Design and control of a tracheal occlusion system for an implantable active artificial larynx

Presented by:
Adrien Mialland

Thesis supervisor
Agnès Bonvilain

ORL surgeon:
Ihab Atallah

Host laboratoiry :
Grenoble Image Parole Signal Automatique (Gipsa-Lab)
Université Grenoble Alpes (UGA)

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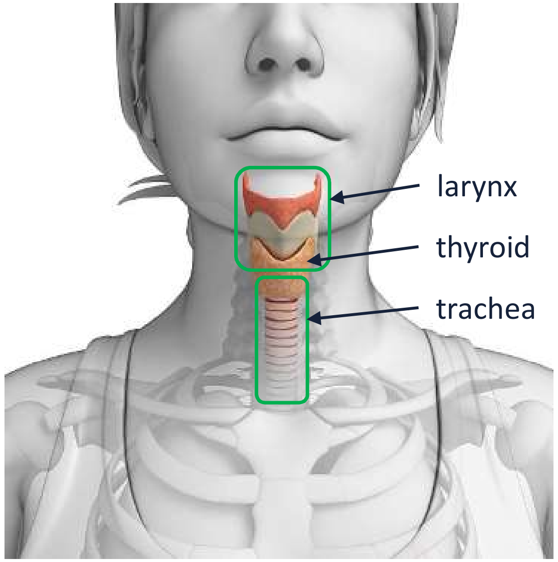
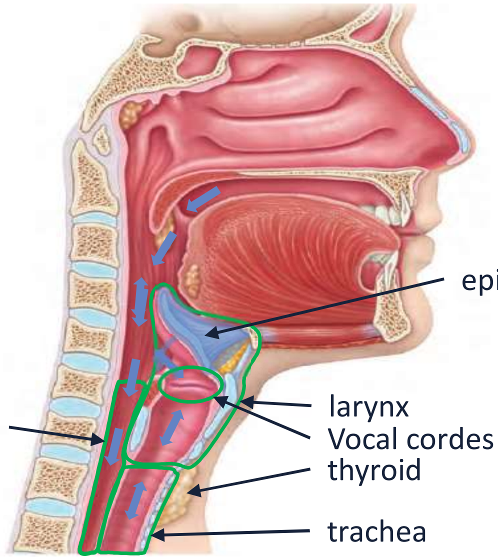
Presentation Plan

1. Context
2. Clinical Research Protocol (CRP)
3. Statistical Study
4. Real time detection
5. Implantable Active Artificiel larynx (IAAL)
6. Conclusion and perspectives

1. Context - larynx



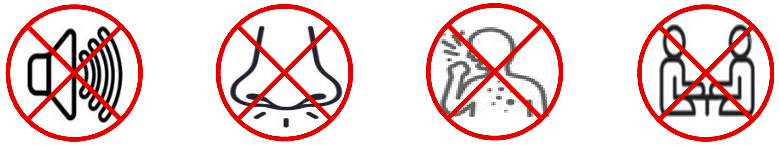


E. Maried et al. 2013

3 main functions:

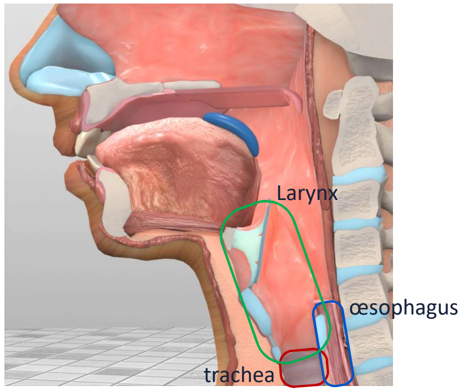
Breathing – Swallowing - Phonation

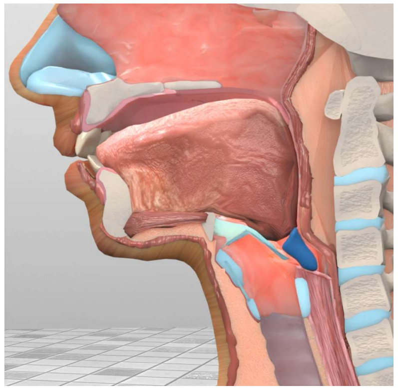
1. Context – Total Laryngectomy

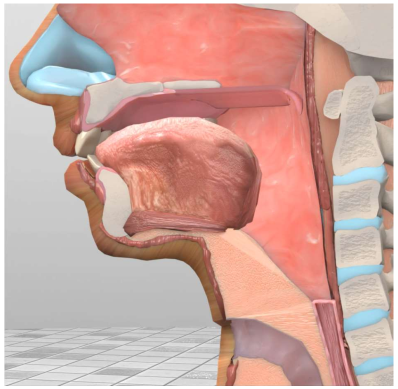


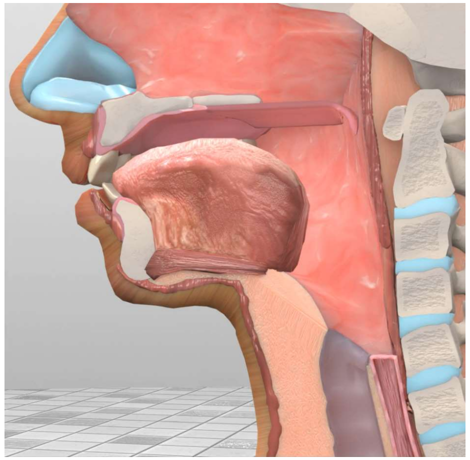
Rehabilitation methods:
- Tracheostomy.
- Voice restoration.

1. Context – Swallowing Restoration









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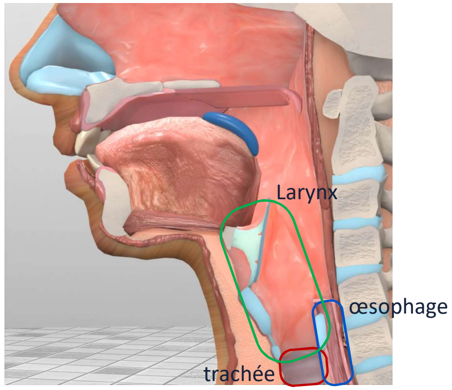
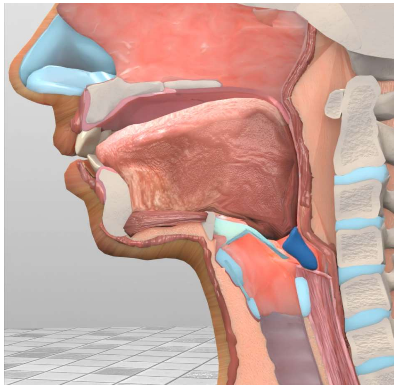
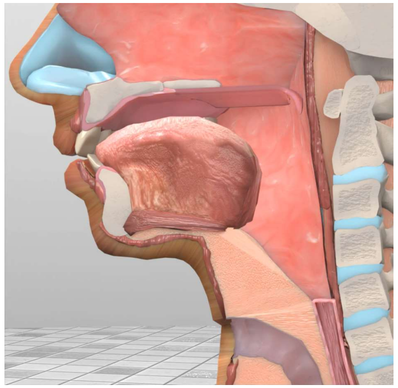
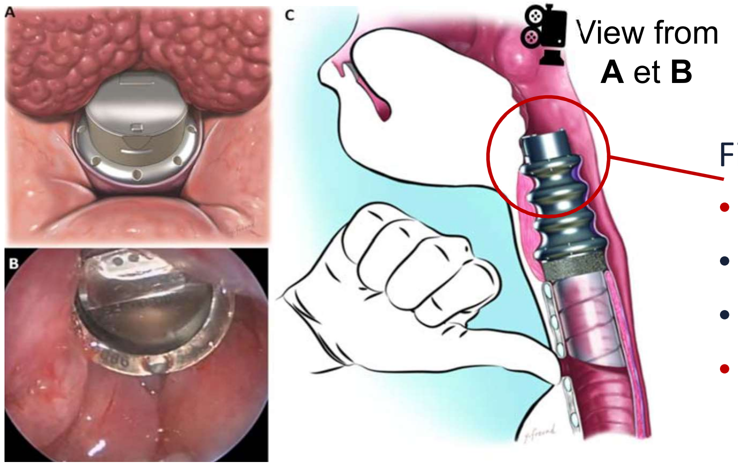






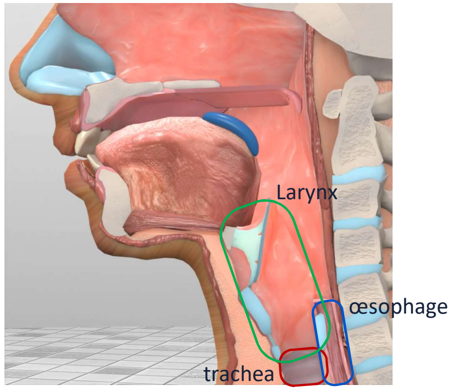


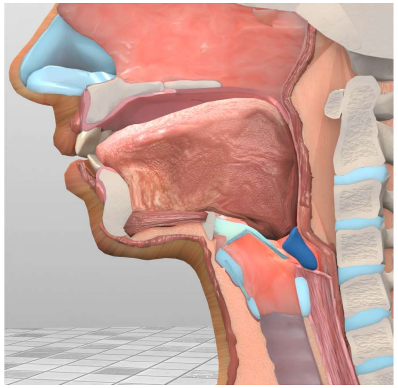
Debry C. et al. 2014.

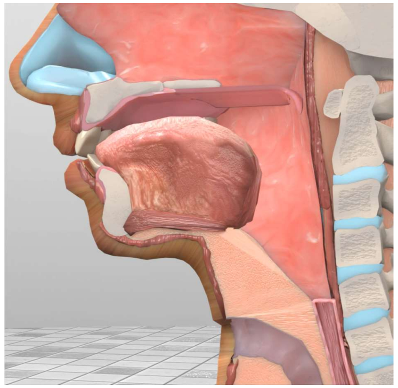
First Artificial Larynx - 2012:

- Valve mechanism - **passive**,
- Implanted on 6 patients,
- Only used under medical control,
- Lack of sealing

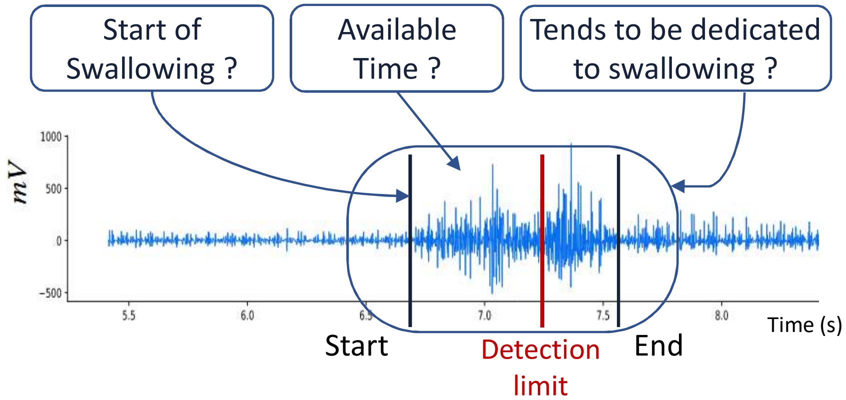
1. Context – Swallowing Restoration

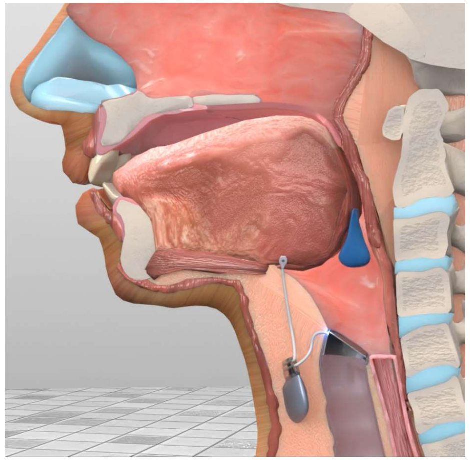






Example of a swallowing signal





Real time detection - constraints:

- Earliness
- Accuracy
- Preservation
- Consomption

Presentation Plan

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2. CRP – Main criteria: earliness

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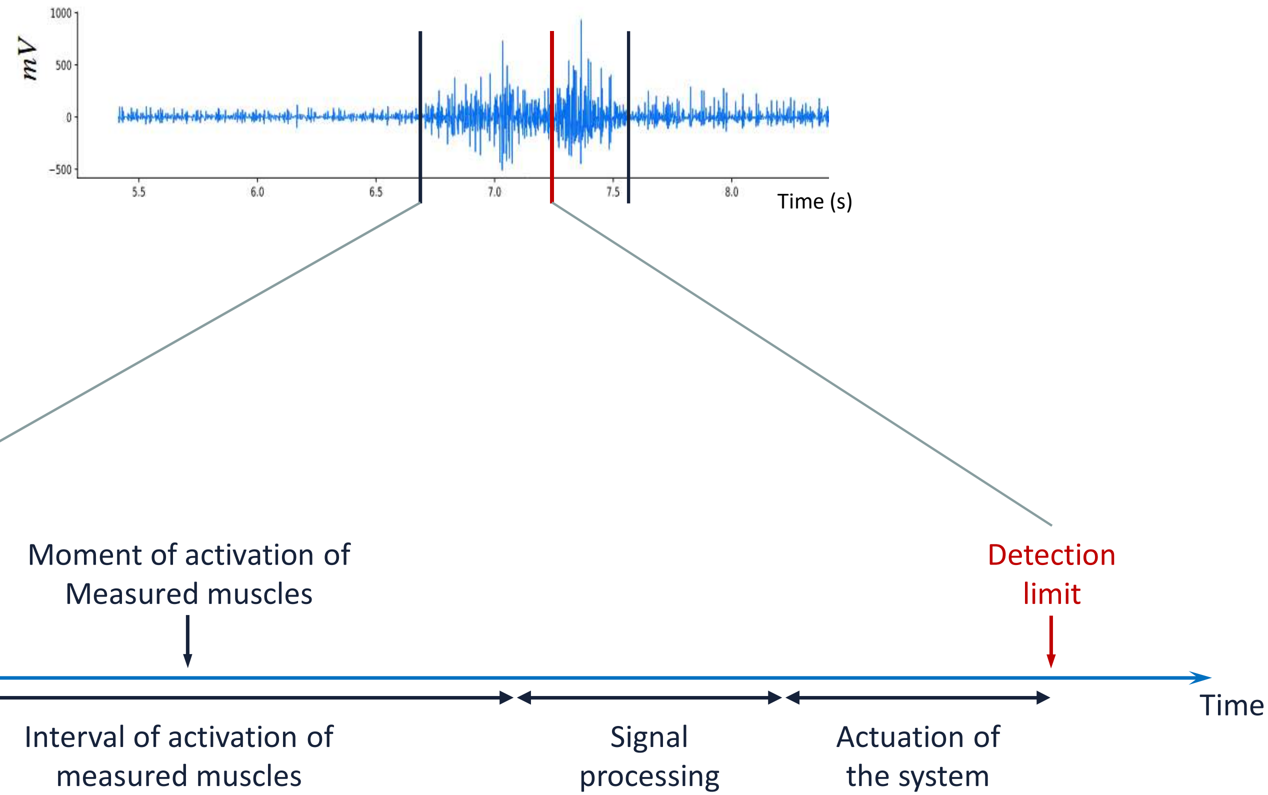

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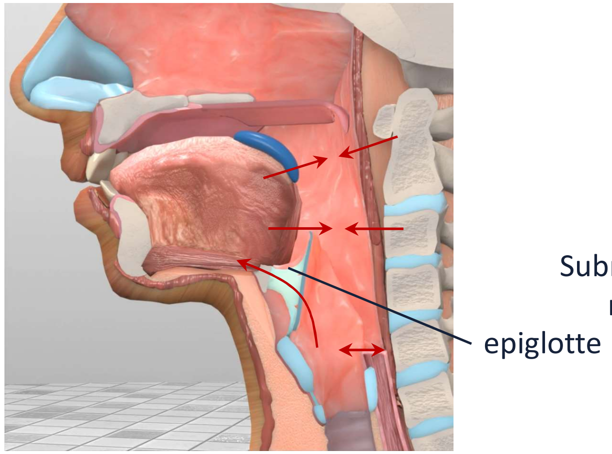

