WESAD Exploration

March 6, 2025

[186]:
```
import pandas as pd
import matplotlib.pyplot as plt
import numpy as np
import flirt
import neurokit2 as nk

%matplotlib widget
```

Load wesad data specimen.

[187]:
```
wesad_data = '/home/art/Downloads/WESAD/S7/S7.pkl'
dataset = pd.read_pickle(wesad_data)
BVP = dataset['signal']['wrist']['BVP'][:,0]
EDA = dataset['signal']['wrist']['EDA'][:,0]
TEMP = dataset['signal']['wrist']['TEMP'][:,0]
RESP = dataset['signal']['chest']['Resp'][:,0]
ECG = dataset['signal']['chest']['ECG'][:,0]
label = dataset['label']
```

Upsample wrist data.

[188]:
```
ECG_down = nk.signal_resample(ECG, sampling_rate=700,␣
 ↪desired_sampling_rate=256, method='interpolation')
RESP_down = nk.signal_resample(RESP, sampling_rate=700,␣
 ↪desired_length=len(ECG_down), method='interpolation')
BVP_up = nk.signal_resample(BVP, desired_length=len(ECG_down), method='FFT')
EDA_up = nk.signal_resample(EDA, desired_length=len(ECG_down), method='poly')
TEMP_up = nk.signal_resample(TEMP, desired_length=len(ECG_down), method='poly')
label_resampled = nk.signal_resample(label, desired_length=len(ECG_down),␣
 ↪method='interpolation')

data_df = pd.DataFrame(
    {
    'BVP': BVP_up,
    'EDA': EDA_up,
    'TEMP': TEMP_up,
    'ECG': ECG_down,
    'RESP': RESP_down,
```

```
    'label' : label_resampled,
}
)

data_df.head()
```

[188]:

	BVP	EDA	TEMP	ECG	RESP	label
0	9.570000	5.973745	33.272443	-0.019226	1.832581	0
1	13.690549	6.038064	33.622649	-0.012980	1.837982	0
2	13.802470	6.099970	33.959122	-0.031913	1.795855	0
3	11.086804	6.159436	34.281717	-0.110225	1.797355	0
4	7.410000	6.216439	34.590313	-0.095998	1.817480	0

Get Features out of WESAD Data.

[189]:
```
ecg_signals, ecg_info = nk.ecg_process(data_df['ECG'], sampling_rate=256)
nk.ecg_plot(ecg_signals, ecg_info)
eda_signals, eda_info = nk.eda_process(data_df['EDA'], sampling_rate=256,␣
 ↪report='Text')
nk.eda_plot(eda_signals, eda_info)
ppg_signals, ppg_info = nk.ppg_process(data_df['BVP'], sampling_rate=256,␣
 ↪report='Text')
nk.ppg_plot(ppg_signals, ppg_info)
resp_signals, resp_info = nk.rsp_process(data_df['RESP'], sampling_rate=256,␣
 ↪method='khodadad2018', method_rvt='harrison2021', report='Text')
nk.rsp_plot(resp_signals, resp_info)
```

```
The raw signal, sampled at 256 Hz, was cleaned using the default method of the
neurokit2 package.

The signal was decomposed into phasic and tonic components using the method
described in neurokit.

The cleaned signal was used to detect peaks using the default method of the
`neurokit2` package.



References
- https://doi.org/10.21105/joss.01667
The raw signal, sampled at 256 Hz, was preprocessed using a bandpass filter
([0.5 - 8 Hz], Butterworth 3rd order; following Elgendi et al., 2013).

The peak detection was carried out using the method described in Elgendi et al.
(2013).

The quality assessment was carried out using template-matching, approximately as
described in Orphanidou et al. (2015).
```

```
   PPG_Rate_Mean  PPG_Rate_SD
0      66.285141    24.456355
```

References

- Elgendi M, Norton I, Brearley M, Abbott D, Schuurmans D (2013)
            Systolic Peak Detection in Acceleration Photoplethysmograms
            Measured from Emergency Responders in Tropical Conditions
            PLoS ONE 8(10): e76585. doi:10.1371/journal.pone.0076585.
- Makowski, D., Pham, T., Lau, Z. J., Brammer, J. C., Lespinasse, F., Pham, H.,
    Schölzel, C., & Chen, S. A. (2021). NeuroKit2: A Python toolbox for
neurophysiological signal processing.
    Behavior Research Methods, 53(4), 1689-1696.
https://doi.org/10.3758/s13428-020-01516-y

- Orphanidou C, Bonnici T, Charlton P, Clifton D, Vallance D, Tarassenko L
(2015)
            Signal-quality indices for the electrocardiogram and
photoplethysmogram: Derivation
            and applications to wireless monitoring
            IEEE Journal of Biomedical and Health Informatics 19(3): 832-838.
doi:10.1109/JBHI.2014.2338351.

The raw signal, sampled at 256 Hz, was preprocessed using a second order 0.05-3 Hz bandpass Butterworth filter.

The peak detection was carried out using the method described in Khoadadad et al. (2018).

