Swallow Detection Algorithm Based on Bioimpedance and EMG Measurements

Holger Nahrstaedt[1], Corinna Schultheiss,[2], Thomas Schauer[1], Rainer O. Seidl[2]

[1]Control Systems Group (Fachgebiet Regelungssysteme)
Technische Universität Berlin, Berlin

[2]Department of Otolaryngology
ukb - Unfallkrankenhaus Berlin

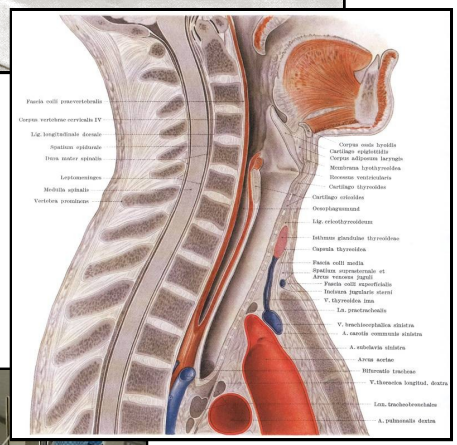
Swallowing and Dysphagia

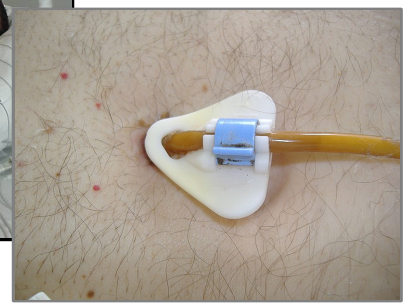
Swallowing

- vital process
- highly complex control
- conscious and unconscious (reflex)
- synchronised with breathing

Dysphagia

- aspiration (to choke on sth.) $\rightsquigarrow$ pneumonia
- malnutrition and dehydration
- cause: stroke - 25% in chronic stage
- treatment for severe swallowing disorders
  - feeding tube
  - tracheal cannula
- reduced quality of life
- high financial costs for health care system

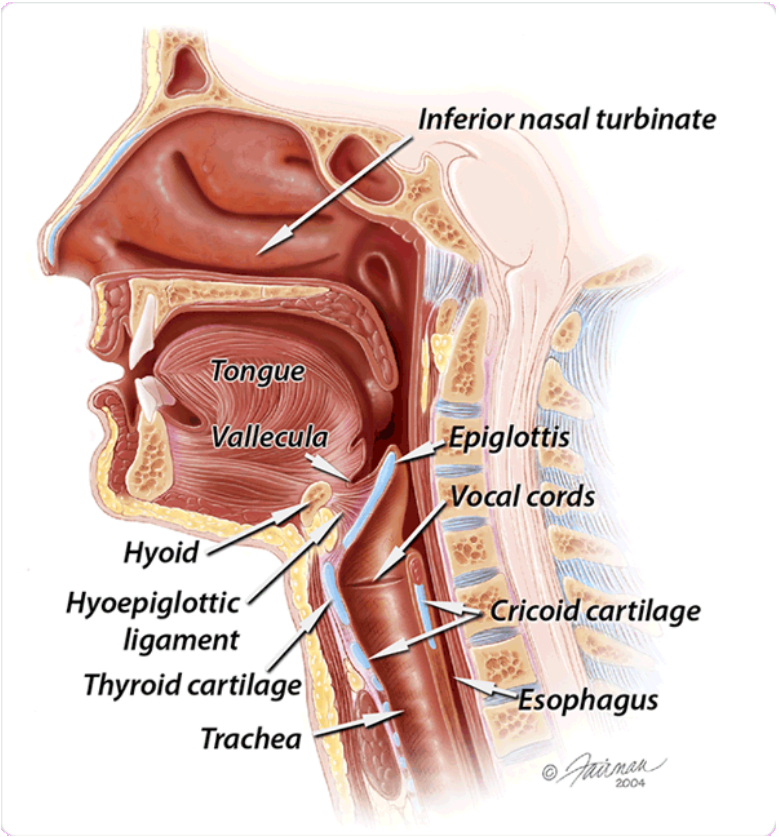




Protection of the Upper Airway

Protective measures

- elevation of the larynx
- flipping of the epiglottis $\rightsquigarrow$ closing the entrance to the trachea



State of the Art in Swallowing Diagnosis

Videofluoroscopy

Endoscopy

- complex, expensive and bulky devices
- exposure to radiation during videoflouroscopy
- only applicable in clinical environments
- not suitable for controlling swallowing implants in daily life

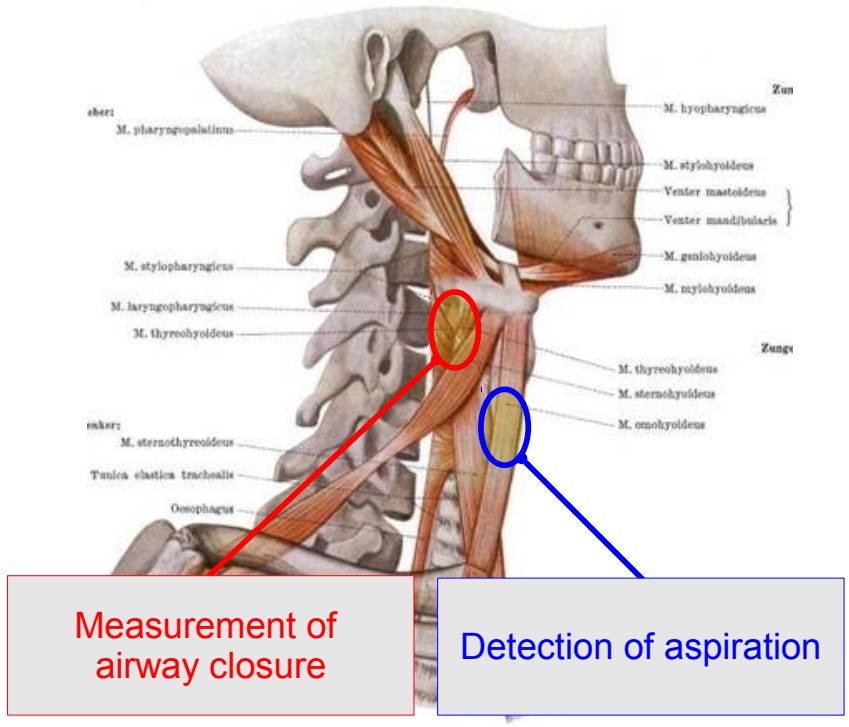
Bioimpedance-Monitoring to Assess Swallowing