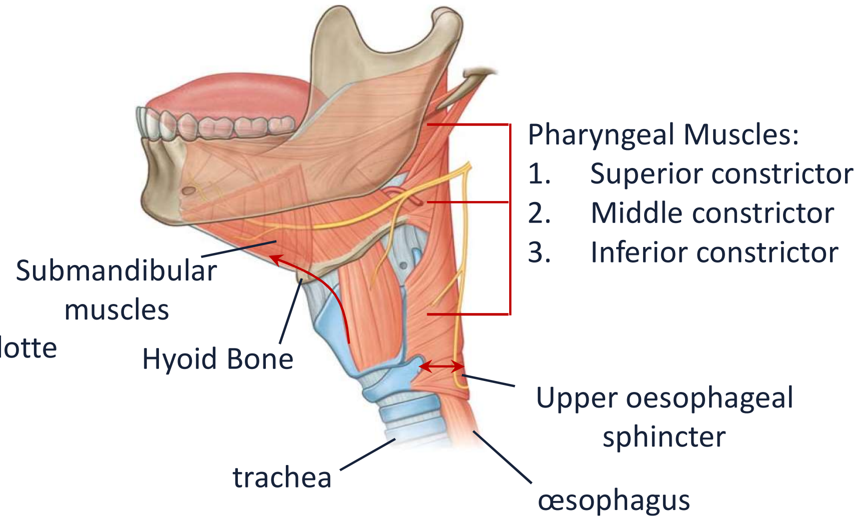

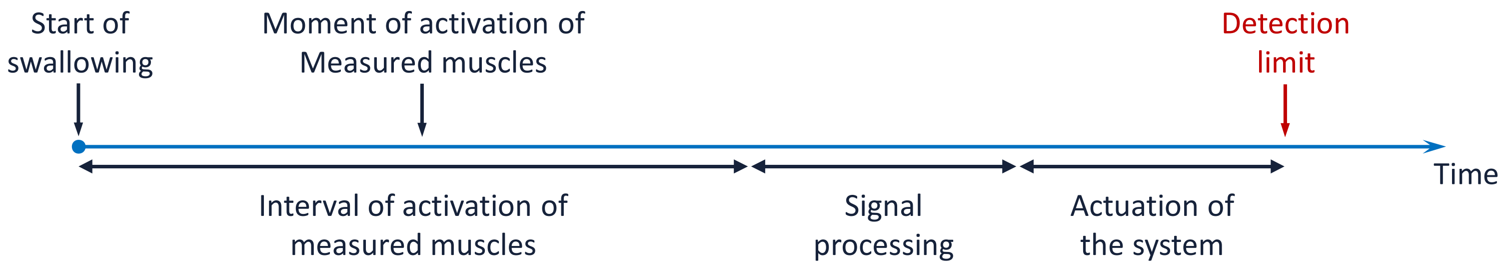

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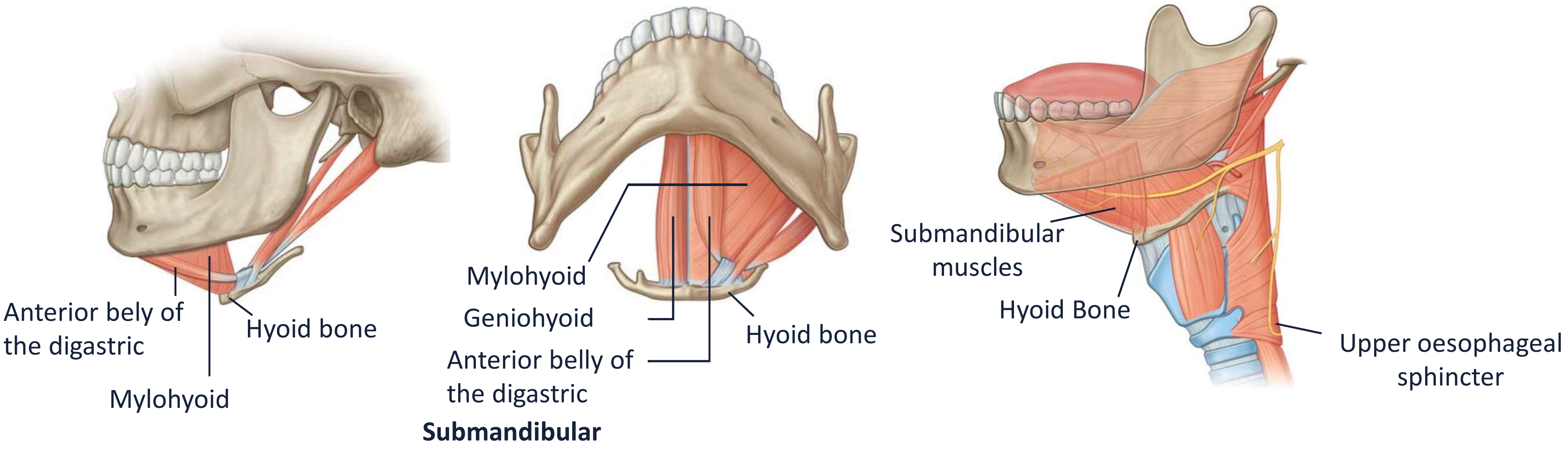
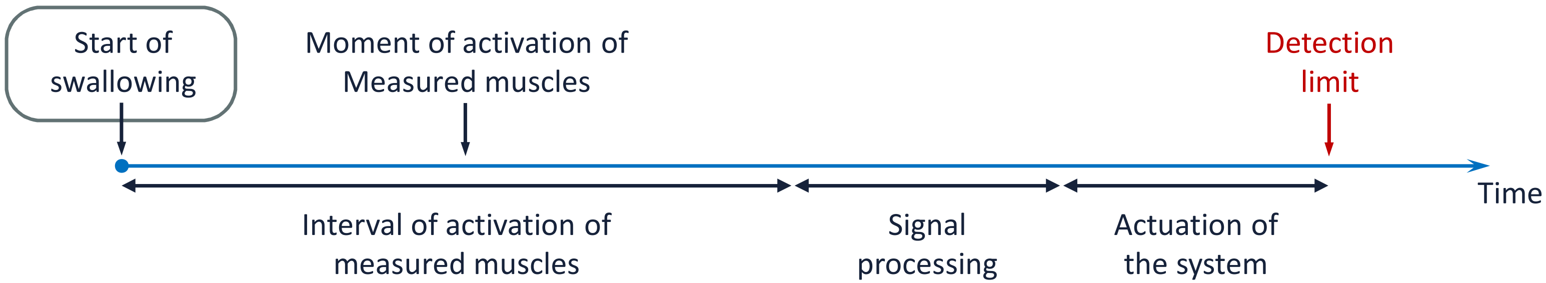
2. CRP – Start of Swallowing

[D. Park et al. 2017, J. Walton et al. 2018, R. L. Drake et al. 2010]





A. Mialland et al. Toward a robust swallowing detection for an implantable active artificial larynx: A survey. In: Med. Biol. Eng. Comput. (2023).

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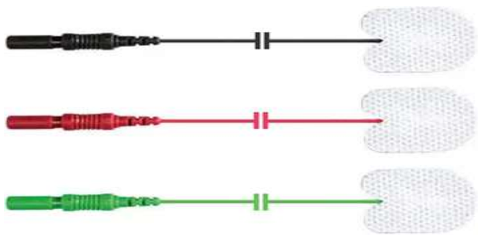
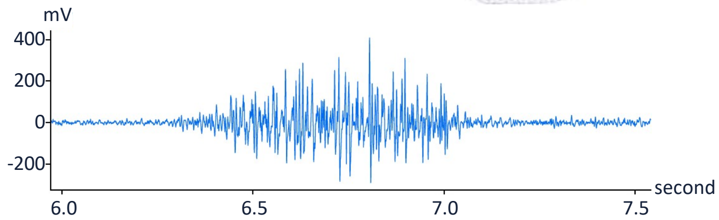
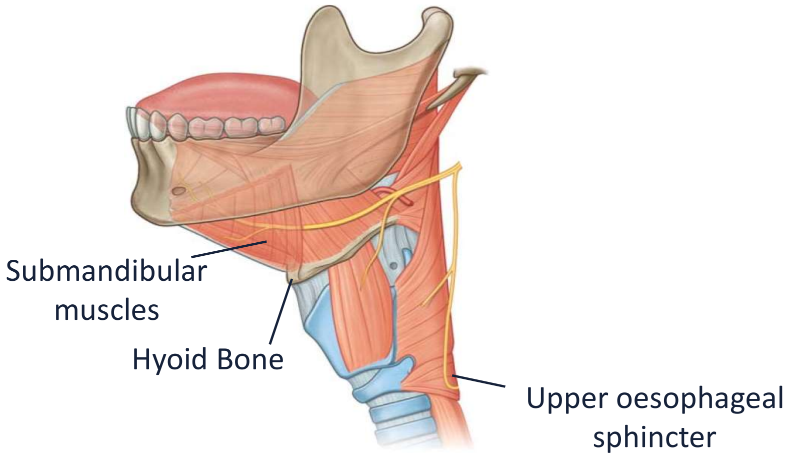
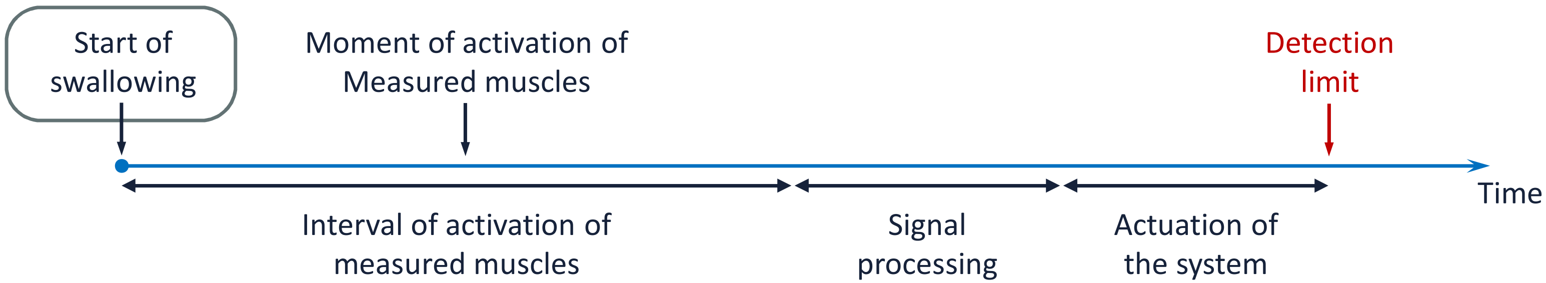
2. CRP – Start of Swallowing

Surface electromyography electrodes





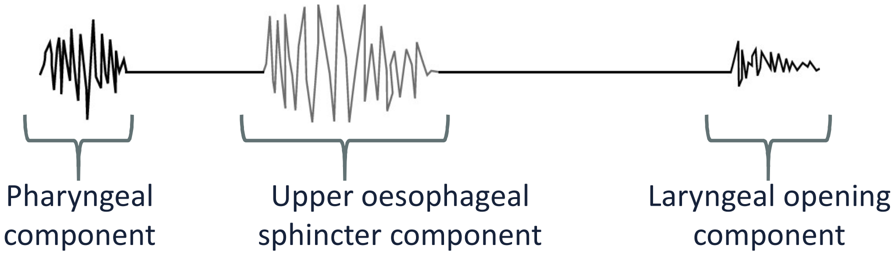


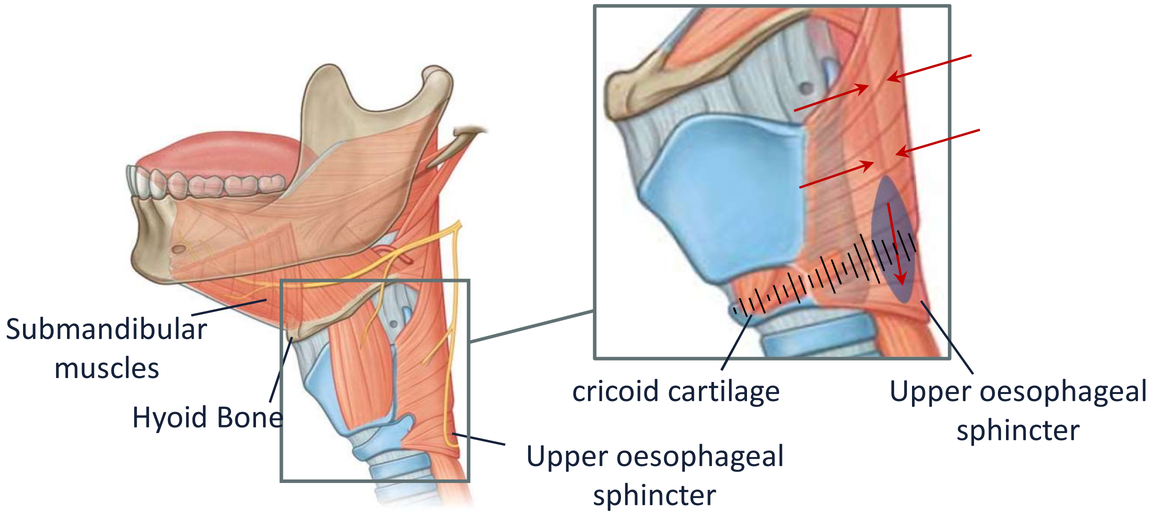


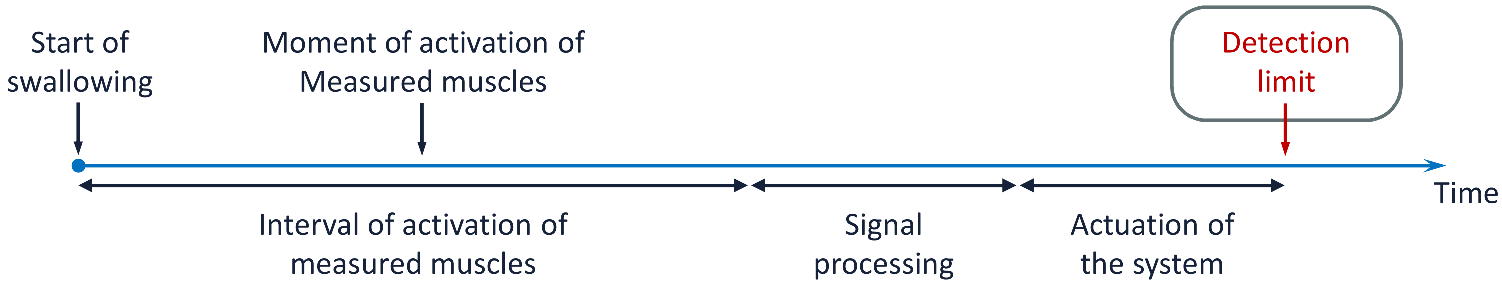
2. CRP – Temporal detection limit

[Morinière et al. 2011, M. Hasegawa et al. 2018, T. Omari et al 2018, A. Pal et al. 2003, J. Lee et al. 2008, J. M. Dudik et al. 2015]

Before total laryngectomy







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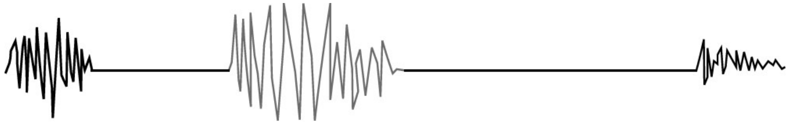
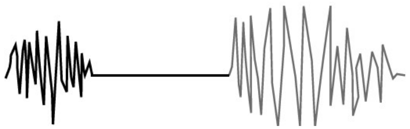
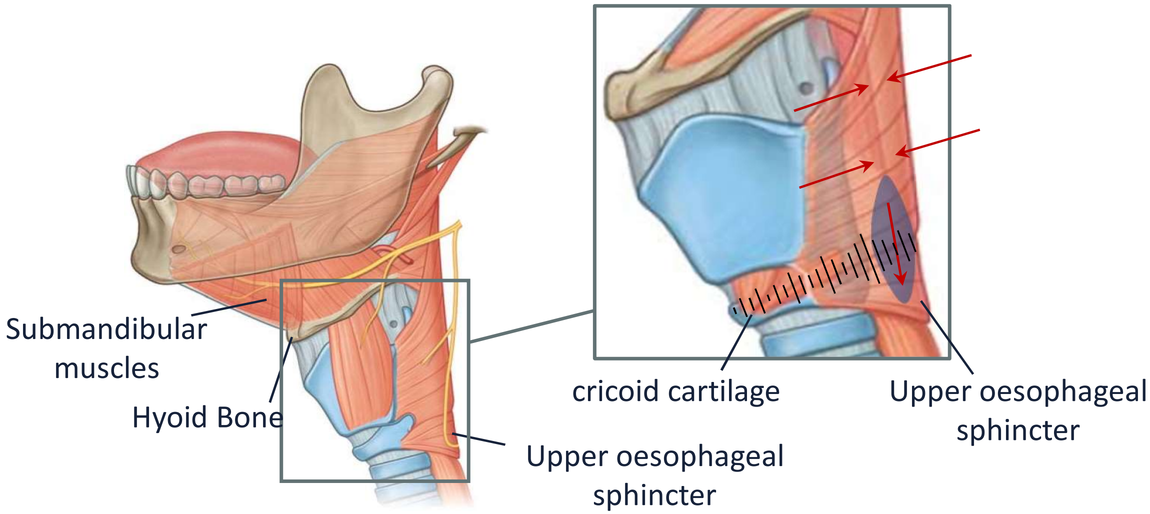
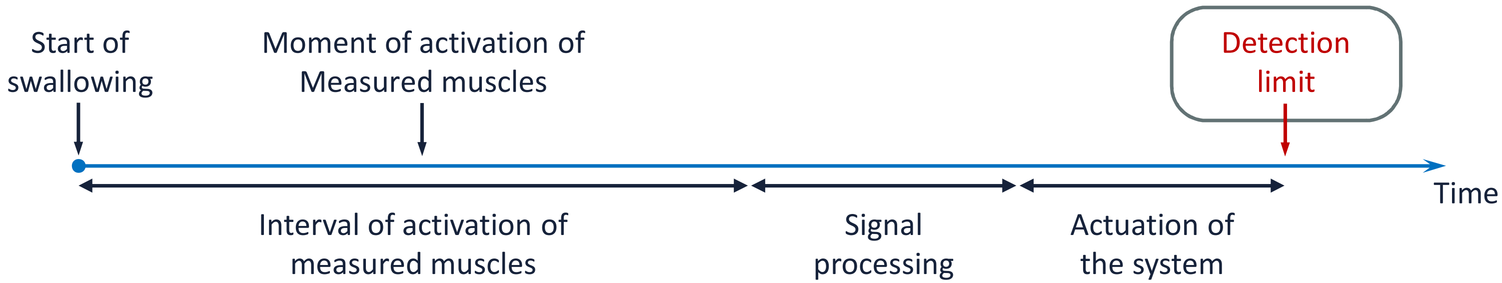


After total laryngectomy





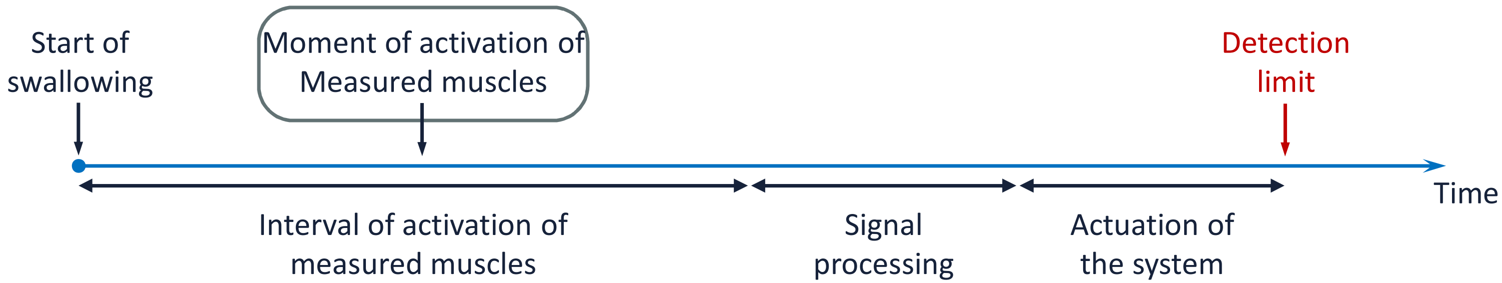


2. PRC – Stylohyoid and posterior digastric muscles

Earliness | Accuracy | Consumption | Preservation

Activation variability of the stylohyoid and posterior digastric muscles:

- Activated at the same time than the submandibular muscles
  - EMG studies on animals [Rebecca Z. German et al. 2009, A. J. Thexton et al. 2007 , R. W. Doty et al. 1956].
  - Imaging study on human [T. Okada et al. 2013]
  - Anatomic properties study on human [W. G. Pearson et al. 2011]



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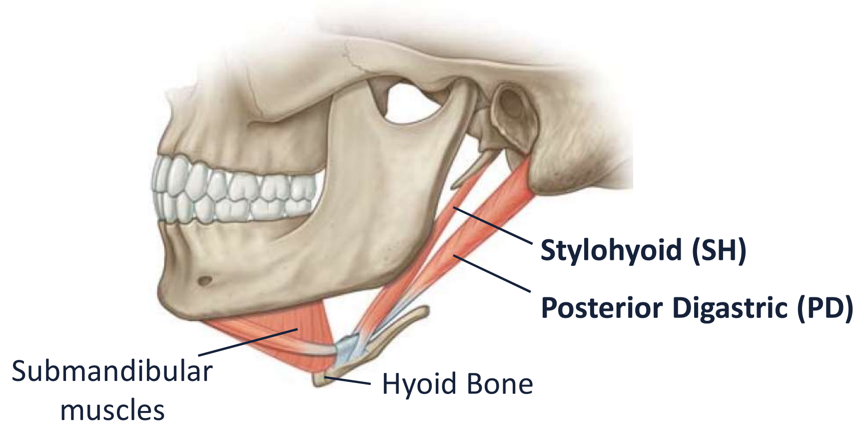
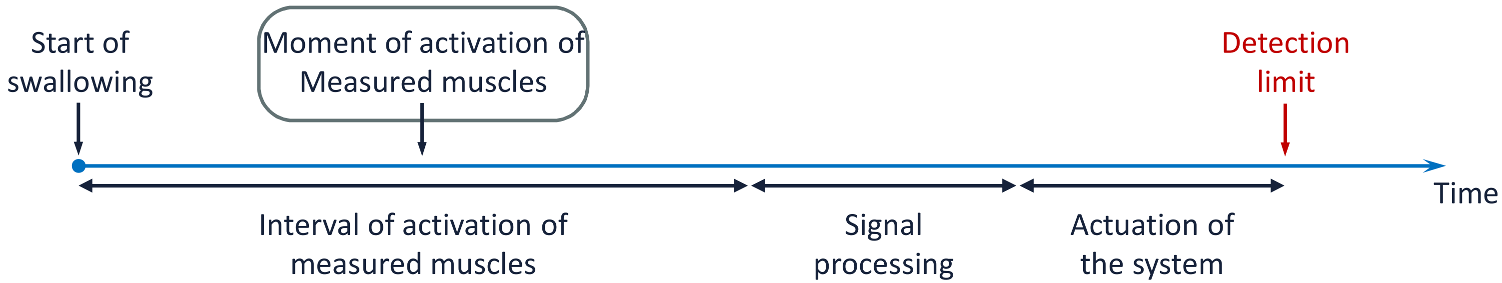
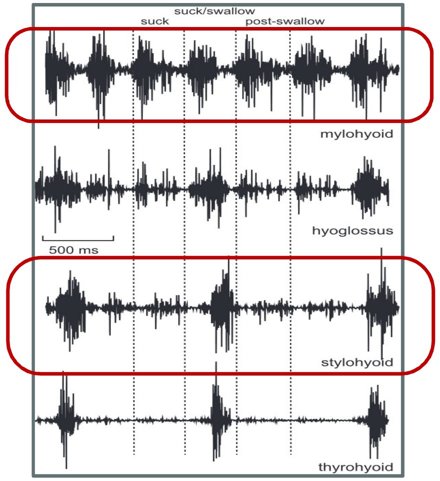




2. PRC – Stylohyoid and posterior digastric muscles

Earliness | Accuracy | Consumption | Preservation

Intramuscular EMG on pigs



A. J. Thexton et al. 2012

Start of swallowing

Moment of activation of Measured muscles

Detection limit

Time

Interval of activation of measured muscles

Signal processing

Actuation of the system

2. PRC – Stylohyoid and posterior digastric muscles

Earliness | **Accuracy** | **Consumption** | Preservation

Intramuscular EMG on pigs

Stylohyoid and posterior digastric muscles:

- Predominently activate for swallowing
  - EMG studies on animals [Rebecca Z. German et al. 2009, C. J. Mayerl et al. 2021, A. J. Thexton et al. 2012].
  - Imaging study on human[W. G. Pearson et al. 2013]
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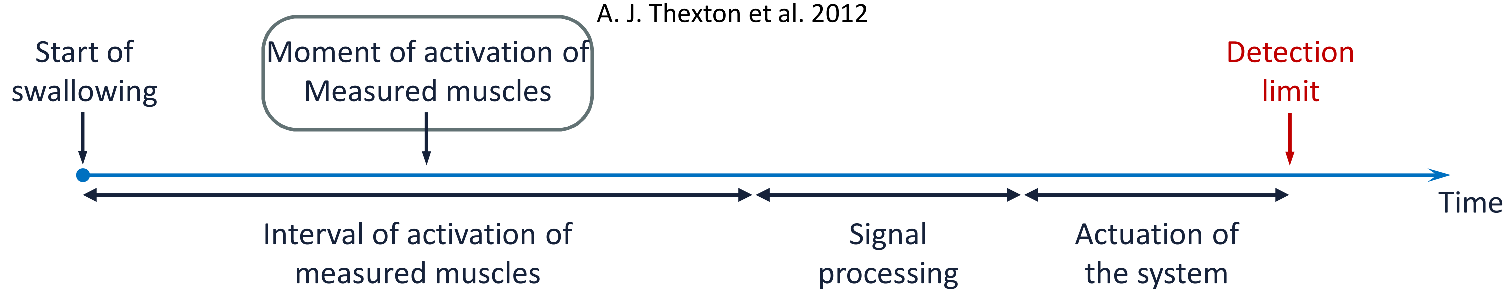
A. J. Thexton et al. 2012



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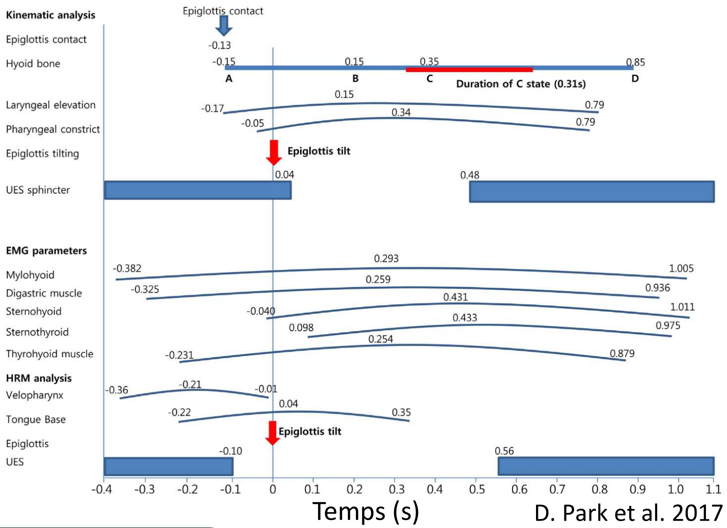
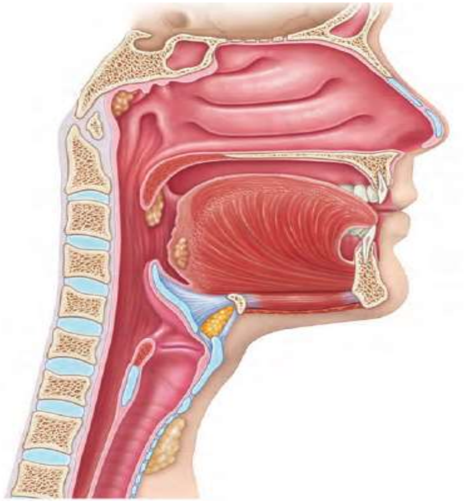
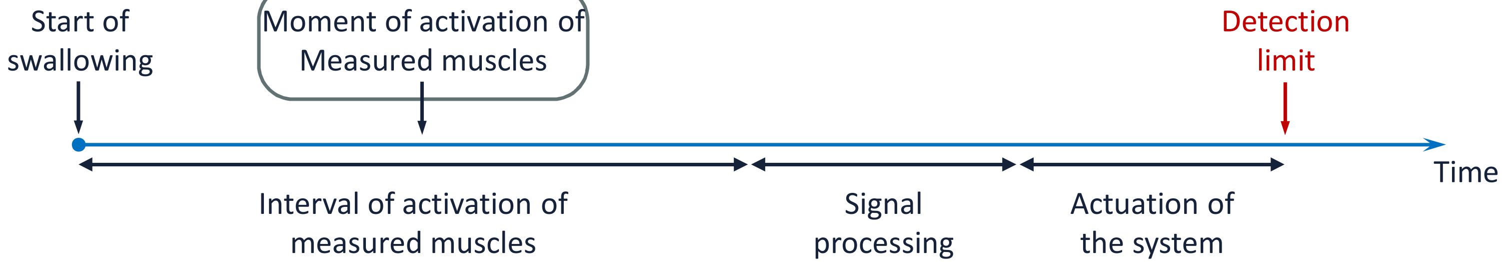
Earliness | Accuracy | Consumption | **Preservation**



D. Park et al. 2017





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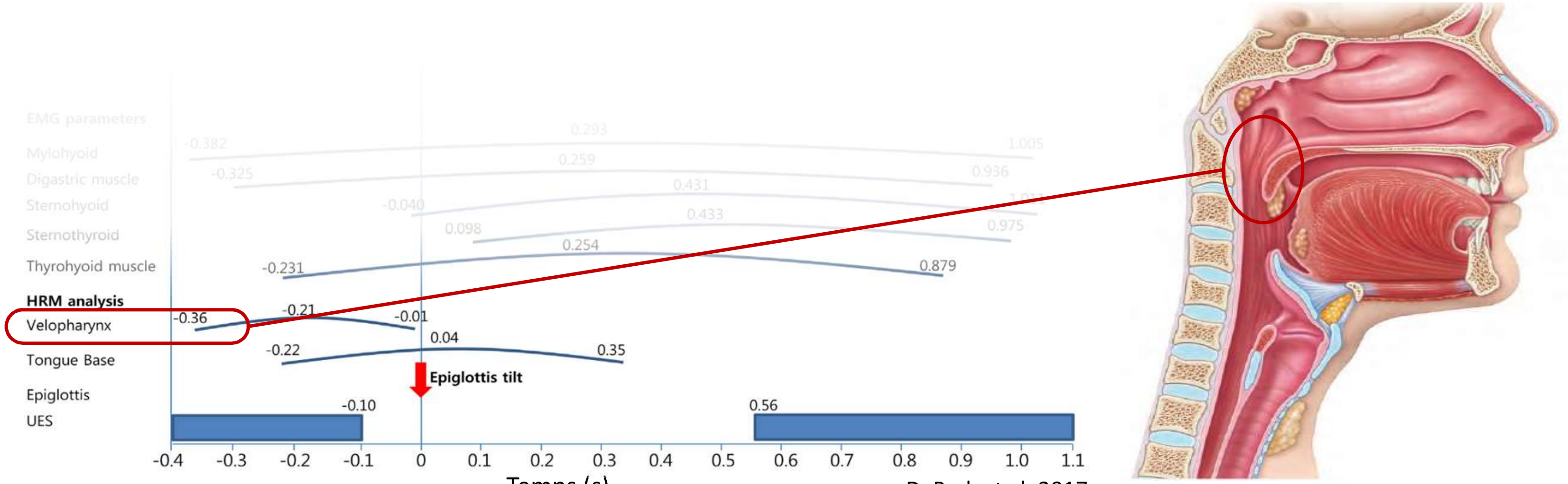

D. Park et al. 2017

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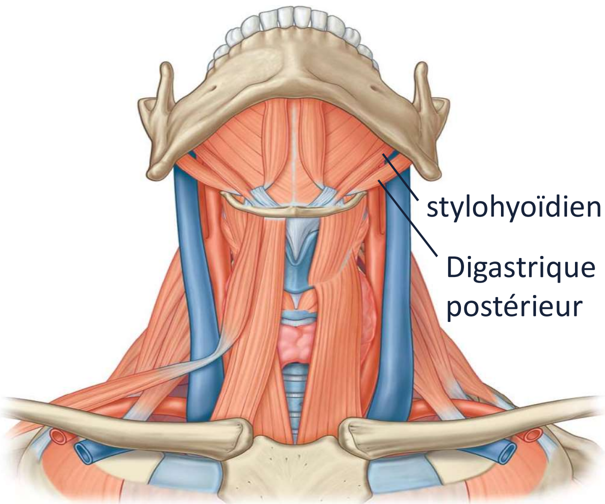

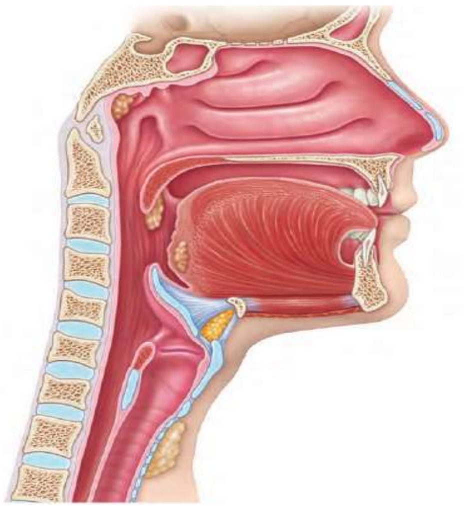

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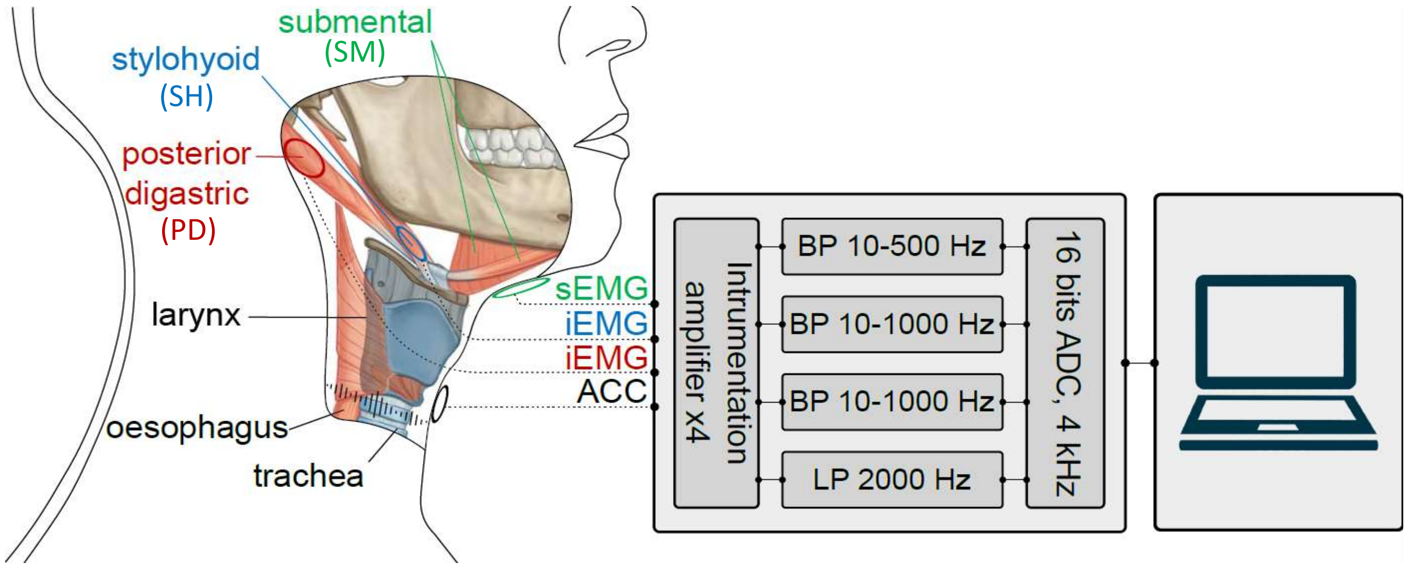
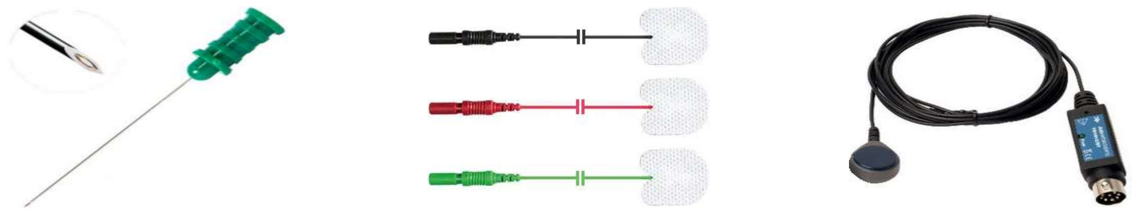
2. PRC – Innovative measurement method





A. Mialland et al. Stylohyoid and posterior digastric measurement with intramuscular EMG, submental EMG and swallowing sound. In: BIOSIGNALS (2023)