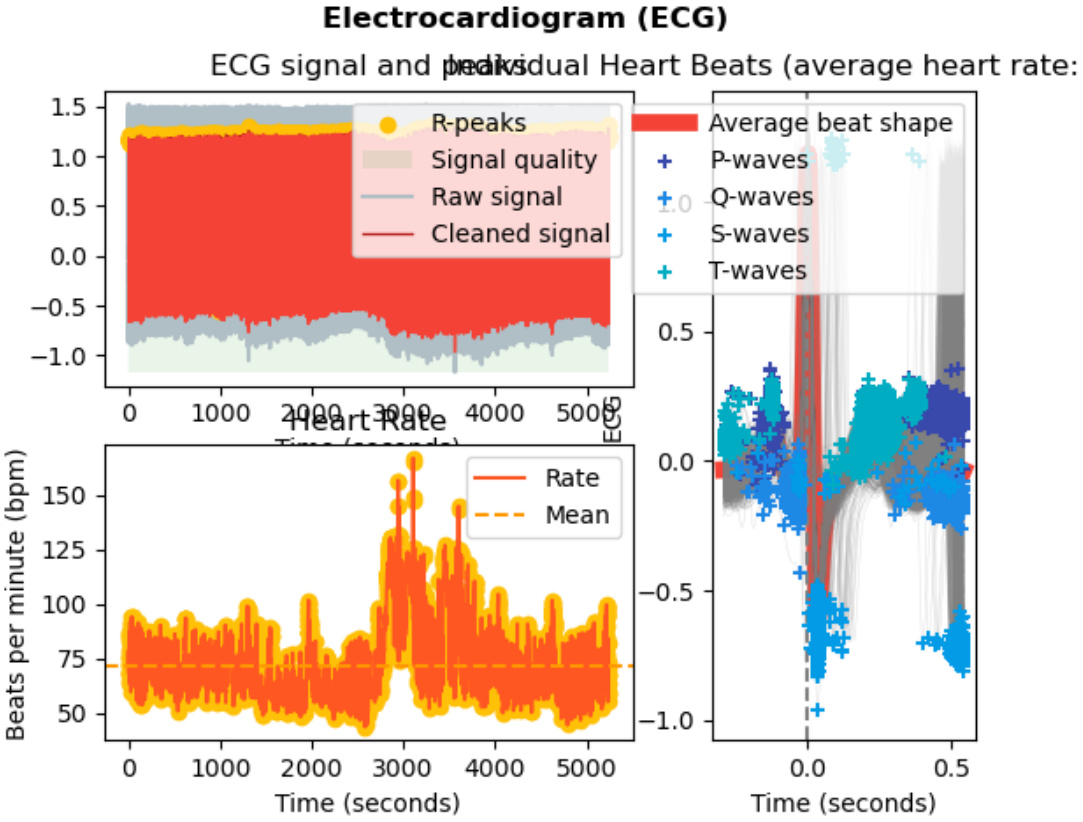
The respiratory volume per time computation was carried out using the method described in Harrison et al. (2021).

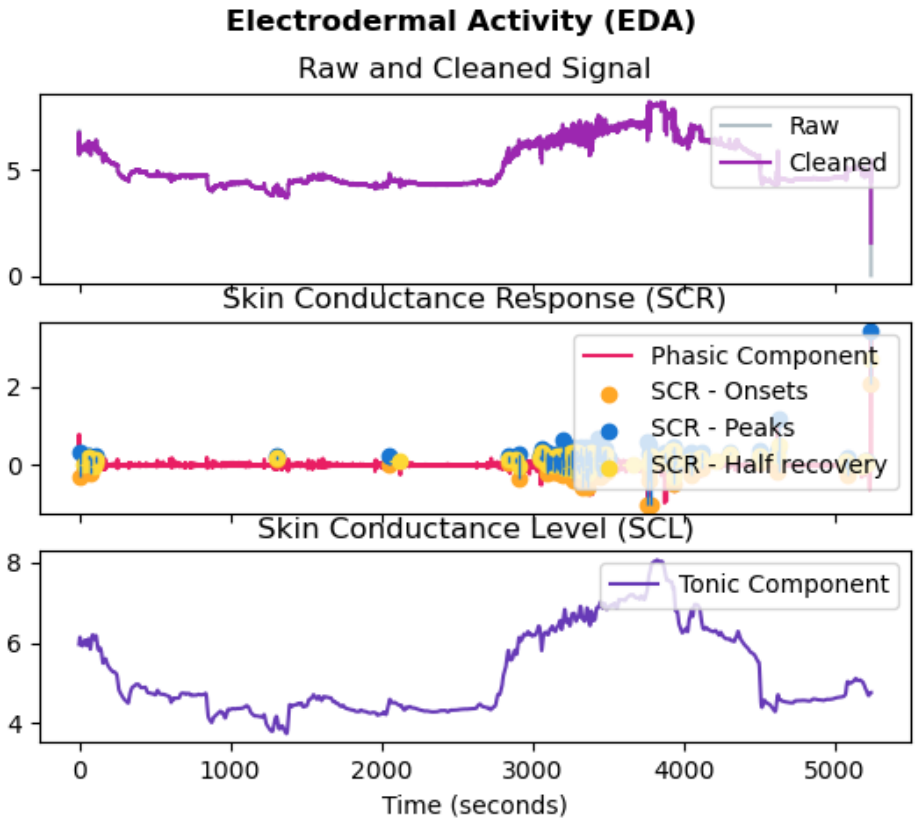
```
   RSP_Rate_Mean  RSP_Rate_SD
0      15.502424      6.14461
```

