Multimodal Signal Processing (MSP) lab
The University of Texas at Dallas
Erik Jonsson School of Engineering and Computer Science

Analysis of the Relationship Between Physiological Signals and Vehicle Maneuvers During a Naturalistic Driving Study

Yuning Qiu
Teruhisa Misu
Carlos Busso

Honda Research Institute US

THE UNIVERSITY OF TEXAS AT DALLAS

UT Dallas MSP Multimodal Signal Processing Laboratory

Introduction

- **Motivations:**
  - Physiological signals

    ↓ indicate

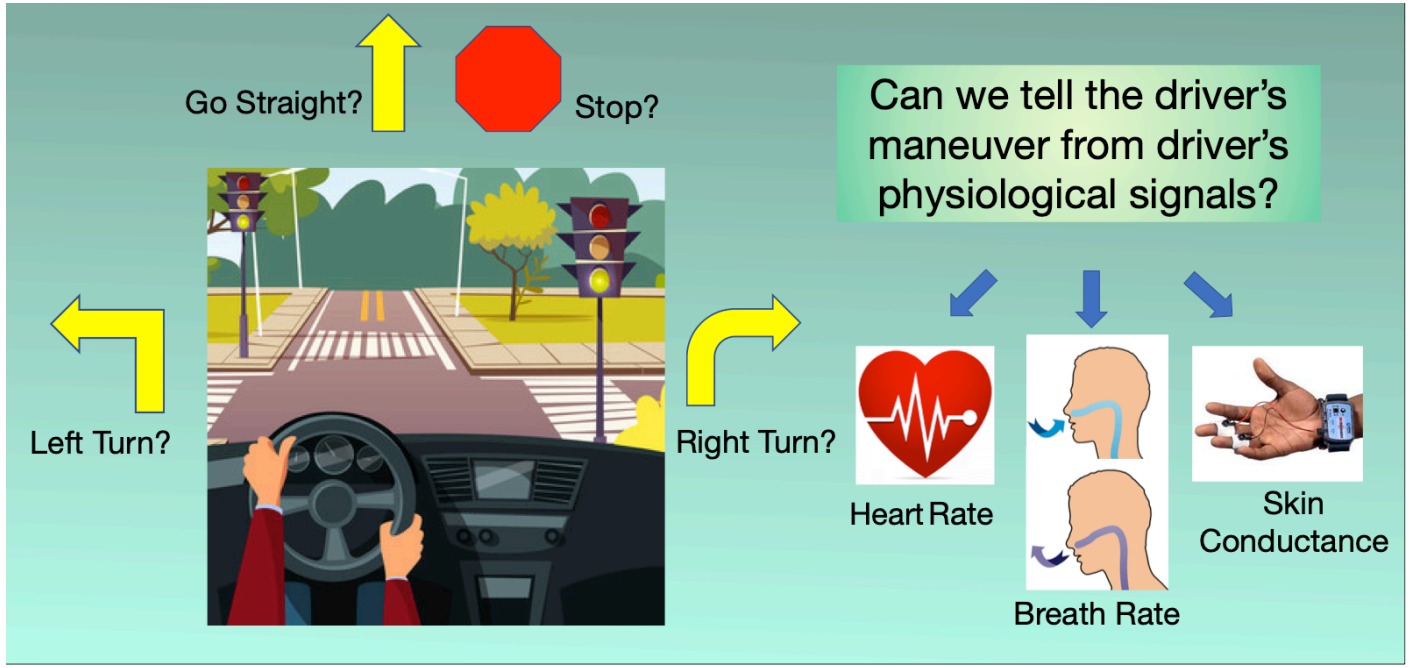
    human's stress & mental states

  - Driving

    ↓ increases

    human's stress level & cognitive workload

Therefore…



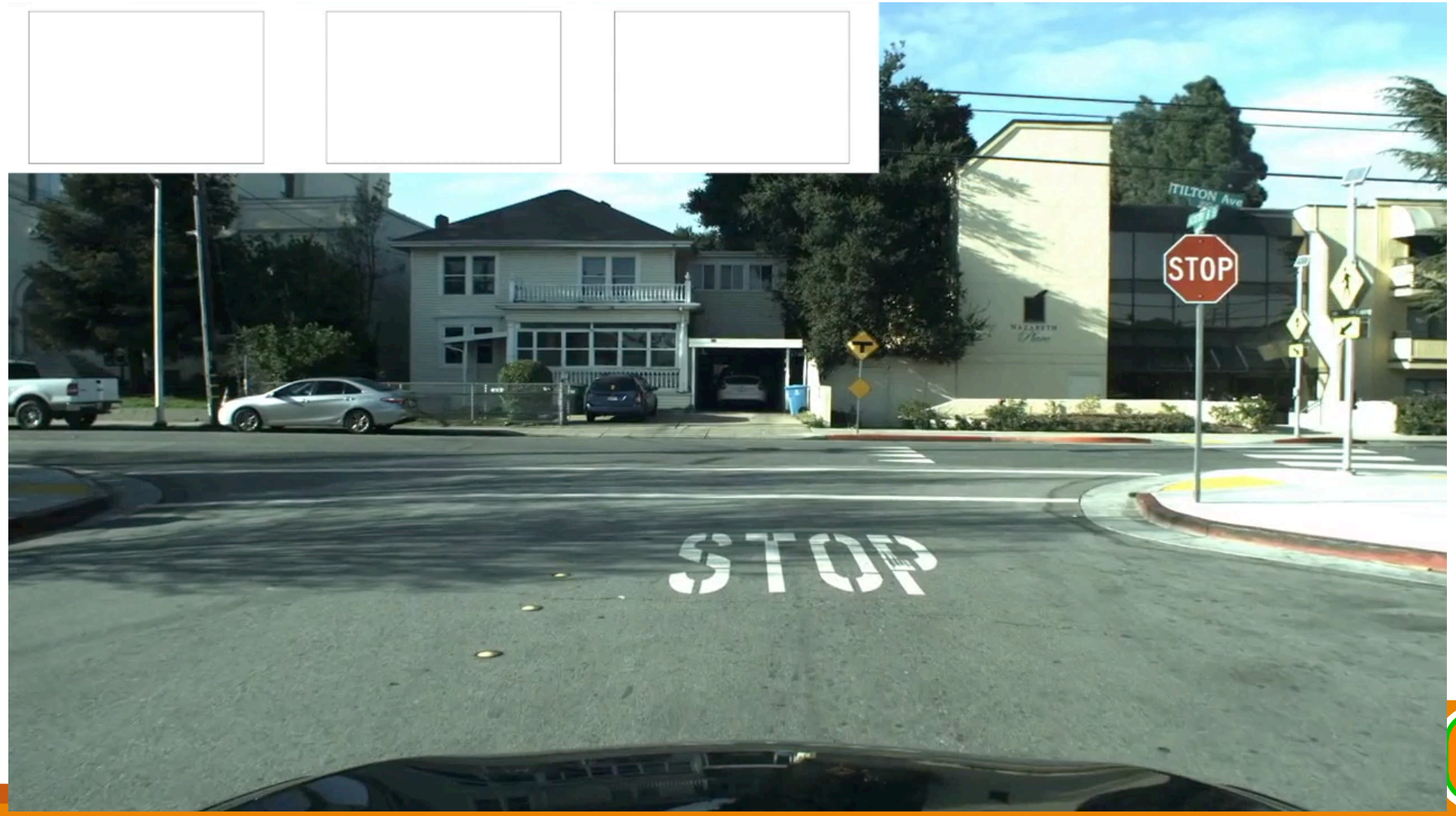
Experimental Analysis

An example of the change of driver's physiological signals during a Left Turn

Heart Rate (HR)

Breath Rate (BR)

Skin Conductance (EDA)