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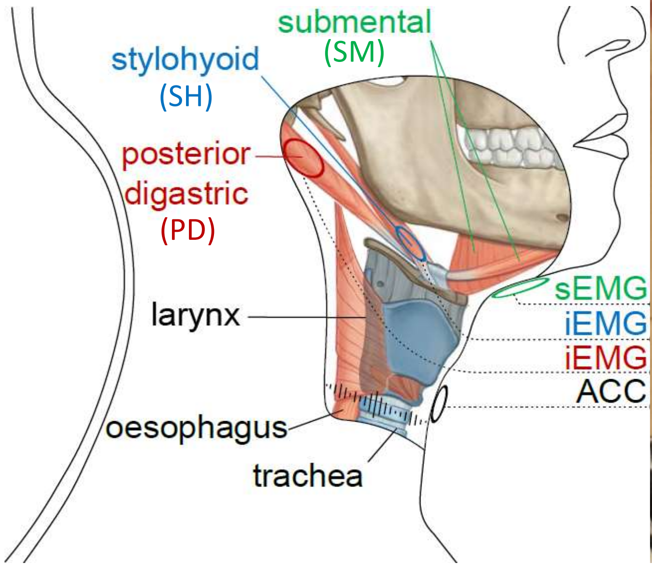
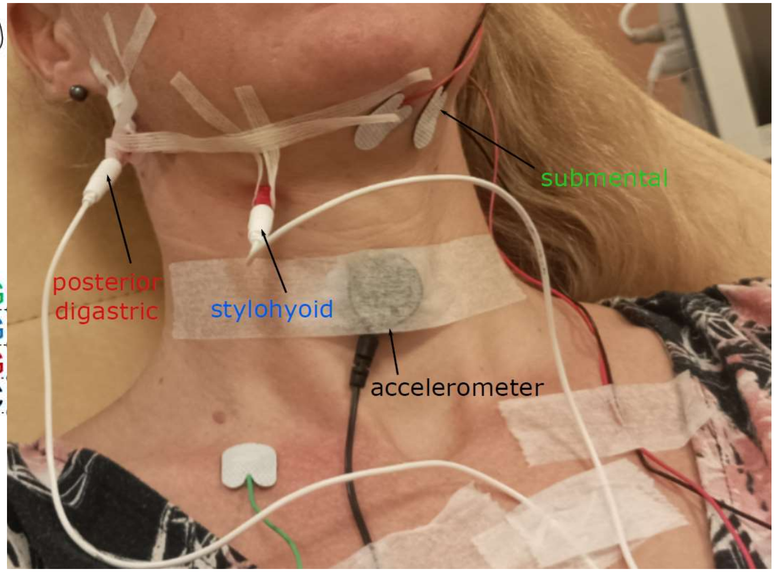


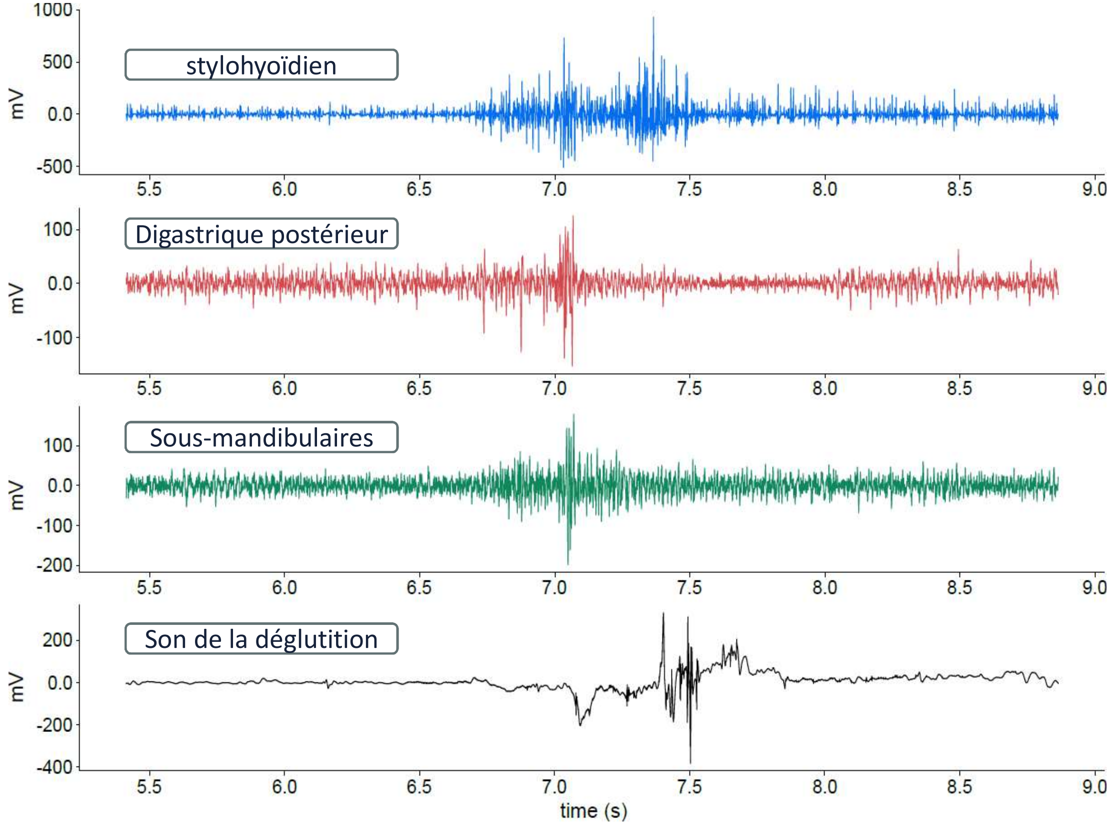


- 17 healthy participants (8 men / 9 women)
- 4 swallowing: saliva, water, thick (compote), solid (madeleine).
- 13 non-swallowing: mouth opening, lips purseing, teeth clenching, smiling, whistling, coughing, blowing, speaking, saying *« iii »*, jaw movements, lateral head movements, head flexion/extension, mastication.

A. Mialland et al. Stylohyoid and posterior digastric measurement with intramuscular EMG, submental EMG and swallowing sound. In: BIOSIGNALS (2023)

2. PRC – Innovative measurement method

Swallowing acquisition exemple



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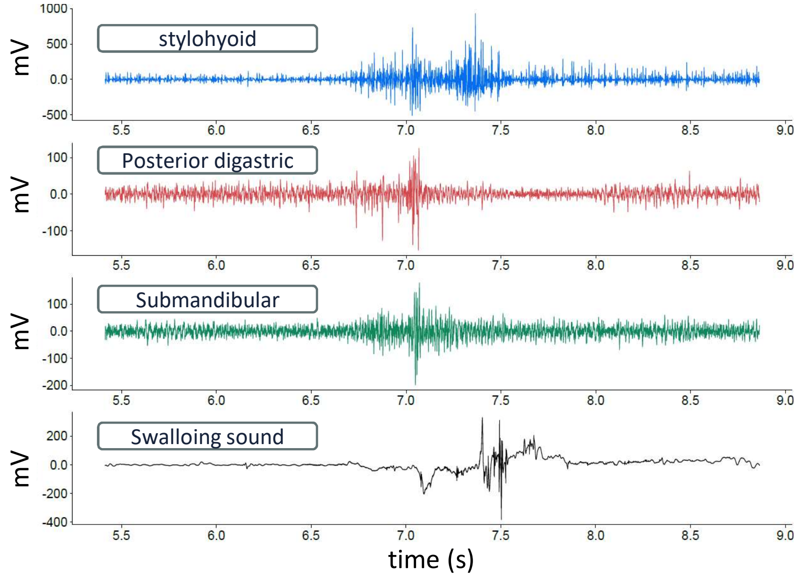
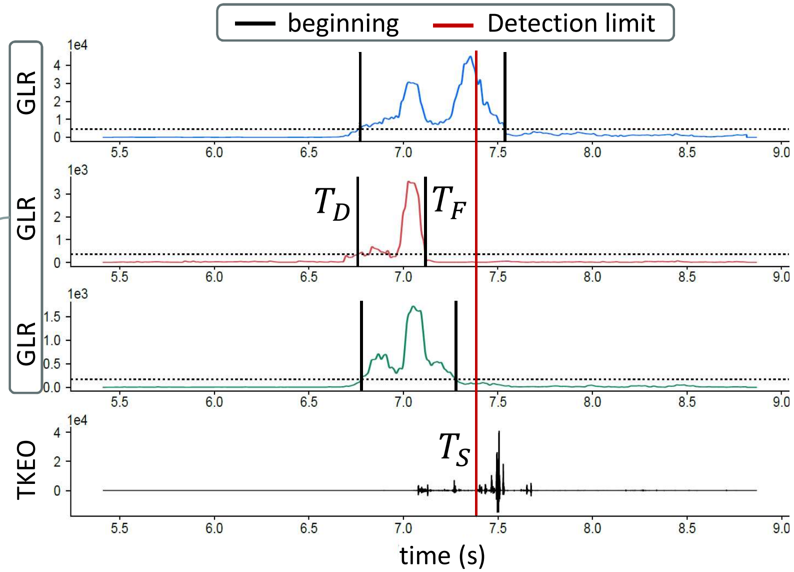
3. Statistical study– Data extraction





Generalized Likelihood Ratio (GLR):

$$\frac{L_1(r, y_0^n)}{L_0(y_0^n)} = \frac{p_0(y_0^{r-1})p_1(y_r^n)}{p_0(y_0^n)} = \prod_{t=r}^{n} \frac{P_1(y(t))}{P_0(y(t))}$$

$P_i\big(y(t)\big)$: actived/non-actived muscle hypothesis.

A. Mialland et al. Stylohyoid and posterior digastric measurement with intramuscular EMG, submental EMG and swallowing sound. In: BIOSIGNALS (2023)

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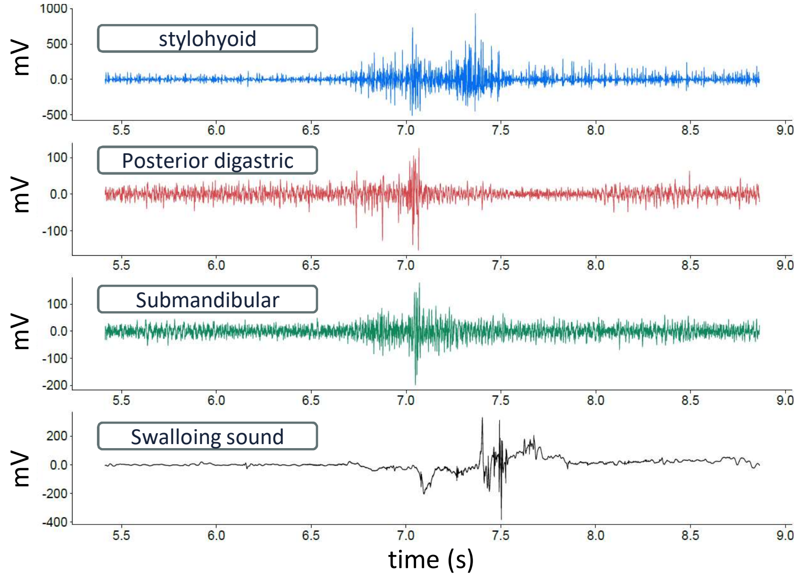
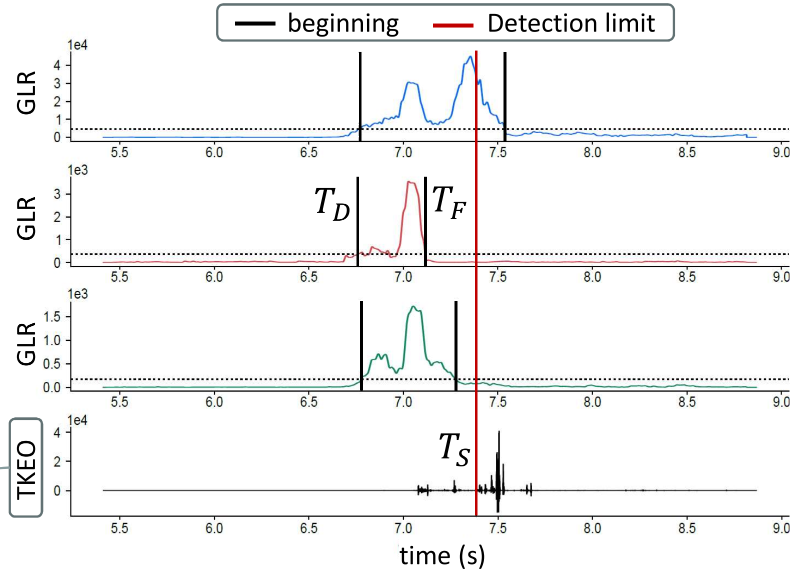


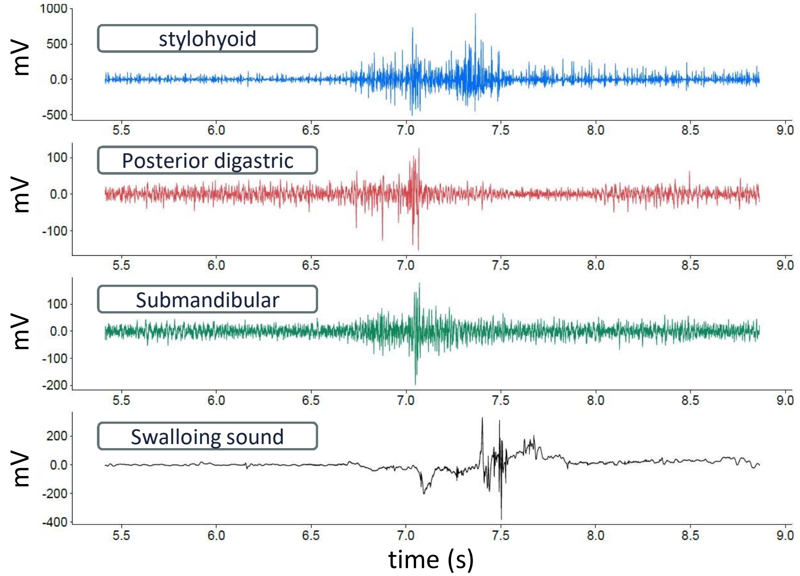


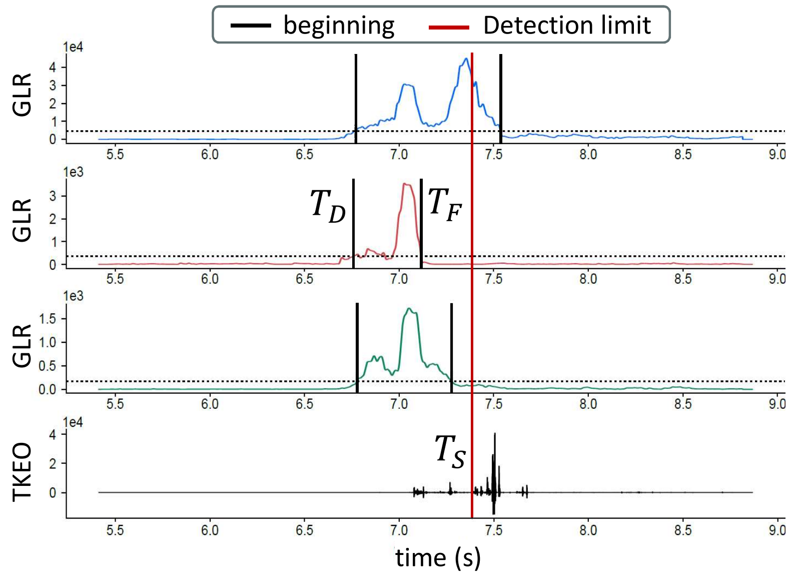
Teager-Kaiser Energy Operator (TKEO):

$$\psi[x(n)] = x(n)^2 - x(n-1)x(n+1)$$

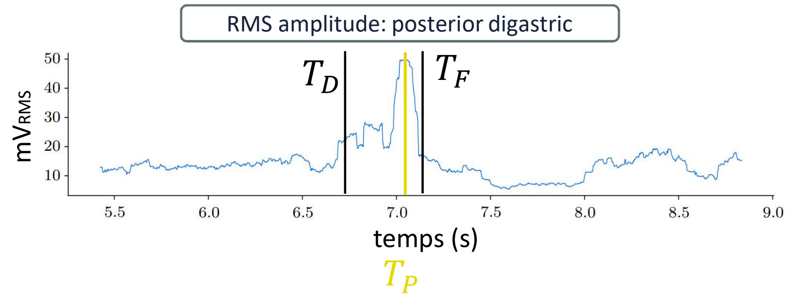
Proportional to the amplitude and to the frequency content of the signal

3. Statistical study– Data extraction





RMS value of the samples contained in a **$200ms$ sliding window**



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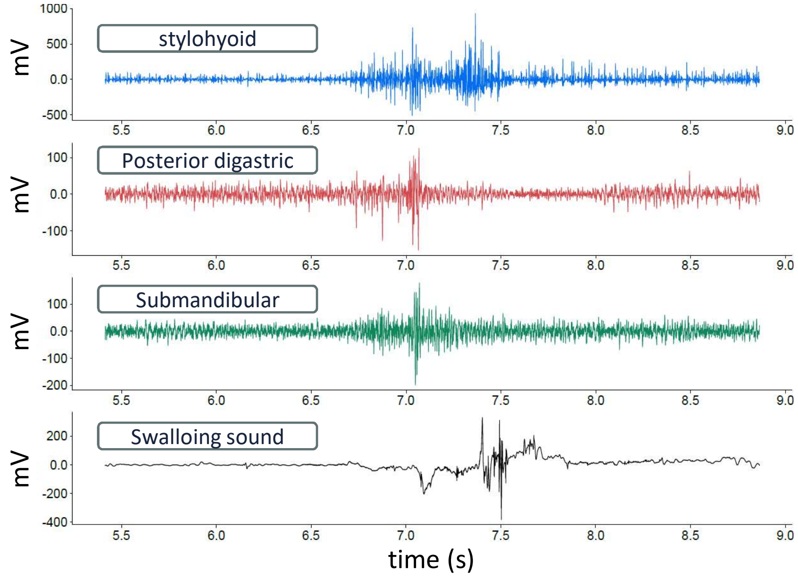
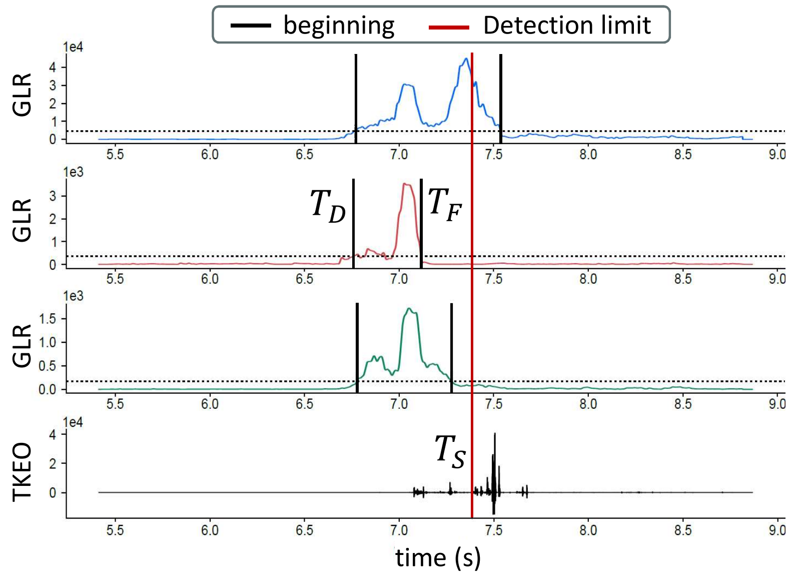
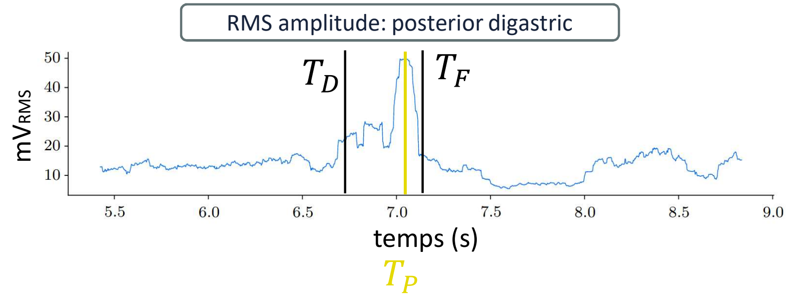


