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SEIZEIT BIOMED STADIUS

Multimodal epileptic seizure detection: towards a wearable solution

Kaat Vandecasteele

Public defense
19-04-2021

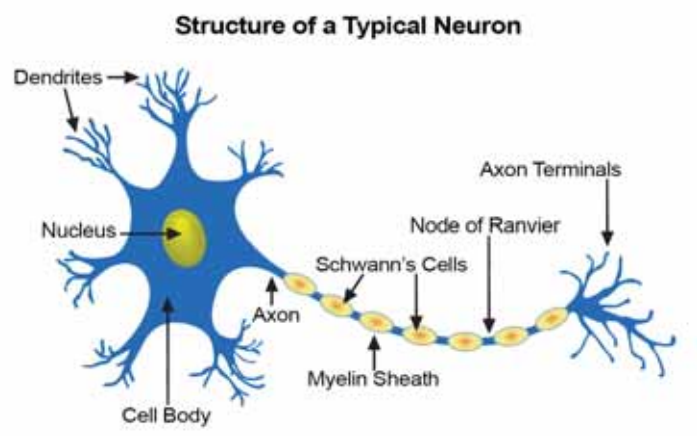
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Contents Overview

1. Introduction to Epilepsy
2. HR-based seizure detection (Contribution 1)
3. Behind-the-ear EEG-based seizure detection (Contribution 2)
4. Multimodal seizure detection (Contribution 3)
5. Conclusions and future work

Epilepsy

- Affects 1% of people worldwide
- Disorder of the brain → abnormal excessive and synchonous activity of the neurons
- Charaterized by epileptic seizures → unpredictable

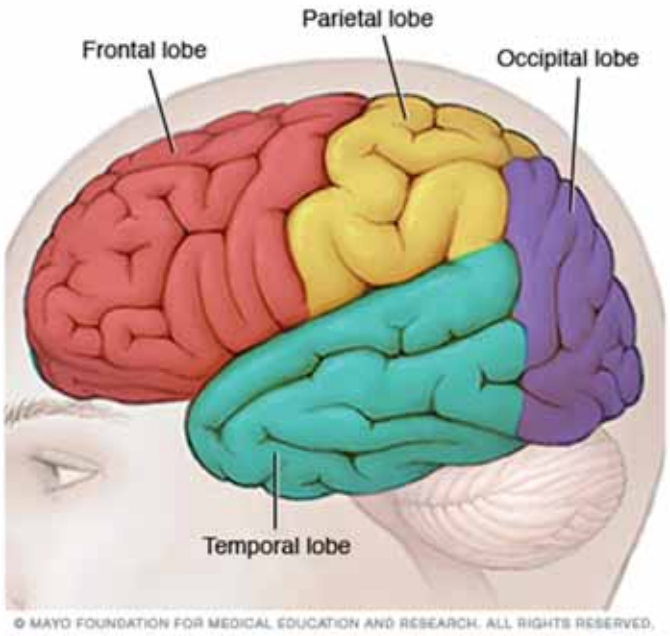




Different seizure types

- Focal onset seizure → onset is in one specific part of the brain
  - Focal aware
  - Focal impaired awareness

  → Onset region: influence on clinical symptoms
- Generalized onset seizure → onset is widespread over the brain
  - Motor (e.g. Tonic Clonic or grand mal)
  - Nonmotor (e.g. Absence)



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Treatments

Anti-epileptic drugs



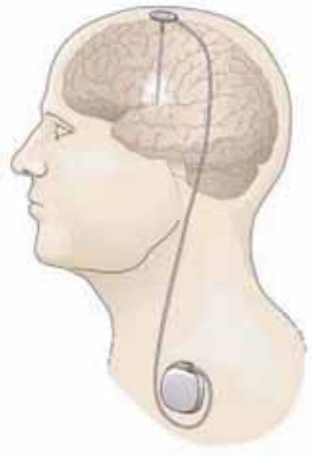
Surgery



Vagus-Nerve Stimulation



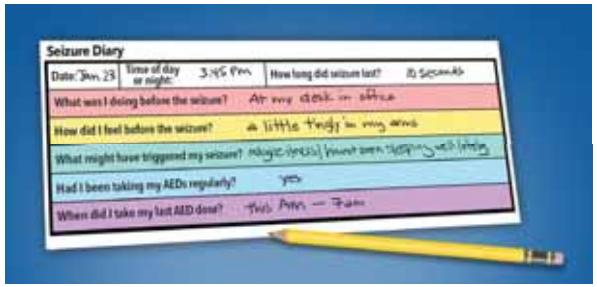
Deep brain stimulation



→ 30% of patients → no suitable treatment: refractory epilepsy → Quality of life ↓

Refractory patients: solutions?

