de maison.

Bien sûr [...]

−

+

d: 654 ms
s: -10
ws: -6.54 s

d: 682 ms
s: +10
ws: -6.82 s

READING PAUSES
METHOD

ASR+VAD

READ TEXT

Automatic estimation of pauses location

Expert annotation

READING SCORES

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

ACOUSTIC FEATURES

Acoustic quality of voice

A

E

reading of a
out loud

ERRORS

P

Number, Duration and Location of pauses during reading out loud

READING PAUSES

A

Errors made by an Automatic Speech Recognition System

ASR ERRORS
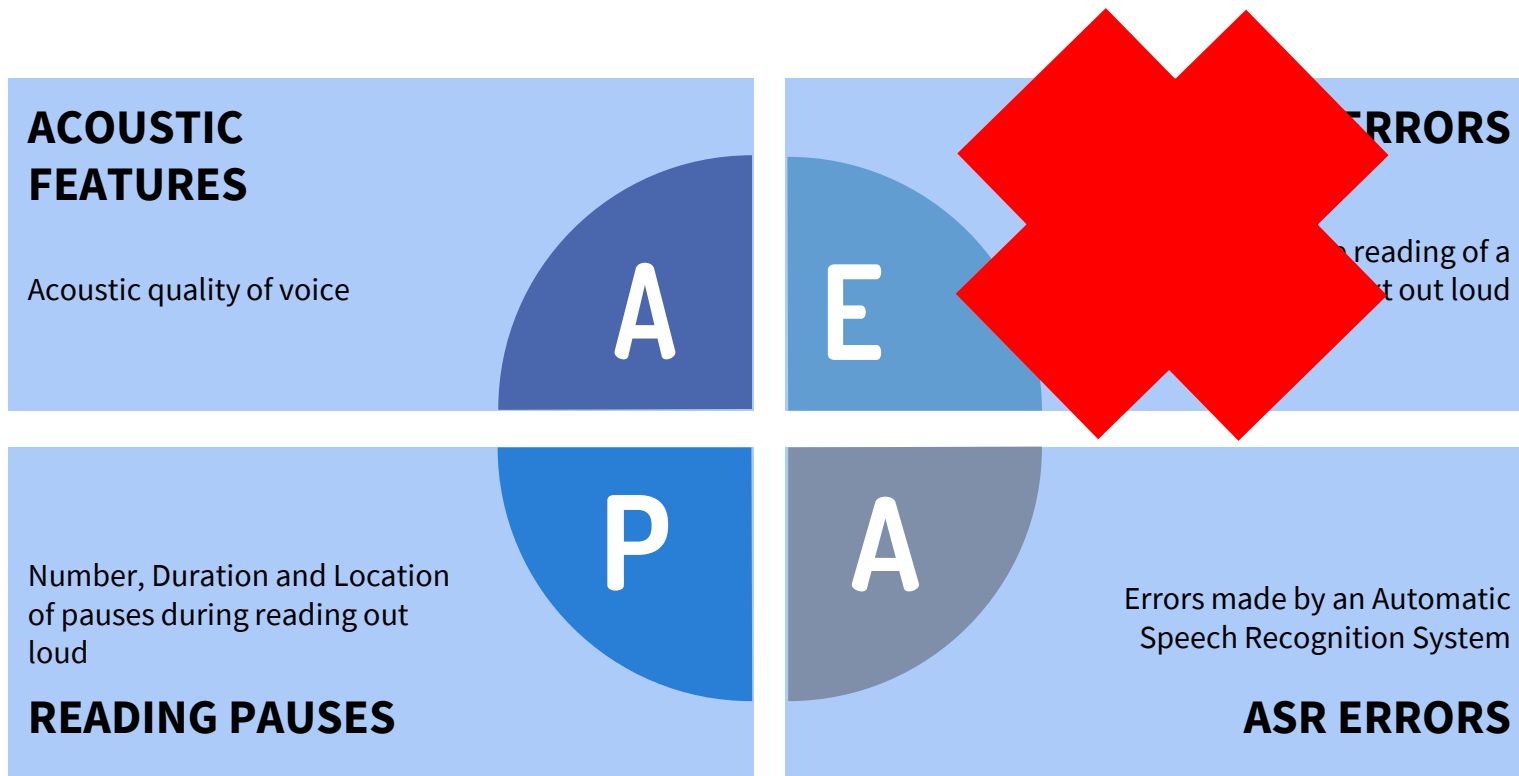
3.
Classification & interpretation

