Impact of Missing Inter-Beat Intervals on Heart Rate Variability Features and Driver Drowsiness Detection

Paper No. 456

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This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101119590

Driver Drowsiness using DMS

Driver Monitoring Systems (DMS)

Vehicle Measures

Steering Angle
Throttle Position
Brake Position
Braking Intensity
Vehicle Heading
Acceleration
Velocity
Headway Distance
Speed Limit Detection
Over/Under Speeding
TLC
Lane Detection
LD
Jerk

Physiological Measures

Skin Conductivity
Respiratory Activity
Heart Activity
Brain Activity

Driver Feedback

Audio
Visual
Vibration
Break/Rest Reminder
Device Lockout
Adaptive Cruise Control
Collision Avoidance
Lane Keeping Assistance

Facial and Body Expression

Gaze Direction
Eye Movements
Eye Blinks
Eye Tightening/Closure
Yawning
Head Movements

A. S. Aghaei *et al.*, "Smart Driver Monitoring: When Signal Processing Meets Human Factors: In the driver's seat," in *IEEE Signal Processing Magazine*, Nov. 2016

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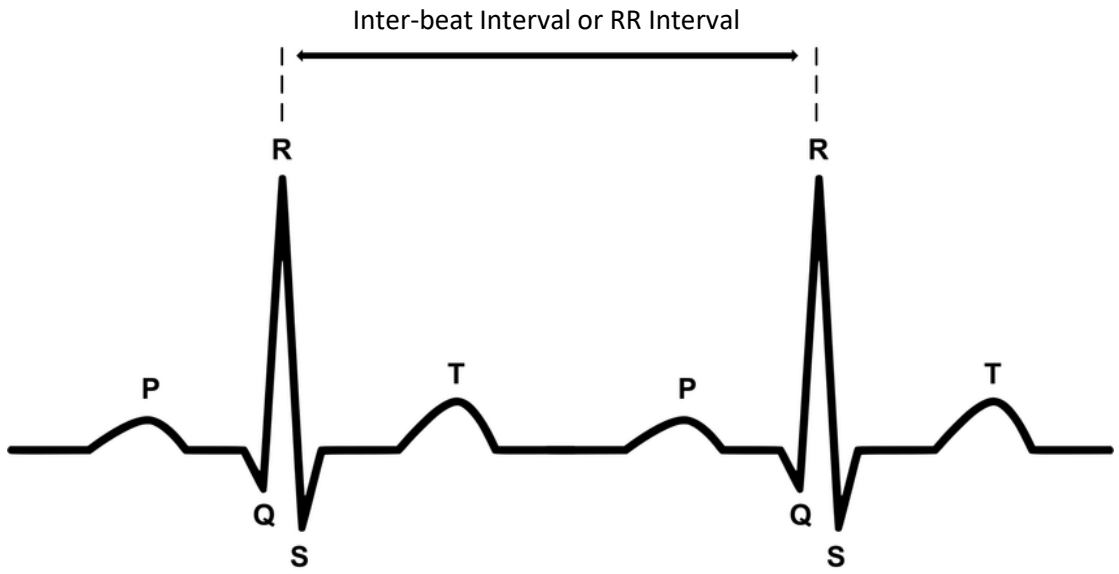
Heart Rate Variability

- ***Electrocardiography (ECG)*** is the record of the electrical activity of the heart.

- ***Heart Rate Variability (HRV)*** is the physiological phenomenon of the variation in the time interval between consecutive heartbeats.



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CardioWheel

CardioWheel is an advanced driver assistance system (ADAS) that assesses driver's status and driving pattern through the combination of **ECG** and **Steering Wheel Angle (SWA) Analysis**. Interacts and alerts the driver whenever drowsiness is detected, based on KSS scale.

Steering Wheel

Smart Conductive Leather or other Conductive material

Cardiowheel Device

Patented eletronics for signal acquisiton and processing

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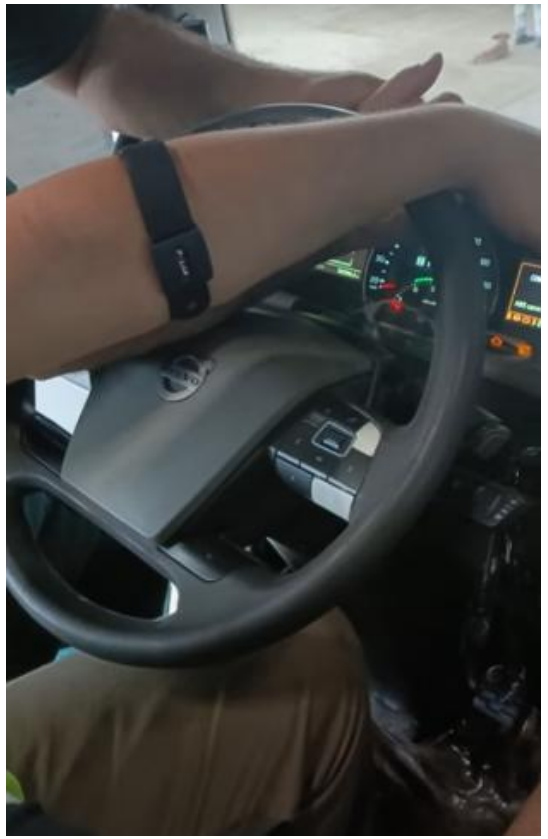
Data Acquisition

