# Project: Final presentation

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1 Introduction

2 RVOT-LVOT classification

3 Our SOO

4 Wavelets

5 SOO classification

# INTRODUCTION

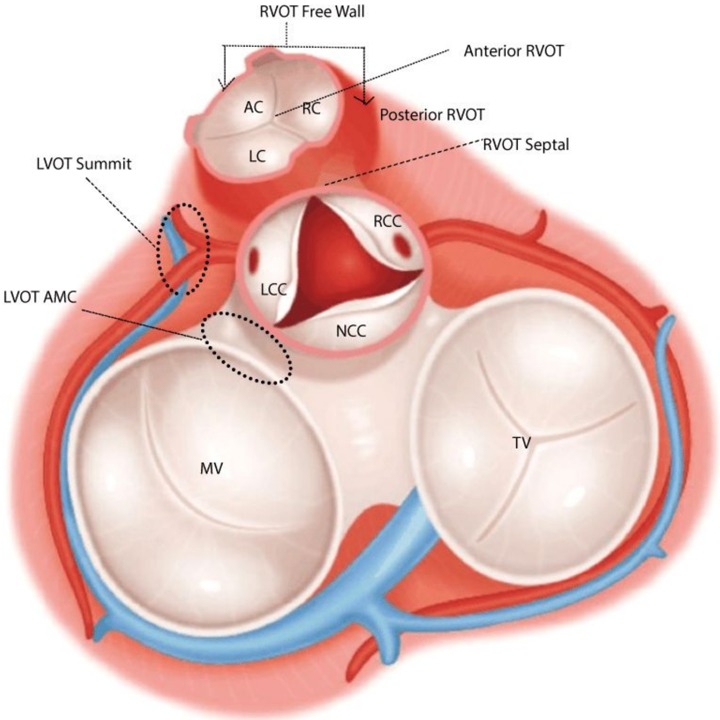



Figure 1: Representation of SOO [1]

**OT:** Outflow tract
**VT:** Ventricular tachycardia
**c-AMP:** Cycled Adenosine Monophosphate

80% arise from **RVOT**, while 12% from **LVOT** [2]


[1] Zheng, J., Fu, G., Anderson, K., Chu, H., & Rakovski, C. (2020). A 12-Lead ECG database to identify origins of idiopathic ventricular arrhythmia containing 334 patients. *Scientific Data*, *7*(1), 98. https://doi.org/10.1038/s41597-020-0440-8

[2] Reviriego, S. M., & Merino, J. L. (2009). Ventricular tachycardia in patients without apparent structural heart disease; focus on ventricular outflow tract tachycardia. *ESC Council for cardiology practice e-journal*. 2009; 8, 11.

# Dataset

Original Dataset: **143 patients**

↓

New Combined Dataset: **620 patients**

# Combined Dataset

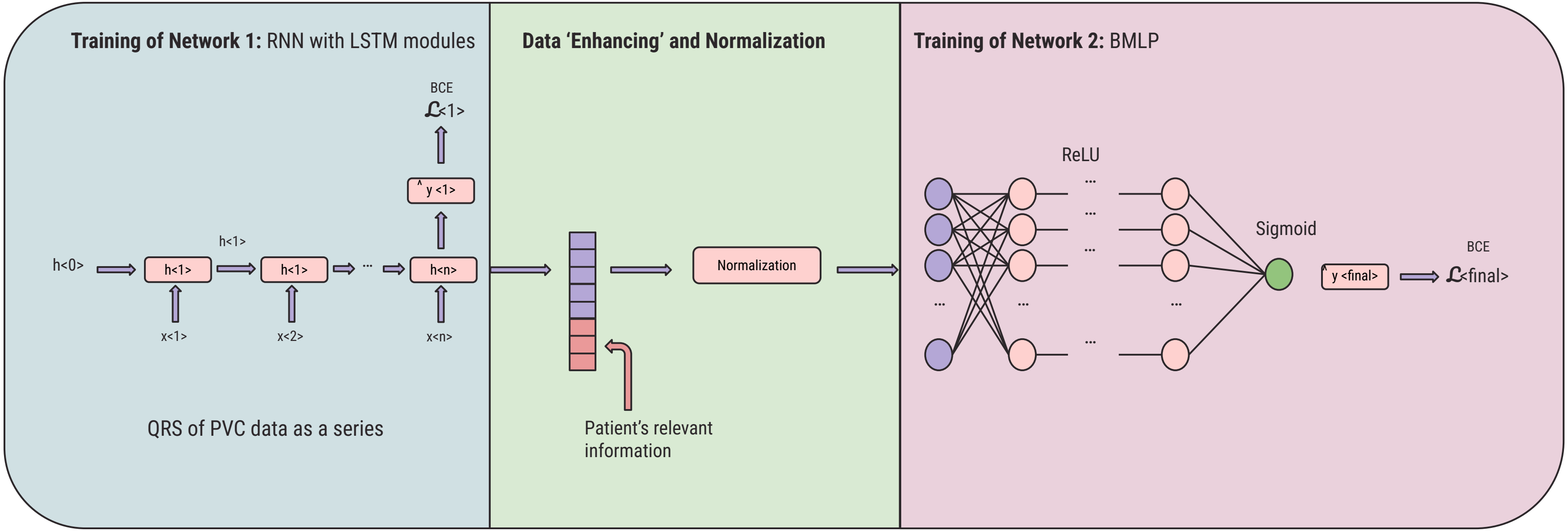
New Combined Dataset: **620 patients**

**Features:**
'I', 'II', 'III', 'AVR', 'AVL', 'AVF', 'V1', 'V2', 'V3', 'V4', 'V5', 'V6', 'Sex', 'Age', 'Weight', 'Height', 'HTA', 'Smoker', 'PVC_transition', 'Simplified'