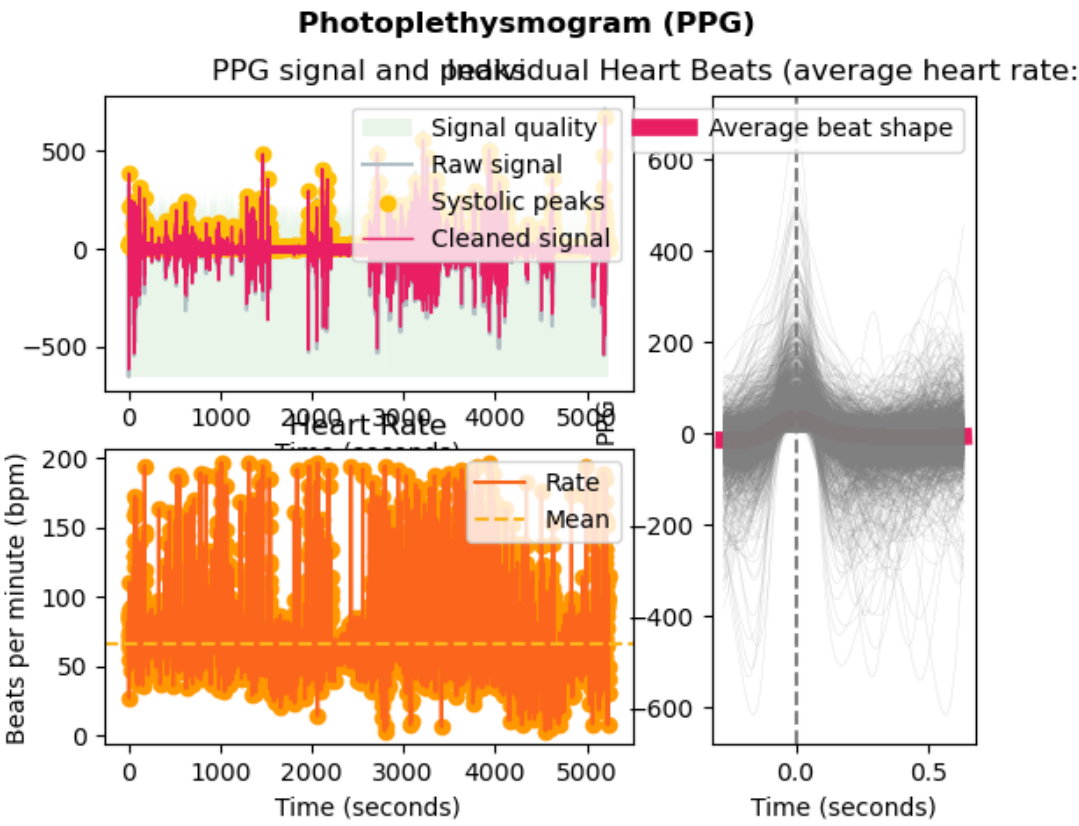
References

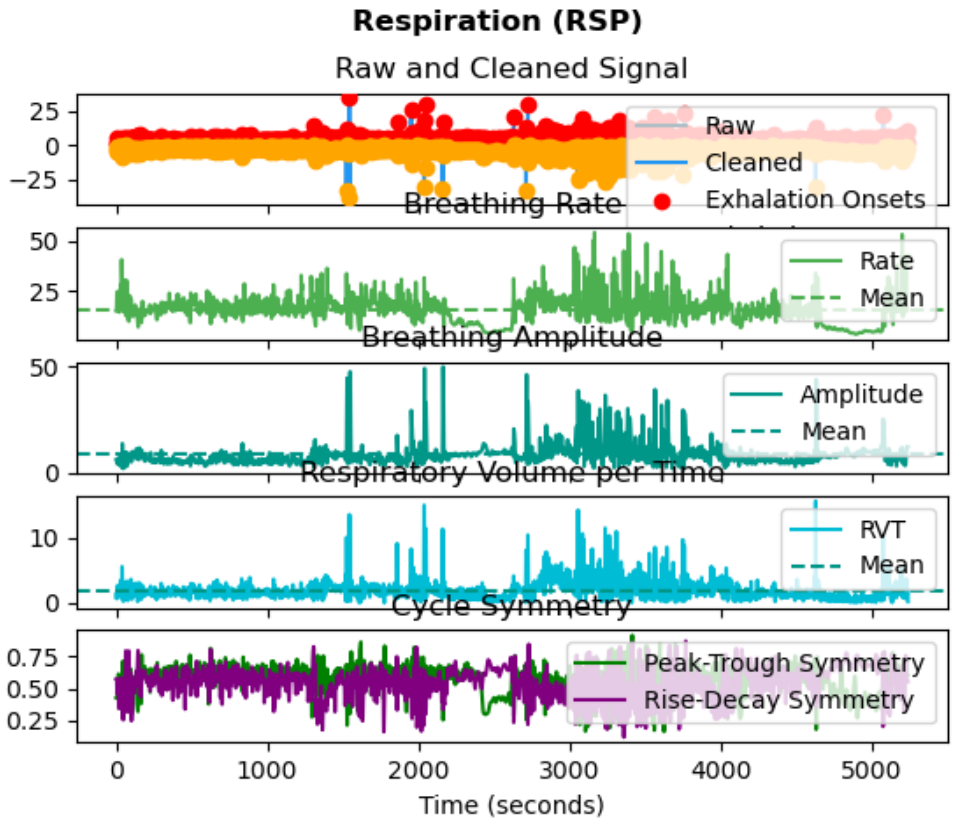
- Harrison, S. J., Bianchi, S., Heinzle, J., Stephan, K. E., Iglesias, S., &
Kasper, L. (2021).
            A Hilbert-based method for processing respiratory timeseries.
            Neuroimage, 230, 117787.
- Khodadad, D., Nordebo, S., Müller, B., Waldmann, A., Yerworth, R., Becher, T.,
… & Bayford, R. (2018).
            Optimized breath detection algorithm in electrical impedance
tomography.
            Physiological measurement, 39(9), 094001.
- Makowski, D., Pham, T., Lau, Z. J., Brammer, J. C., Lespinasse, F., Pham, H.,
    Schölzel, C., & Chen, S. A. (2021). NeuroKit2: A Python toolbox for
neurophysiological signal processing.
    Behavior Research Methods, 53(4), 1689-1696.

https://doi.org/10.3758/s13428-020-01516-y




Electrodermal Activity (EDA)
Raw and Cleaned Signal
Raw
Cleaned
5
0
Skin Conductance Response (SCR)
Phasic Component
SCR - Onsets
SCR - Peaks
SCR - Half recovery
2
0
Skin Conductance Level (SCL)
Tonic Component
8
6
4
0
1000
2000
3000
4000
5000
Time (seconds)


Photoplethysmogram (PPG)
PPG signal and peaks
Individual Heart Beats (average heart rate:
Signal quality
Raw signal
Systolic peaks
Cleaned signal
Average beat shape
Heart Rate
Rate
Mean
Beats per minute (bpm)
Time (seconds)
Time (seconds)



[190]:
```
quick_feat = flirt.with_.empatica('/home/art/Downloads/WESAD/S7/S7_E4_Data.zip',
                                  window_length= 60,
                                  window_step_size = 1,
                                  hrv_features = True,
                                  eda_features = True,
                                  acc_features = True)
```