CardioWheel

Wearable alternative



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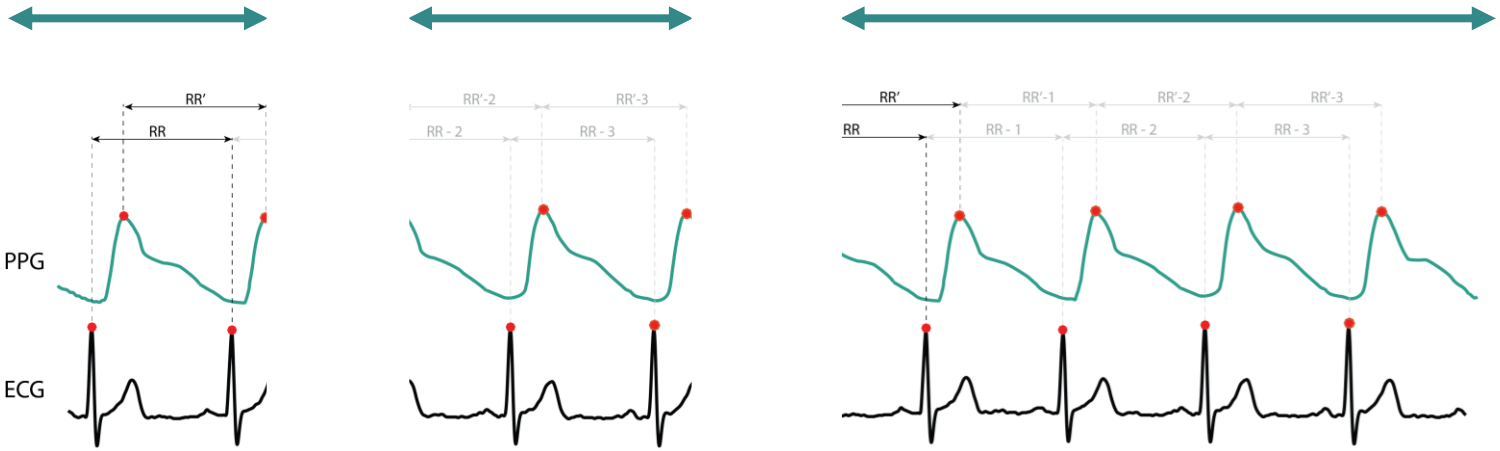
Missing Inter-Beat Intervals

- Motion artifacts
- Sensor displacement
- Inconsistent skin contact



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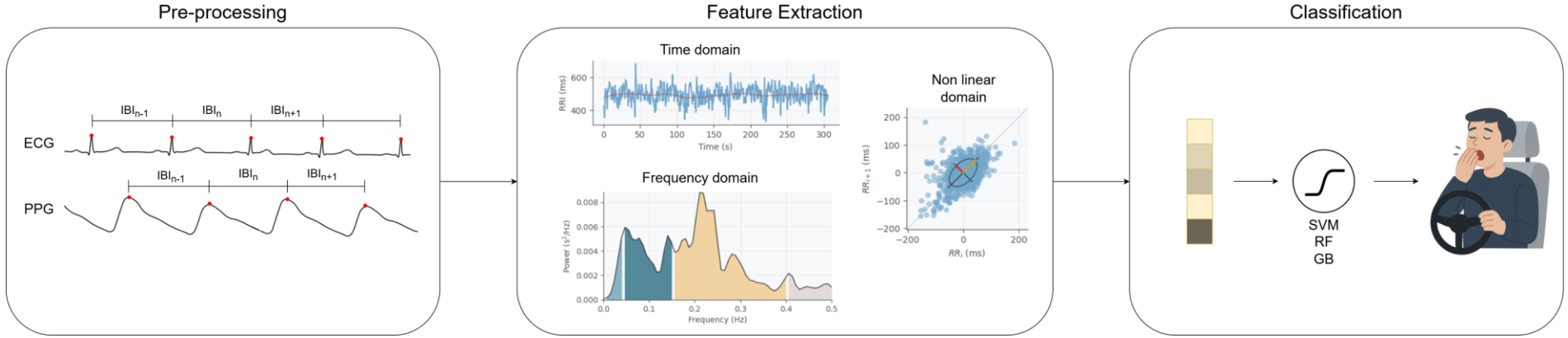
ML based Drowsiness Detection

- Input: ECG or PPG or other signal, Ground Truth: KSS
- Pre-processing: Filtering, Artifact removal, R-peak detection
- Feature extraction: Time domain, Frequency domain, Non linear domain
- Feature based models: Support Vector Machine, Random Forest, Gradient Boosting