QRS of PVC:
Manually segmented taking as reference R peak in 2 s

# CLASSIFICATION RVOT–LVOT

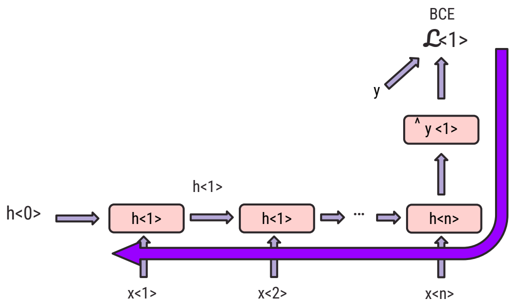
## Model Core Idea:



# CLASSIFICATION RVOT-LVOT

## Model Core Idea:

**Training of Network 1:** RNN with LSTM modules



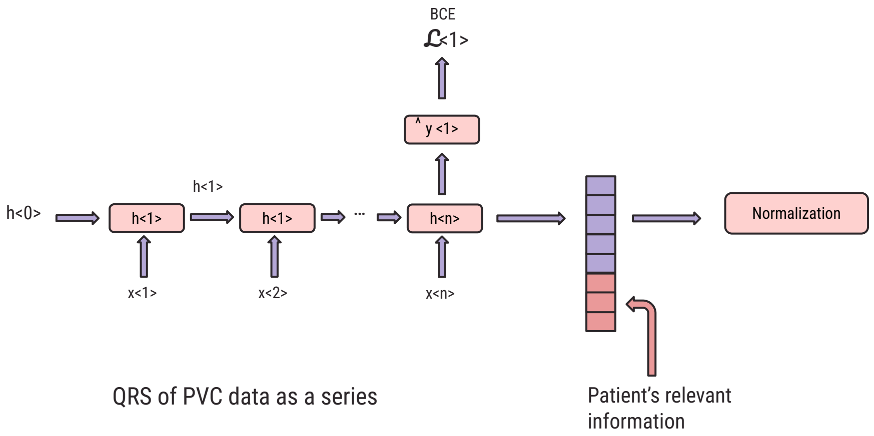

QRS of PVC data as a series

# CLASSIFICATION RVOT-LVOT

## Model Core Idea:

**Training of Network 1:** RNN with LSTM modules

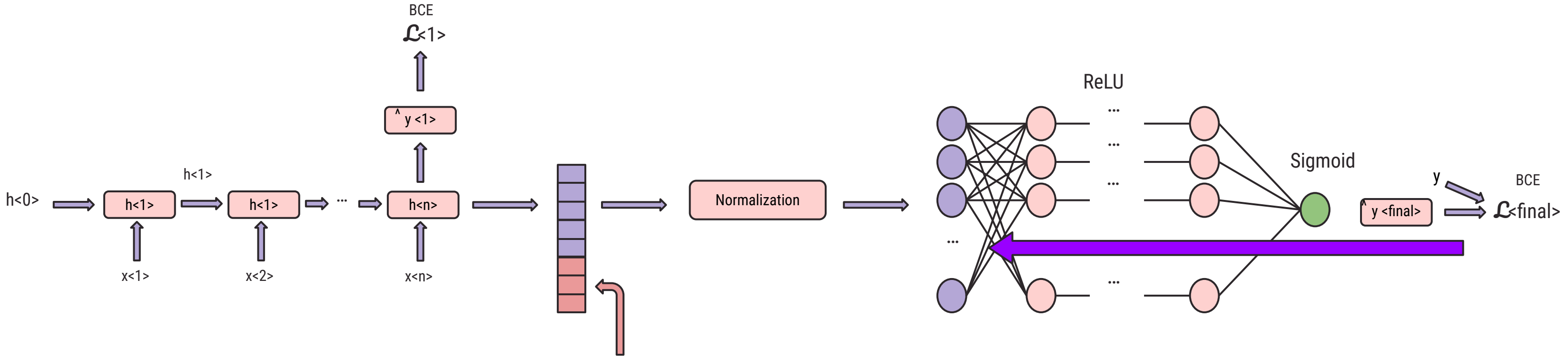
