Swallow Detection Algorithm Based on Bioimpedance and EMG Measurements

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Swallowing and Dysphagia

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

**Dysphagia**
- aspiration (to choke on sth.) → 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 → closing the entrance to the trachea
State of the Art in Swallowing Diagnosis

- **Videofluoroscopy**
  - Complex, expensive and bulky devices
  - Exposure to radiation during videofluoroscopy
  - Only applicable in clinical environments
  - Not suitable for controlling swallowing implants in daily life

- **Endoscopy**
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 ...

Detection of aspiration
Electrodes above the entrance to the larynx

Measurement of airway closure
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
EMG & BI Activity during Swallowing

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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

- 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 $\zeta$.
- The parameters r,n and $\zeta$ are optimized by maximizing the true-positive rate and minimizing the false-negative rate.
- In order to calculate $\zeta$ the noise variance in the EMG has to be estimated.
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.

Figure : Example for BI segmentation and valley detection.
Detection of swallowing events

Valley detection algorithm

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<thead>
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<th>$j+2=3$</th>
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<th>5</th>
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Detection of swallowing events

Possible combinations for minimum at position 4

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Detection of swallowing events

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

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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.

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

$$V_{\text{start}} = V_{\text{min}} + \left( \frac{B_{I_{\text{start}}}-B_{I_{\text{min}}}}{2} \right)$$

$$V_{\text{end}} = V_{\text{min}} - \left( \frac{B_{I_{\text{start}}}-B_{I_{\text{end}}}}{2} \right)$$
Automatic Detection of Swallowing

1st step - physiological pre-selection
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- 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.
the BI and EMG sequence is taken 0.4s before $B_{I_{\text{start}}}$ to 1.6s after $B_{I_{\text{start}}}$

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
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

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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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