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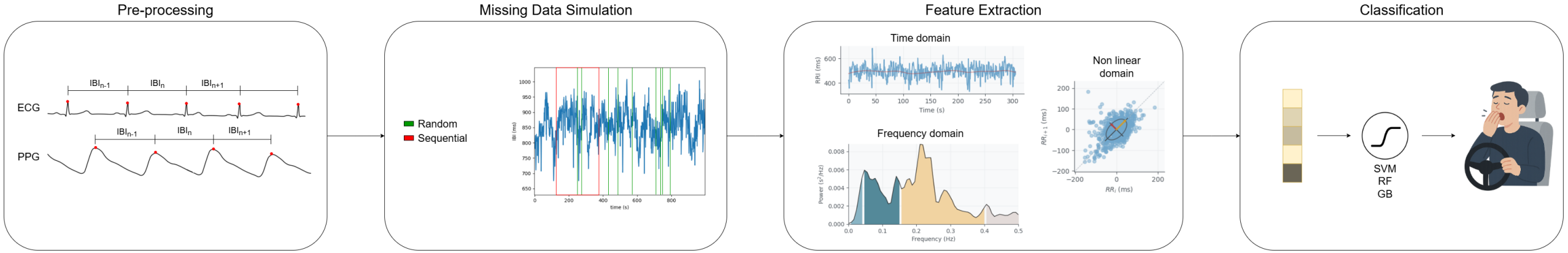
Missing Data Handling Workflow



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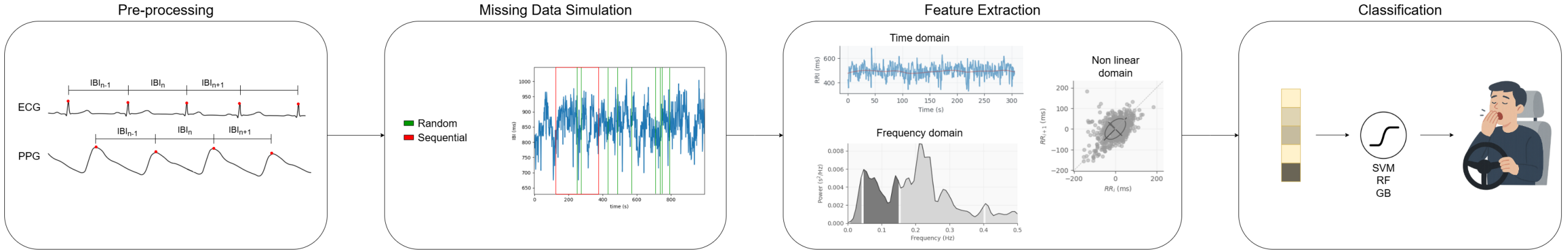

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Karolinska Sleepiness Scale

ALERT	1	Extremely Alert
	2	Very Alert
	3	Alert
	4	Rather Alert
	5	Neither Alert nor Sleepy
	6	Some Signs of Sleepiness
DROWSY	7	Sleepy, but no effort to keep awake
	8	Sleepy, some efforts to keep awake
	9	Sleepy, great effort to keep awake, fighting sleep

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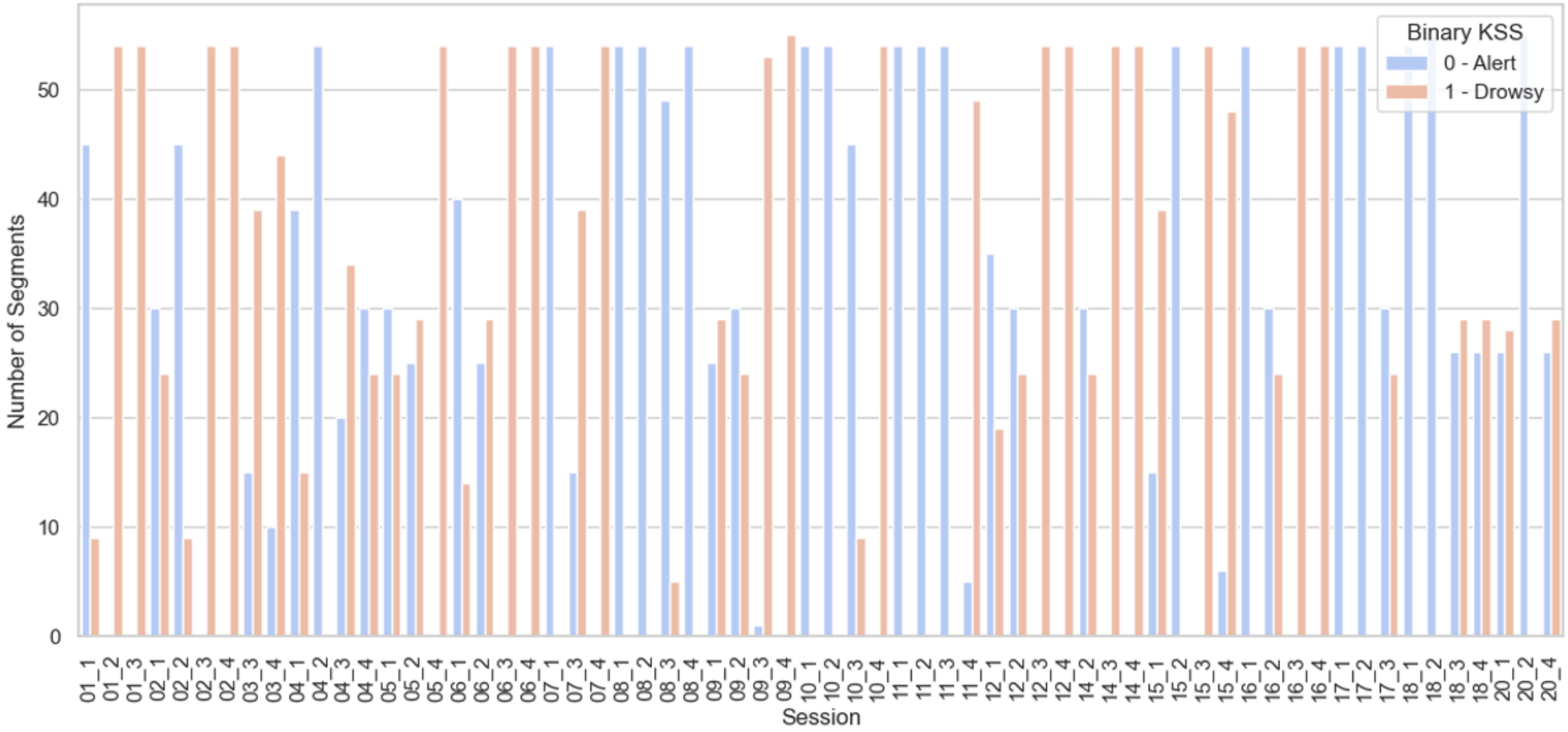
Binary KSS distribution per session