Bioimpedance (BI)

- describes the passive electrical properties of biological materials
- ratio between sinusoidal voltage and sinusoidal current

BI recordings at the neck

- is related to swallowing and aspiration
- external measurement system certified for clinical use
- transcutaneous measurement for biofeedback applications, diagnosis ...



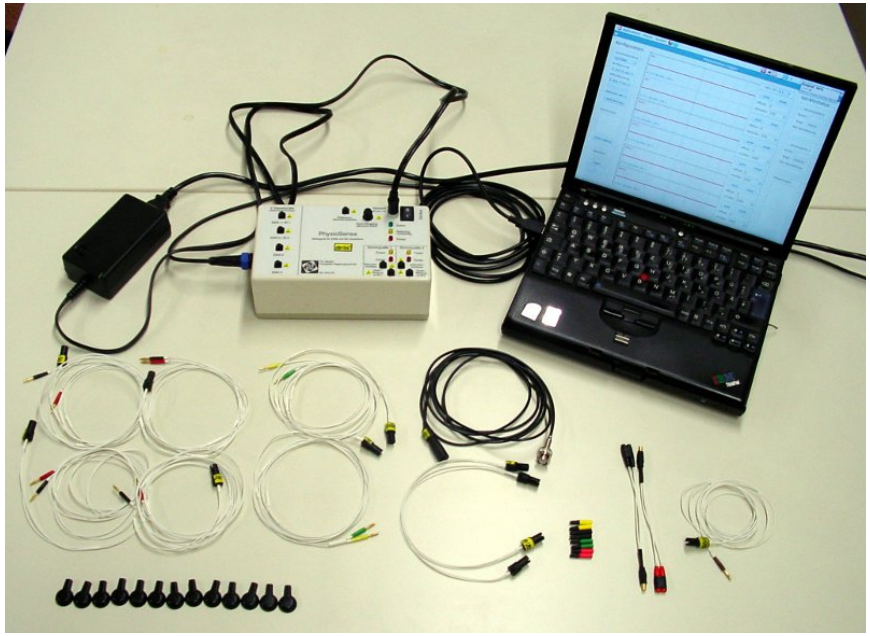
Electrodes above the entrance to the larynx