- Wearable seizure detection devices → seizure monitoring in out-patient setting, daily life
  - Seizure prediction
  - Real-time seizure detection → alarming
  - **Offline seizure detection** → construct automatically a seizure diary



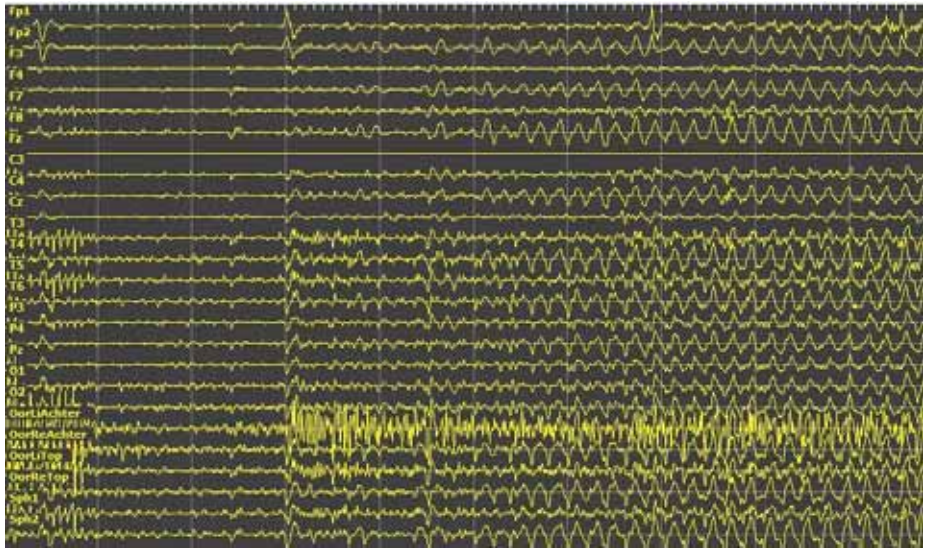
➔Important for follow-up and evaluation of the treatment

➔Seizure diaries kept by the patient → unreliable

Golden standard in the hospital

Video-Encephalography (EEG) → monitoring of neural activity over time





Requirements for seizure detection devices

Comfortable
Non-stigmatizing







High accuracy:
- High sensitivity
- Low false detection rate



- Existing seizure detection devices
  - ➔ Focus only on generalized tonic-clonic seizures (strong muscle and motor activity)
  - ➔ Using only accelerometer or electromyogram

Goal of the thesis

- Focus on **focal seizures** without typical motion activity
- Automated detection methods → using **wearable** signals
- **Offline** constructing a seizure diary









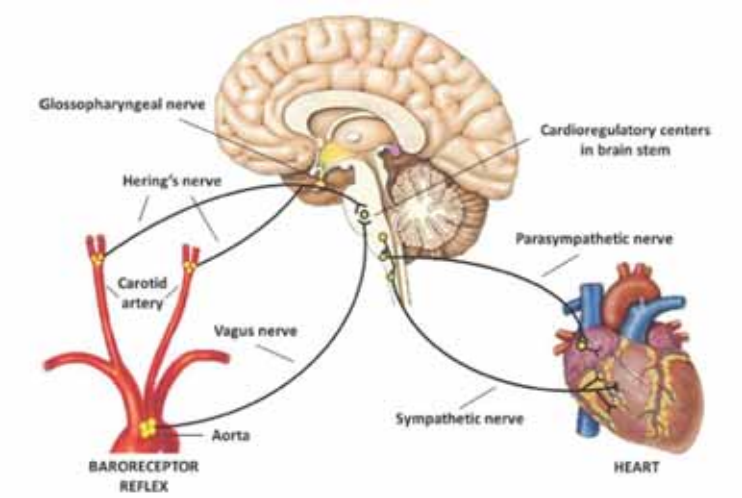


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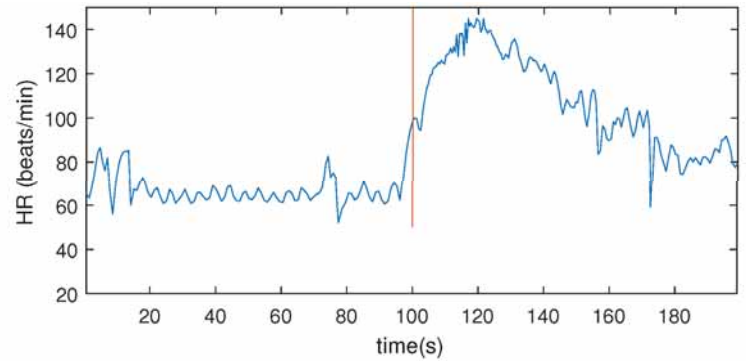
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HR-based seizure detection (Contribution 1)