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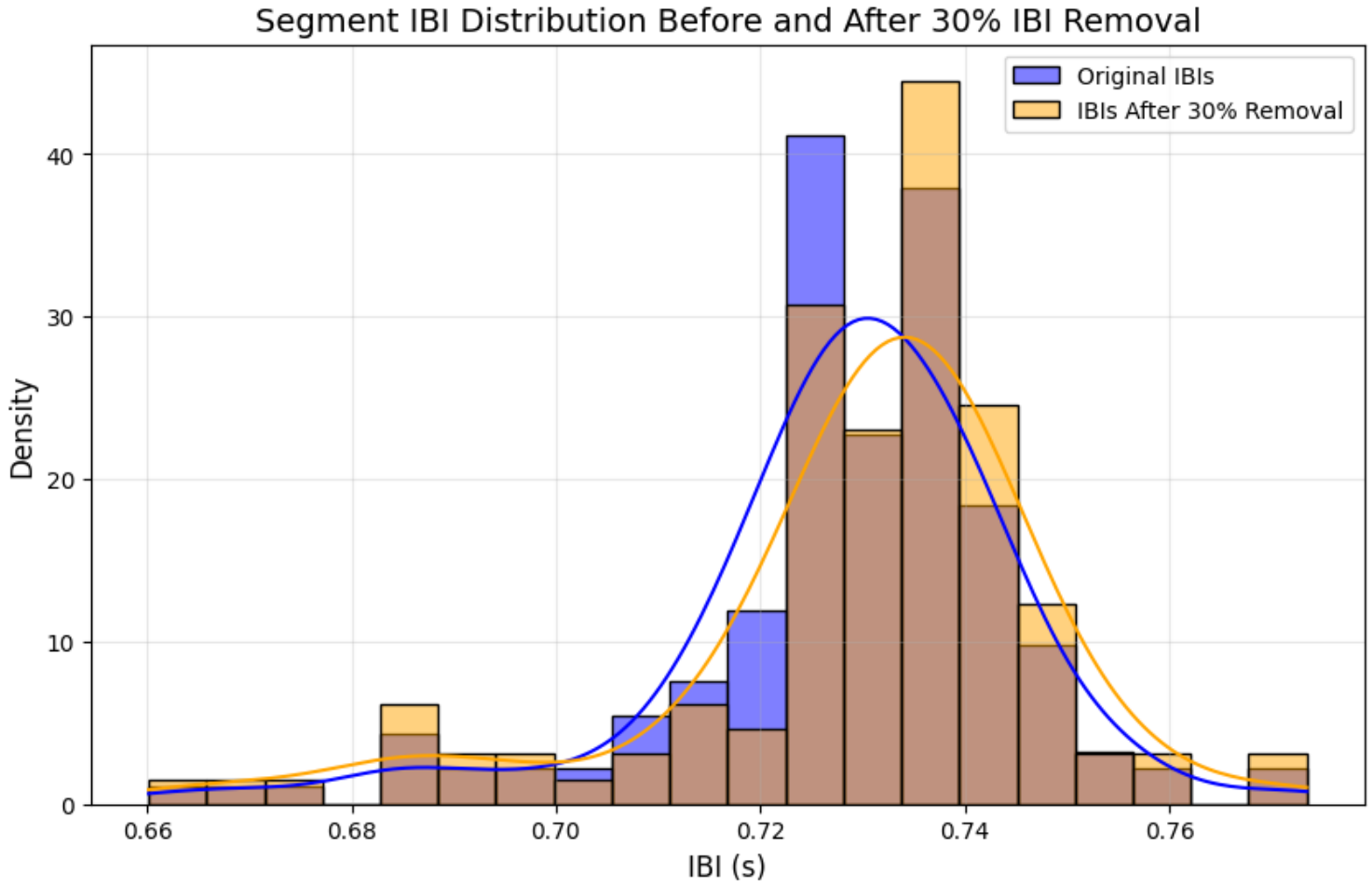
Distribution Analysis