Electrodes below the vocal folds

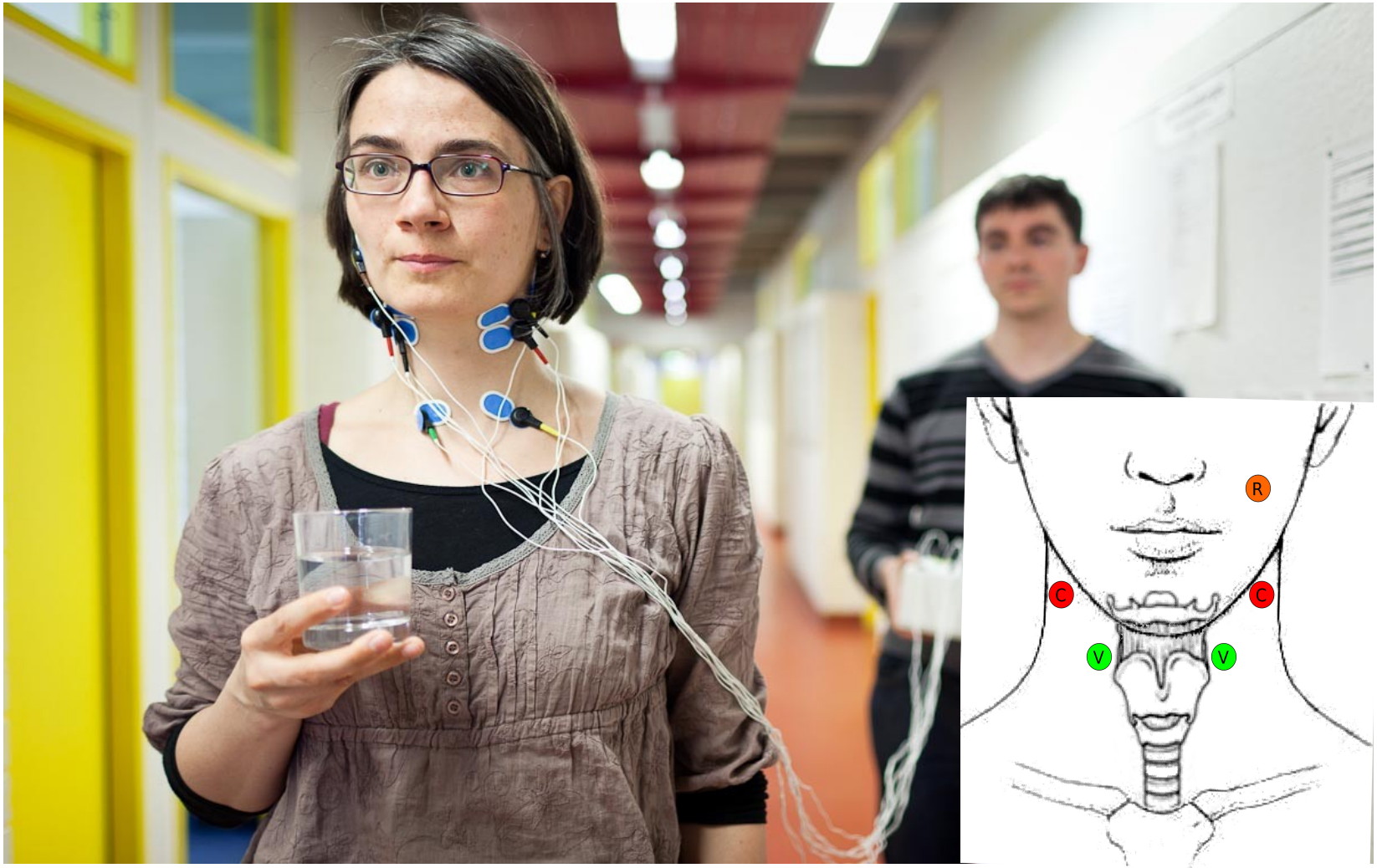
Measurement Device

PhysioSense

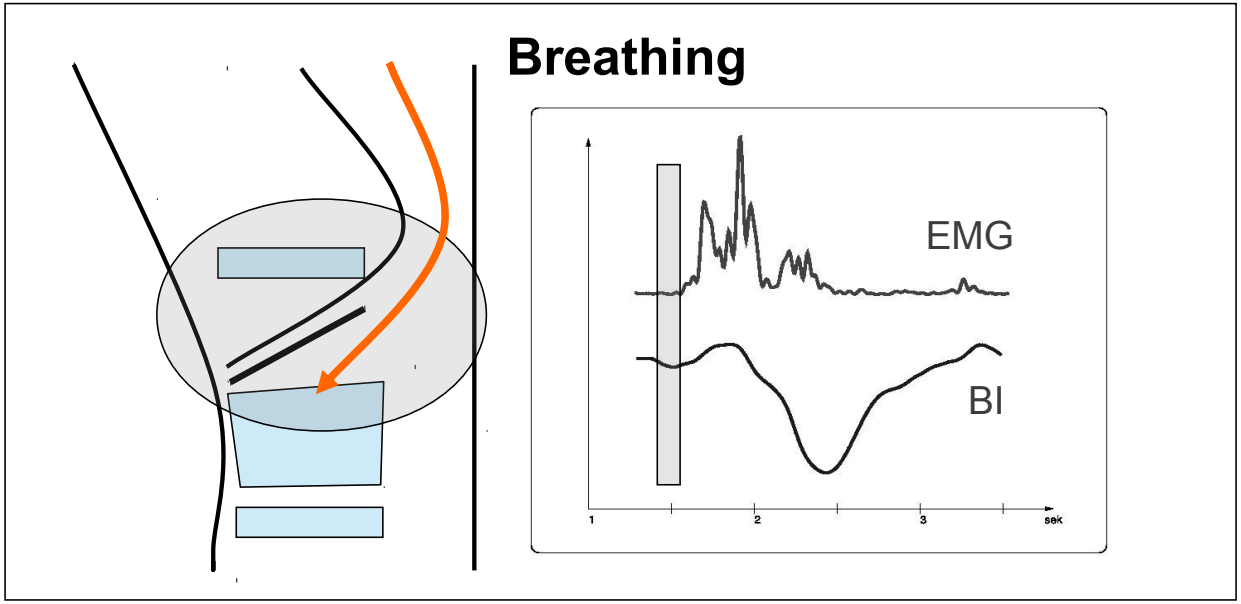
- 2 current sources (50kHz, 100kHz)
- 2- and 4- point measurement of BI
- up to 2x BI & up to 4x EMG
  - stimulation safe
  - automatic setting of current and gain for BI measurement
- EN 60601 type BF
- certified for clinical use
- needle / surface electrodes
- 4 kHz sampling time
- real-time capable



Placement of electrodes



EMG & BI Activity during Swallowing



BI curve form

- independent of conductivity
- depends on amount of bolus and consistency
- good reproducibility