**Data 'Enhancing' and Normalization**



# CLASSIFICATION RVOT-LVOT

## Model Core Idea:

**Training of Network 1:** RNN with LSTM modules **Data ‘Enhancing’ and Normalization** **Training of Network 2:** BMLP

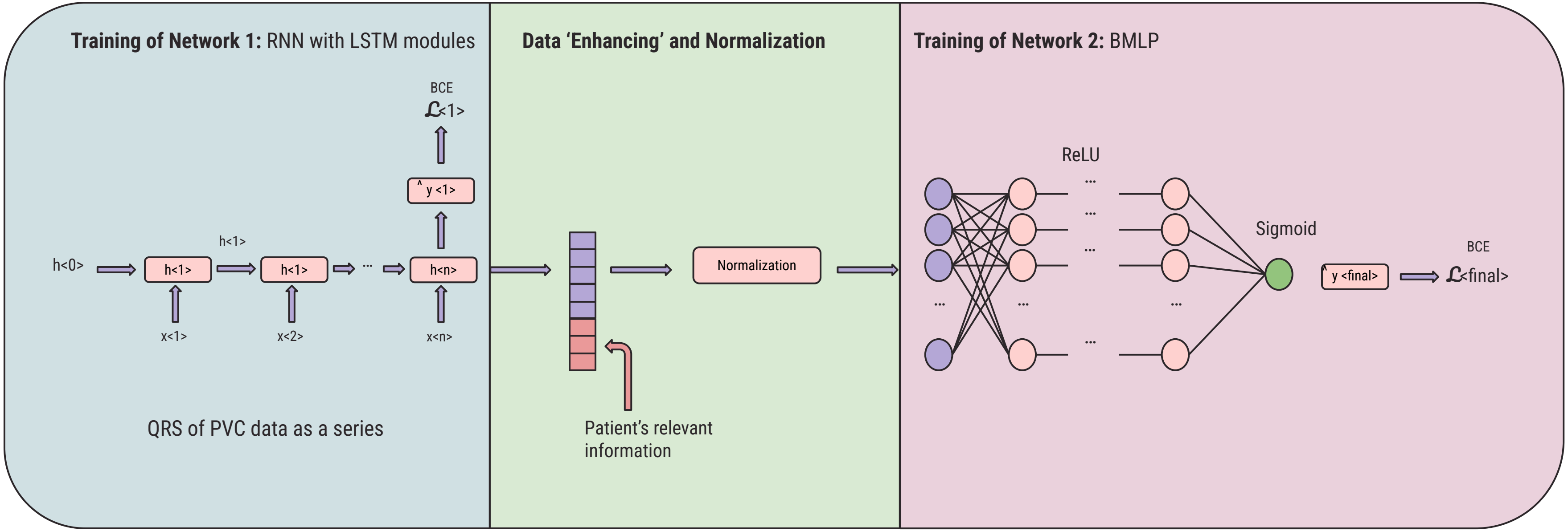



QRS of PVC data as a series

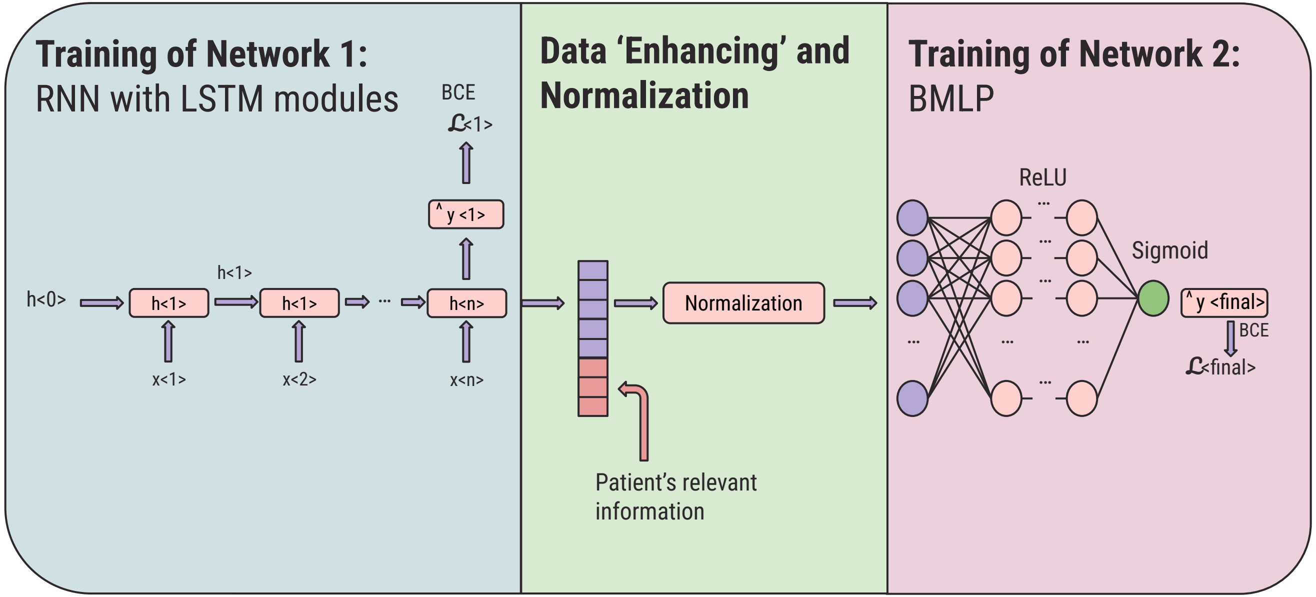
Patient’s relevant information

# CLASSIFICATION RVOT-LVOT

## Model Core Idea:



# CLASSIFICATION RVOT–LVOT



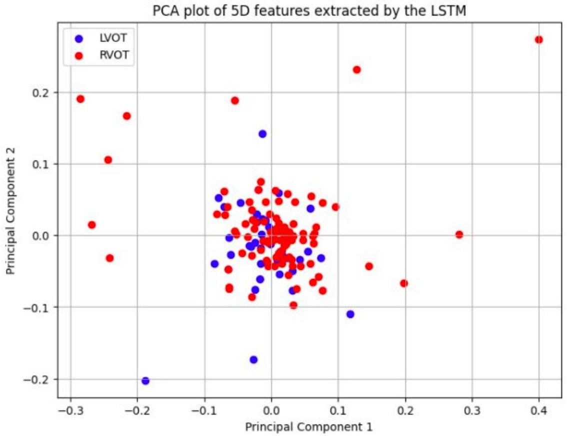
# CLASSIFICATION RVOT-LVOT (previous)

## Data Used in first Models:

180 patients → 143   (removal of empty and undefined SOO)