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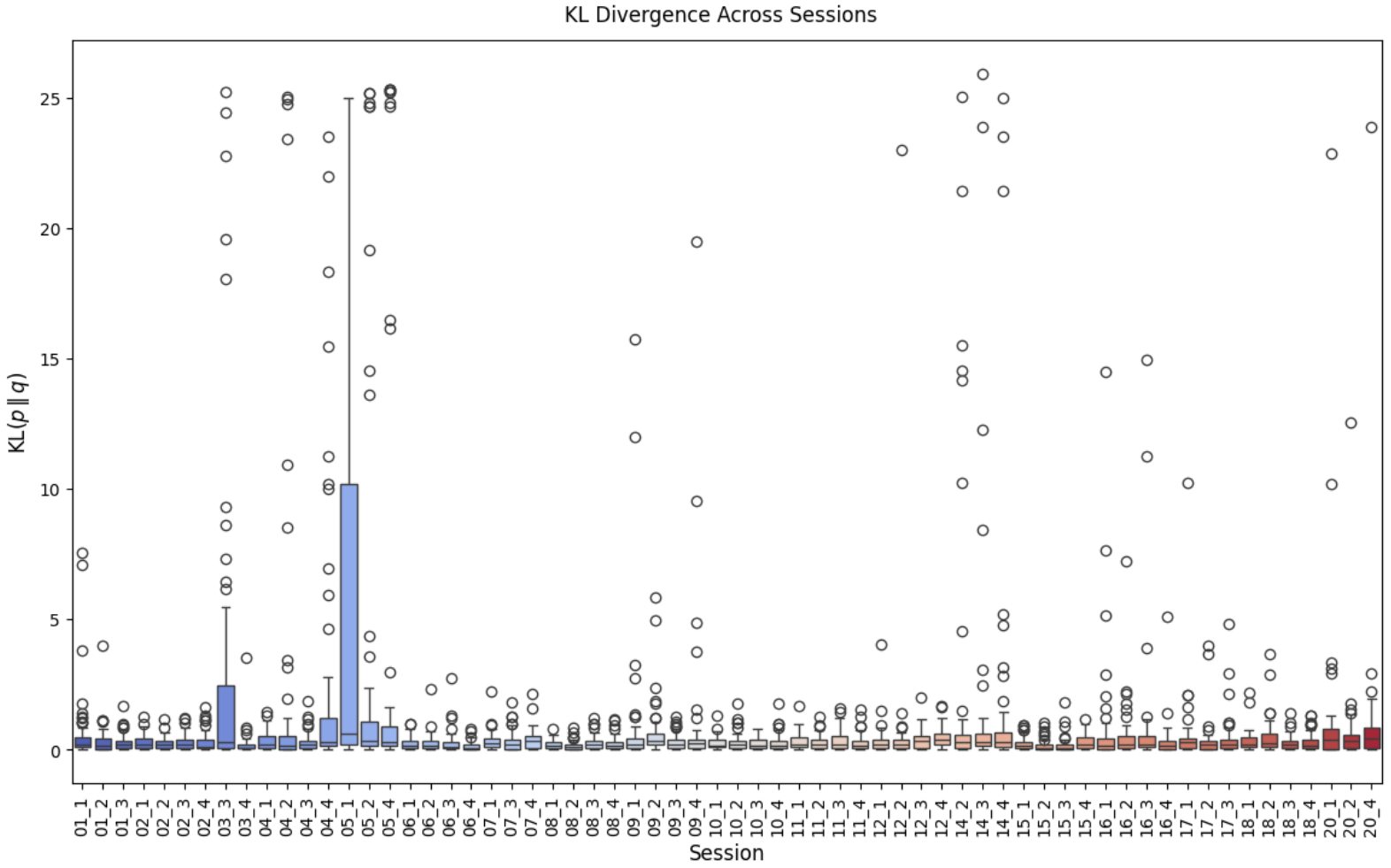