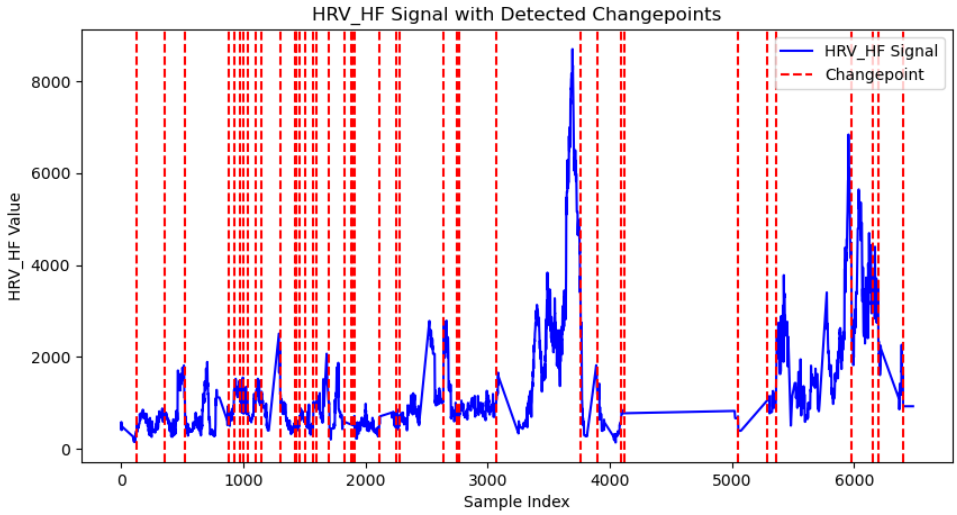
```
HRV features: 100%|      | 6403/6403 [00:05<00:00, 1116.35it/s]

EDA features:   0%|          | 0/6494 [00:00<?, ?it/s]

/tmp/ipykernel_335021/1998099736.py:1: UserWarning: phasic_entropy contains more
than 5% (actual: 63.3%) nan, inf, or -inf values. We recommend to delete this
feature column.
  quick_feat =
flirt.with_.empatica('/home/art/Downloads/WESAD/S7/S7_E4_Data.zip',

ACC features:   0%|          | 0/6495 [00:00<?, ?it/s]

/home/art/miniconda3/envs/biosig/lib/python3.12/site-
packages/flirt/stats/common.py:35: RuntimeWarning: Precision loss occurred in
moment calculation due to catastrophic cancellation. This occurs when the data
are nearly identical. Results may be unreliable.
```

```
  results[key] = value(data)
/home/art/miniconda3/envs/biosig/lib/python3.12/site-
packages/flirt/stats/common.py:35: RuntimeWarning: Precision loss occurred in
moment calculation due to catastrophic cancellation. This occurs when the data
are nearly identical. Results may be unreliable.
  results[key] = value(data)
```

[192]:
```
from skchange.change_detectors import MovingWindow
from skchange.change_scores import CUSUM

detector = MovingWindow(
    change_score=CUSUM(),  # measures the difference in mean between two␣
 ↪intervals.
    bandwidth=20,
    threshold_scale=1.0,
)
display(detector)
```

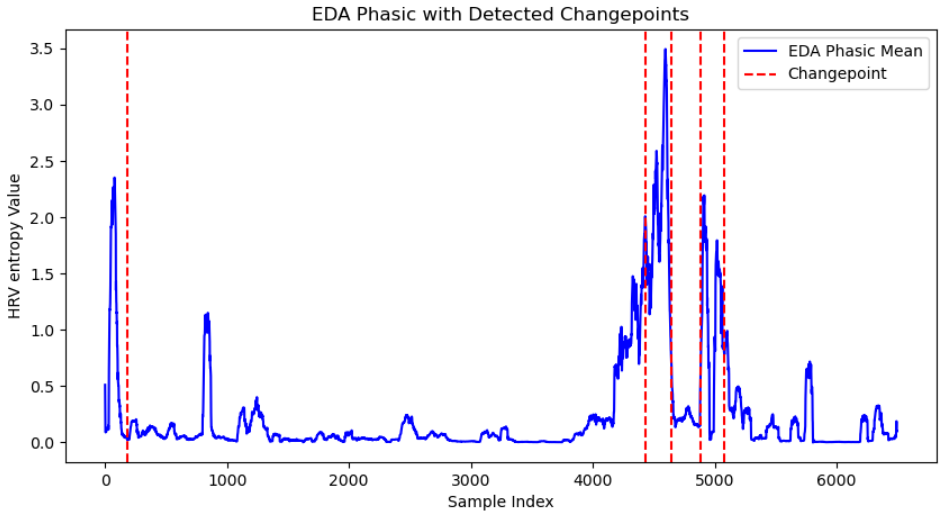
```
MovingWindow(bandwidth=20, change_score=CUSUM(), threshold_scale=1.0)
```

[193]:
```
hrv_hf = quick_feat['hrv_hf'].dropna().reset_index(drop=True)
hrv_hf_detections = detector.fit_predict(hrv_hf)
hrv_changepoints = hrv_hf_detections.get("ilocs", [])

fig, ax = plt.subplots(figsize=(10, 5))
ax.plot(hrv_hf.index, hrv_hf.values, label="HRV_HF Signal", color="blue")

for i, hrv_changepoint in enumerate(hrv_changepoints):
    ax.axvline(x=hrv_changepoint, linestyle="dashed", color="red",␣
 ↪label="Changepoint" if i == 0 else "")

ax.set_title("HRV_HF Signal with Detected Changepoints")
ax.set_xlabel("Sample Index")
ax.set_ylabel("HRV_HF Value")
ax.legend()
plt.show()
```



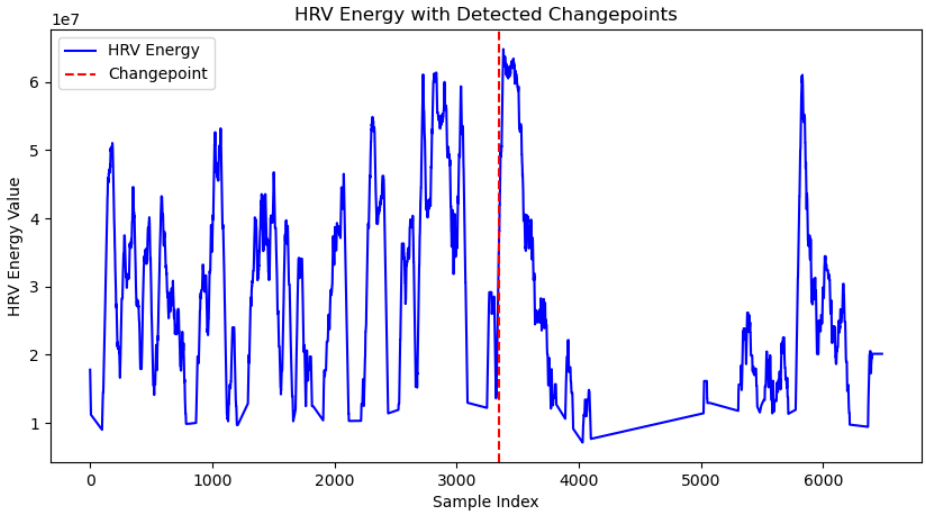
[194]:
```
detector = MovingWindow(change_score=CUSUM(), bandwidth=180, threshold_scale=1.
 ↪0)
display(detector)
eda_phasic_mean = quick_feat['eda_phasic_mean'].dropna().reset_index(drop=True)
eda_phasic_detect = detector.fit_predict(eda_phasic_mean)
eda_phasic_changepoints = eda_phasic_detect.get("ilocs", [])

fig, ax = plt.subplots(figsize=(10, 5))
ax.plot(eda_phasic_mean.index, eda_phasic_mean.values, label="EDA Phasic Mean",␣
 ↪color="blue")

for i, eda_phasic_changepoints in enumerate(eda_phasic_changepoints):
    ax.axvline(x=eda_phasic_changepoints, linestyle="dashed", color="red",␣
 ↪label="Changepoint" if i == 0 else "")

ax.set_title("EDA Phasic with Detected Changepoints")
ax.set_xlabel("Sample Index")
ax.set_ylabel("HRV entropy Value")
ax.legend()
plt.show()
```

```
MovingWindow(bandwidth=180, change_score=CUSUM(), threshold_scale=1.0)
```