- Replaced empty values of age, weight and height for mean values

## Previous models



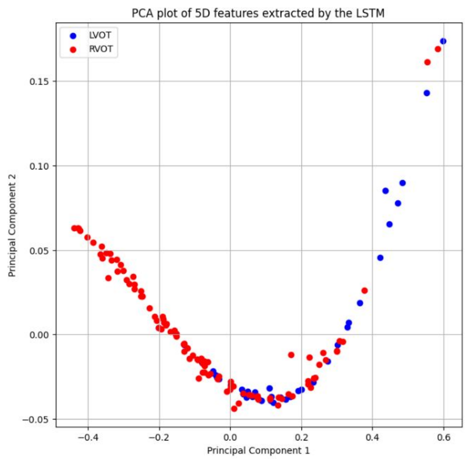

**Model 0:**

- RNN: 5 features extraction
- Input: raw leads

# CLASSIFICATION RVOT-LVOT (previous)

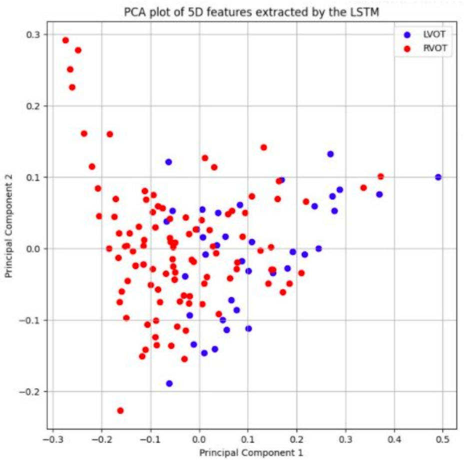
**Model 1:**

- RNN
- Input: QRS from V2 -100
- Accuracy 0.69




**Model 2:**

- RNN
- Input: QRS from V2 & V3 -100
- Accuracy 0.72



# Dataset change

Original Dataset: **143 patients**

- With heavy bias on RVOT

New Combined Dataset: **620 patients**

- Also with heavy bias on RVOT: 355 RVOT, 124 LVOT

**Balanced Training Set**

- 114 RVOT
- 104 LVOT

**Testing Set**

- 28 RVOT
- 20 LVOT

# CLASSIFICATION RVOT–LVOT

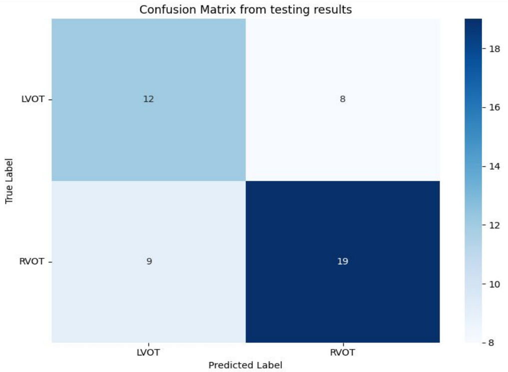
## Model 3.0: RNN + MLP

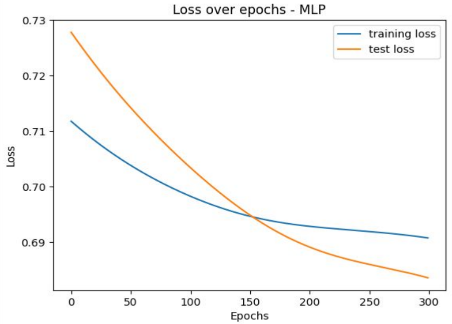
**Input Data:** concatenation of v2 & v3 QRS

| RNN |
|---|
| **Input**: 1D |
| **Embedding**: 5D |

| BMLP |
|---|
| **Input**: 8D |
| **Hidden s.**: [8, 8] |

**Features:** [Age, Height, Weight]




| Precision | |
|---|---|
| **LVOT:** | 57.1% |
| **RVOT**: | 67.9% |

| Recall | |
|---|---|
| **LVOT:** | 60.0% |
| **RVOT**: | 67.9% |

**Accuracy:**
**training**: 0.6513
**testing**: 0.6458

# CLASSIFICATION RVOT–LVOT

## Model 3.2: RNN + MLP

**Input Data:** 2-D vector v2 & v3 QRS

| RNN | BLMP |
|---|---|
| **Input**: 2D | **Input**: 6D |
| **Embedding**: 3D | **Hidden s.**: [5, 5] |

**Features:** [Age, Height, Weight]

**Idea not continued:**

- QRS complexes may not be synchronized
- Accuracy on training data is low and not improving

**Accuracy:**
**training**: 0.564

# CLASSIFICATION RVOT-LVOT

## Model 3.3: RNN + MLP

**Input Data:** Only v2 QRS

| RNN |
| --- |
| **Input**: 1D |
| **Embedding**: 5D |

| BLMP |
| --- |
| **Input**: 8D |
| **Hidden s.**: [10, 10] |

**Features:** [Age, Height, Weight]

**Idea not continued:**

- Accuracy on training data is low and not improving

**Accuracy:**
**training**: 0.591

# CLASSIFICATION RVOT-LVOT

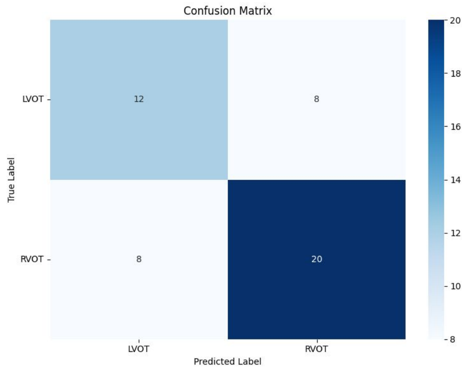
## Model 3.4: RNN + MLP

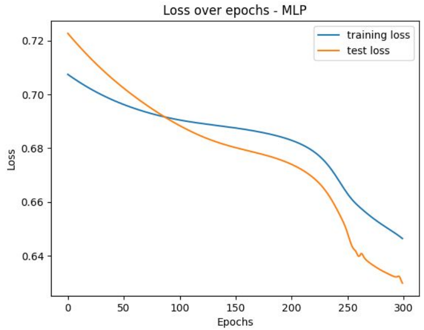
**Input Data:** concatenation of v2 & v3 QRS

| RNN |
|---|
| **Input**: 1D |
| **Embedding**: 10D |

| BLMP |
|---|
| **Input**: 16D |
| **Hidden s.**: [20, 5, 5] |

**Features:**
[Age, Height, Weight, Smoker, HTA, PVC Transition]




| Precision |
|---|
| **LVOT**: 60.0% |
| **RVOT**: 71.1% |

| Recall |
|---|
| **LVOT**: 60.0% |
| **RVOT**: 71.1% |

**Accuracy:**
**training**: 0.7064
**testing**: 0.7083

# CLASSIFICATION RVOT-LVOT

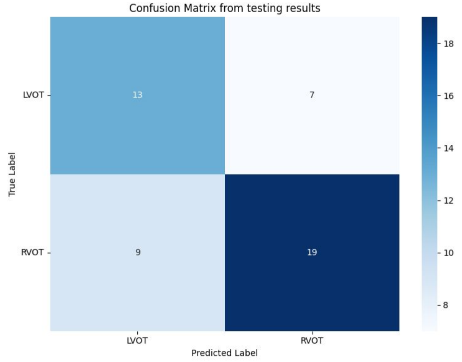
## Model 3.5: RNN + MLP

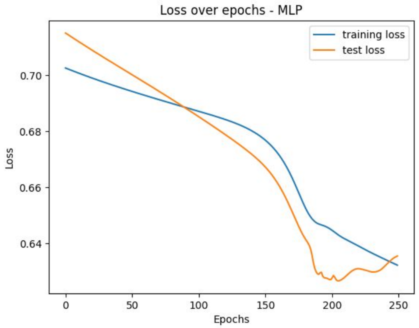
**Input Data:** concatenation of v2 & v3 QRS