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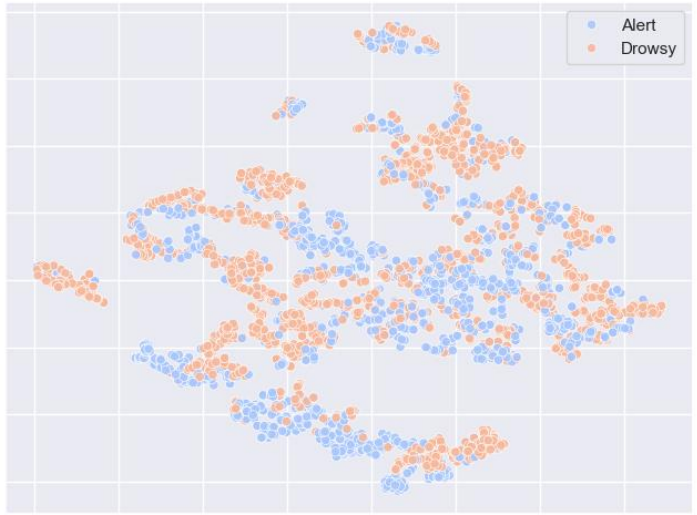
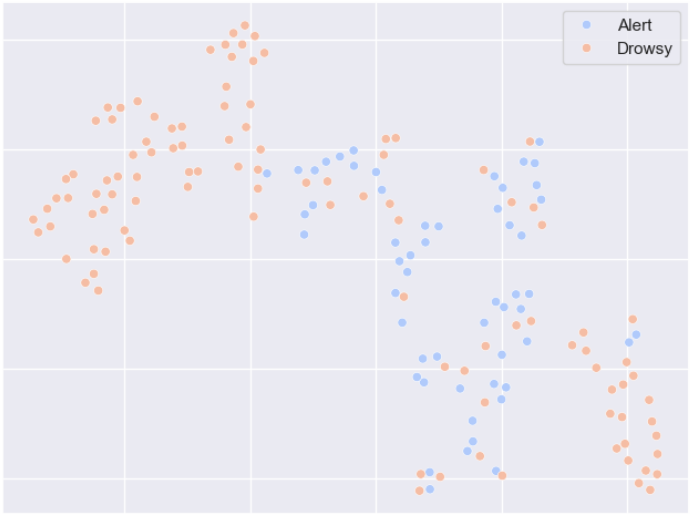
tSNE Analysis

tSNE plot across all Participants



tSNE plot for Participant 1

tSNE plot for Participant 5



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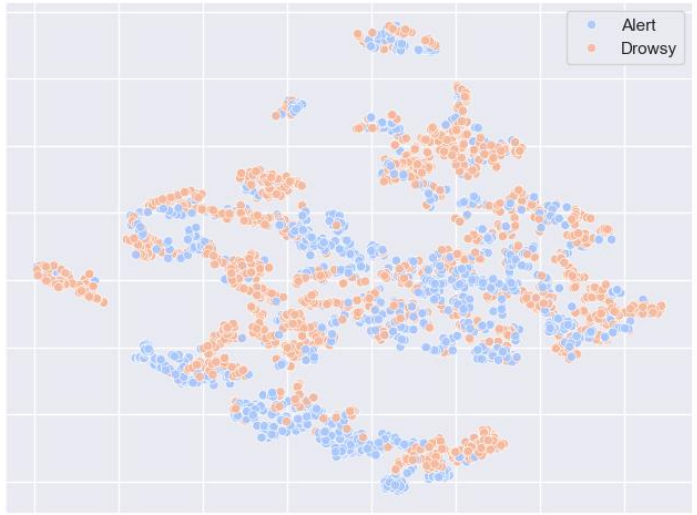
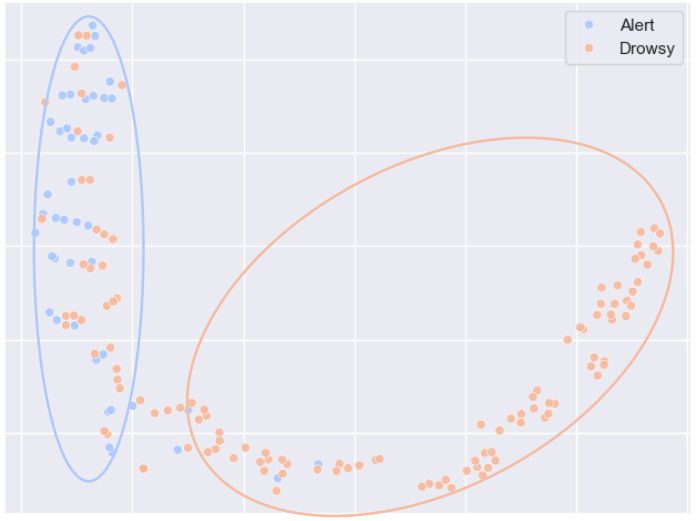
tSNE Analysis