Introduction

- **Main Contribution:**

Drivers' physiological signals  *Driving maneuvers*

- **Physiological signals are complementary to CAN-Bus signal**
  - Anticipatory signals

- **Analysis methods**
  - Explore extreme changes on the driver's physiological signals
  - Statistical analysis of physiological data during specific driving maneuvers
  - Discriminant analysis on physiological features to recognize specific driving maneuvers

1. Introduction
2. Related Work
3. Honda Research Institute Driving Dataset (HDD corpus)
4. Experimental Analysis
5. Conclusion

Related Work

- Human's physiological signals respond to the human's autonomous nervous system
  - People experiencing anxiety can exhibit sustained periods with high Heart Rate and low variability [Kitney et al., 1981]
  - The ratio between low frequency (LF) components and high frequency (HF) components of the Heart Rate power spectrum is discriminative of stress level of an individual
    - An increase of **LF/HF** is associated with an increase in his/her stress level [Haruyuki et al., 1997]
  - Respiration Rate changes when the participants' mental states change from relaxed to stressed [Begum et al., 2014]

Related Work

- Driving a vehicle can increase the driver's stress level, which increases the level of HR, BR and EDA signals [Nishigaki et al., 2018] & [Healey et al, 2005]

- Previous studies analyze the relation between the driver's physiological signals and driving maneuvers.
  - Features extracted from the HR and BR signals are used to cluster the physiological data into three classes: "normal", "event", and "noise" [Li et al., 2016]
    - Class "event" includes driver maneuvers
  - Features extracted from physiological data are used to predict lane change action [Murphey et al., 2015]
  - Physiological signals are useful for driving maneuver classification when combined with features extracted from the controller area network (CAN) bus data [Li et al., 2016]

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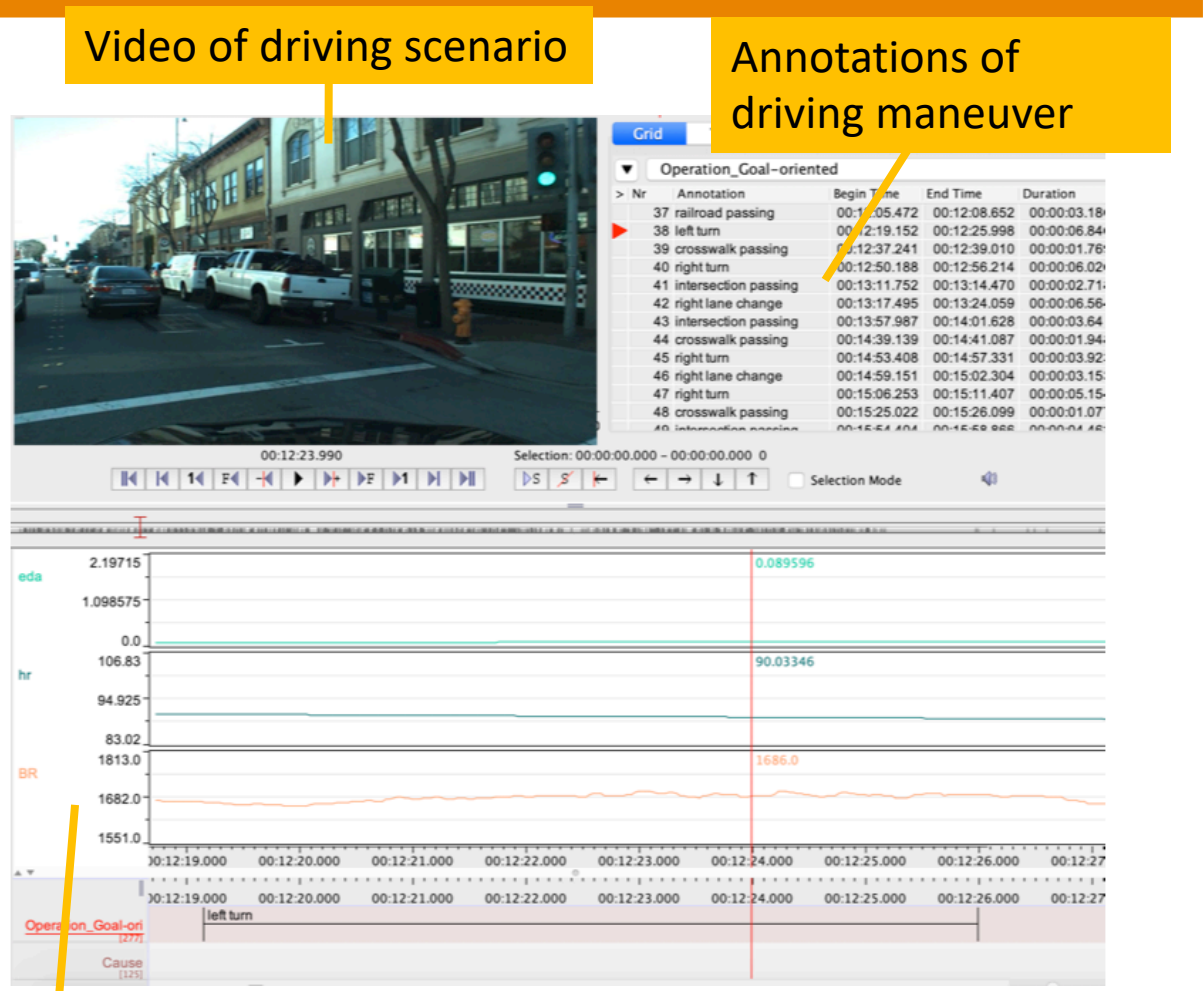
Honda Research Institute Driving Dataset