AUTOMATIC CLASSIFICATION CONSTRAINTS

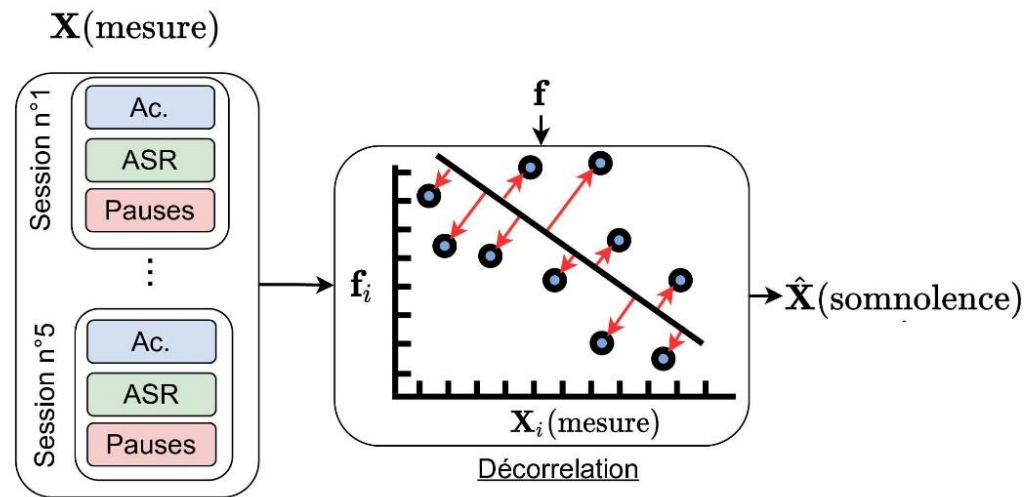How to detect **sleep propensity** using the previous features?

Explainibility
Ability to explain the decision to clinicians

Sensitivity
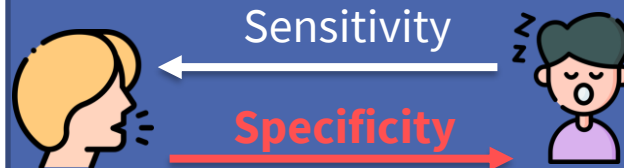
Specificity

Biomarkers =
*Sensitivity **AND** Specificity*

AUTOMATIC CLASSIFICATION
METHOD

$\mathbf{X}(\text{mesure})$

Session n°1: Ac., ASR, Pauses

Session n°5: Ac., ASR, Pauses

$\mathbf{f}$

$\mathbf{f}_i$

$\mathbf{X}_i(\text{mesure})$

Décorrelation

$\hat{\mathbf{X}}(\text{somnolence})$

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

Specificity

Session n°5

Ac.