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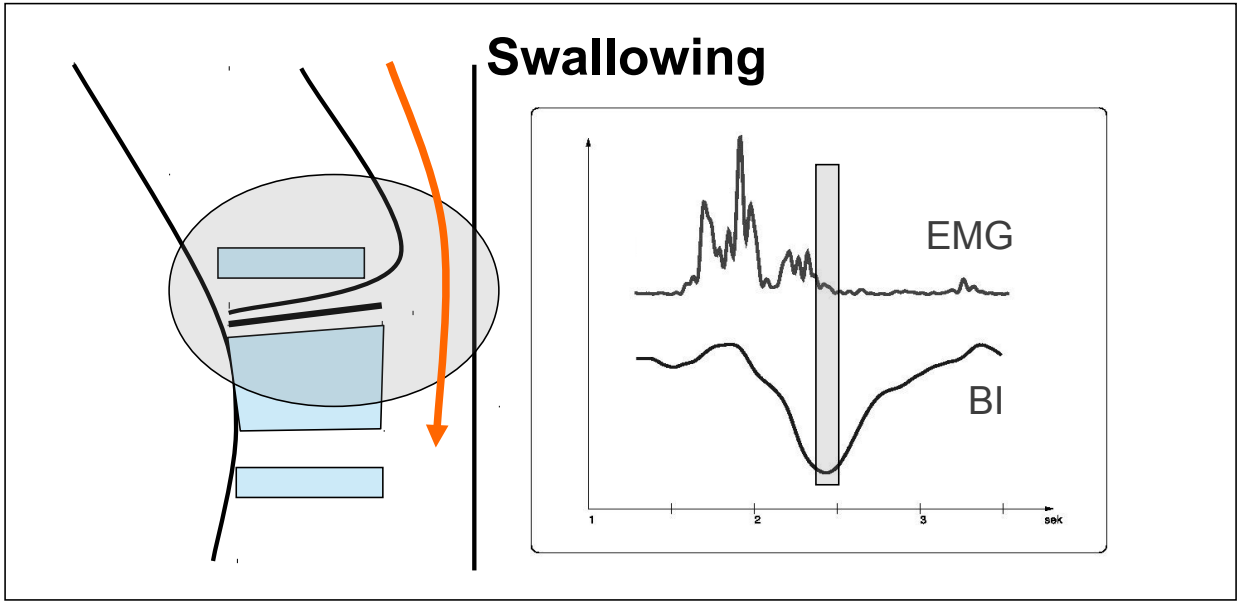

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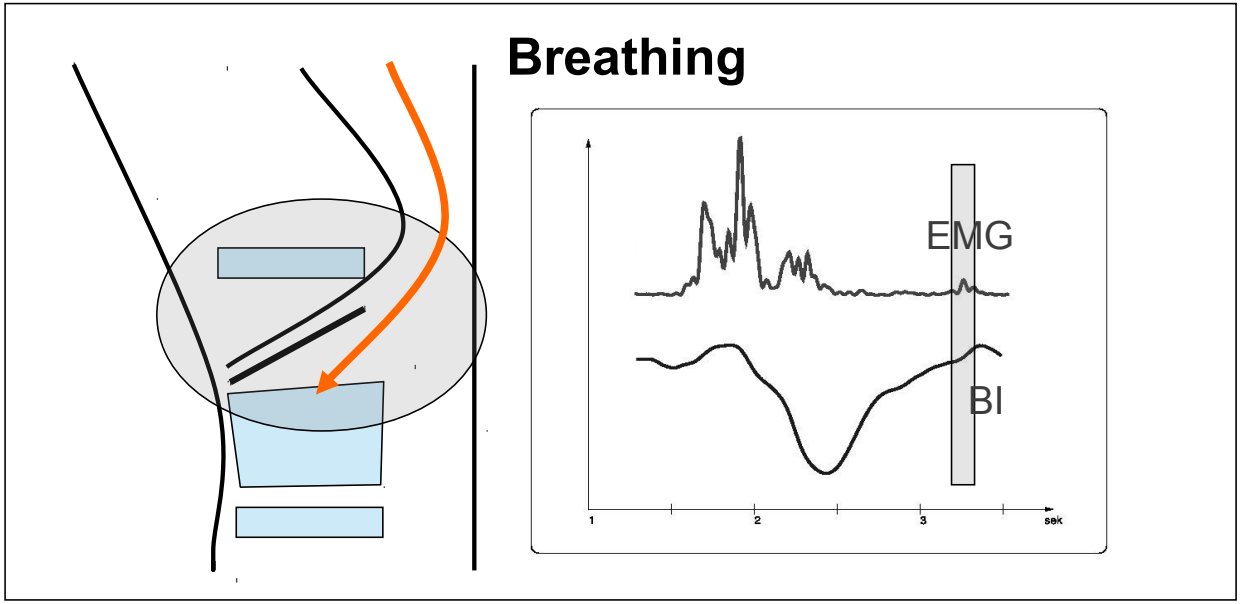
EMG & BI Activity during Swallowing



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- independent of conductivity
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- good reproducibility

Automatic Detection of Swallowing

1st step - physiological pre-selection

- detection of potential swallowing events
  - drop-off in BI
  - EMG activity
- EMG: double onset detector
- BI: online segmentation

2nd step - classifier

- head and tongue movements can also cause a drop in BI together with EMG activity
- feature extraction for all pre-selected events
- classifier separates swallows from non-swallow events.

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Detection of EMG activity

Detection of EMG activity

- disturbances (spikes/jumps) are removed
- non-causal band pass of 4th order (90-250Hz)
- double onset detector

Double onset detector

- An onset is detected if r values in the next n sliding windows are above the threshold ζ.
- The parameters r,n and ζ are optimized by maximizing the true-positive rate and minimizing the false-negative rate.
- In order to calculate ζ the noise variance in the EMG has to be estimated.

Detection of BI activity

Detection of BI activity

- piecewise linear approximation (PLA) of the BI signal
- valley detection algorithm
- one valley for each local minimum
- adjustment of found start, minimum and end points for each valley.