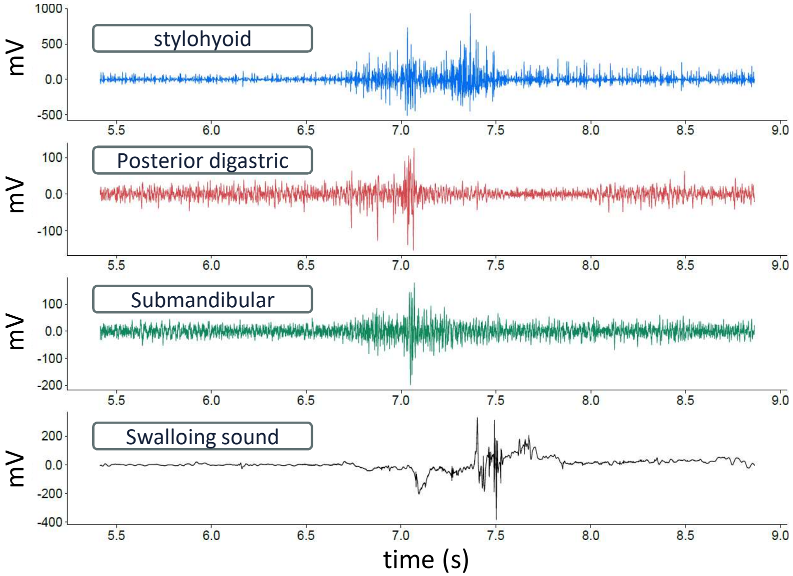


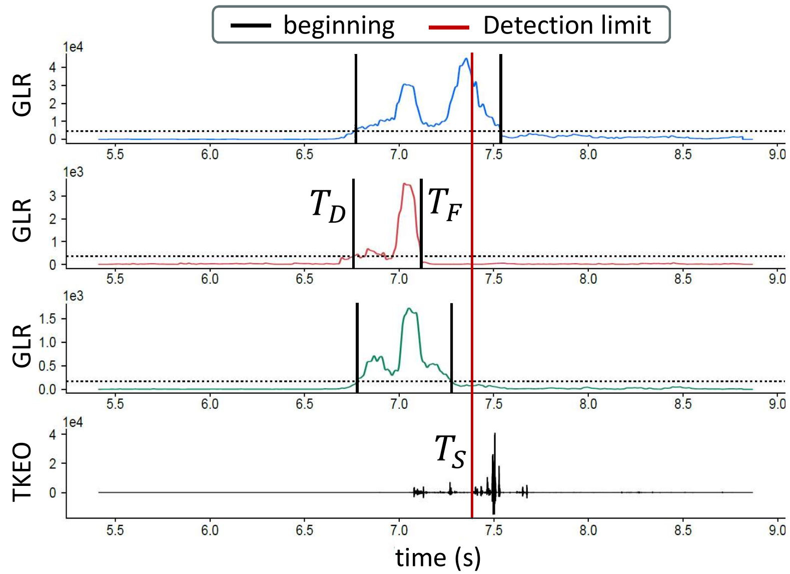
$$M_{md} = \frac{1}{N}\sum_{T_D}^{T_F} A_{RMS_{md}}(i)$$

$$P_{md} = \max(A_{RMS_{md}})$$



3. Statistical study– Data extraction





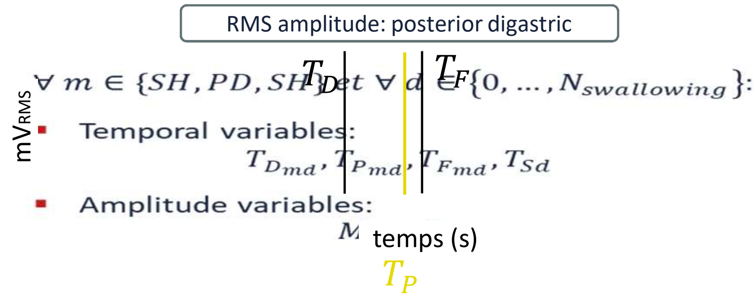
$\forall\, m \in \{SH, PD, SH\}\ et\ \forall\, d \in \{0, \dots, N_{swallowing}\}$:

- Temporal variables:

  $T_{D_{md}}, T_{P_{md}}, T_{F_{md}}, T_{Sd}$

- Amplitude variables:

  M_{md}, P_m



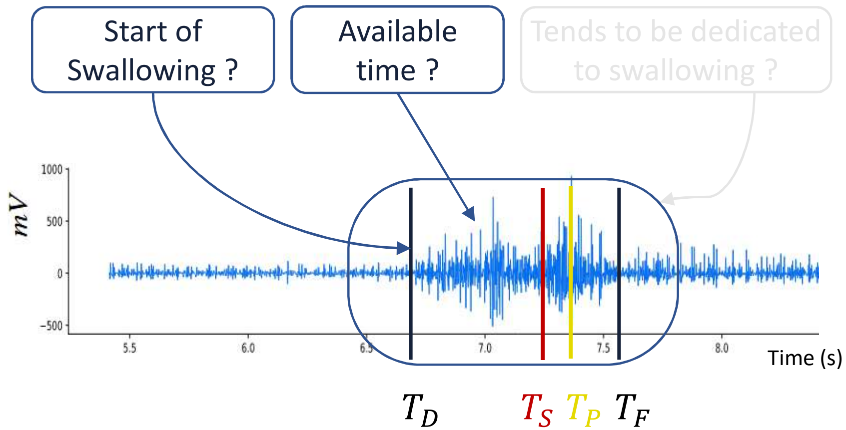
3. Statistical study– Timing analysis

Normalized temporal variables:

- $T_{DS_m} = T_{D_m} - T_S$
- $T_{PS_m} = T_{P_m} - T_S$
- $T_{FS_m} = T_{F_m} - T_S$

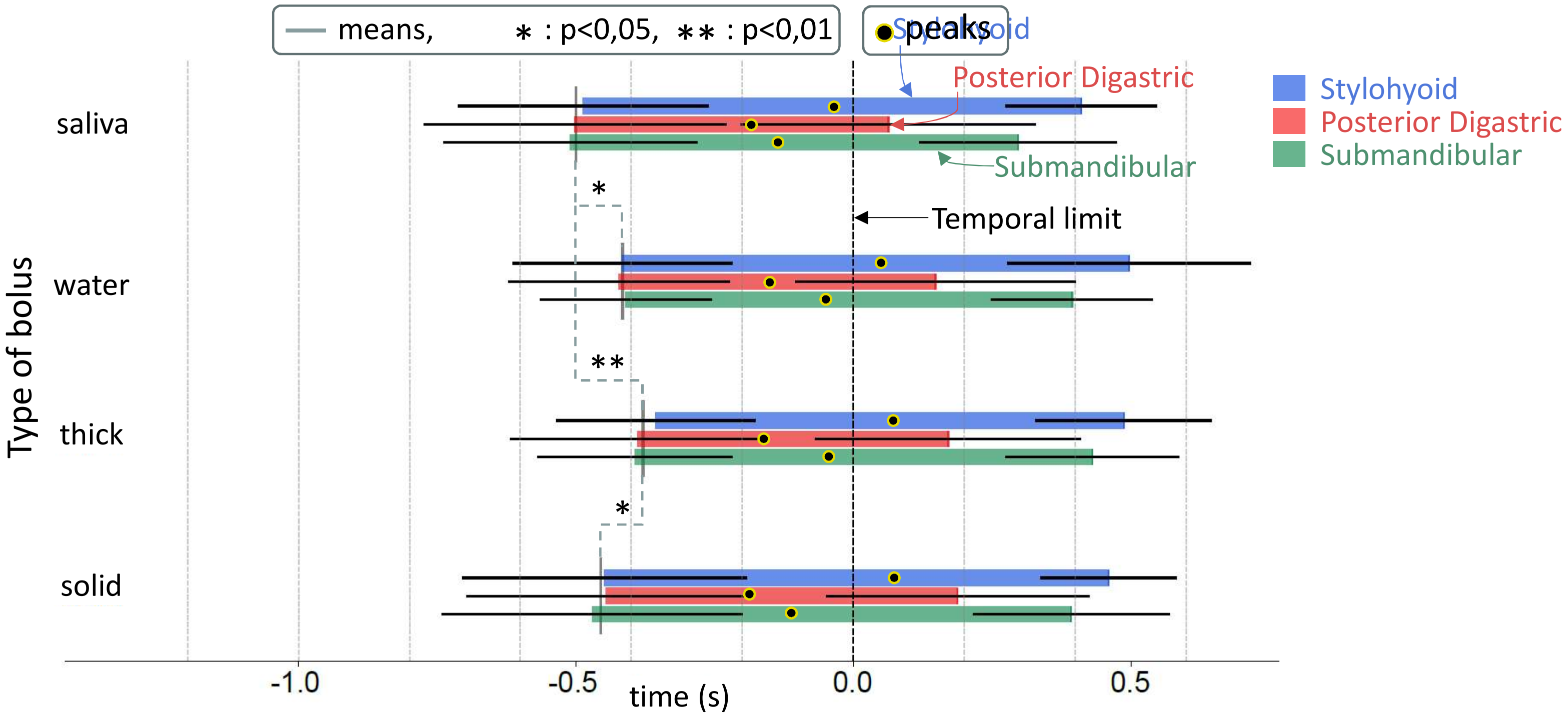
➢ **Repeated mesure ANOVA:**

  ➢ Effect of bolus type ?
  ➢ Effect of muscle type ?

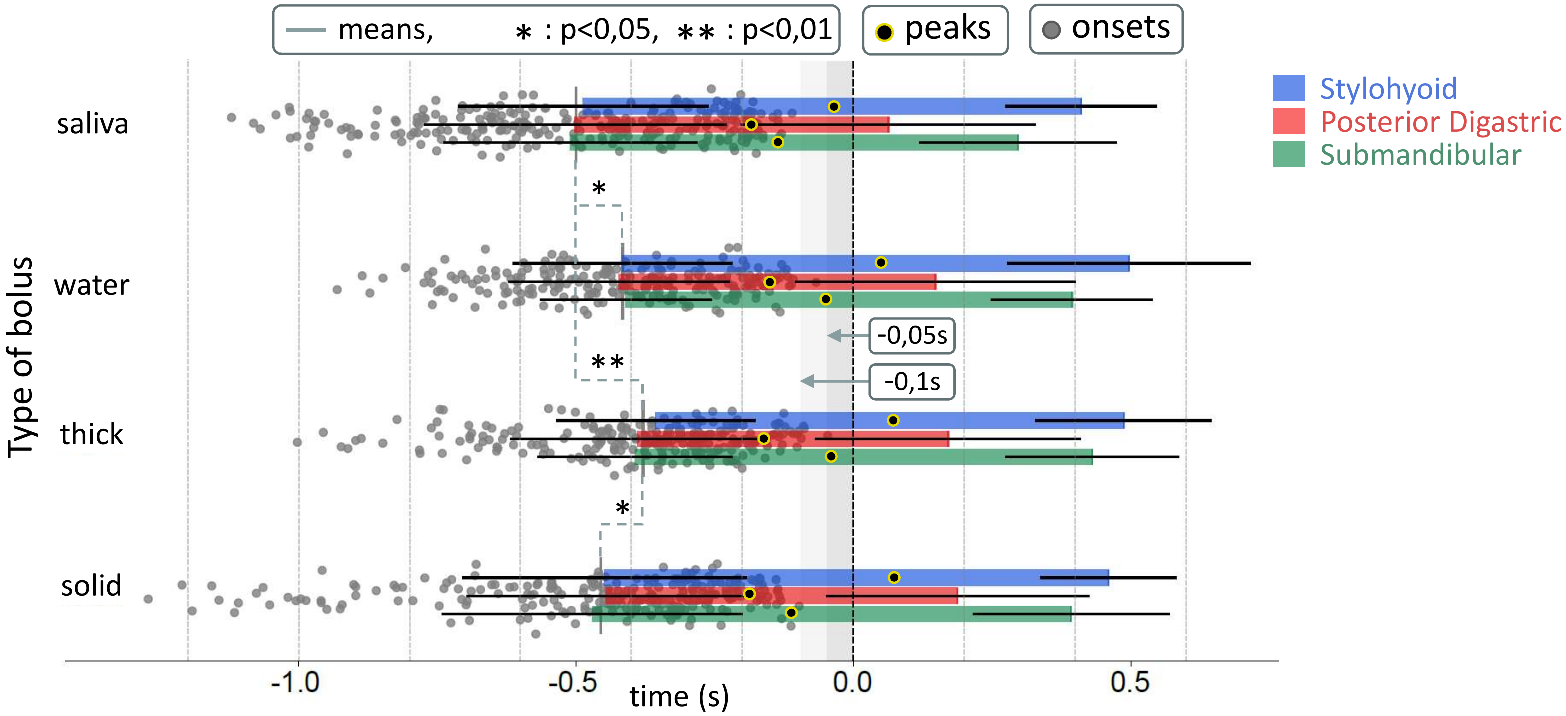


A. Mialland et al. Stylohyoid and posterior digastric timing evaluation. In: BSN (2023)

3. Statistical study– Timing analysis



3. Statistical study– Timing analysis

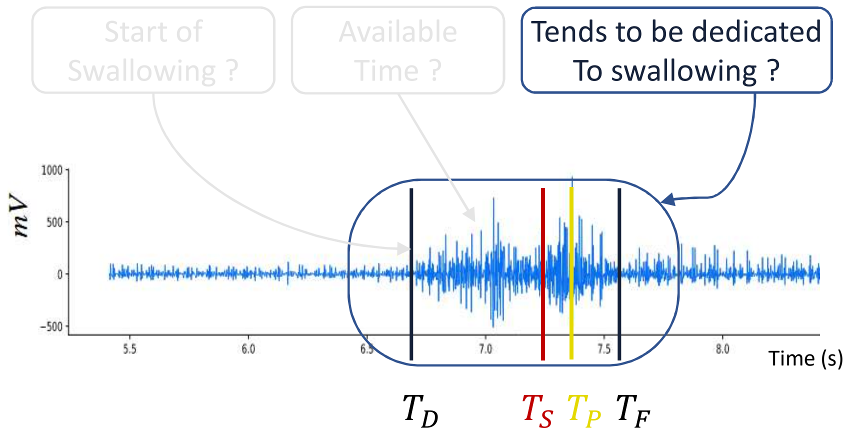


3. Statistical study– Recruitment pattern analysis

Amplutude Variables:

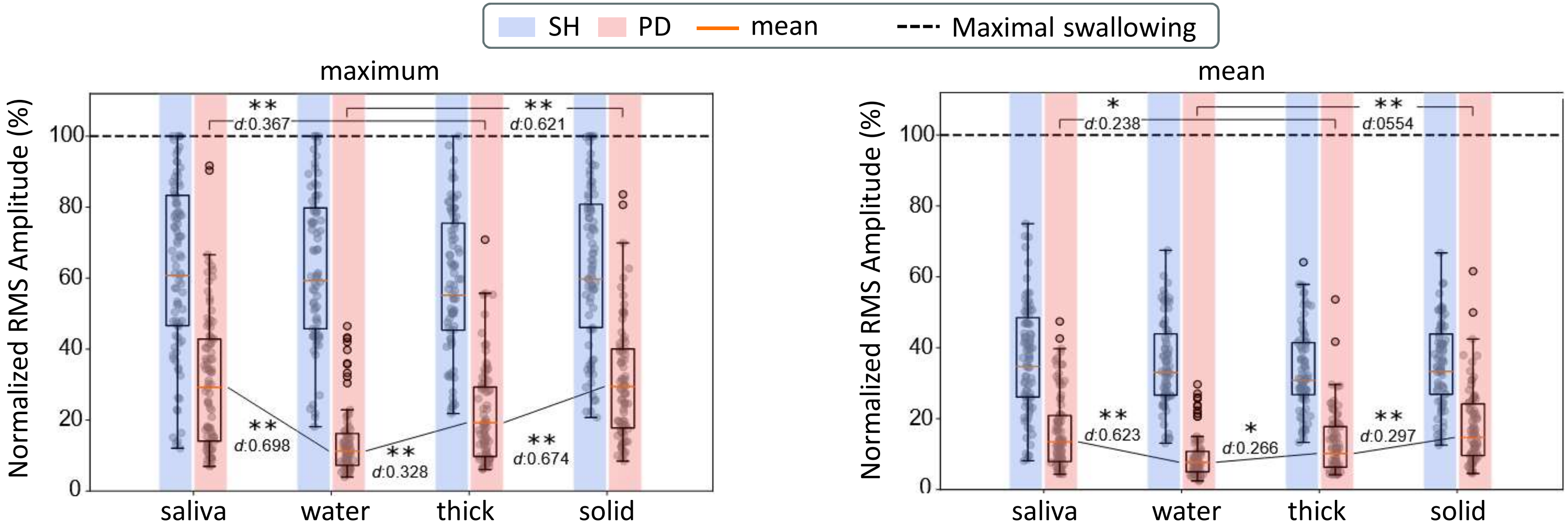
- M_m
- P_m

- **Linear Mixed Models**
  - Effect of muscle type ?
  - Effect of type of task ?