- **Honda Research Institute Driving Dataset (HDD corpus)**
  - 180 hours of naturalistic driving recordings (76 hours used in this task)
  - Collected by Honda Research Institute, USA, in San Francisco Bay Area
  - Road condition recorded by forward-facing in-vehicle camera
  - Annotations are manually added to the corpus with driving events
  - Drivers' physiological data
    - Heart Rate (HR)
    - Breath Rate (BR)
    - Skin conductance (EDA)



Honda Research Institute Driving Dataset

- **Annotations**
  - A four-layer representation
  - Relative to characterize driver distractions

	Annotations
Goal-driven Action	Intersection passing; Left turn; Right turn; Left lance change; Right lance change; Crosswalk passing; U-turn; Left lane branch; Right lane branch; Merge
Stimulus-driven Action	Stop; Deviate
Cause	Sign; Congestion; Traffic light; Pedestrian; Parked car
Attention	Crossing vehicle; Crossing pedestrian; Red light; Cut-in; Sign; On-road bicyclist; Parked vehicle; Merging vehicle; Yellow light; Road work; Pedestrian near ego lane

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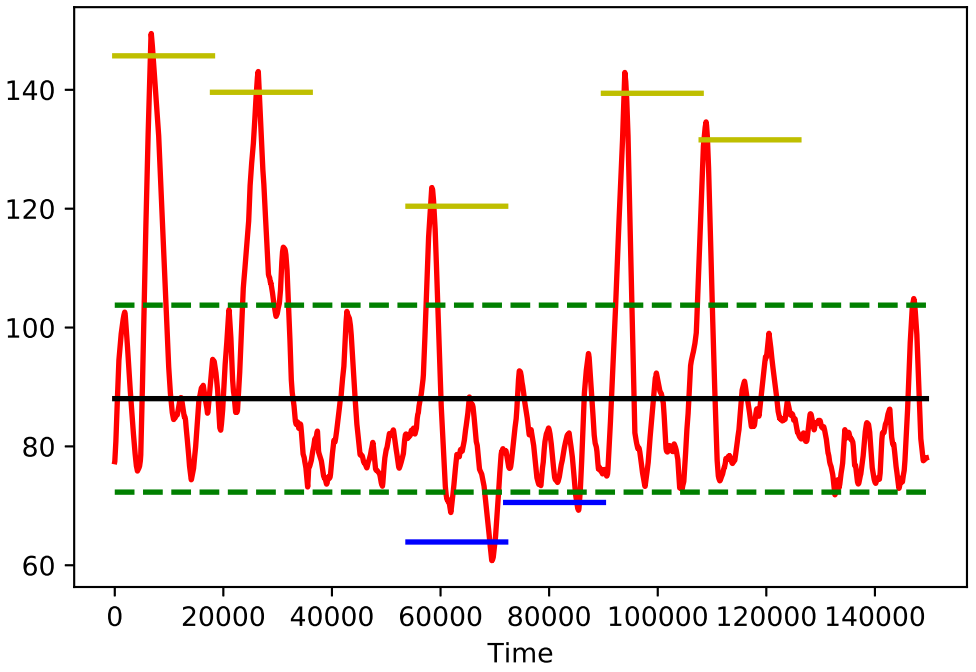
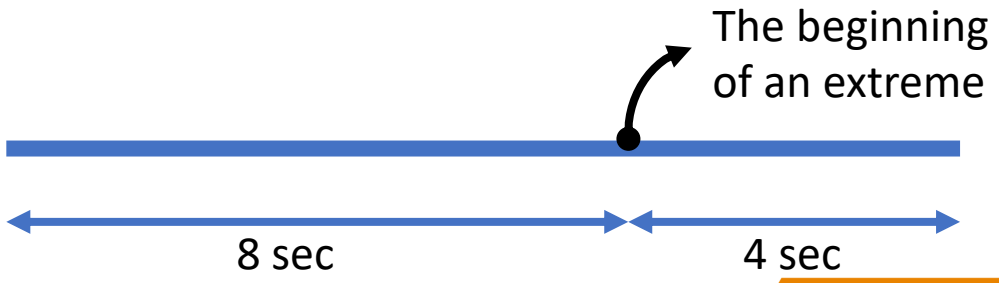
Experimental Analysis

- **Extreme Value of Physiological Signals**
  - Physiological Signals:
    - Heart Rate (HR)
    - Breath Rate (BR)
    - Skin Conductance (EDA)
  - Window size: 10 min
  - Thresholds (green dash lines):
    - Mean $\pm$ Standard deviation
  - 5% (blue) and 95% (yellow) quantiles outside the range between thresholds as Extreme Values

An example of Physiological signal





Experimental Analysis

- **Extreme Value of Physiological Signals**
  - Overlap between selected videos and events
  - Baseline: 1,200 randomly selected 12s-videos
- **Observation**
  - Driving events often cooccur with extreme values of physiological data, but not always

	HR		BR		EDA		Random
	5%	95%	5%	95%	5%	95%	
With Events	638	709	287	444	2456	465	516
Without Events	86	74	395	364	74	207	684
Total	724	783	682	808	2530	672	1200
	89.4%		49.1%		91.2%		43%

- With events:

  Including right turn, Left turn, U turn, Intersection passing, Left lane change, and right lane change
- Without events (normal):