Piecewise linear approximation

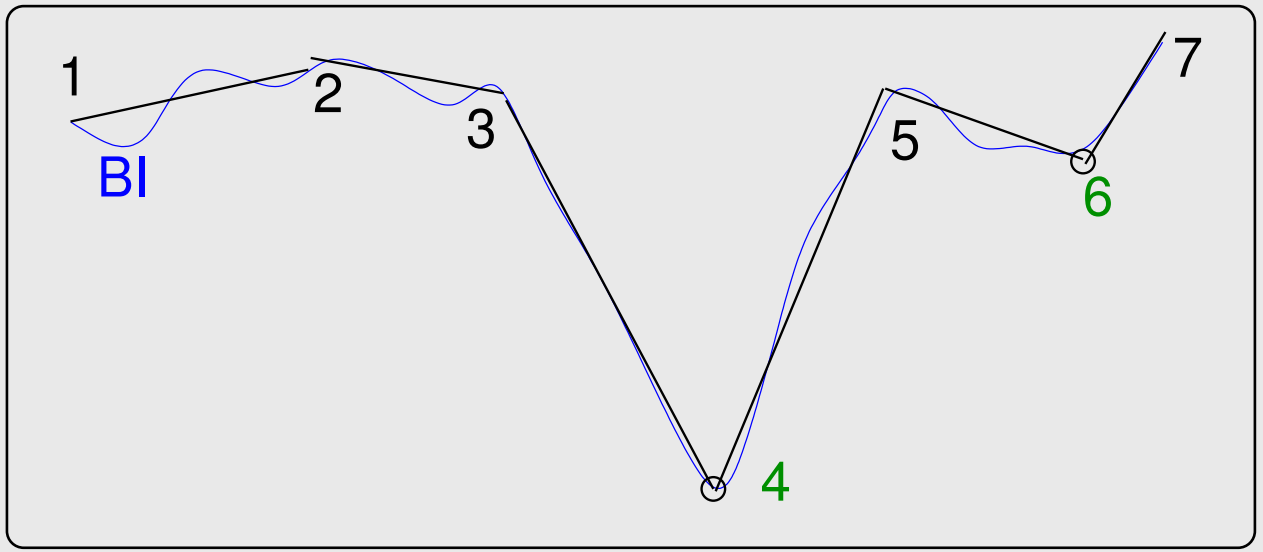
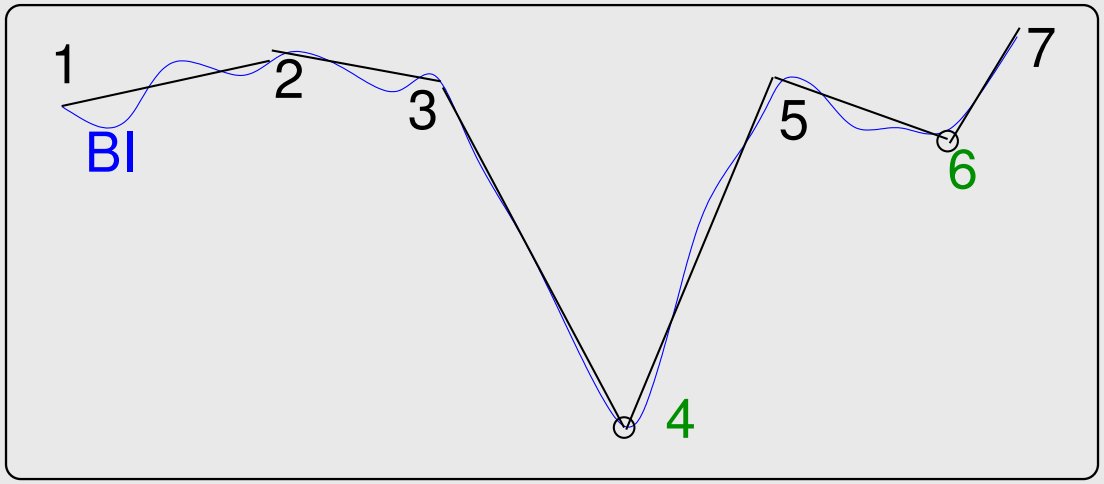


Figure : Example for BI segmentation and valley detection.

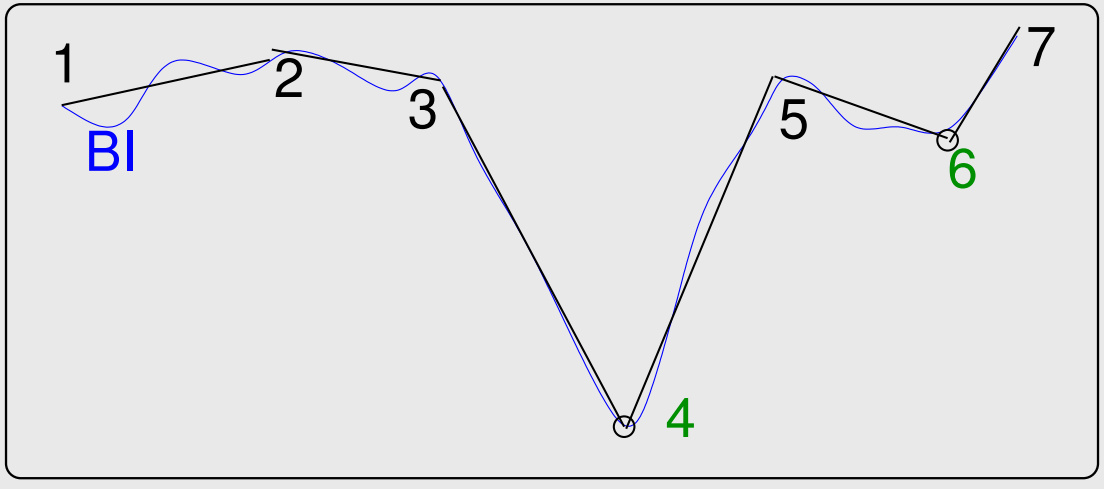
Detection of swallowing events



Valley detection algorithm

T	j+2=3	4	5	6	7	M
i=1	-1	-1	-1	-1	-1	4
2		-1	4	-1	4	6
3			4	-1	4	
4				-1	-1	
5					6	