A. Mialland et al. Stylohyoid and posterior digastric recruitment pattern evaluation in swallowing and non-swallowing tasks. In: IRBM (2023). Submitted

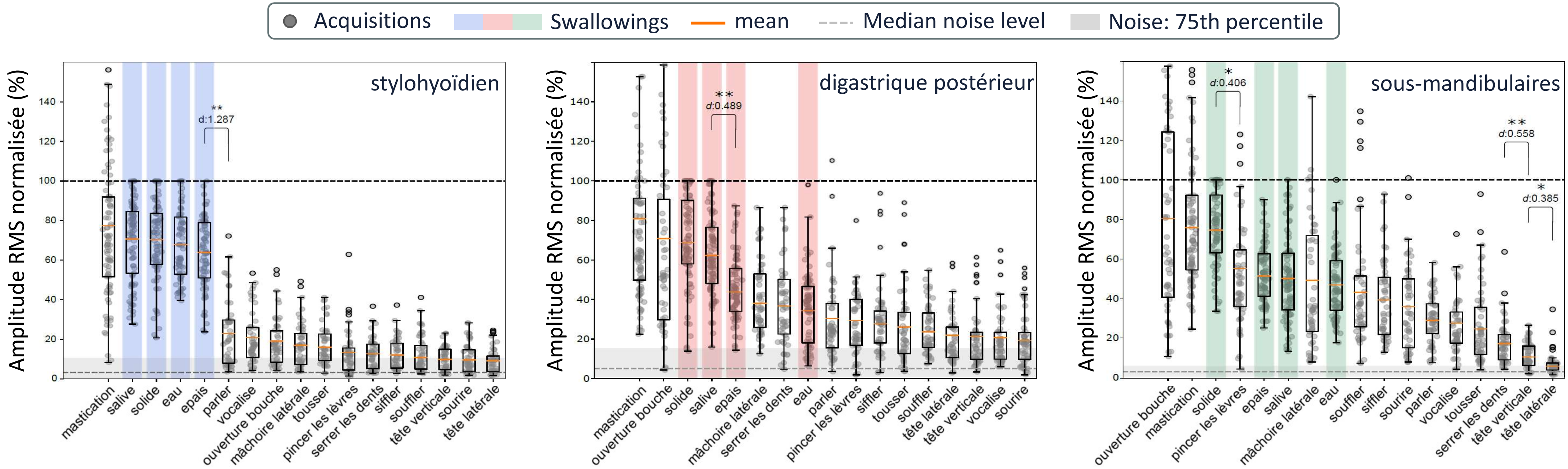
3. Statistical study– Recruitment pattern analysis



Normalization: for each subject, the RMS signals are divided by the **maximum value from all the swallowing** extracted from both the **stylohyoid and posterior digastric muscles**.

- The posterior digastric has the smallest amplitude.
- The stylohyoid has no significant variation depending on the type of bolus.

3. Statistical study– Recruitment pattern analysis



Normalisation: for each subject, the RMS signals are divided by the **maximum value from all the swallowing,** extracted from the **currently considered muscle.**

- Net predisposition for swallowing of the stylohyoid. Trend for the posterior digastric.
- No clear tendency for the submandibular muscles,

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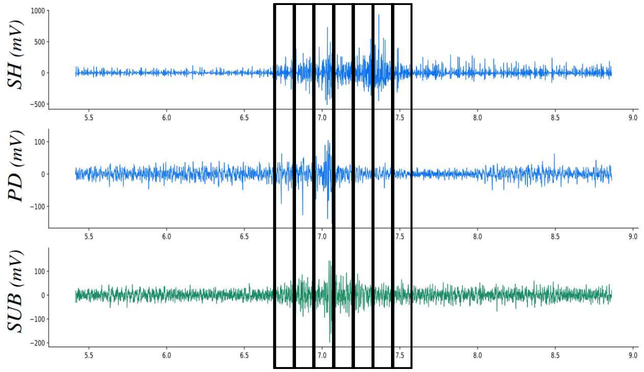
Presentation Plan

1. Context
2. Clinical Research Protocol (CRP)
3. Statistical Study
4. **Real time detection**
5. Implantable Active Artificiel larynx (IAAL)
6. Conclusion and perspectives

4. Real Time Detection – Literature Comparison

200ms window, step of 50ms



Feature	Equation	Feature	Equation
RMS	$\sqrt{\frac{1}{N}\sum_{n=1}^{N} x_n^2}$	SSI	$\sum_{n=1}^{N-1} x_n^2$
MAV	$\frac{1}{N}\sum_{n=1}^{N} \lvert x_n \rvert$	MYOP	$\frac{1}{N}\sum_{n=1}^{N} \phi(x_n)$
WL	$\sum_{n=1}^{N-1} \lvert x_{n+1} - x_n \rvert$	WAMP	$\frac{1}{N}\sum_{n=1}^{N-1} \phi(\lvert x_n - x_{n+1} \rvert)$
M2	$\sum_{n=1}^{N-1} (x_{n+1} - x_n)^2$	DVARV	$\frac{1}{N-2}\sum_{n=1}^{N-1} (x_{n+1} - x_n)^2$
ZC	$\sum_{n=1}^{N-1} [\phi(x_n \times x_{n+1}) \cap \lvert x_n - x_{n+1} \rvert \geqslant thr]$	DAMV	$\frac{1}{N-1}\sum_{n=1}^{N-1} \lvert x_{n+1} - x_n \rvert$
SSC	$\sum_{n=2}^{N} \phi[(x_n - x_{n-1}) \times (x_n - x_{n+1})]$	DASDV	$\sqrt{\frac{1}{N-1}\sum_{n=1}^{N-1} (x_{n+1} - x_n)^2}$

A. Phinyomark et al. 2017.

Boruta → **LDA / SVM** →

Reproduction of similar studies:

- Constantinescu et al. 2018:
  - Surface EMG: submandibular muscles.
  - Swallowing, lips purseing, head movements, tongue movements.

  ➢ swallowing, lips purseing, lateral head movements, head flexion/extension.

- McNulty et al. 2021:
  - Healthy subjects and total laryngectomies
  - Surface EMG: submandibular muscles, diaphragm, intercostal muscles.
  - Swallowing, coughing, speaking, sit up, sit down, touch head, turn torso, walking.

  1. Swallowing, coughing, speaking, saying "iii", head movements, head flexion/extension.

A. Mialland et al. Stylohyoid and posterior digastric potential evaluation for a real-time swallowing detection, with intramuscular EMG. In: IEEE trans MRB (2023). Submitted

4. Real Time Detection – Literature Comparison

Comparing with Constantinescu et al.
precision : 83.9%, recall : 92.3%, F1-score : 87.9%

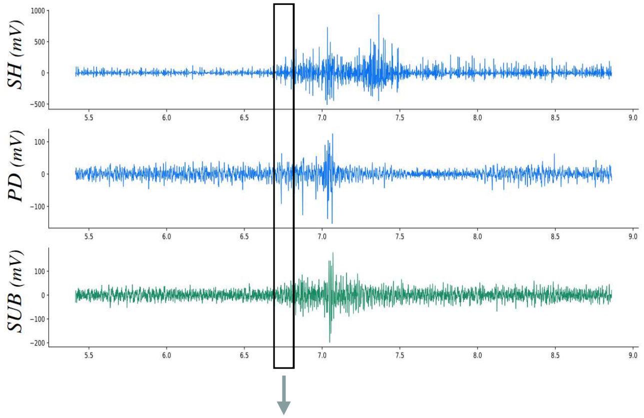
	LDA				SVM			
	Précision	Rappel	F1-score	D-Rappel	Précision	Rappel	F1-score	D-Rappel
SH-PD-SM	95.31 (0.41)	89.72 (1.25)	92.43 (0.62)	98.27 (0.54)	98.87 (0.37)	99.31 (0.29)	99.09 (0.15)	99.94 (0.16)
SH-SM	94.26 (0.66)	90.93 (1.13)	92.57 (0.68)	98.11 (0.87)	98.54 (0.45)	97.83 (0.64)	98.18 (0.38)	99.85 (0.23)
PD-SM	84.03 (1.32)	80.89 (1.43)	82.43 (1.09)	92.88 (1.12)	95.74 (0.61)	94.43 (0.86)	95.08 (0.52)	99.03 (0.63)
SH-PD	95.07 (0.63)	89.97 (0.95)	92.45 (0.59)	97.66 (0.69)	98.42 (0.43)	97.97 (0.47)	98.19 (0.31)	99.74 (0.35)
SH	93.87 (0.98)	92.17 (0.87)	93.01 (0.49)	97.91 (0.71)	96.93 (0.52)	95.58 (0.66)	96.25 (0.37)	99.24 (0.59)
PD	81.15 (2.12)	47.07 (2.59)	59.58 (2.28)	61.34 (2.61)	81.31 (1.61)	70.06 (2.41)	75.27 (1.88)	88.06 (2.28)
SM	83.06 (1.21)	80.65 (1.48)	81.83 (0.86)	91.66 (1.24)	88.44 (1.13)	83.54 (1.38)	85.92 (0.78)	94.93 (1.29)

Comparing with McNulty et al.
precision : 77%, recal : 57%, F1-score : 66%

	LDA				SVM			
	Précision	Rappel	F1-score	D-Rappel	Précision	Rappel	F1-score	D-Rappel
SH-PD-SM	92.51 (0.52)	81.58 (1.38)	86.71 (0.91)	94.59 (1.13)	97.79 (0.45)	98.02 (0.52)	97.91 (0.32)	99.78 (0.32)
SH-SM	92.56 (0.72)	83.01 (1.31)	87.53 (0.81)	94.74 (0.84)	95.86 (0.76)	94.19 (0.81)	95.02 (0.55)	99.26 (0.58)
PD-SM	86.67 (1.24)	74.76 (1.56)	80.28 (1.09)	89.98 (1.29)	93.42 (1.03)	90.99 (1.06)	92.19 (0.74)	98.37 (0.82)
SH-PD	90.82 (0.96)	82.38 (1.27)	86.39 (0.84)	94.91 (1.07)	96.01 (0.75)	94.64 (0.69)	95.32 (0.56)	99.32 (0.46)
SH	90.92 (1.01)	84.87 (1.16)	87.79 (0.81)	94.74 (1.09)	93.31 (0.96)	88.55 (1.13)	90.87 (0.81)	96.78 (0.98)
PD	75.03 (2.58)	36.54 (1.78)	49.15 (1.95)	50.79 (2.51)	75.65 (2.15)	58.88 (2.35)	66.22 (1.88)	78.95 (2.82)
SM	85.07 (1.04)	73.87 (1.48)	79.08 (1.02)	88.21 (1.42)	90.44 (0.97)	74.94 (1.64)	81.96 (1.08)	89.19 (1.54)

- The closest results to the literature.
- Substantial increase with the stylohyoid muscle alone.
- Potentiel synergestic effect between SH and PD muscles.

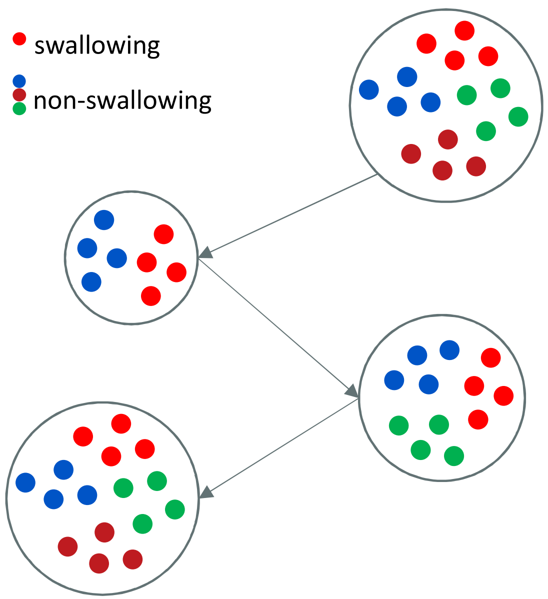
4. Real Time Detection – Literature Comparison



Feature	Equation	Feature	Equation
RMS	$\sqrt{\frac{1}{N}\sum_{n=1}^{N} x_n^2}$	SSI	$\sum_{n=1}^{N-1} x_n^2$
MAV	$\frac{1}{N}\sum_{n=1}^{N}\lvert x_n\rvert$	MYOP	$\frac{1}{N}\sum_{n=1}^{N}\phi(x_n)$
WL	$\sum_{n=1}^{N-1}\lvert x_{n+1}-x_n\rvert$	WAMP	$\frac{1}{N}\sum_{n=1}^{N-1}\phi(\lvert x_n - x_{n+1}\rvert)$
M2	$\sum_{n=1}^{N-1}(x_{n+1}-x_n)^2$	DVARV	$\frac{1}{N-2}\sum_{n=1}^{N-1}(x_{n+1}-x_n)^2$
ZC	$\sum_{n=1}^{N-1}[\phi(x_n \times x_{n+1}) \cap \lvert x_n - x_{n+1}\rvert \geqslant thr]$	DAMV	$\frac{1}{N-1}\sum_{n=1}^{N-1}\lvert x_{n+1}-x_n\rvert$
SSC	$\sum_{n=2}^{N}\phi[(x_n - x_{n-1})\times(x_n - x_{n+1})]$	DASDV	$\sqrt{\frac{1}{N-1}\sum_{n=1}^{N-1}(x_{n+1}-x_n)^2}$

Boruta → **LDA / SVM** →

Method:
Sequential forward selection



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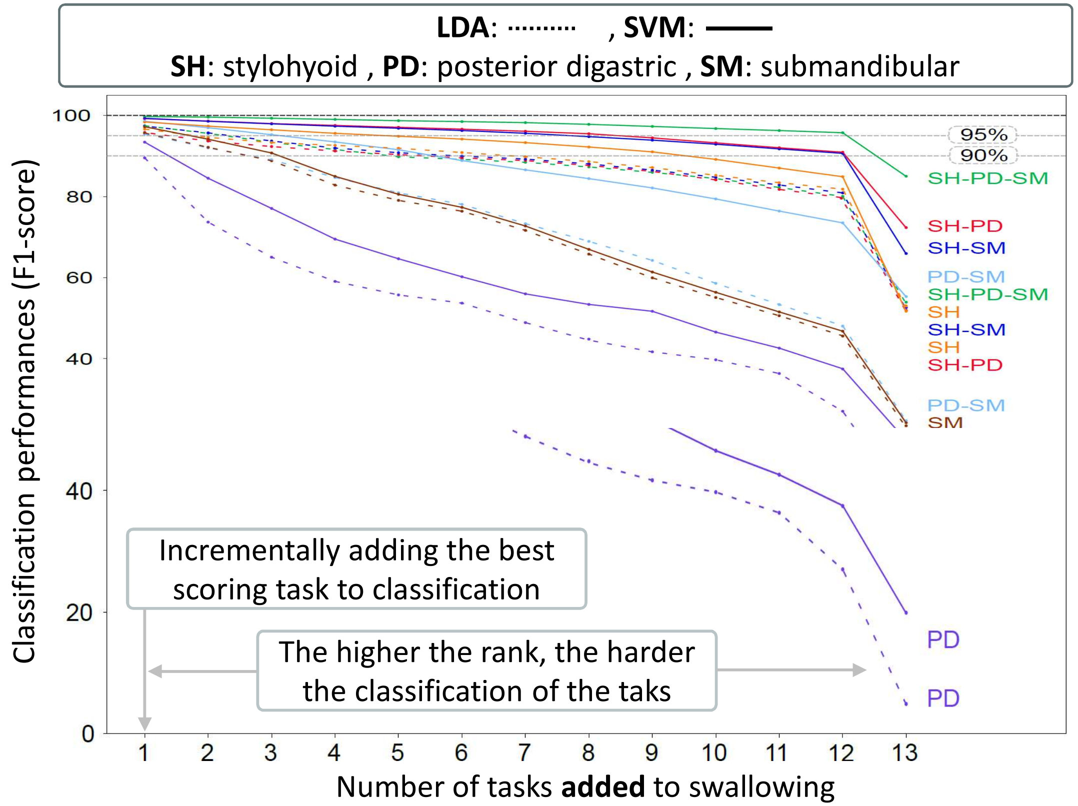
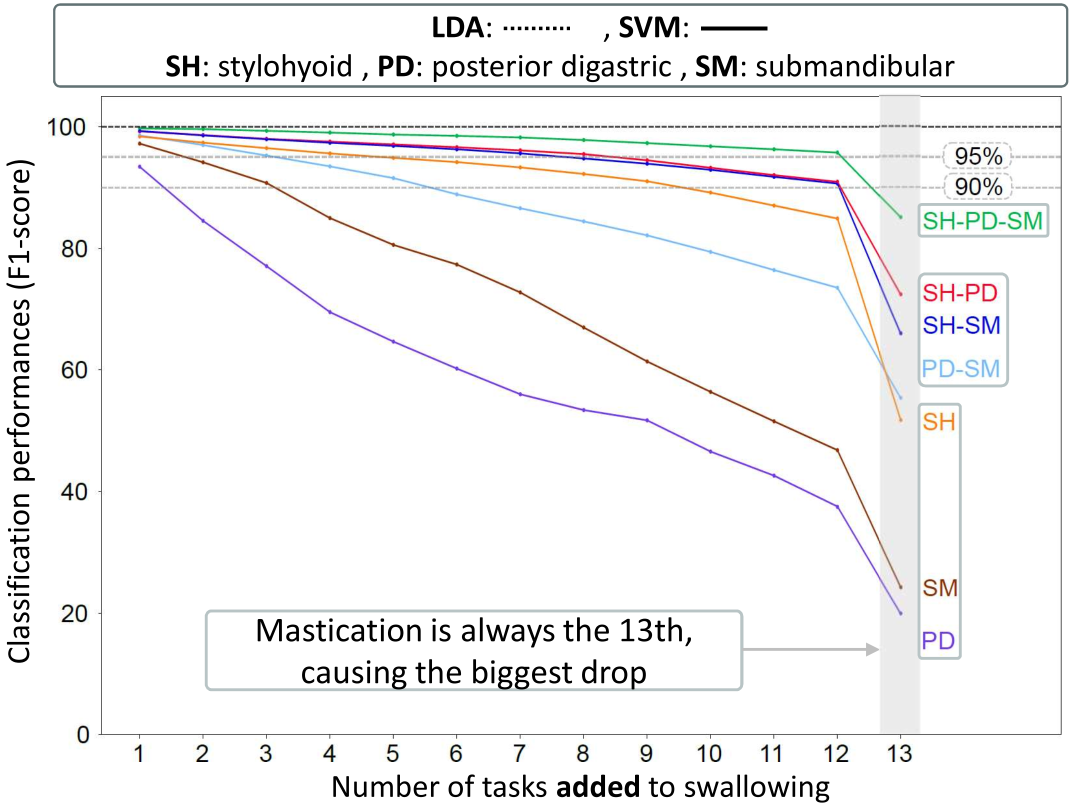
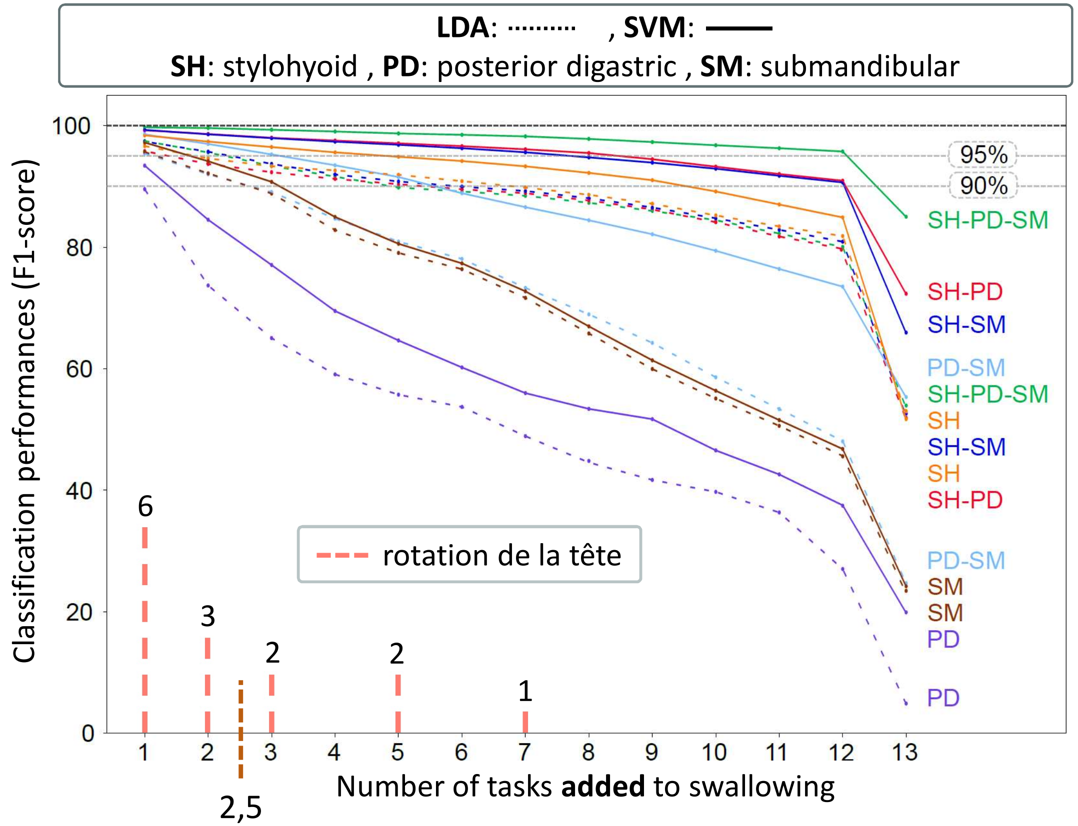
4. Real Time Detection – Literature Comparison