- Changes in autonomic nervous system (e.g. heart rate) in ± 70% - 80% of focal seizures
  - More frequent changes in seizures with onset in temporal lobe



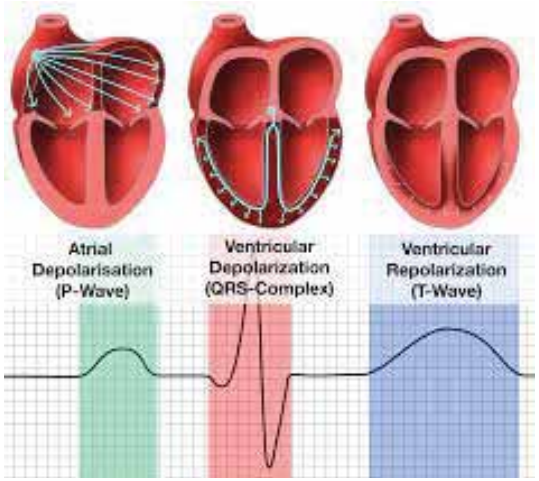
Example of heart rate increase during a seizure



Electrocardiography (ECG)

- How to monitor the heart rate?
  - Option 1: Electrocardiography (ECG)

One cardiac cycle

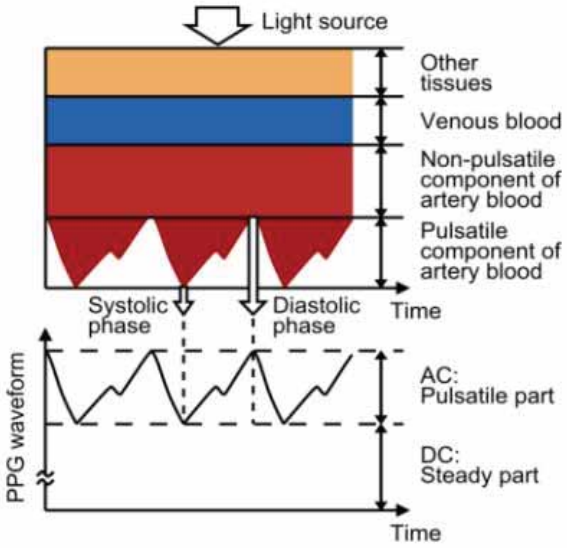


Wearable ECG device → two electrodes placed on the chest



Photoplethysmography (PPG)

- How to monitor the heart rate?
  - Option 2: Photoplethysmography (PPG)





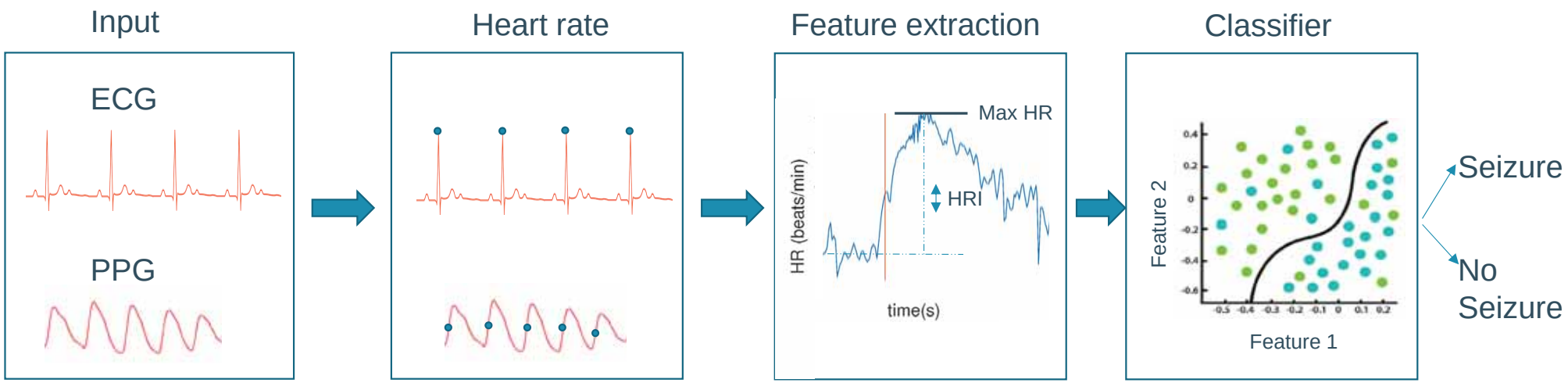






HR-based seizure detection

- Based on the heart rate (HR) → automated detection of seizures
- Pipeline of algorithm