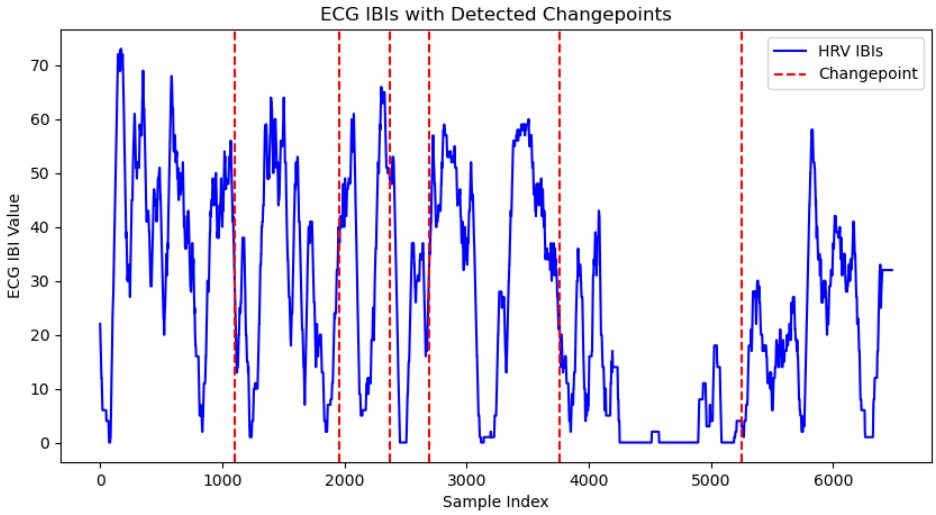
[195]:
```
detector = MovingWindow(change_score=CUSUM(), bandwidth=180, threshold_scale=1)
display(detector)
hrv_energy = quick_feat['hrv_energy'].dropna().reset_index(drop=True)
hrv_energy_detect = detector.fit_predict(hrv_energy)
hrv_energy_changepoints = hrv_energy_detect.get("ilocs", [])

fig, ax = plt.subplots(figsize=(10, 5))
ax.plot(hrv_energy.index, hrv_energy.values, label="HRV Energy", color="blue")

for i, hrv_energy_changepoints in enumerate(hrv_energy_changepoints):
    ax.axvline(x=hrv_energy_changepoints, linestyle="dashed", color="red",␣
 ↪label="Changepoint" if i == 0 else "")

ax.set_title("HRV Energy with Detected Changepoints")
ax.set_xlabel("Sample Index")
ax.set_ylabel("HRV Energy Value")
ax.legend()
plt.show()
```

```
MovingWindow(bandwidth=180, change_score=CUSUM(), threshold_scale=1)
```



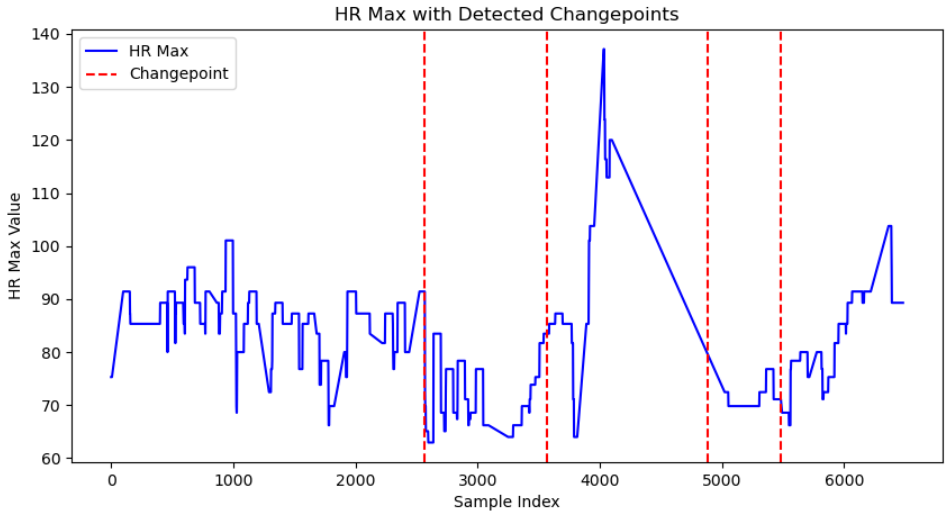
[196]:
```
detector = MovingWindow(change_score=CUSUM(), bandwidth=1000, threshold_scale=1.
 ↪0)
display(detector)
ECG_IBIs = quick_feat['num_ibis'].dropna().reset_index(drop=True)
ecg_ibi_detect = detector.fit_predict(ECG_IBIs)
ecg_ibi_changepoints = ecg_ibi_detect.get("ilocs", [])

fig, ax = plt.subplots(figsize=(10, 5))
ax.plot(ECG_IBIs.index, ECG_IBIs.values, label="HRV IBIs", color="blue")

for i, ecg_ibi_changepoints in enumerate(ecg_ibi_changepoints):
    ax.axvline(x=ecg_ibi_changepoints, linestyle="dashed", color="red",␣
 ↪label="Changepoint" if i == 0 else "")

ax.set_title("ECG IBIs with Detected Changepoints")
ax.set_xlabel("Sample Index")
ax.set_ylabel("ECG IBI Value")
ax.legend()
plt.show()
```

```
MovingWindow(bandwidth=1000, change_score=CUSUM(), threshold_scale=1.0)
```