Detection of swallowing events



Possible combinations for minimum at position 4

T	j+2=3	4	5	6	7	M
i=1	-1	-1	-1	-1	-1	4
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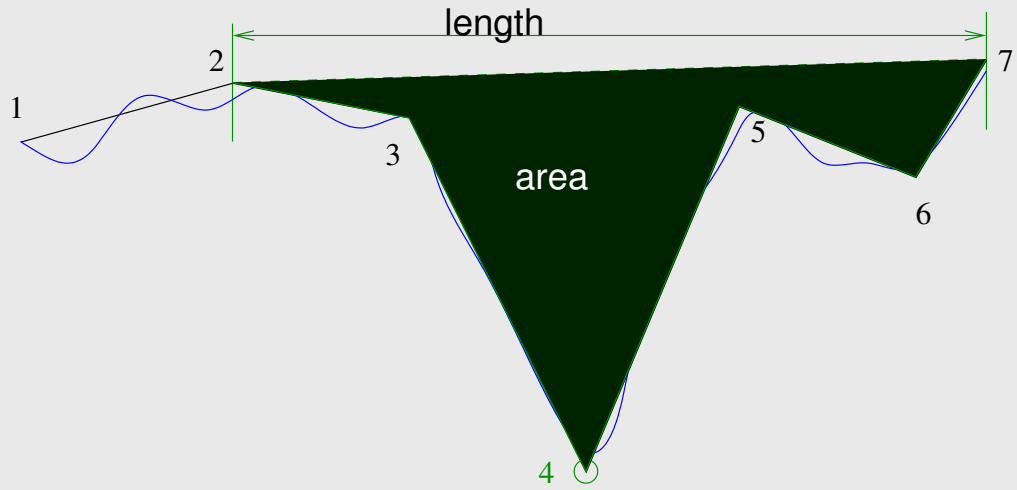
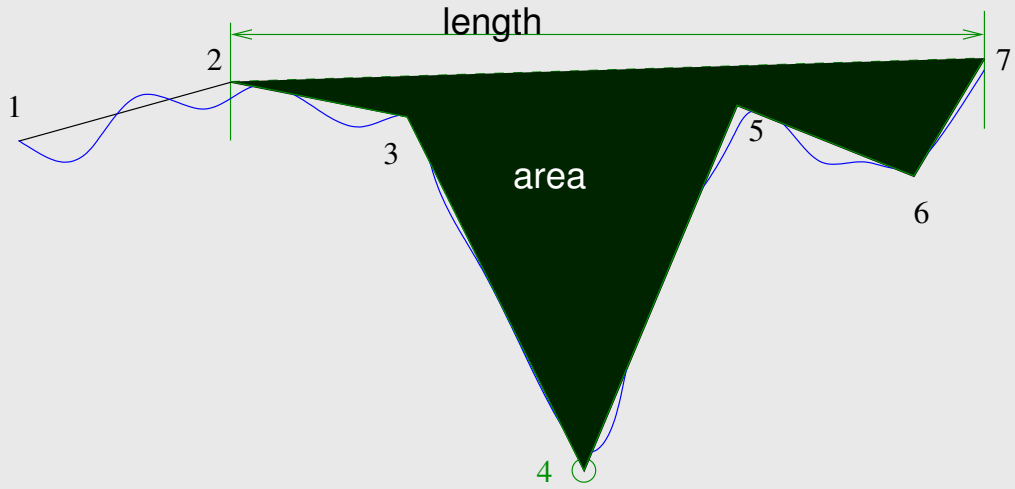
Detection of swallowing events



Cost matrix ($f = \frac{area}{length^{1.2}}$) for minimum at position 4

T	j+2=3	4	5	6	7
i=1					
2			0.1355764		0.1306289
3			0.1714890		0.1401881
4					
5					