* HRI = heart rate increase

Dataset + Results

- Dataset: 11 patients and 47 seizures
- UZ Leuven
- Results:

	Sensitivity	FP/h
Hospital ECG	57%	2,05
Wearable ECG	64%	2,35
Wearable PPG	33%	1,88

Video – EEG
+ hospital ECG



+

Wearable ECG



+

Wearable PPG



Golden standard:
Neurologist annotated seizures

Vandecasteele, K., De Cooman, T., Gu, Y., Cleeren, E., Claes, K., Van Paesschen, W., Van Huffel, S., Hunyadi, B. (2017). Automated Epileptic Seizure Detection Based on Wearable ECG and PPG in a Hospital Environment. *Sensors*, *17* (10), 1-12

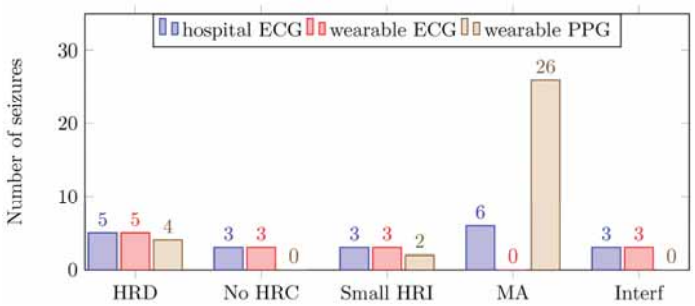
Results

- Results:

	Sensitivity	FP/h
Hospital ECG	57%	2,05
Wearable ECG	64%	2,35
Wearable PPG	33%	1,88

Good enough for practical use?

Reasons for missed seizures



HRD: Heart Rate Decrease
HRC: Heart Rate Change
HRI: Heart Rate Increase
MA: Motion Artifacts
Interf: Interference (12 Hz)

Reasons for false alarms

- Artifacts
- Physiological heart rate increases

Vandecasteele, K., De Cooman, T., Gu, Y., Cleeren, E., Claes, K., Van Paesschen, W., Van Huffel, S., Hunyadi, B. (2017). Automated Epileptic Seizure Detection Based on Wearable ECG and PPG in a Hospital Environment. *Sensors*, *17* (10), 1-12

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Behind-the-ear EEG-based seizure detection (Contribution 2)



Full EEG → not suitable for long-term monitoring during daily life



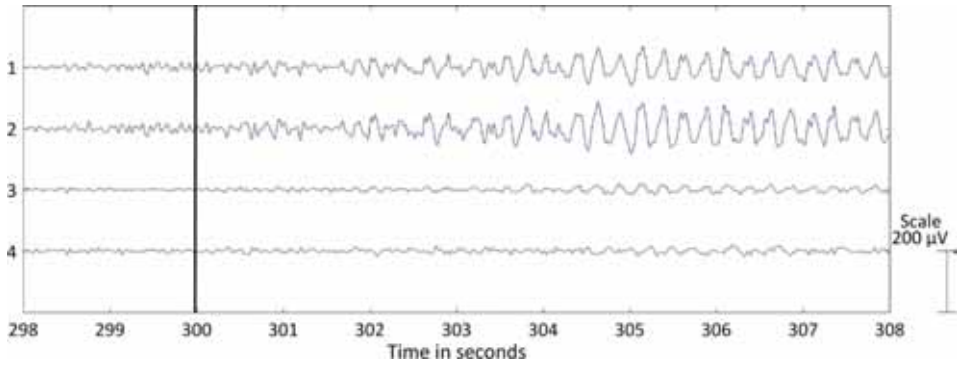
Measure only a few EEG channels located behind-the-ear

Behind-the-ear EEG-based seizure detection

Main research questions:

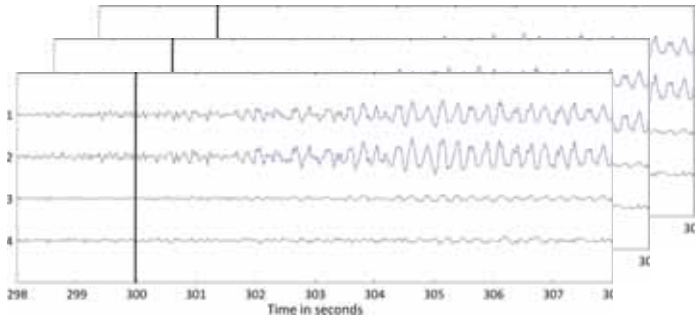
1. Visual seizure recognition using behind-the-ear EEG [by a neurologist]
2. Automated seizure detection





Visual seizure recognition

- Dataset: 54 patients with 182 seizures
- Experimental protocol:
  - 182 seizure segments + 172 non-seizure segments
  - Randomly shown to a neurologist
    → seizure or non-seizure?