[197]:
```
detector = MovingWindow(change_score=CUSUM(), bandwidth=1000, threshold_scale=1.
 ↪0)
display(detector)
hr_max = quick_feat['hrv_max_hr'].dropna().reset_index(drop=True)
hr_max_detect = detector.fit_predict(hr_max)
hr_max_changepoints = hr_max_detect.get("ilocs", [])

fig, ax = plt.subplots(figsize=(10, 5))
ax.plot(hr_max.index, hr_max.values, label="HR Max", color="blue")

for i, hr_max_changepoints in enumerate(hr_max_changepoints):
    ax.axvline(x=hr_max_changepoints, linestyle="dashed", color="red",␣
 ↪label="Changepoint" if i == 0 else "")

ax.set_title("HR Max with Detected Changepoints")
ax.set_xlabel("Sample Index")
ax.set_ylabel("HR Max Value")
ax.legend()
plt.show()
```

```
MovingWindow(bandwidth=1000, change_score=CUSUM(), threshold_scale=1.0)
```



[ ]:
```
fig, axes = plt.subplots(nrows=7, ncols=1, figsize=(12, 22), sharex=True)
fig.suptitle("Subject 7")
signals = [
    ("hrv_max_hr", "HR Max"),
    ("num_ibis", "ECG IBIs"),
    ("hrv_energy", "HRV Energy"),
    ("eda_phasic_mean", "EDA Phasic Mean"),
    ("hrv_hf", "HRV_HF Signal"),
    ("hrv_rmssd", "HRV RMMSD"),
    ("hrv_lf_hf_ratio", "HRV LF/HF Ratio")
]
# Hyperparamaters....
detectors = [
    MovingWindow(change_score=CUSUM(), bandwidth=1000, threshold_scale=1.0),
    MovingWindow(change_score=CUSUM(), bandwidth=1000, threshold_scale=1.0),
    MovingWindow(change_score=CUSUM(), bandwidth=1000, threshold_scale=1.0),
    MovingWindow(change_score=CUSUM(), bandwidth=1000, threshold_scale=1.0),
    MovingWindow(change_score=CUSUM(), bandwidth=1000, threshold_scale=1.0),
    MovingWindow(change_score=CUSUM(), bandwidth=1000, threshold_scale=1.0),
    MovingWindow(change_score=CUSUM(), bandwidth=1000, threshold_scale=1.0)
]

for ax, (signal_name, title), detector in zip(axes, signals, detectors):
    signal_data = quick_feat[signal_name].dropna().reset_index(drop=True)
    detection_results = detector.fit_predict(signal_data)
    changepoints = detection_results.get("ilocs", [])

    ax.plot(signal_data.index, signal_data.values, label=title, color="blue")
```

```
    for i, changepoint in enumerate(changepoints):
        ax.axvline(x=changepoint, linestyle="dashed", color="red",␣
 ↪label="Changepoint" if i == 0 else "")

    ax.set_title(f"{title} with Detected Changepoints")
    ax.set_ylabel(f"{title} Value")
    ax.legend()

axes[-1].set_xlabel("Sample Index")

plt.show()
```