Detection of swallowing events



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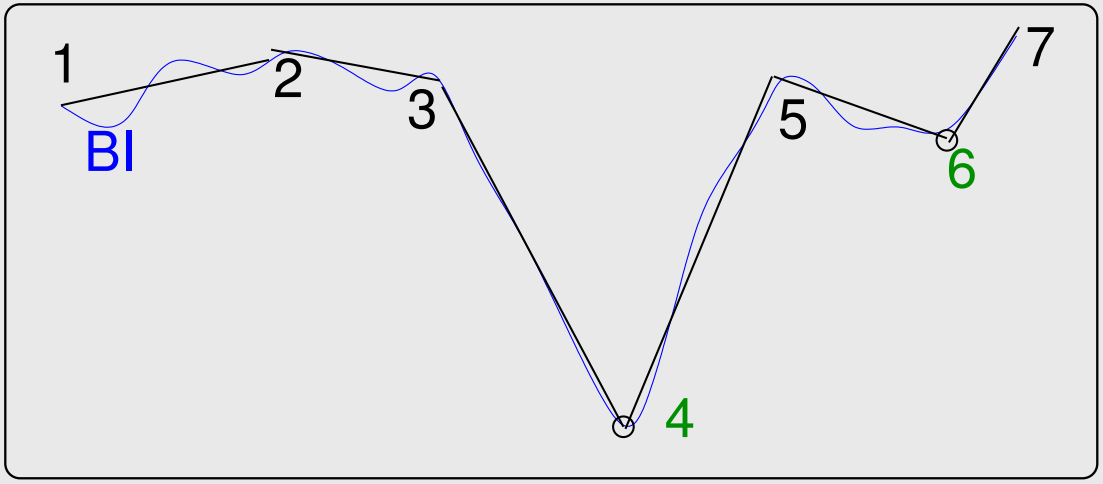
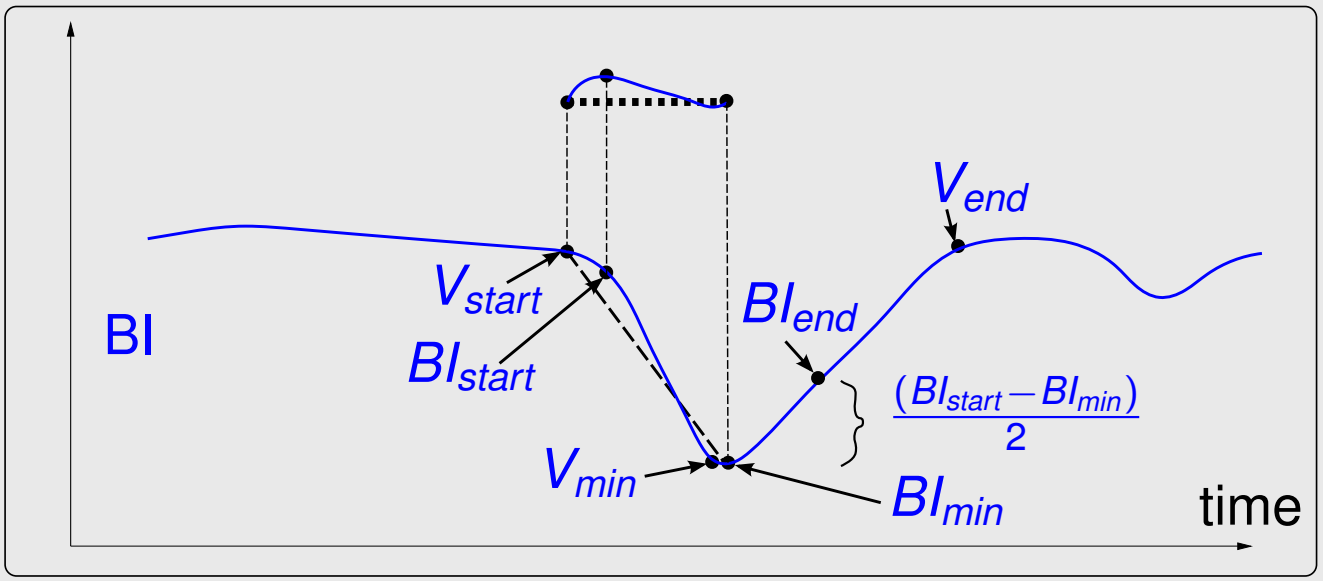


Results

The following valleys will be selected (start - minimum - end):

- 3 - 4 - 5
- 5 - 6 - 7

Adjustment of start, minimum and end.



- BI_{start} is set at the maximum of the difference between a straight line from start to min and the BI curve.
- BI_{min} is set to the minimum in the BI curve
- BI_{end} is set to the point of the BI curve behind BI_{min} which is at $\frac{BI_{start}-BI_{end}}{2}$

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- EMG: double onset detector
- BI: online segmentation
- detection of potential swallowing events:
  - Only detected valleys in which EMG activity is present are selected!

2nd step - classifier

- feature extraction for each possible swallow:
- times, areas, amplitudes
- Symbolic Aggregate approXimation (SAX)