…

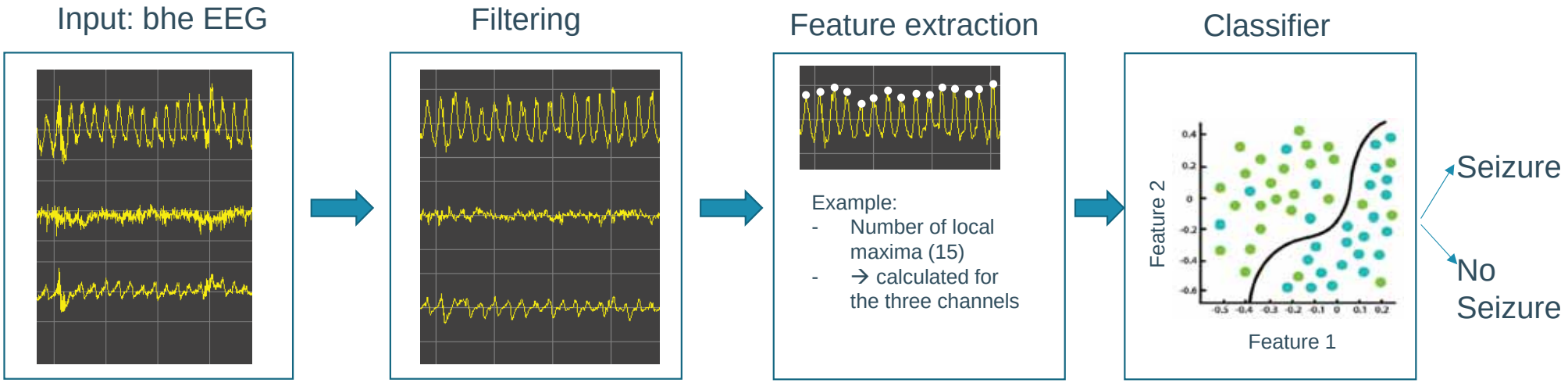
- Results:

	Sensitivity	Specificity
Visual analysis	65,7%	94%

Vandecasteele, K., De Cooman, T., Dan, J., Cleeren, E., Van Huffel, S., Hunyadi, B., Van Paesschen, W. (2020). Visual seizure annotation and automated seizure detection using behind-the-ear electroencephalographic channels. *EPILEPSIA*, *61* (4), 766-775.

Automated seizure detection

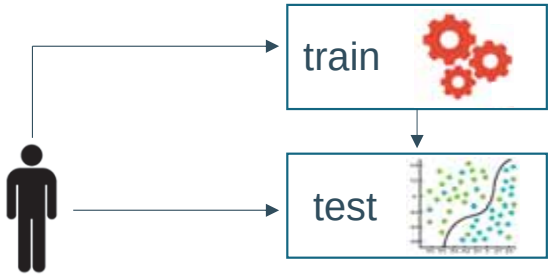
- Based on the behind-the-ear (bhe) EEG → automated detection of seizures
- Pipeline of algorithm



Automated seizure detection: Classifier

- Classification model = Data-driven
  - ➔ training data needed!

1. Patient-specific model



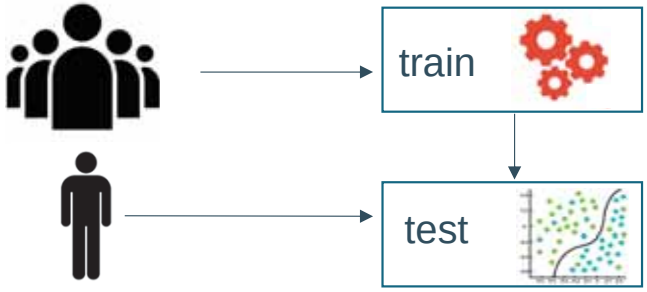


Higher performance (seizures → patient-specific)