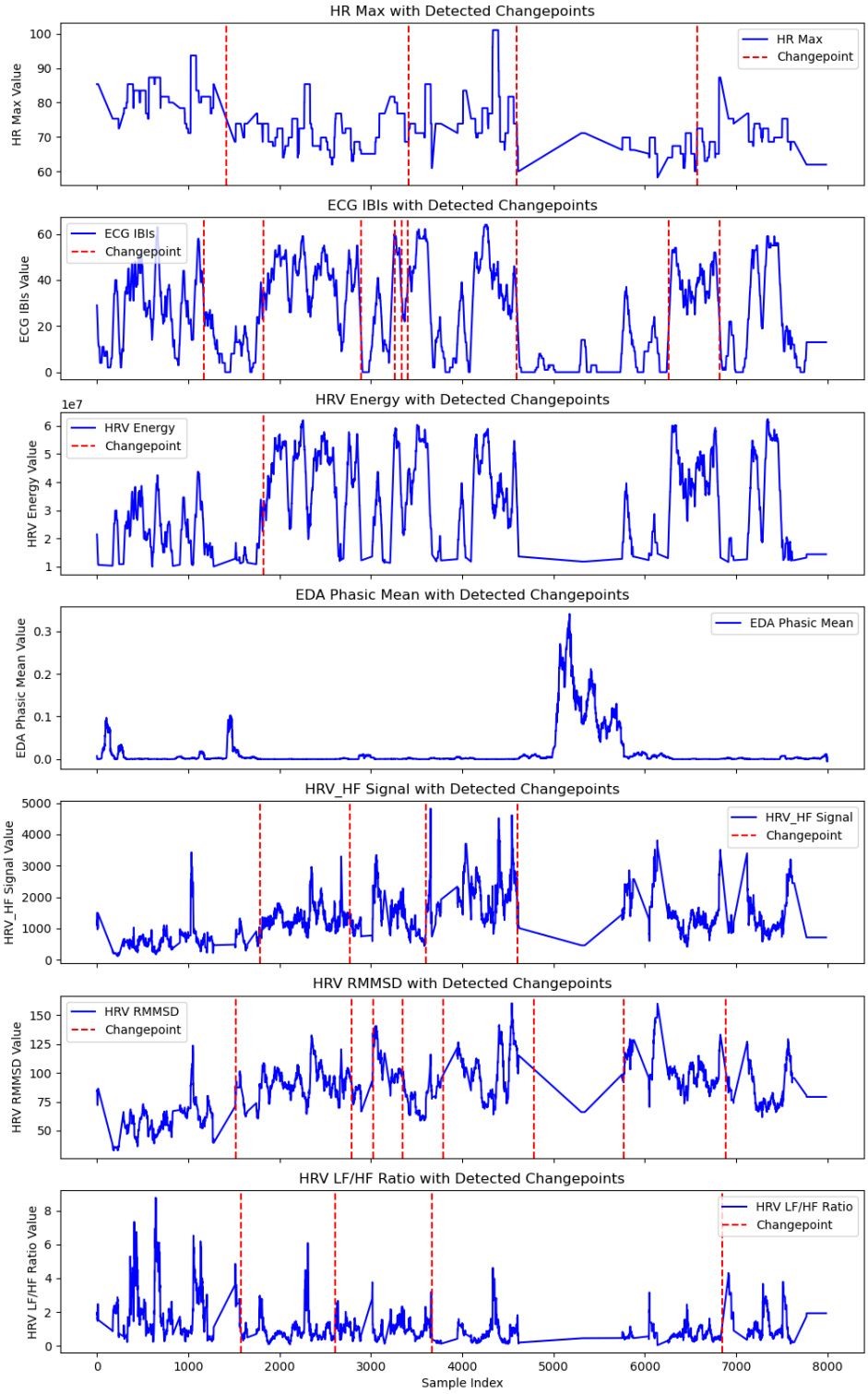
Subject 4

[199]:
```
quick_feat4 = flirt.with_.empatica('/home/art/Downloads/WESAD/S4/S4_E4_Data.
 ↪zip',
                                   window_length= 60,
                                   window_step_size = 1,
                                   hrv_features = True,
                                   eda_features = True,
                                   acc_features = True,
                                   debug = True
                                   )
```

```
Reading files
Calculating HRV features
HRV features: 100%|      | 7771/7771 [00:00<00:00, 12245.69it/s]
Calculating EDA features
EDA features:   0%|          | 0/8000 [00:00<?, ?it/s]
Calculating ACC features
/tmp/ipykernel_335021/419229283.py:1: UserWarning: phasic_entropy contains more
than 5% (actual: 73.44%) nan, inf, or -inf values. We recommend to delete this
feature column.
  quick_feat4 =
flirt.with_.empatica('/home/art/Downloads/WESAD/S4/S4_E4_Data.zip',
ACC features:   0%|          | 0/8000 [00:00<?, ?it/s]
/home/art/miniconda3/envs/biosig/lib/python3.12/site-
packages/flirt/stats/common.py:35: RuntimeWarning: Precision loss occurred in
moment calculation due to catastrophic cancellation. This occurs when the data
are nearly identical. Results may be unreliable.
  results[key] = value(data)
```

[200]:
```
fig, axes = plt.subplots(nrows=7, ncols=1, figsize=(12, 20), sharex=True)
fig.suptitle('Subject 4')
signals = [
    ("hrv_max_hr", "HR Max"),
    ("num_ibis", "ECG IBIs"),
    ("hrv_energy", "HRV Energy"),
    ("eda_phasic_mean", "EDA Phasic Mean"),
    ("hrv_hf", "HRV_HF Signal"),
    ("hrv_rmssd", "HRV RMMSD"),
    ("hrv_lf_hf_ratio", "HRV LF/HF Ratio")
]
# Hyperparamaters....
detectors = [
    MovingWindow(change_score=CUSUM(), bandwidth=1000, threshold_scale=.5),
    MovingWindow(change_score=CUSUM(), bandwidth=1000, threshold_scale=.5),
    MovingWindow(change_score=CUSUM(), bandwidth=1000, threshold_scale=.5),
    MovingWindow(change_score=CUSUM(), bandwidth=1000, threshold_scale=.5),
    MovingWindow(change_score=CUSUM(), bandwidth=1000, threshold_scale=.5),
    MovingWindow(change_score=CUSUM(), bandwidth=1000, threshold_scale=.5),
    MovingWindow(change_score=CUSUM(), bandwidth=1000, threshold_scale=.5)
]

for ax, (signal_name, title), detector in zip(axes, signals, detectors):
    signal_data = quick_feat4[signal_name].dropna().reset_index(drop=True)
    detection_results = detector.fit_predict(signal_data)
    changepoints = detection_results.get("ilocs", [])

    ax.plot(signal_data.index, signal_data.values, label=title, color="blue")

    for i, changepoint in enumerate(changepoints):
        ax.axvline(x=changepoint, linestyle="dashed", color="red",␣
 ↪label="Changepoint" if i == 0 else "")

    ax.set_title(f"{title} with Detected Changepoints")
    ax.set_ylabel(f"{title} Value")
    ax.legend()

axes[-1].set_xlabel("Sample Index")
plt.show()
```

Subject 4


HR Max with Detected Changepoints
HR Max Value
HR Max
Changepoint
ECG IBIs with Detected Changepoints
ECG IBIs Value
ECG IBIs
Changepoint
HRV Energy with Detected Changepoints
1e7
HRV Energy Value
HRV Energy
Changepoint
EDA Phasic Mean with Detected Changepoints
EDA Phasic Mean Value
EDA Phasic Mean
HRV_HF Signal with Detected Changepoints
HRV_HF Signal Value
HRV_HF Signal
Changepoint
HRV RMMSD with Detected Changepoints
HRV RMMSD Value
HRV RMMSD
Changepoint
HRV LF/HF Ratio with Detected Changepoints
HRV LF/HF Ratio Value
HRV LF/HF Ratio
Changepoint
Sample Index