4. Real Time Detection – Literature Comparison

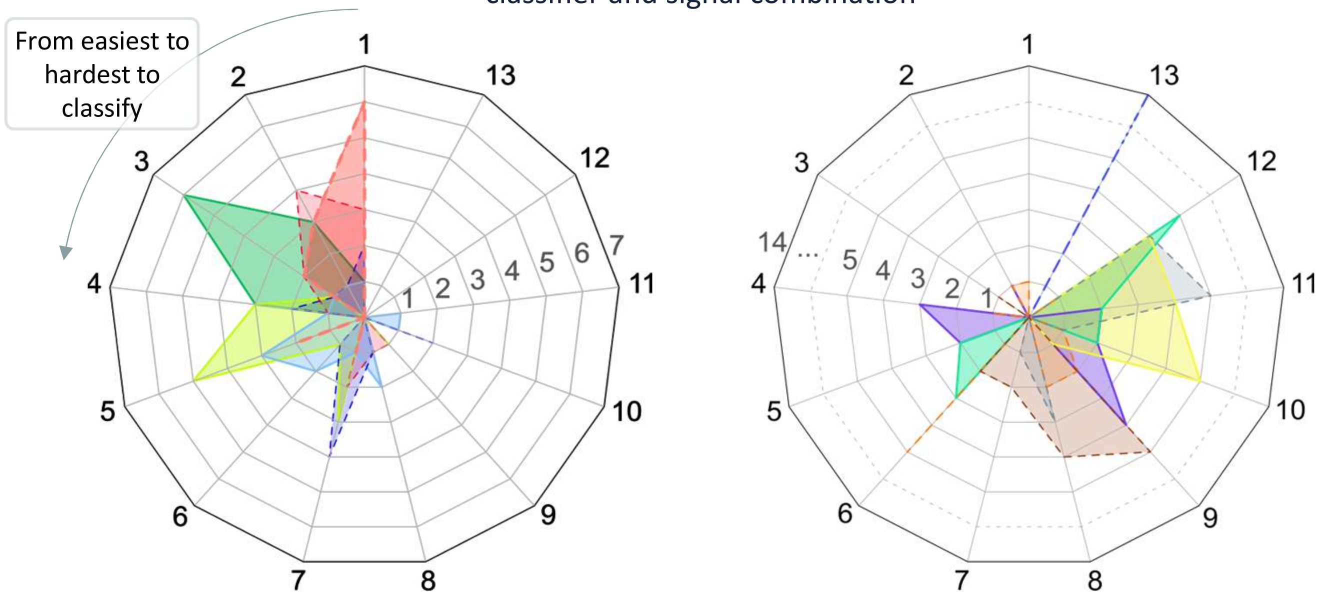


4. Real Time Detection – Literature Comparison



4. Real Time Detection – Literature Comparison

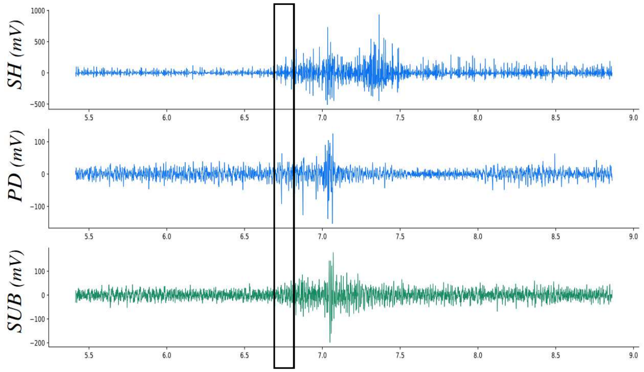
Inclusion rank of the task, for each classifier and signal combination



Rang moyen de chaque tâche:

- 2,5: lateral head movements
- 3,2: head flexion/extension
- 3,7: coughing
- 5,4: lips purseing
- 5,5: whistle
- 5,8: clench teeth
- 6,6: smilling
- 7,3: saying « iii »
- 7,6: blow
- 9,3: speaking
- 10,3: jaw opening
- 10,8: lateral jaw movements
- 13: mastication

4. Real Time Detection – Participants subgroups



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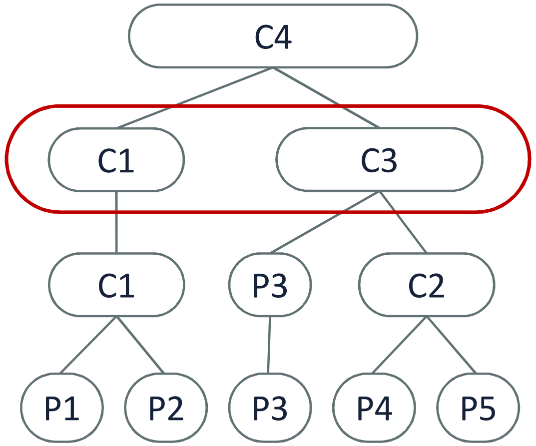
WL	$\sum_{n=1}^{N-1}\lvert x_{n+1}-x_n\rvert$	WAMP	$\frac{1}{N}\sum_{n=1}^{N-1}\phi(\lvert x_n - x_{n+1}\rvert)$
M2	$\sum_{n=1}^{N-1}(x_{n+1}-x_n)^2$	DVARV	$\frac{1}{N-2}\sum_{n=1}^{N-1}(x_{n+1}-x_n)^2$
ZC	$\sum_{n=1}^{N-1}[\phi(x_n \times x_{n+1}) \cap \lvert x_n - x_{n+1}\rvert \geqslant thr]$	DAMV	$\frac{1}{N-1}\sum_{n=1}^{N-1}\lvert x_{n+1}-x_n\rvert$
SSC	$\sum_{n=2}^{N}\phi[(x_n - x_{n-1})\times(x_n - x_{n+1})]$	DASDV	$\sqrt{\frac{1}{N-1}\sum_{n=1}^{N-1}(x_{n+1}-x_n)^2}$

Boruta → **LDA / SVM** →

Method:
Agglomerative hierarchical clustering



Mean Euclidean distance between swallowing.

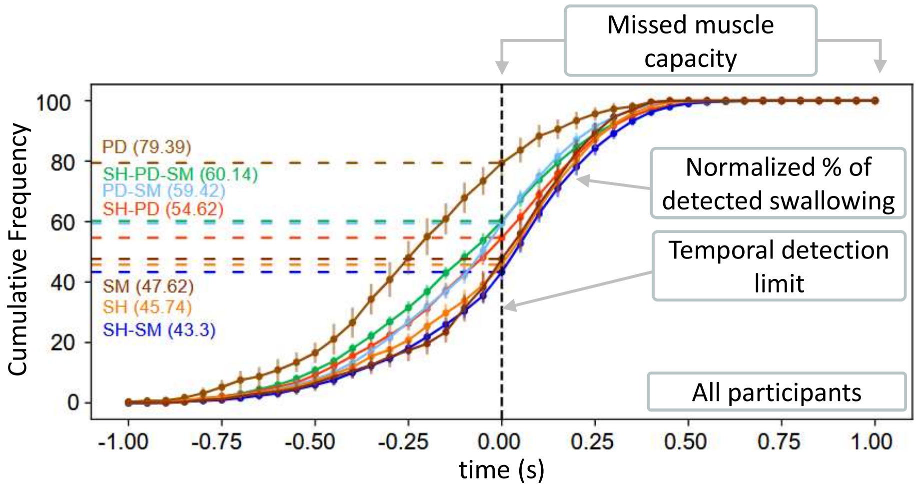
4. Real Time Detection – Participants subgroups

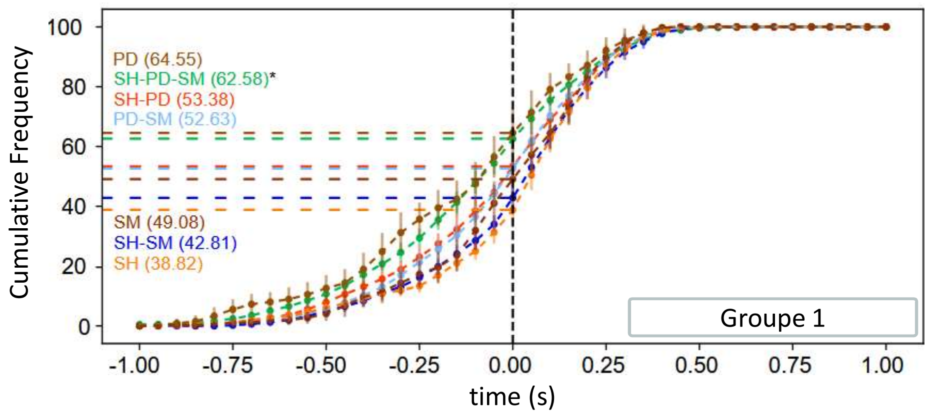
Effect of subgroups of participants

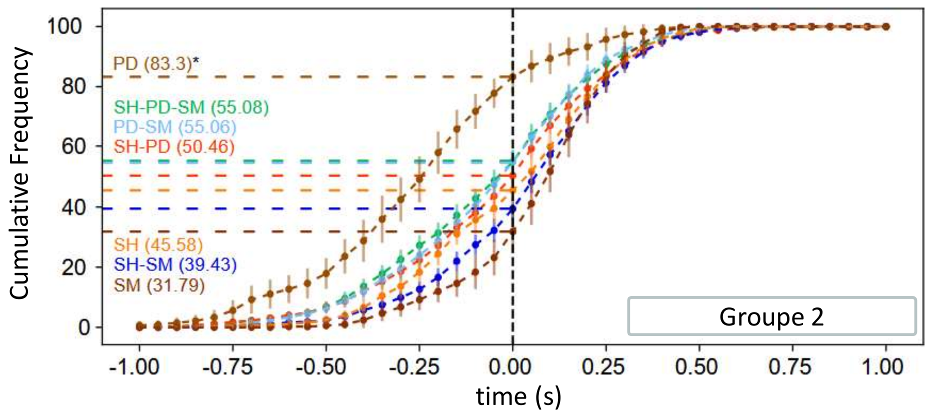
	Précision	Rappel	F1-score	D-Rappel
Tout les participants				
SH-PD-SM	90.36 (1.03)	80.27 (1.31)	84.98 (0.76)	96.31 (1.49)
SH-SM	82.51 (1.52)	54.77 (1.56)	65.84 (1.33)	84.83 (2.31)
PD-SM	80.79 (2.01)	41.98 (1.49)	55.25 (1.51)	70.65 (2.21)
SH-PD	76.72 (1.01)	68.39 (1.51)	72.28 (1.44)	90.11 (1.44)
SH	73.86 (1.86)	39.71 (1.74)	51.65 (1.68)	68.46 (2.58)
PD	61.51 (6.01)	11.81 (0.93)	19.81 (1.92)	19.95 (1.81)
SM	47.71 (3.11)	15.91 (1.29)	23.85 (1.74)	33.51 (1.57)
Groupe 1				
SH-PD-SM	92.65 (1.29)	86.47 (1.67)	89.45 (1.13)*	97.71 (1.33)
SH-SM	86.81 (1.64)	63.82 (2.41)	73.56 (1.83)*	90.76 (2.26)
PD-SM	86.17 (2.23)	55.62 (2.53)	67.59 (2.11)*	81.93 (3.04)
SH-PD	86.37 (2.01)	69.58 (2.37)	77.07 (1.74)*	90.56 (2.33)
SH	77.22 (2.37)	49.23 (2.43)	60.13 (2.15)*	77.17 (3.69)
PD	75.45 (9.94)	15.01 (1.21)	25.04 (2.91)*	26.77 (1.76)
SM	53.39 (4.07)	24.84 (2.15)	33.87 (2.57)*	36.38 (3.82)
Groupe 2				
SH-PD-SM	91.77 (1.45)	85.06 (1.58)	89.29 (1.11)*	96.81 (1.42)
SH-SM	83.35 (2.28)	62.61 (2.06)	71.64 (1.74)*	89.56 (2.65)
PD-SM	81.55 (2.44)	46.78 (2.31)	59.45 (2.05)*	71.46 (3.21)
SH-PD	80.67 (1.66)	73.91 (1.86)	77.14 (1.52)*	93.22 (2.11)
SH	72.52 (2.91)	34.98 (2.34)	47.19 (2.34)	58.06 (3.34)
PD	75.92 (8.98)	10.96 (1.71)	19.15 (3.19)	20.05 (2.81)
SM	47.52 (3.52)	21.94 (1.13)	29.98 (2.01)*	36.25 (1.05)

Greatest increase from the group containing all the participants

4. Real Time Detection – Participants subgroups







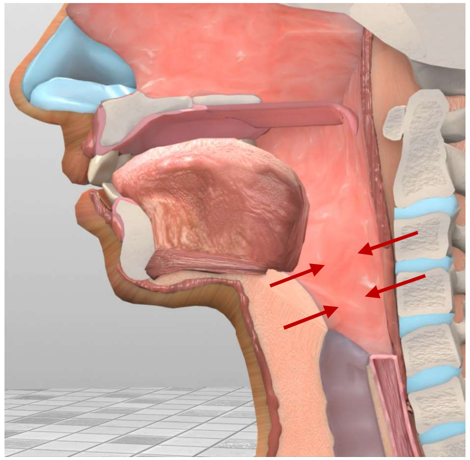
Presentation Plan

1. Context
2. Clinical Research Protocol (CRP)
3. Statistical Study
4. Real time detection
5. **Implantable Active Artificiel larynx (IAAL)**
6. Conclusion and perspectives

5. IAAL - Feasibility

Airway reconstruction

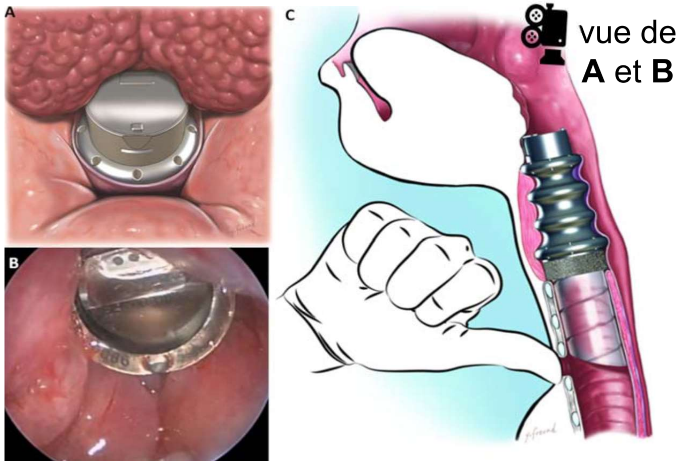
Active protective mechanism



[H. C. Grillo 2002] synthetic prosthesis are not effective.