Limited training data
Less practical: patient-specific data needed

2. General model





Lower performance



More training data
Practical: no patient-specific data needed

Dataset + results

- Dataset: 54 patients with 182 seizures

	Sensitivity	FP/h
General model	72.7 %	1,425
Patient-specific model	63.4 %	0,037

Higher than manual seizure diaries

Video – EEG



+

EEG recorded behind the ear



Golden standard:
Neurologist annotated seizures

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Multimodal seizure detection (Contribution 3)

EEG recorded behind the ear

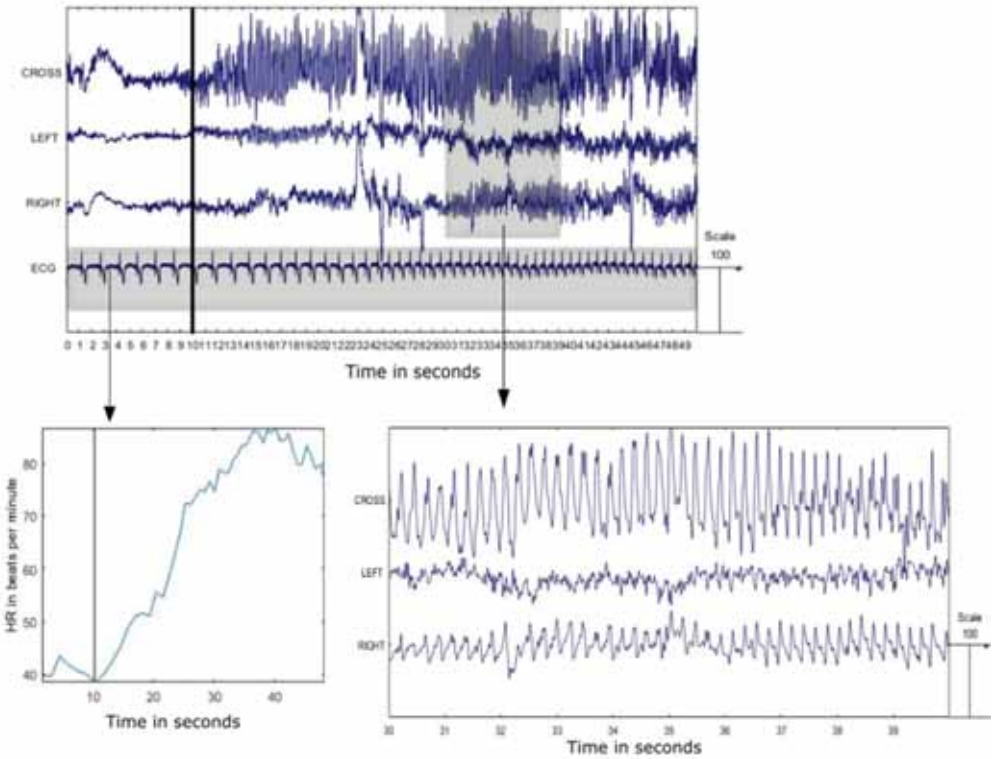


+

ECG



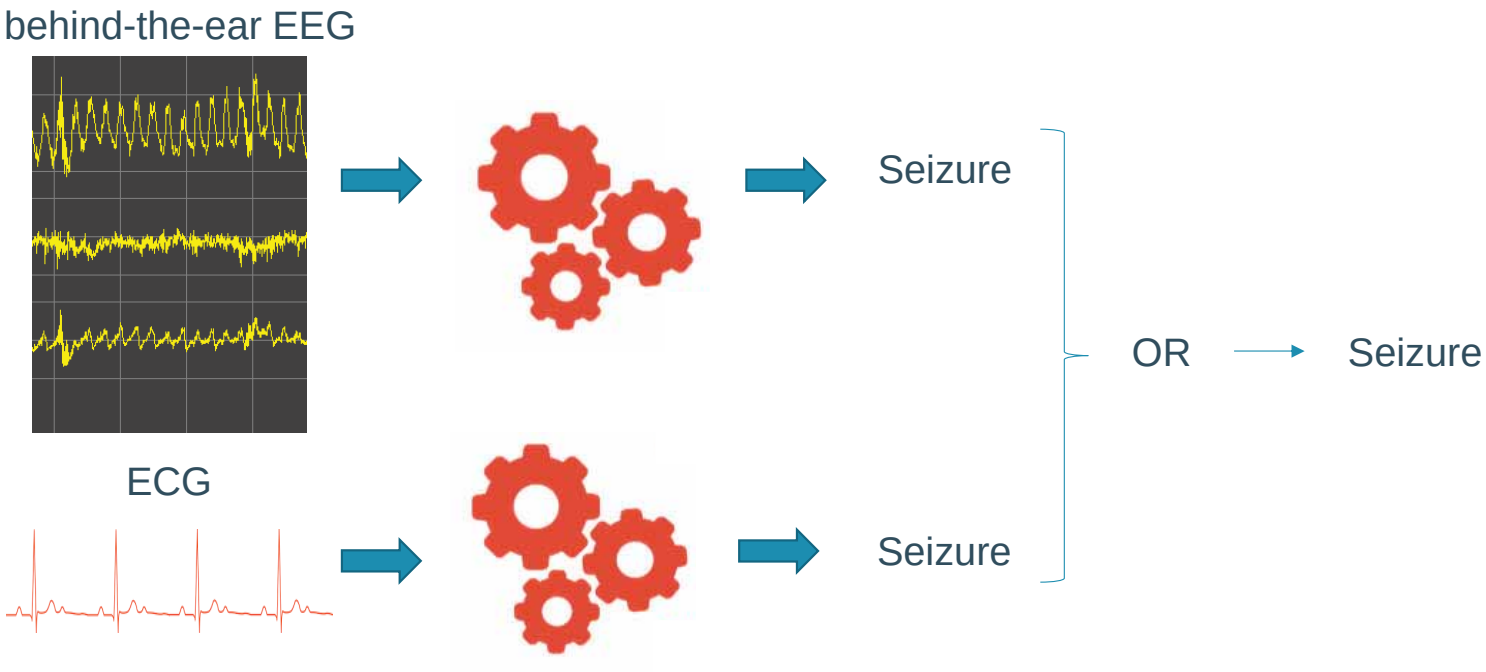