ASR

Pauses

$\mathbf{X}_i(\text{mesure})$

Décorrelation

$\mathbf{X}(\text{somnolence})$

[Ins, **Del**, **Sub**, Correct]

Filtrage des erreurs de STA

Normalisation

Augmentation de données
[none, SMOTE, BorderlineSMOTE]

S   NS

$\hat{\mathbf{X}}_i(\text{somnolence})$

Sensibilité: test de MW
α = [0.01,0.05,0.075,0.1,1]

ACP
η = [70, 75, 80,85, 90,95,100]%

Classification
[LDA, Reg. Log.,SVC]
SVC: [C=1,γ='auto',
kernel = {'linear', 'rbf',
'poly'}, degree={2,3,4}]

LOSOCV
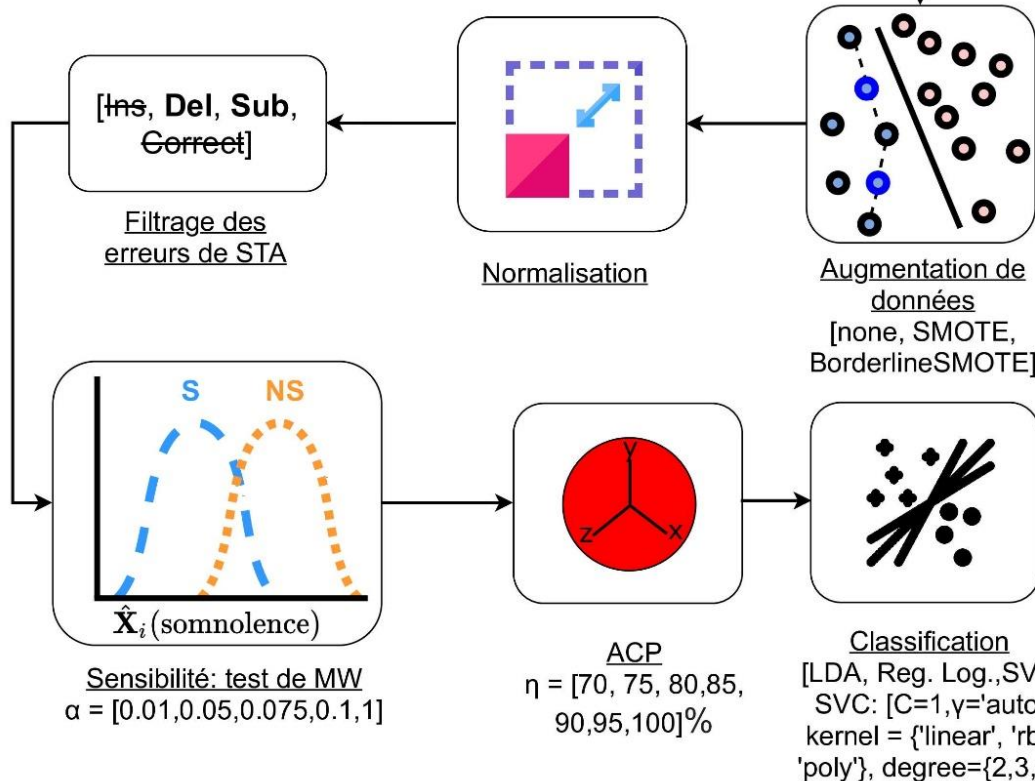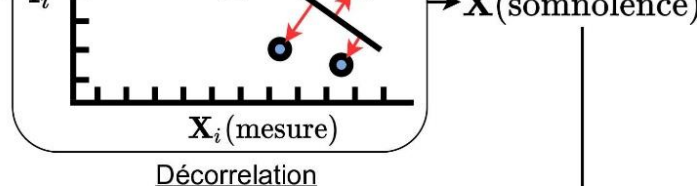
✓ **Sensitivity**

✓ **Specificity**

AUTOMATIC CLASSIFICATION RESULTS

Obj.Sleepiness

Avg. MSLT≤ 8min

UAR = 84,6% ✔

AUTOMATIC CLASSIFICATION OBJECTIVES

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

Pathological sleep propensity
Avg. MSLT ≤ 8min.
<u>Objective</u> evaluation
21 Subjects

Excessive Daytime Sleepiness
ESS > 15
<u>Subj.</u> evaluation (1 execution)
39 Subjects