Subject 6

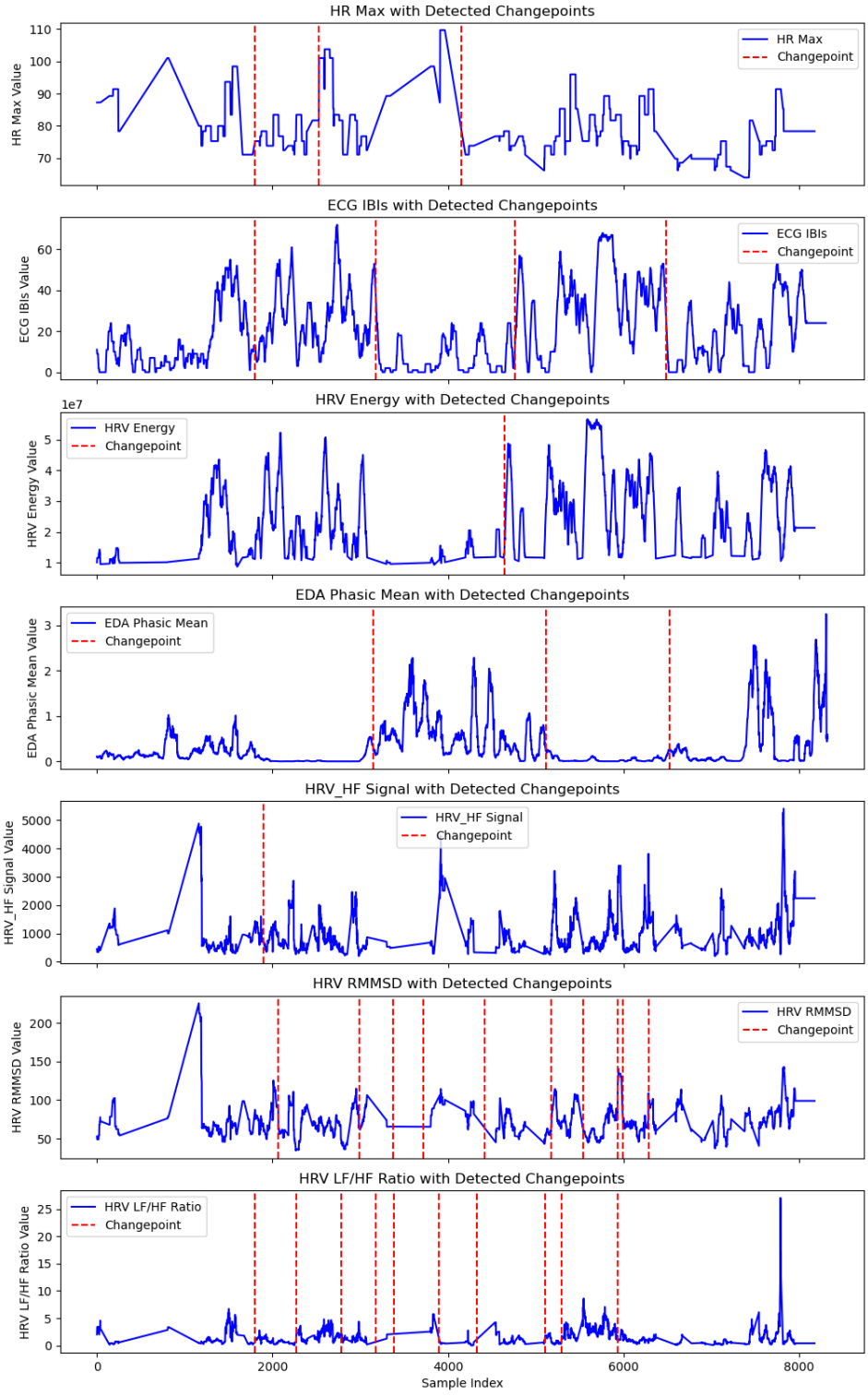
[201]:
```
quick_feat6 = flirt.with_.empatica('/home/art/Downloads/WESAD/S6/S6_E4_Data.
 ↪zip',
                                   window_length= 60,
                                   window_step_size = 1,
                                   hrv_features = True,
                                   eda_features = True,
                                   acc_features = True,
                                   debug = True
                                   )
```

```
Reading files
Calculating HRV features

HRV features: 100%|      | 8085/8085 [00:00<00:00, 40700.97it/s]

Calculating EDA features

EDA features:   0%|          | 0/8324 [00:00<?, ?it/s]

Calculating ACC features

/tmp/ipykernel_335021/1399992444.py:1: UserWarning: phasic_entropy contains more
than 5% (actual: 63.27%) nan, inf, or -inf values. We recommend to delete this
feature column.
  quick_feat6 =
flirt.with_.empatica('/home/art/Downloads/WESAD/S6/S6_E4_Data.zip',

ACC features:   0%|          | 0/8324 [00:00<?, ?it/s]
```

[202]:
```
fig, axes = plt.subplots(nrows=7, ncols=1, figsize=(12, 20), sharex=True)
fig.suptitle('Subject 6')
signals = [
    ("hrv_max_hr", "HR Max"),
    ("num_ibis", "ECG IBIs"),
    ("hrv_energy", "HRV Energy"),
    ("eda_phasic_mean", "EDA Phasic Mean"),
    ("hrv_hf", "HRV_HF Signal"),
    ("hrv_rmssd", "HRV RMMSD"),
    ("hrv_lf_hf_ratio", "HRV LF/HF Ratio")
]
# Hyperparamaters....
detectors = [
    MovingWindow(change_score=CUSUM(), bandwidth=1800, threshold_scale=.5),
    MovingWindow(change_score=CUSUM(), bandwidth=1800, threshold_scale=.5),
    MovingWindow(change_score=CUSUM(), bandwidth=1800, threshold_scale=.5),
    MovingWindow(change_score=CUSUM(), bandwidth=1800, threshold_scale=.5),
```

```
    MovingWindow(change_score=CUSUM(), bandwidth=1800, threshold_scale=.5),
    MovingWindow(change_score=CUSUM(), bandwidth=1800, threshold_scale=.5),
    MovingWindow(change_score=CUSUM(), bandwidth=1800, threshold_scale=.5)
]

for ax, (signal_name, title), detector in zip(axes, signals, detectors):
    signal_data = quick_feat6[signal_name].dropna().reset_index(drop=True)
    detection_results = detector.fit_predict(signal_data)
    changepoints = detection_results.get("ilocs", [])

    ax.plot(signal_data.index, signal_data.values, label=title, color="blue")

    for i, changepoint in enumerate(changepoints):
        ax.axvline(x=changepoint, linestyle="dashed", color="red",␣
 ↪label="Changepoint" if i == 0 else "")

    ax.set_title(f"{title} with Detected Changepoints")
    ax.set_ylabel(f"{title} Value")
    ax.legend()

axes[-1].set_xlabel("Sample Index")
plt.show()
```

Subject 6


HR Max with Detected Changepoints
HR Max
Changepoint
HR Max Value
ECG IBIs with Detected Changepoints
ECG IBIs
Changepoint
ECG IBIs Value
HRV Energy with Detected Changepoints
1e7
HRV Energy
Changepoint
HRV Energy Value
EDA Phasic Mean with Detected Changepoints
EDA Phasic Mean
Changepoint
EDA Phasic Mean Value
HRV_HF Signal with Detected Changepoints
HRV_HF Signal
Changepoint
HRV_HF Signal Value
HRV RMMSD with Detected Changepoints
HRV RMMSD
Changepoint
HRV RMMSD Value
HRV LF/HF Ratio with Detected Changepoints
HRV LF/HF Ratio
Changepoint
HRV LF/HF Ratio Value
Sample Index