Example of a seizure:



Combine EEG recorded behind-the-ear + ECG
Better performances?

Multimodal seizure detection: Approach

- Focus on high sensitivity
- Pipeline of algorithm:



Dataset + results

- Different centers:
  - Leuven (SeizeIT1): 42 patients with 221 seizures
  - Freiburg (Epilepsiae): 30 patients with 275 seizures
  - Paris (Epilepsiae): 63 patients with 400 seizures
  - ➔ Total: 135 patients with 896 seizures

	Sensitivity (Multimodal)	Sens (Unimodal EEG)	FP/hour
Leuven	92%	81%	1.85
Freiburg	90%	82%	1.94
Paris	84%	84%	1.90

→ Sensitivity ↑ ➔ 11%

→ Sensitivity ↑ ➔ 8%

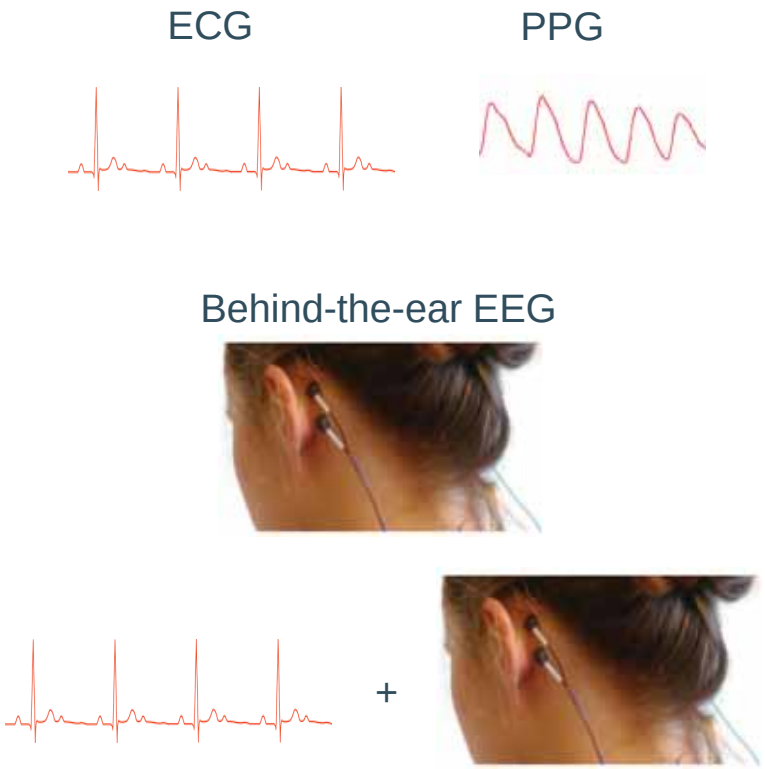
→ Sensitivity ↑ ➔ 0%
(lower quality of ECG observed)