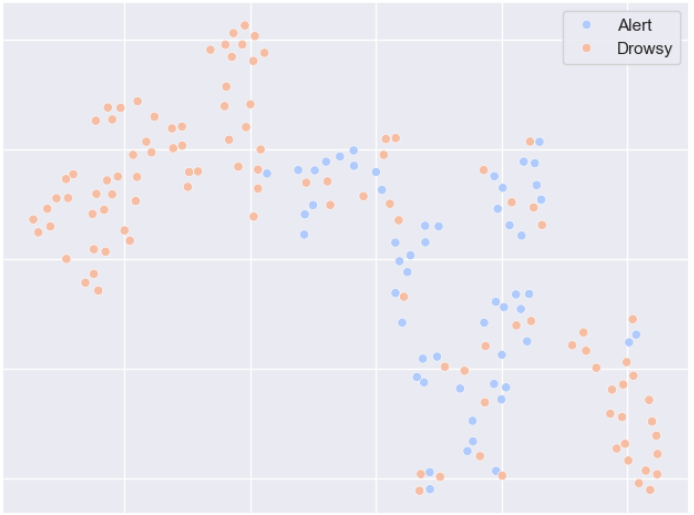
tSNE plot across all Participants



tSNE plot for Participant 1



tSNE plot for Participant 5



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Results

- 10-fold cross-validation

Model	Metric	Baseline	Random Missing Data		Sequential Missing Data	
			15%	30%	15%	30%
SVM	Accuracy	71.20 ± 3.0	70.10 ± 2.8	69.55 ± 2.4	70.13 ± 2.5	70.71 ± 2.3
	Precision	71.41 ± 3.1	70.39 ± 2.9	69.90 ± 2.4	70.32 ± 2.6	70.95 ± 2.4
	Recall	71.20 ± 3.0	70.10 ± 2.8	69.56 ± 2.4	70.13 ± 2.5	70.71 ± 2.3
	F1-score	71.13 ± 3.0	69.98 ± 2.8	69.40 ± 2.4	70.05 ± 2.5	70.62 ± 2.3
	MCC	42.60 ± 6.2	40.48 ± 5.8	39.44 ± 4.9	40.44 ± 5.1	41.65 ± 4.7
RF	Accuracy	78.77 ± 2.6	77.38 ± 2.3	74.26 ± 1.6	77.38 ± 1.6	75.90 ± 2.0
	Precision	78.80 ± 2.5	77.47 ± 2.2	74.38 ± 1.4	77.44 ± 1.6	75.97 ± 2.0
	Recall	78.77 ± 2.6	77.38 ± 2.3	74.26 ± 1.6	77.38 ± 1.6	75.90 ± 2.0
	F1-score	78.76 ± 2.6	77.35 ± 2.3	74.22 ± 1.7	77.37 ± 1.6	75.89 ± 2.0
	MCC	57.57 ± 5.2	54.85 ± 4.5	48.64 ± 3.1	54.82 ± 3.2	51.88 ± 4.1
GB	Accuracy	75.82 ± 1.9	74.66 ± 2.5	72.76 ± 2.0	74.40 ± 2.5	72.76 ± 2.0
	Precision	75.93 ± 2.0	74.77 ± 2.4	72.86 ± 2.0	74.49 ± 2.5	72.86 ± 2.0
	Recall	75.82 ± 1.9	74.66 ± 2.5	72.76 ± 2.0	74.40 ± 2.5	72.76 ± 2.0
	F1-score	75.79 ± 1.9	74.63 ± 2.5	72.72 ± 2.0	74.37 ± 2.5	72.72 ± 2.0
	MCC	51.75 ± 3.9	49.44 ± 4.9	45.62 ± 4.0	48.89 ± 5.1	47.46 ± 4.1

- Leave one subject out cross-validation

Model	Metric	Baseline	Random Missing Data		Sequential Missing Data	
			15%	30%	15%	30%
SVM	Accuracy	55.61 ± 17.9	55.26 ± 17.9	54.32 ± 18.3	54.49 ± 18.1	55.85 ± 17.2
	Precision	71.14 ± 12.4	68.77 ± 18.8	66.22 ± 20.5	70.89 ± 12.2	71.22 ± 12.1
	Recall	55.61 ± 17.9	55.26 ± 17.9	54.32 ± 18.3	54.49 ± 18.1	55.85 ± 17.2
	F1-score	52.25 ± 20.5	51.80 ± 21.0	50.62 ± 21.3	51.27 ± 20.6	53.08 ± 19.3
	MCC	14.45 ± 20.1	14.44 ± 20.3	13.04 ± 20.3	12.91 ± 18.8	14.34 ± 18.9
RF	Accuracy	56.28 ± 17.7	56.05 ± 16.8	53.90 ± 16.5	56.81 ± 16.4	57.39 ± 16.3
	Precision	68.64 ± 12.6	69.48 ± 11.6	68.25 ± 11.7	68.75 ± 12.1	69.38 ± 11.6
	Recall	56.28 ± 17.7	56.05 ± 16.8	53.90 ± 16.5	56.81 ± 16.4	57.39 ± 16.3
	F1-score	54.63 ± 20.7	54.47 ± 19.4	52.10 ± 19.4	55.98 ± 18.3	56.54 ± 18.4
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GB	Accuracy	54.88 ± 17.9	55.67 ± 16.8	53.87 ± 16.0	52.30 ± 16.2	55.01 ± 16.4
	Precision	70.67 ± 10.7	71.54 ± 11.8	68.88 ± 12.8	70.60 ± 12.4	70.21 ± 12.2
	Recall	54.88 ± 17.9	55.67 ± 16.8	53.87 ± 16.0	52.30 ± 16.2	55.01 ± 16.4
	F1-score	51.72 ± 21.9	53.49 ± 19.8	51.73 ± 18.6	49.39 ± 20.3	53.40 ± 19.3
	MCC	14.21 ± 20.1	15.22 ± 19.9	10.92 ± 19.4	12.79 ± 18.1	13.35 ± 20.0