5. IAAL - Feasibility

Airway reconstruction



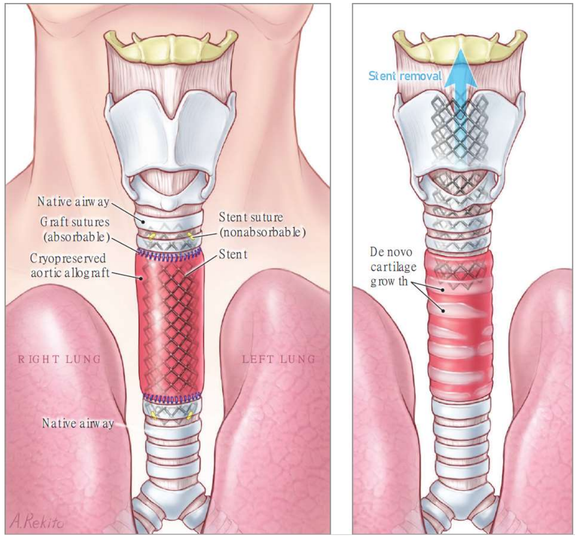
Debry C. et al. 2014.

5. IAAL - Feasibility

Airway reconstruction

Functional tracheal prosthesis [H. Etienne et al. 2018, H. C. Grillo 2002]:

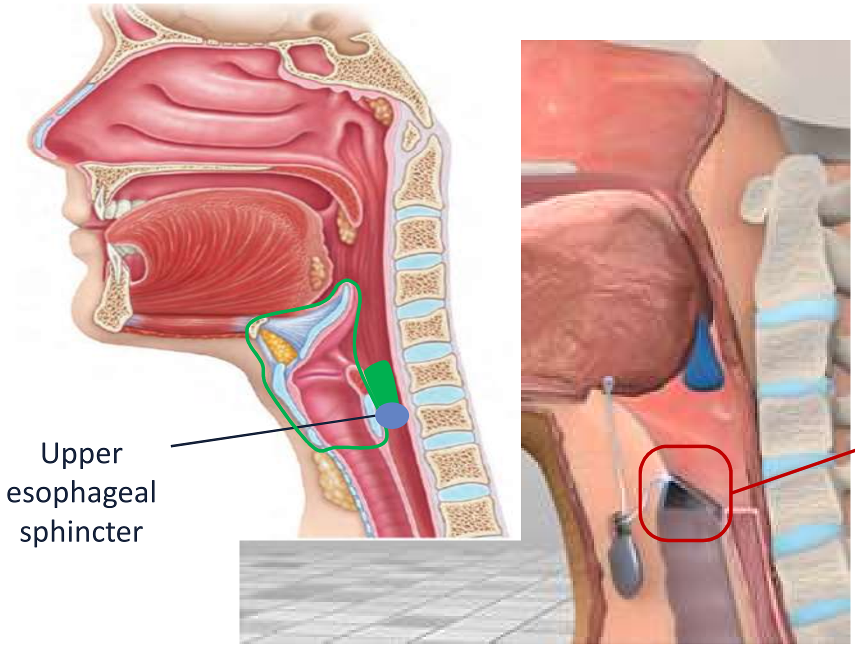
- Longitudinal flexibility.
- Rigidity.
- Impermeability: respiratory epithelium.
- Non-immunogenicity.
- reliability et reproducibility of the method.
- Biocompatibility of the materials.



E. Martinod et al. 2018

5. IAAL - Feasibility

Active protective mechanism

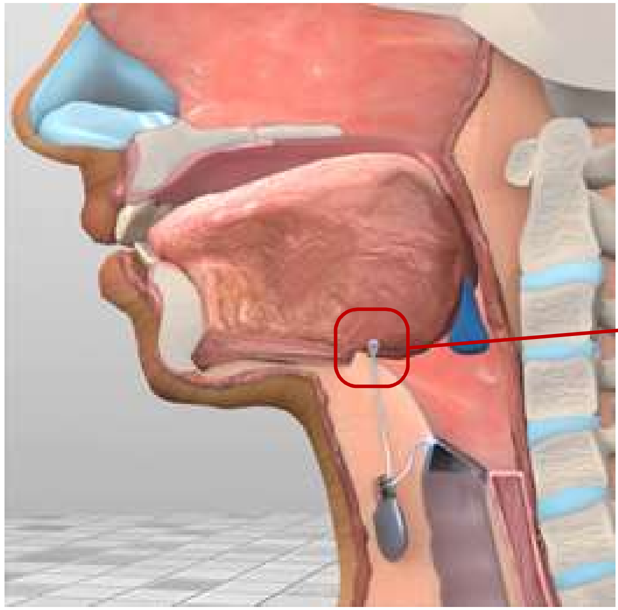


Functional protective mechanism:

- Increased height of the trachea
- Diversion of the bolus
- Allow surgical intervention
- Compatibility with radiotherapy
- Allow expectoration of secretions
- Prohibit any permanent closure
- Closing speed
- Small size

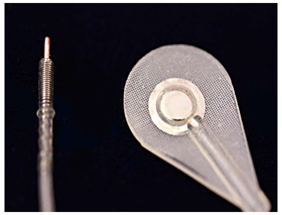
5. IAAL - Feasibility

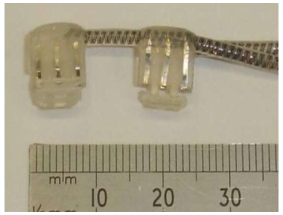
Active protective mechanism



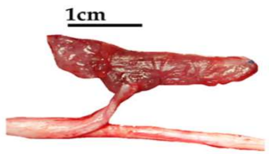
Implantable measurement:

- K. A. Yildiz et al. 2020 (survey)





- Vue et al. 2020, K. L. Burke et al. 2022:



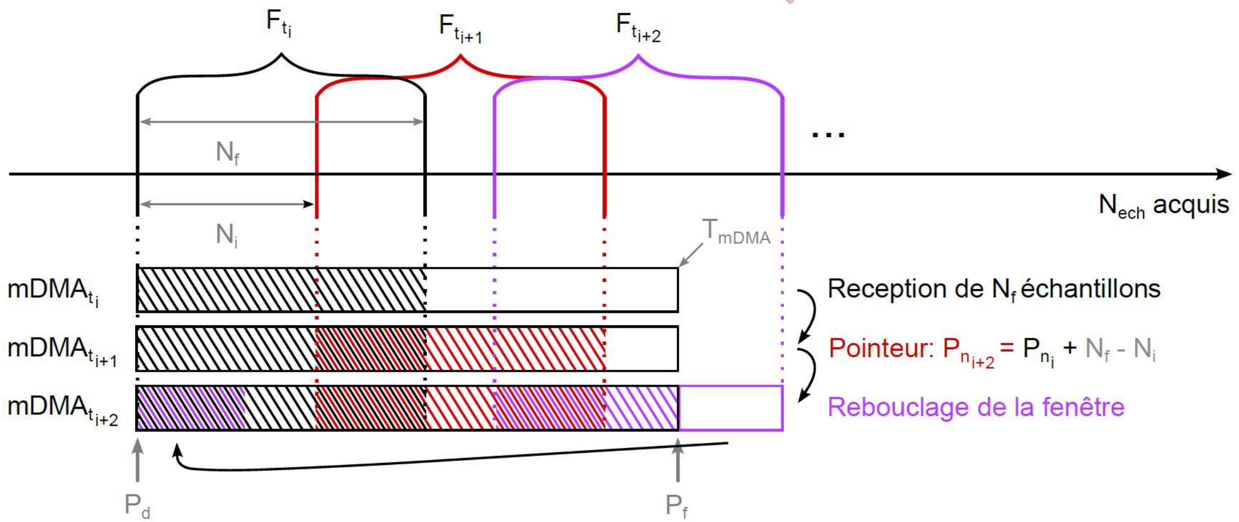
5. IAAL – Laboratory Prototype

PC → UART → DMA → CPU → Power Circuit → Protective mechanism

- Serial communication.
- Real-time.

5. IAAL – Laboratory Prototype

PC → UART → DMA → CPU → Power Circuit → Protective mechanism



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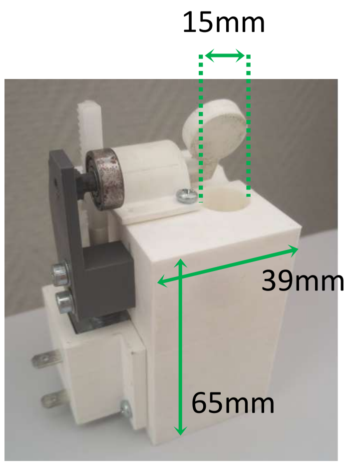

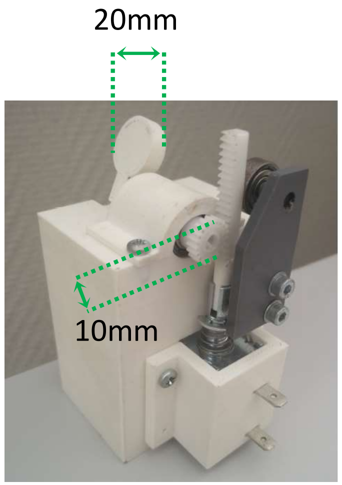

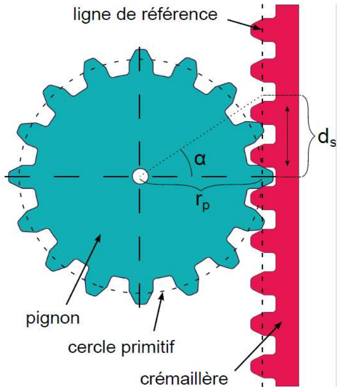

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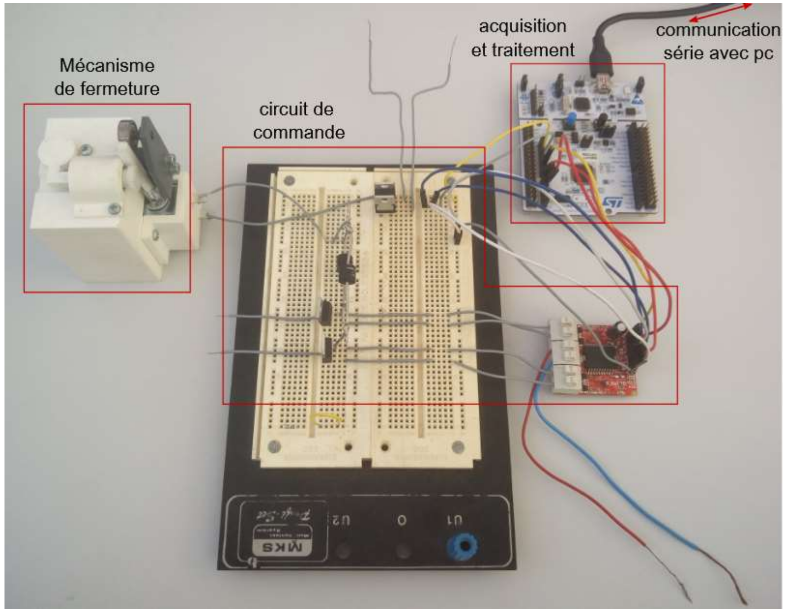


Microcontrollers tested

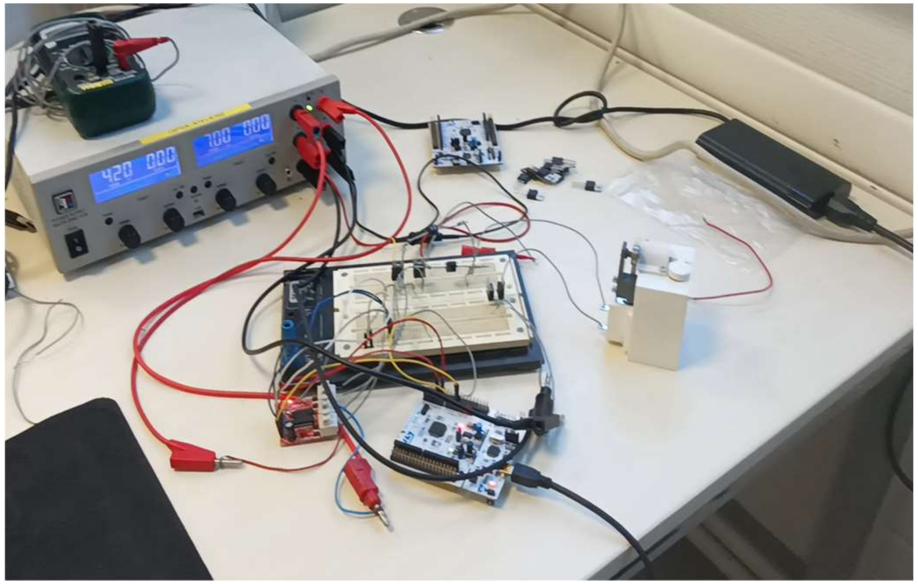
	CPU	Fréquence CPU max (MHz)	Mémoire Flash (Kbytes)	Consommation (μA/MHz)	UART	DMA	FPU	DSP
NUCLEO-L010RB	Cortex M0	32	128	93	✓	✓	✗	✗
NUCLEO-F446RE	Cortex M4	180	512	100	✓	✓	✓	✓
NUCLEO-U575ZI	Cortex M33	160	2000	19.5	✓	✓	✓	✓

✓ : module présent, ✗ : module non-présent.

Evaluated Configurations:

- Classifiers: LDA, SVM, ANN
- Window size: 200 samples, 400 samples
- Window step: 50 ms
- Signal combinations: SH-PD, SH-PD-SM

5. IAAL – Laboratory Prototype



Results per configuration

microcontrôleur	classifieur	taille de la fenêtre	signaux	temps (ms)	consommation (mA)	durée (ms)
L010RB	LDA	400	SH-PD	72.78	5.15	100
			SH-PD-SM	108.85	7.15	100
		200	SH-PD	38.18	5.44	50
			SH-PD-SM	55.26	3.93	100
	ANN	–	–	–	–	–
	SVM	–	–	–	–	–
F446RE ■	LDA	400	SH-PD	1.41	8.13	50
			SH-PD-SM	1.92	8.37	50
		200	SH-PD	0.76	7.91	50
			SH-PD-SM	1.13	8.03	50
	ANN	400	SH-PD-SM	2.31	24	50
	SVM	–	–	–	–	–
U575ZI ■	LDA	400	SH-PD-SM	2.69	1.93	50
	ANN	400	SH-PD-SM	3.27	1.95	50
	SVM	400	SH-PD-SM	135	3.5	50

■ classifieurs non implémentés. ■ possède un module FPU et DSP.

Speed camera (1000 fps):

- Swallowing detection turns a LED on.
- $T_a = T_f - T_{LED}$

➢ $\boldsymbol{T_a = 22ms}$

Total time worst case - 400 samples, SH-PD-SM, ANN:

T_T = 22 + 3,27 = **25,27ms**

Presentation Plan

1. Context
2. Clinical Research Protocol (CRP)
3. Statistical Study
4. Real time detection
5. Implantable Active Artificiel larynx (IAAL)
6. **Conclusion and perspectives**

6. Conclusion and perspectives

- Stylohyoid (SH) and posterior digastric (PD) muscles measurement:
  - Innovative measurement method with intramuscular electromyography.
- Timings:
  - SH and PD muscles activates at the beginning of swallowing.
  - Earliness of PD muscle activity.
- Amplitude:
  - Predisposition of SH muscle to swallowing.
  - Stability of SH muscle.

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6. Conclusion and perspectives

- Real time detection:
  - Significant improvement in detection **Accuracy** with SH muscle alone.
  - Significant improvement in **Earliness** of detection with PD muscle alone.
  - Potential synergistic effect between SH and PD muscles.
- Implantable active artificial larynx:
  - Measurement and airway reconstruction methods are promising.
  - Laboratory prototype actuated in **25,27ms.**

6. Conclusion and perspectives

- Research of additional information on neck activity.
- Development of a active protective mechanism of the trachea.
- Evaluated the hypotheses of total laryngectomees.
- Elaboration of a algorithm with strong temporal constraints.
- Evaluation of corner cases: vomiting, sleep, evolution through time, …

Publications

- International peer-reviewed journals:
  - Survey
    - **A. Mialland**, I. Atallah et A. Bonvilain. *"Toward a robust swallowing detection for an implantable active artificial larynx : a survey".* In : Medical & Biological Engineering & Computing (2023), p. 1299-1327. doi : 10.1007/s11517-023-02772-8.
  - Articles
    - **A. Mialland**, I. Atallah et A. Bonvilain. *"Stylohyoid and posterior digastric potential evaluation for a real-time swallowing detection, with intramuscular EMG".* In: IEEE Transactions on Medical Robotics and Bionics (2023). Doi: 10.1109/TMRB.2023.3336960.
    - **A. Mialland**, I. Atallah et A. Bonvilain. "Stylohyoid and posterior digastric recruitment pattern evaluation in swallowing and non-swallowing tasks". In : Innovation and Research in BioMedical engineering (2023). Doi: 10.1016/j.irbm.2024.100823.
    - **A. Mialland** et al. *"Submental MechanoMyoGraphy (MMG) to Characterize the Swallowing Signature".* In : Innovation and Research in BioMedical engineering (2021). doi : 10.1016/j.irbm.2021.05.001.
- International peer-reviewed conference:
    - **A. Mialland**, I. Atallah et A. Bonvilain. *"Stylohyoid and posterior digastric measurement with intramuscular EMG, submental EMG and swallowing sound."* In :Biomedical Engineering Systems and Technologies (2023). Lisbonne. doi : 10.5220/0011628100003414.
    - **A. Mialland**, I. Atallah et A. Bonvilain. *"Stylohyoid and posterior digastric timing evaluation".* In : Body Sensor Networks (2023). Boston. Doi: 10.1109/BSN58485.2023.10331308.
- Internationale conference:
    - **A. Mialland**, I. Atallah et A. Bonvilain. *The inherent complexity of an implantable active artificial larynx*. Recherche en Imagerie et Technologies pour la Santé. Brest. 2022.
- Nationale conference:
    - **A. Mialland**, I. Atallah et A. Bonvilain. *Vers la faisabilité d'un larynx artificiel implantable actif.* Société Française de Phoniatrie et Laryngologie. Tours. 2021.
- Clinical research Protocol:
    - **A. Mialland**, I. Atallah et A. Bonvilain. *Detection of Early Swallowing Time by Electromyogram and Sound Recording in Healthy Volunteers.* https://clinicaltrials.gov/. Protocol ID : 38RC22.0096.2022.