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Feature selection

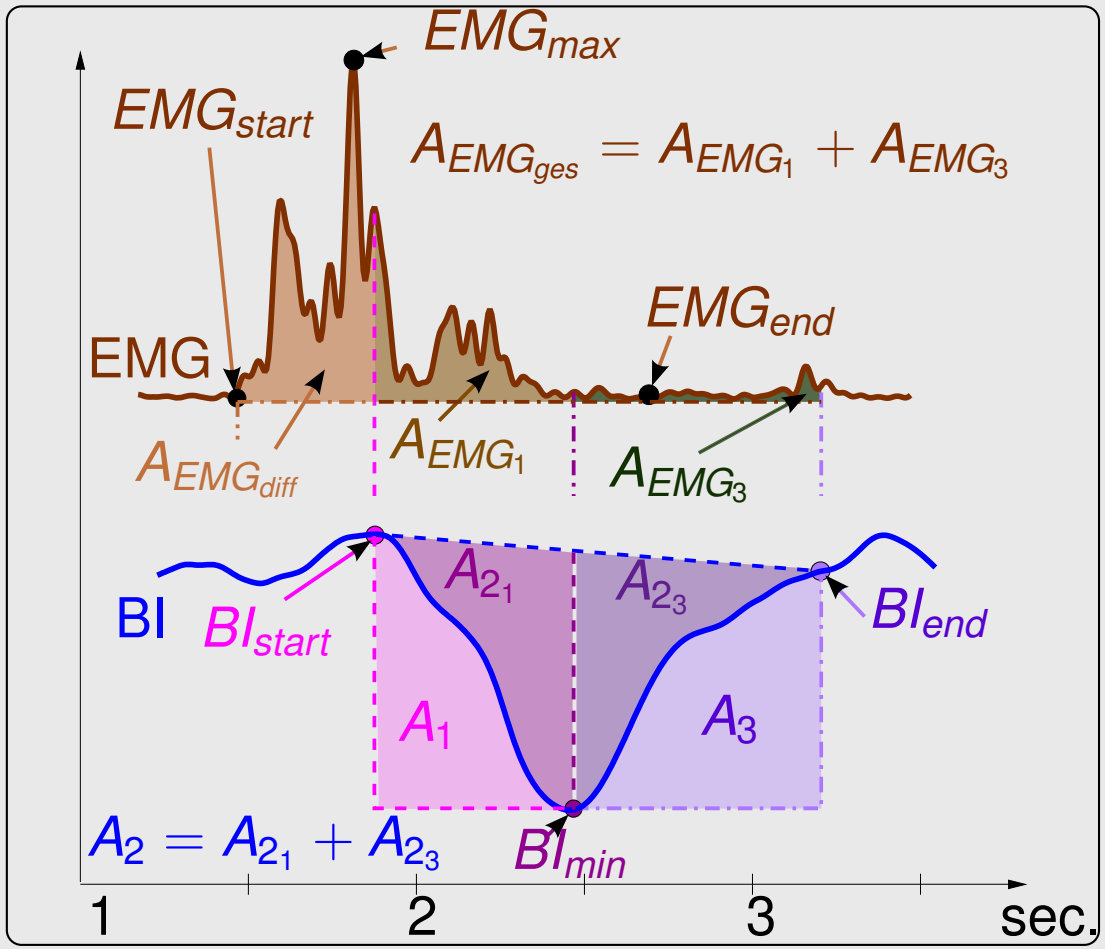
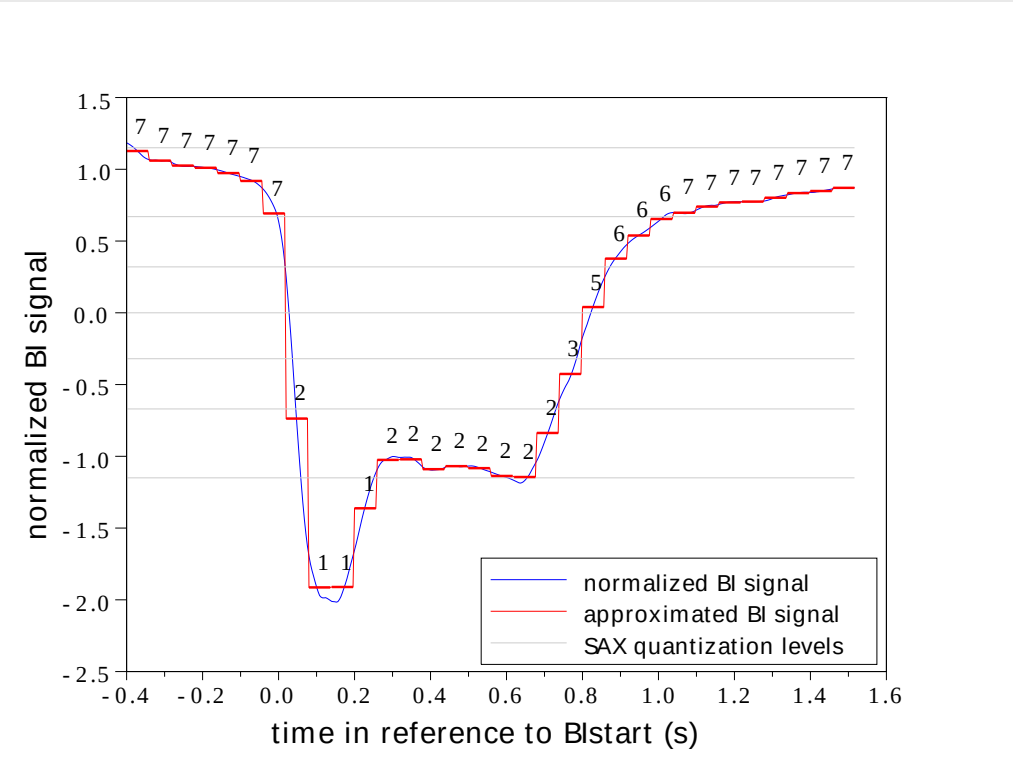


Figure : Definition of area (A) based features.

Features

- t_{min}, $t_{emgdiff}$, t_{emgmax}, t_{emgend}
- Δ_{min}, emg_{max}
- slope from BI_{start} to BI_{min}
- slope from BI_{min} to BI_{end}
- areas

Symbolic Aggregate approXimation (SAX)



- the BI and EMG sequence is taken 0.4s before BI_{start} to 1.6s after BI_{start}
- Data are normalized in this range to $\mu = 0$ and $\sigma^2 = 1$
- BI is reduced from 500 samples to 32 samples and quantized to an alphabet size of 8
- EMG is reduced to 8 samples and quantized to an alphabet size of 4

Support vector machine

- times, areas, amplitudes and SAX-string of BI and EMG are used as features
- feature vector with 65 entries for each possible swallow
- classifier: support vector machine
- feature vector is normalized to a range [0,1]
- the classifier is trained with training data
- swallows marked by hand

Results

1st step - physiological pre-selection

- 9 healthy subjects
- 1370 swallows (all marked) plus other movements
- good: 99.3% (1360 swallows) detected
- bad: 4128 other events detected as swallows

Results 2nd step (classifier)

- training data set: subjects 1-5, 703 swallows included
- test data set: subjects 6-9, 667 swallows included

	swallows	non-swallows
positive	636	49
negative	26	1646

- sensitivity: 96.1%
- specificity: 97.1%

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Outlook

Future work

- study with patients
- enhancement of the classifier in order to detect consistency and swallow quality
- online detection of swallowing in order to be able to trigger a stimulation

Thank You for your attention!

More information at: www.bigdyspro.de

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