ESS
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* doze
1 = *slight* chance of dozing
2 = *moderate* change of dozing
3 = *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
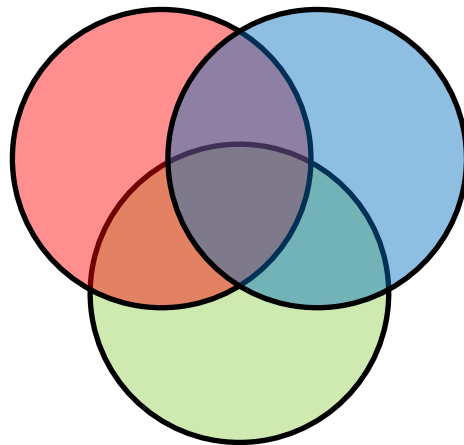
AUTOMATIC CLASSIFICATION OBJECTIVES

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

Pathological sleep propensity
Avg. MSLT ≤ 8min.
Objective evaluation
21 Subjects

Excessive Daytime Sleepiness
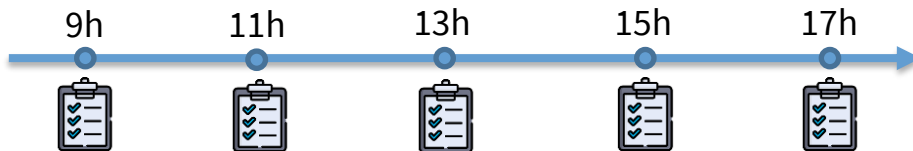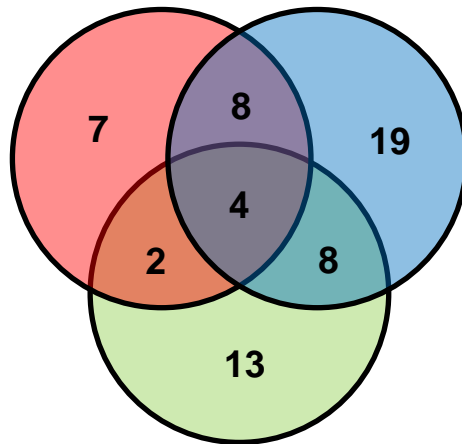**ESS > 15**
Subj. evaluation (1 execution)
39 Subjects

Average daytime sleepiness
Avg. Of 5 KSS > 5
Subj. evaluation (5 executions)
27 Subjects

9h   11h   13h   15h   17h

KSS
Karolinska Sleepiness Scale

	Français	Anglais
1	Parfaitement éveillé(e)	Extremely alert
2	Très éveillé(e)	Very alter
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

AUTOMATIC CLASSIFICATION OBJECTIVES

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

Pathological sleep propensity
Avg. MSLT ≤ 8min.
Objective evaluation
21 Subjects

Excessive Daytime Sleepiness
ESS > 15
Subj. evaluation (1 execution)
39 Subjects

7   8   19

2   4   8

13

Average daytime sleepiness
Avg. Of 5 KSS > 5
Subj. evaluation (5 executions)
27 Subjects

9h   11h   13h   15h   17h

AUTOMATIC CLASSIFICATION
RESULTS

Obj.Sleepiness

Avg. MSLT≤ 8min

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

45.6%

19.1%

35.3%
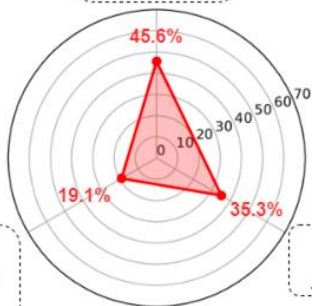
Pauses
Ratio +, -
N-
D moy
D é-t

STA
Sub, Ins

HIGH LEVEL

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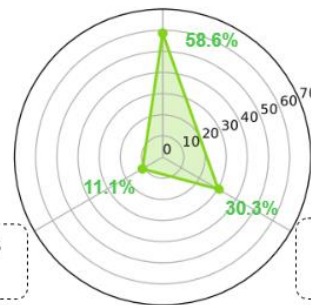F0var