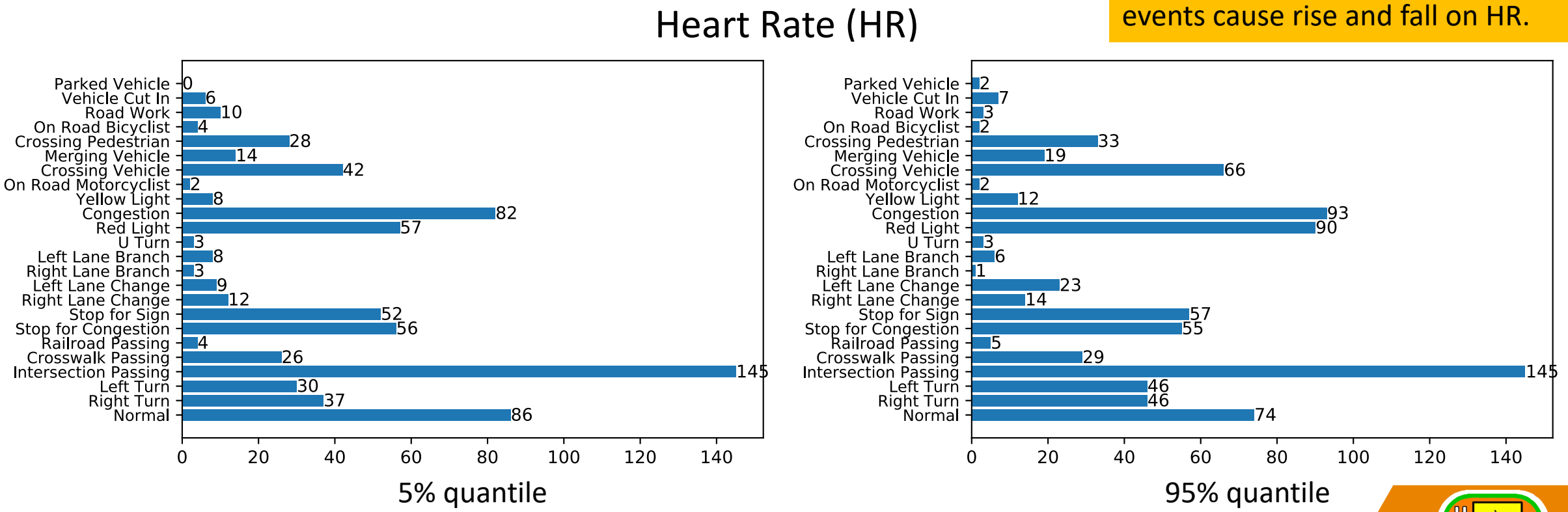
  No driving events observed during the segments

Number of the selected segments with extreme values in the physiological data, whether with or without driving events overlapping with the selected recordings

Experimental Analysis - Heart Rate (HR)