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Results

- 10-fold cross-validation

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	MCC	42.60 ± 6.2	40.48 ± 5.8	39.44 ± 4.9	40.44 ± 5.1	41.65 ± 4.7
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RF	Accuracy	78.77 ± 2.6	77.38 ± 2.3	74.26 ± 1.6	77.38 ± 1.6	75.90 ± 2.0
	Precision	78.80 ± 2.5	77.47 ± 2.2	74.38 ± 1.4	77.44 ± 1.6	75.97 ± 2.0
	Recall	78.77 ± 2.6	77.38 ± 2.3	74.26 ± 1.6	77.38 ± 1.6	75.90 ± 2.0
	F1-score	78.76 ± 2.6	77.35 ± 2.3	74.22 ± 1.7	77.37 ± 1.6	75.89 ± 2.0
	MCC	57.57 ± 5.2	54.85 ± 4.5	48.64 ± 3.1	54.82 ± 3.2	51.88 ± 4.1
GB	Accuracy	75.82 ± 1.9	74.66 ± 2.5	72.76 ± 2.0	74.40 ± 2.5	72.76 ± 2.0
	Precision	75.93 ± 2.0	74.77 ± 2.4	72.86 ± 2.0	74.49 ± 2.5	72.86 ± 2.0
	Recall	75.82 ± 1.9	74.66 ± 2.5	72.76 ± 2.0	74.40 ± 2.5	72.76 ± 2.0
	F1-score	75.79 ± 1.9	74.63 ± 2.5	72.72 ± 2.0	74.37 ± 2.5	72.72 ± 2.0
	MCC	51.75 ± 3.9	49.44 ± 4.9	45.62 ± 4.0	48.89 ± 5.1	47.46 ± 4.1

- Leave one subject out cross-validation

Model	Metric	Baseline	Random Missing Data		Sequential Missing Data	
			15%	30%	15%	30%
SVM	Accuracy	55.61 ± 17.9	55.26 ± 17.9	54.32 ± 18.3	54.49 ± 18.1	55.85 ± 17.2
	Precision	71.14 ± 12.4	68.77 ± 18.8	66.22 ± 20.5	70.89 ± 12.2	71.22 ± 12.1
	Recall	55.61 ± 17.9	55.26 ± 17.9	54.32 ± 18.3	54.49 ± 18.1	55.85 ± 17.2
	F1-score	52.25 ± 20.5	51.80 ± 21.0	50.62 ± 21.3	51.27 ± 20.6	53.08 ± 19.3
	MCC	14.45 ± 20.1	14.44 ± 20.3	13.04 ± 20.3	12.91 ± 18.8	14.34 ± 18.9
RF	Accuracy	56.28 ± 17.7	56.05 ± 16.8	53.90 ± 16.5	56.81 ± 16.4	57.39 ± 16.3
	Precision	68.64 ± 12.6	69.48 ± 11.6	68.25 ± 11.7	68.75 ± 12.1	69.38 ± 11.6
	Recall	56.28 ± 17.7	56.05 ± 16.8	53.90 ± 16.5	56.81 ± 16.4	57.39 ± 16.3
	F1-score	54.63 ± 20.7	54.47 ± 19.4	52.10 ± 19.4	55.98 ± 18.3	56.54 ± 18.4
	MCC	15.06 ± 21.5	15.30 ± 19.7	11.05 ± 18.7	15.13 ± 20.1	15.32 ± 19.7
GB	Accuracy	54.88 ± 17.9	55.67 ± 16.8	53.87 ± 16.0	52.30 ± 16.2	55.01 ± 16.4
	Precision	70.67 ± 10.7	71.54 ± 11.8	68.88 ± 12.8	70.60 ± 12.4	70.21 ± 12.2
	Recall	54.88 ± 17.9	55.67 ± 16.8	53.87 ± 16.0	52.30 ± 16.2	55.01 ± 16.4
	F1-score	51.72 ± 21.9	53.49 ± 19.8	51.73 ± 18.6	49.39 ± 20.3	53.40 ± 19.3
	MCC	14.21 ± 20.1	15.22 ± 19.9	10.92 ± 19.4	12.79 ± 18.1	13.35 ± 20.0

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101119590

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Conclusion

- Missing IBI data does not significantly impact HRV-based drowsiness detection models
- HRV feature distributions remain stable even with increased data loss
- Inter-individual variability is important!
  - Results suggest the need for personalized or adaptive models

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Future Work

- Investigate and compare missing data handling techniques
- Assess impact on frequency-domain & nonlinear HRV features
- Improve model performance via hyperparameter tuning and feature importance analysis
- Incorporate temporal HRV dynamics across multiple time windows, instead of single-segment analysis

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101119590

Thank you

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This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101119590