LOW LEVEL

45.1%

14.8%

40.1%
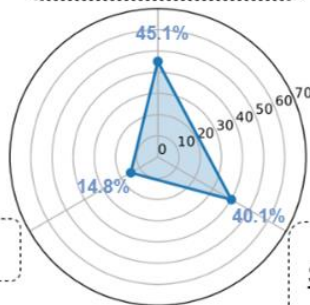
Pauses

STA
Sub, Ins,
Del

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

58.6%

11.1%

30.3%

Pauses
D max.

STA
Sub, Ins

Classification: conclusion

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

Perspectives

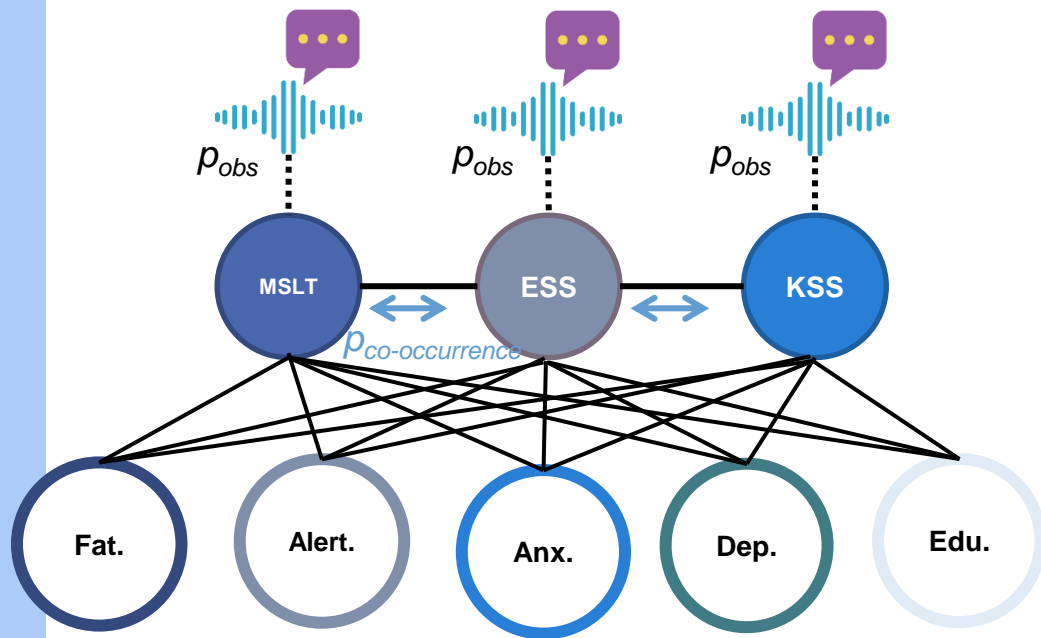New databases & Symptom networks

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*
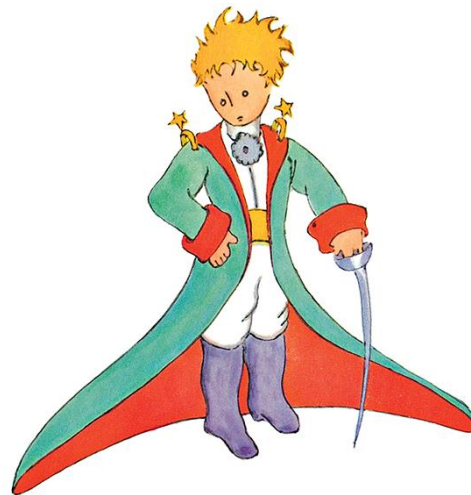 ▸ What graph?
  ▸ Transitions?

→ **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?

 vincent.martin@labri.fr

 @V_P_Martin

 Vincent-P-Martin