- **Extreme Value of Physiological Signals**
  - Events annotated during the segments with extreme value

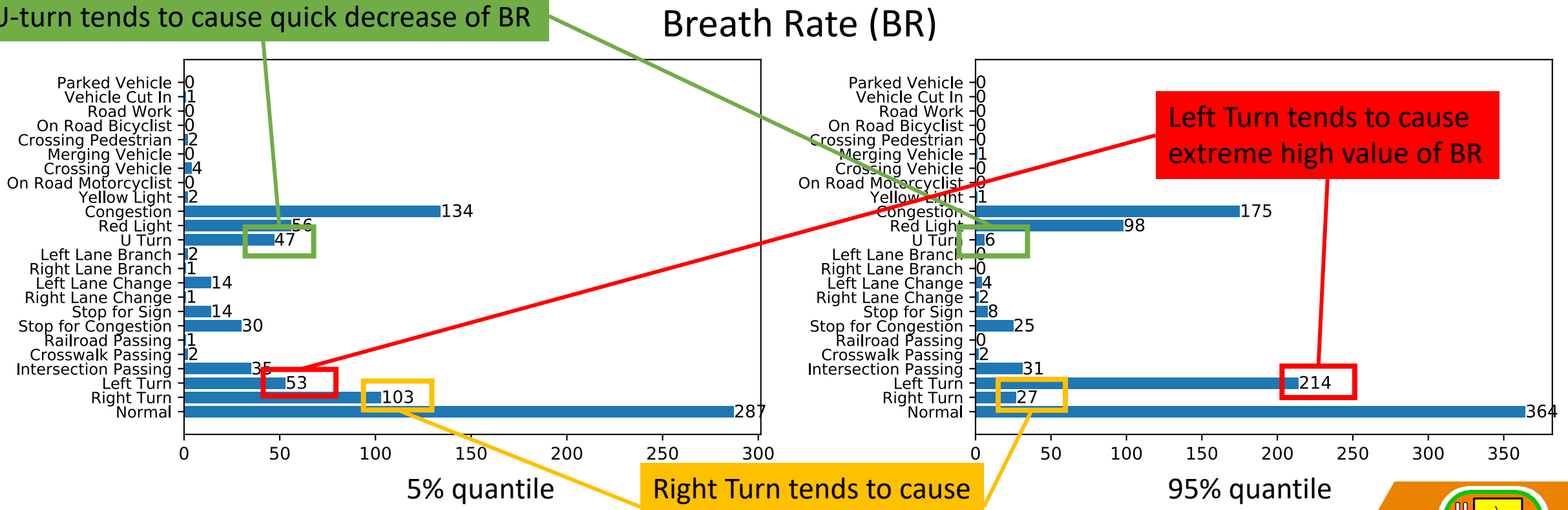
Observations:
95% quantile and 5% quantile share similar distribution of segments, indicating that driving events cause rise and fall on HR.