| RNN |
|---|
| **Input**: 1D |
| **Embedding**: 10D |

| BLMP |
|---|
| **Input**: 13D |
| **Hidden s.**: [11, 5, 5] |

**Features:**
[Age, HTA, PVC Transition]




| Precision |
|---|
| **LVOT**: 59.0% |
| **RVOT**: 73.1% |

| Recall |
|---|
| **LVOT**: 65.0% |
| **RVOT**: 67.9% |

**Accuracy:**
**training**: 0.6605
**testing**: 0.6666

# CLASSIFICATION RVOT-LVOT

## RVOT-LVOT conclusion:

**Accuracy 3.0:**
training: 0.6513
testing: 0.6458

**Accuracy 3.4:**
training: 0.7064
testing: 0.7083

**Accuracy 3.2:**
training: 0.564

**Accuracy 3.5:**
training: 0.6605
testing: 0.6666

**Accuracy 3.3:**
training: 0.591

**Balanced Training Set**
- 114 RVOT
- 104 LVOT

**Testing Set**
- 28 RVOT
- 20 LVOT

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2 RVOT-LVOT classification

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# OUR SOO

## LVOT SUMMIT

- Triangular area
- 14.5% of LV VAs [3]

## LCC

- Left Coronary Cusp
- 64.3% of LVOT Arrhythmias [4]

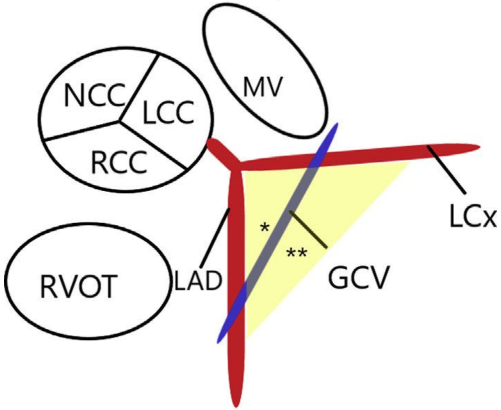



Figure 2: Schematic representation of SOO, Extracted from [5]

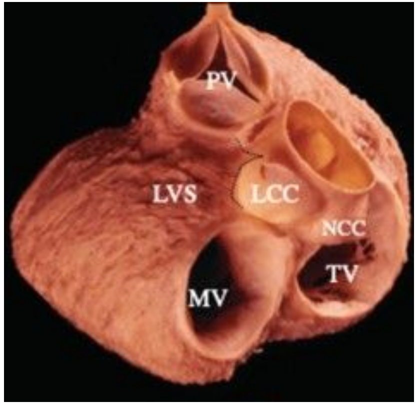



Figure 3: Anatomical position of SOO, extracted from [6]


[3] Yamada T, McElderry HT, Doppalapudi H, Okada T, Murakami Y, Yoshida Y, Yoshida N, Inden Y, Murohara T, Plumb VJ, Kay GN. Idiopathic ventricular arrhythmias originating from the left ventricular summit: anatomic concepts relevant to ablation. Circ Arrhythm Electrophysiol 2010;3:616–623.
[4] Tovia-Brodie, O., Michowitz, Y., Glick, A., Rosso, R., & Belhassen, B. (2016). Left ventricular outflow tract arrhythmias: clinical characteristics and site of origin. Dep. Cardiol, 18, 114-18.
[5] Candemir, B., Baskovski, E., Duzen, V., Coskun, F., Vurgun, K., Goksuluk, H., ... & Erol, C. (2019). Late elimination of challenging idiopathic ventricular arrhythmias originating from left ventricular summit by anatomical ablation. *Indian Pacing and Electrophysiology Journal*, *19*(3), 114-118.
[6] Candemir, B., Baskovski, E., Duzen, V., Coskun, F., Vurgun, K., Goksuluk, H., Ozyuncu, N., Kurklu, S. T., Altin, T., Akyurek, O., & Erol, C. (2019). Late elimination of challenging idiopathic ventricular arrhythmias originating from left ventricular summit by anatomical ablation. *Indian Pacing and Electrophysiology Journal*, *19*(3), 114–118. https://doi.org/10.1016/j.ipej.2019.02.001

# OUR SOO

## LVOT SUMMIT

- ECG: RBBB or LBBB pattern, early PVC transition (V2-3) [7]

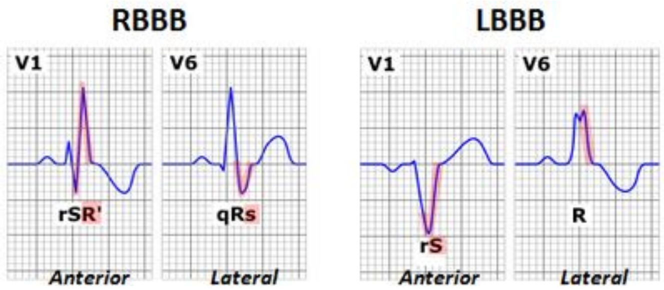



Figure 4: RBBB and LBBB ECG pattern, taken from [9]

## LCC

- ECG: qrS pattern V1-V3 [8]


Figure 5: ECG of PVC originating from LCC, taken from [8]

[7] Liang, J. J., Shirai, Y., Lin, A., & Dixit, S. (2019). Idiopathic outflow tract ventricular arrhythmia ablation: pearls and pitfalls. Arrhythmia & Electrophysiology Review, 8(2), 116.
[8] Yamada, T., Yoshida, N., Murakami, Y., Okada, T., Muto, M., Murohara, T., ... & Kay, G. N. (2008). Electrocardiographic characteristics of ventricular arrhythmias originating from the junction of the left and right coronary sinuses of Valsalva in the aorta: the activation pattern as a rationale for the electrocardiographic characteristics. Heart Rhythm, 5(2), 184-192.
[9] https://medictests.com/units/bundle-branch-blocks-right-left-complete-vs-incomplete