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Conclusions

- **Contribution 1**: HR-based seizure detection
  - Wearable PPG sensor (wrist) → lower performances compared to wearable ECG
  - Using ECG alone for seizure detection → results are not yet good enough
- **Contribution 2**: Behind-the-ear EEG-based seizure detection
  - Visual seizure recognition is possible using only 3 EEG channels recorded behind the ear
  - Automated seizure detection → higher sensitivities than manual seizure diaries
- **Contribution 3**: Multimodal seizure detection
  - ECG has an added value in 2 of the 3 databases



Future work

- Wearable seizure detection device → under **full supervision of the neurologist**
  - First stage: Seizure diaries → constructed in a semi-automated way (EEG expert/neurologist shall take a look at the detected seizures)
  - Second stage: Seizure diaries → constructed in an automated way (for the patients with clear EEG patterns / heart rate increases)
  - Third stage: Online seizure detection → if requested by the patient

- Only ECG and EEG → discussed in this thesis, **other signals** (muscle activity, motion, …) might be of benefit for particular patients

- **Personalized** solution: seizures (+ signals) → highly patient-specific

Scientific publications (PART 1)

Papers in international journals

1. **Vandecasteele K.**, De Cooman T., Gu Y., Cleeren E., Claes K., Van Paesschen W., Van Huffel S., Hunyadi B., "Automated Epileptic Seizure Detection Based on Wearable ECG and PPG in a Hospital Environment", Sensors, Special Issue on Wearable and Ambient Sensors for Healthcare and Wellness Applications, vol. 17, no. 10, Oct. 2017, pp. 1 - 12.

2. De Cooman T.*, **Vandecasteele K.***, Varon C., Hunyadi B., Cleeren E., Van Paesschen W., Van Huffel S., "Personalizing Heart Rate-Based Seizure Detection Using Supervised SVM Transfer Learning", Frontiers in Neurology, vol. 11, no. 145, Feb. 2020, pp. 1-13. [Authors [*] contributed equally to the work.]

3. **Vandecasteele K.**, De Cooman T., Dan J., Cleeren E., Van Huffel S., Hunyadi B., Van Paesschen W., "Visual seizure annotation and automated seizure detection using behind-the-ear electroencephalographic channels", Epilepsia, vol. 61, no. 4, Apr. 2020, pp. 766-775.

4. Becker, T., **Vandecasteele, K**., Chatzichristos, C., Van Paesschen, W., Valkenborg, D., Van Huffel, S., De Vos, M. "Classification with a Deferral Option and Low-Trust Filtering for Automated Seizure Detection", Sensors, Special issue on Healthcare Monitoring and Management with Artificial Intelligence, vol. 21, no. 4., February 2021, 1046.

Papers submitted to international journals

1. **Vandecasteele, K**., De Cooman, T., Chatzichristos, C., Cleeren, E., Swinnen, L., Ortiz, J. M., Van Huffel, S., Dümpelmann, M., Schulze-Bonhage, A., De Vos, M., Van Paesschen, W., Hunyadi, B., "The power of ecg in multimodal seizure monitoring: visual recognition and added value to an eeg-based detector using limited channels", Epilepsia, revised version submitted in March 2021 (ESAT-Stadius report number: 21-03).

Scientific publications (PART 2)

2. Swinnen, L., Chatzichristos, C., Jansen, K., Lagae, L., Depondt, C., Seynaeve, L., Vancaester, L., Van Dycke, A., Macea Ortiz, J., **Vandecasteele, K.,** Broux, V., De Vos, M., Van Paesschen, W., "Accurate detection of typical absence seizures using a two-channel EEG wearable behind the ears", Epilepsia, submitted in April 2021.

Papers in proceedings of international conferences

1. **Vandecasteele K**., Lázaro J., Cleeren E., Claes K., Van Paesschen W., Van Huffel S., Hunyadi B., "Artifact detection of wrist photoplethysmograph signals", Biostec (Biosignals), Funchal, Madeira - Portugal, 19-21 January 2018, 8 p.

2. Chatzichristos C.*, Dan J.*, Narayanan A. M.*, Seeuws N.*, **Vandecasteele K.***, De Vos M., Bertrand A., Van Huffel S., "Epileptic Seizure Detection in EEG via Fusion of Multi-View Attention-Gated U-net Deep Neural Networks", The 2020 IEEE Signal Processing in Medicine and Biology Symposium (SPMB), Philadelphia, USA, 2020.7p. [Authors [*] contributed equally to the work. This paper received the SPMB best paper award.]

Thank you!