# OUR APPROACH

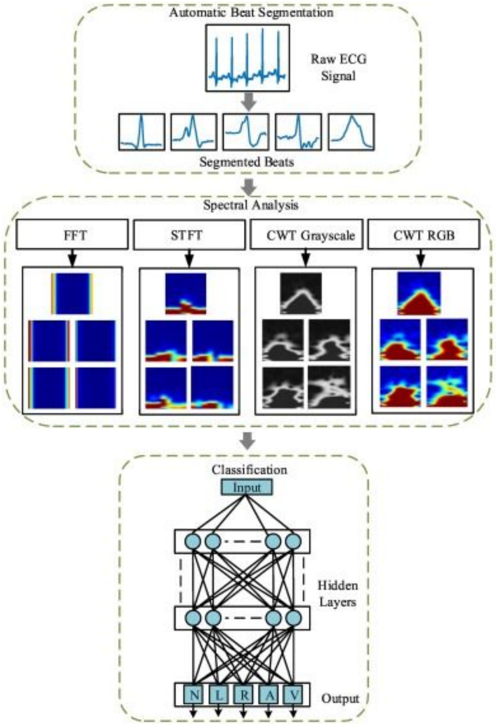



Figure 6: Block diagram of reference [10]

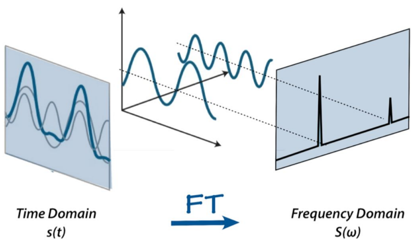



Figure 7: Fourier Transform representation [11]

→ Limited interpretability

## Morlet Wavelet:

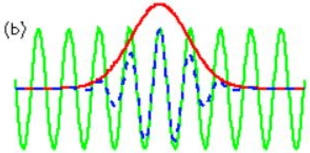



Figure 8: Morlet Wavelet composition [12]

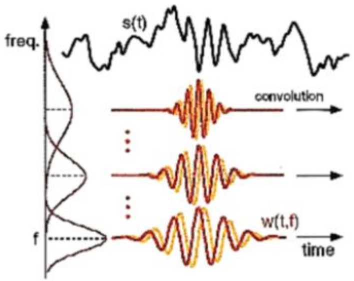



Figure 9: Wavelet convolution [13]


[10] Paper: Mohonta, S. C., Motin, M. A., & Kumar, D. K. (2022). Electrocardiogram based arrhythmia classification using wavelet transform with deep learning model. *Sensing and Bio-Sensing Research*, *37*(100502), 100502.

[11] https://medium.com

[12]https://atoc.colorado.edu/research/wavelets/wavelet2.html

# CWT

$$CWT(a,b) = \langle f, \psi_{a,b} \rangle = \frac{1}{\sqrt{a}} \int_{-\infty}^{+\infty} f(t).\, \psi^{*}\left(\frac{t-b}{a}\right) dt$$

Inner product → wavelet coefficients in function of a (scale) and b (position)

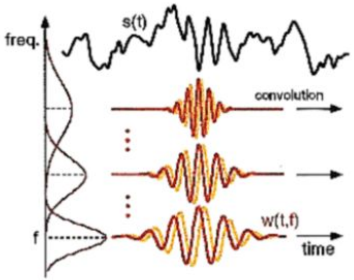



Figure 9: Wavelet convolution [13]

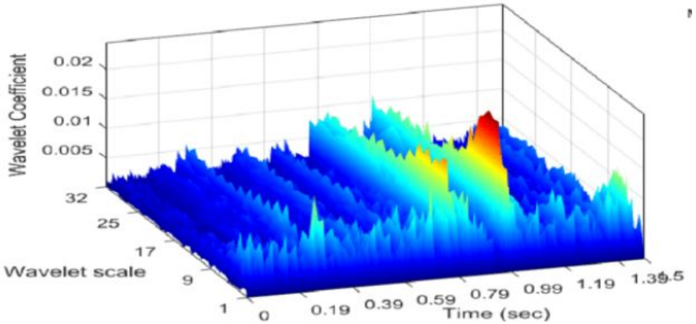
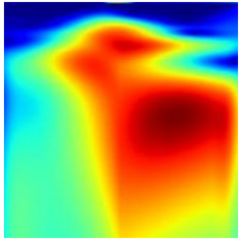



Figure 10: 3D CWT coefficients [14]



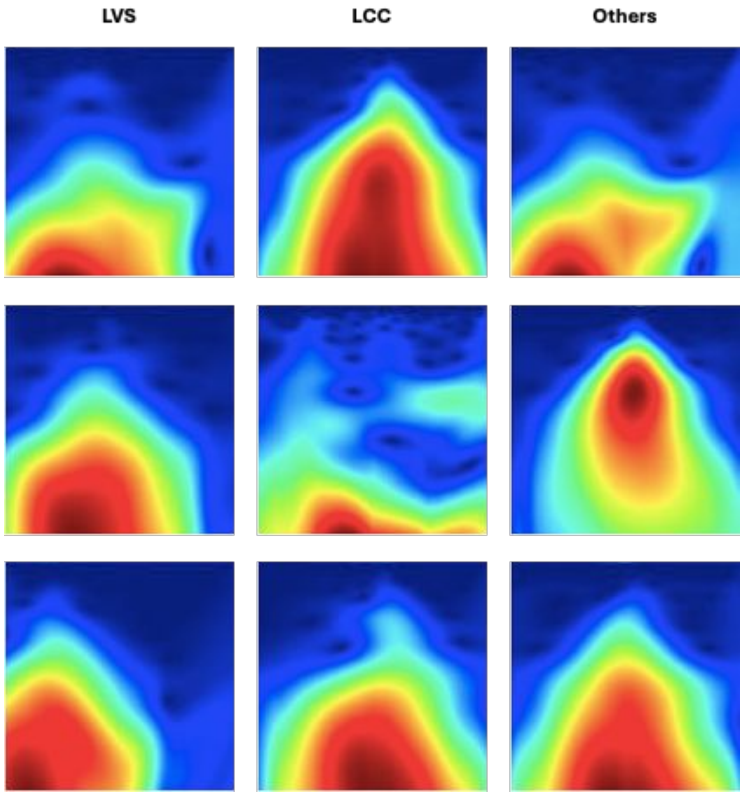

[13] Menassa, D. (2013). Magnetoencephalography and neuropathological studies of autism spectrum disorders and the comorbidity with epilepsy (Doctoral dissertation, Oxford University, UK).

[14] Ali, A., & Sheng-Chang, C. (2022). Seismic reflections de-noising and recognition using Empirical Mode Decomposition and Continuous Wavelet Transformation. Natural and Applied Sciences International Journal (NASIJ), 3(1), 1-12.

# OUR APPROACH: USE OF WAVELETS

1. ECG data
2. Pre-processing and data cleaning
3. Obtain QRS
4. Transform CWT
5. CNN
6. Evaluate accuracy of classification

# SCALOGRAM



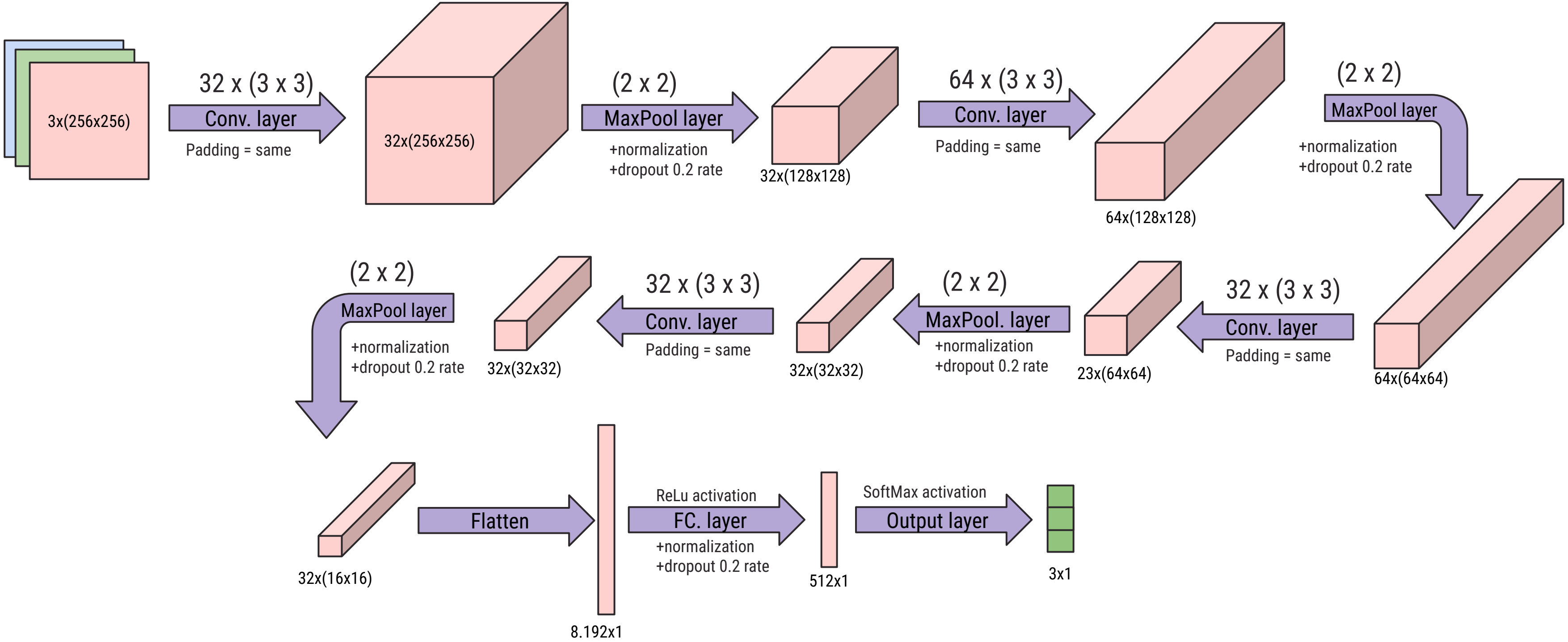

Labelling:

- LVS [1, 0, 0]
- LCC [0, 1, 0]
- Others [0, 0, 1]

Function using scipy.signal.cwt [15]

[15] Scipy.Signal.Cwt — SciPy v1.12.0 manual. (s/f). Scipy.org. https://docs.scipy.org/doc/scipy-1.12.0/reference/generated/scipy.signal.cwt.html

# CNN for SOO Classification



# CLASSIFICATION LVS–LCC–OTHERS

From the original dataset:

- **Approach 1:** Unbalanced data from V2-3
- **Approach 2:** Balanced data from V1-6
- **Approach 3:** Unbalanced data from 12 leads

From the combined dataset:

- **Approach 1:** Balanced data from V2-3
- **Approach 2:** Balanced data from V1-6 (only LVS and LCC classification)

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# CLASSIFICATION LVS–LCC

## Approach 1: Unbalanced data from V2-3

**18 LVS / 44 LCC / 300 others**

**Training**: 10 LVS / 30 LCC / 250 others

| | Learning rate | Batch size, epochs | Optimizer | Accuracy |
|---|---|---|---|---|
| **Attempt 1** | 5e-4 | 20, 70 | Adam | 0.93 |
| **Attempt 2** | 1e-4 | 15, 60 | Adam | 0.97 |
| **Attempt 3** | 1e-3 | 15, 60 | Adam | 1 |

Saved final weights

# CLASSIFICATION LVS-LCC

## Approach 2: Balanced data from V1-6

**Only 54 LVS**

**Training**: 40 LVS / LCC / oth

**Testing**: 6 LVS / LCC / oth

**Validation**: 8 LVS / LCC / oth

| | Learning rate | Batch size, epochs | Optimizer | Accuracy |
|---|---|---|---|---|
| Attempt 1 | 5e-4 | 10, 30 | Adam | 0.73 |
| Weights → Attempt 2 | 8e-4 | 15, 40 | Adam | 0.8 |
| Weights → Attempt 3 | 8e-3 | 15, 40 | Adagrad | 0.87 |

# CLASSIFICATION LVS–LCC

## Approach 3: Unbalanced data from 12 leads

**Training**: 80 LVS / 120 LCC / 170 oth

**Testing**: 9 LVS / 30 LCC / 30 oth

**Validation**: 9 LVS / 50 LCC /  oth

| | Learning rate | Batch size, epochs | Optimizer | Accuracy |
|---|---|---|---|---|
| Weights **Attempt 1** | 8e-4 | 10, 60 | Adam | 0.63 |
| **Attempt 2** | 8e-4 | 15, 40 | Adam | 0.57 |
| Weights **Attempt 3** | 8e-3 | 15, 40 | Adadelta | 0.43 |

Only 54 LVS

# CLASSIFICATION LVS–LCC

## Approach 1: Balanced data from V2-3

**Training**: 40 LVS / LCC / others

**Testing**: 7 LVS / LCC / others

**Validation**: 7 LVS / LCC / others

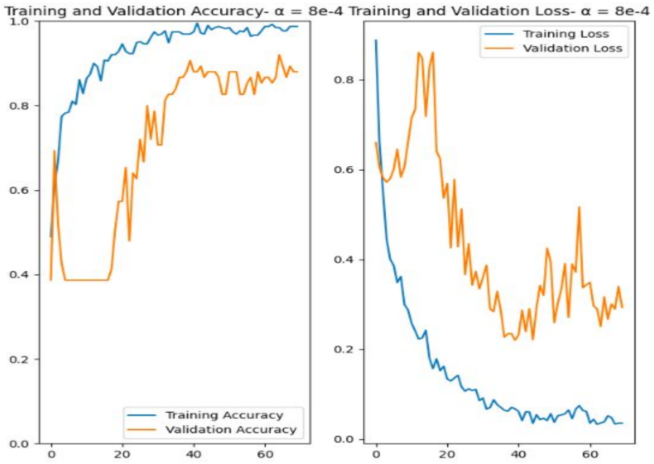
| | Learning rate | Batch size, epochs | Optimizer | Accuracy | Precision |
|---|---|---|---|---|---|
| **Attempt 1** | 8e-4 | 20, 70 | Adam | 0.88 | 81.25% |
| **Attempt 2** | 5e-4 | 15, 45 | Adam | 0.89 | 81.94% |

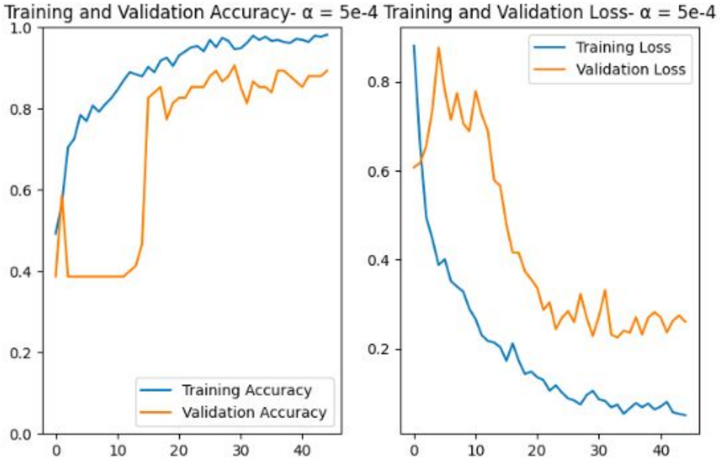
Only 54 LVS

# CLASSIFICATION LVS–LCC

## Approach 1: Balanced data from V2-3

| | Learning rate | Batch size, epochs | Optimizer | Accuracy | Precision |
|---|---|---|---|---|---|
| **Attempt 1** | 8e-4 | 20, 70 | Adam | 0.88 | 81.25% |
| **Attempt 2** | 5e-4 | 15, 45 | Adam | 0.89 | 81.94% |



# CLASSIFICATION LVS–LCC

## Approach 2: Balanced data from V1-6

**135 LVS**

**Training**: 110 LVS / LCC

**Testing**: 15 LVS / LCC

**Validation**: 8 LVS / LCC

| | Learning rate | Batch size, epochs | Optimizer | Accuracy | Precision |
|---|---|---|---|---|---|
| **Attempt 1** | 5e-4 | 10, 40 | Adam | 0.87 | 90% |

```
Ground truth
['lcc', 'lcc', 'lcc', 'lcc', 'lcc', 'lcc', 'lcc', 'lcc', 'lcc', 'lcc', 'lvs', 'lvs', 'lvs', 'lvs', 'lvs', 'lvs', 'lvs', 'lvs', 'lvs', 'lvs']

prediction
['lvs', 'lcc', 'lcc', 'lcc', 'lcc', 'lcc', 'lcc', 'lcc', 'lcc', 'lcc', 'lvs', 'lvs', 'lvs', 'lvs', 'lvs', 'lcc', 'lvs', 'lvs', 'lvs', 'lvs']

Comprovación
['wrong', 'good', 'good', 'good', 'good', 'good', 'good', 'good', 'good', 'good', 'good', 'good', 'good', 'good', 'good', 'wrong', 'good', 'good', 'good', 'good']
90.0
```

# CONCLUSION

- V2 & V3 leads: enable a good classification
- LVS as the limitant

→ Frequency and time unfolding + CNN for extracting features

## Future work:

- SAK implementation for more accurate QRS segments.
- Other metrics for evaluating unbalanced attempts

# Thank you
# for your attention