Experimental Analysis - Breath Rate (BR)

- **Extreme Value of Physiological Signals**
  - Events annotated during the segments with extreme value

U-turn tends to cause quick decrease of BR



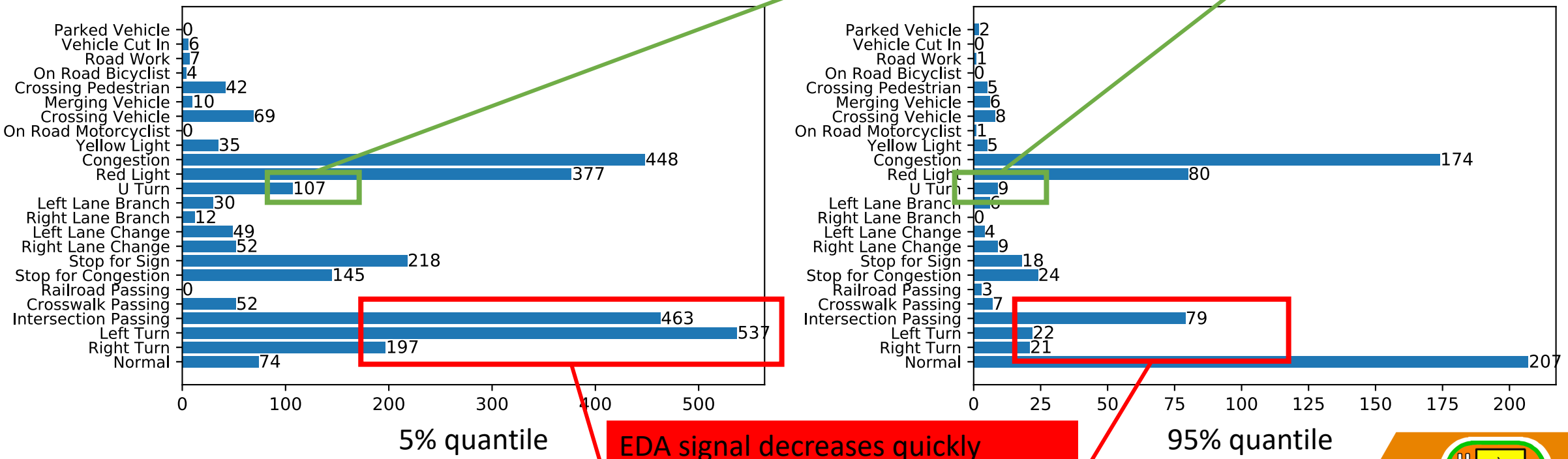
Left Turn tends to cause extreme high value of BR

Right Turn tends to cause extreme low value of BR

Experimental Analysis - Skin Conductance (EDA)

- **Extreme Value of Physiological Signals**
  - Events annotated during the segments with extreme value

U-turn tends to cause extreme low value of EDA



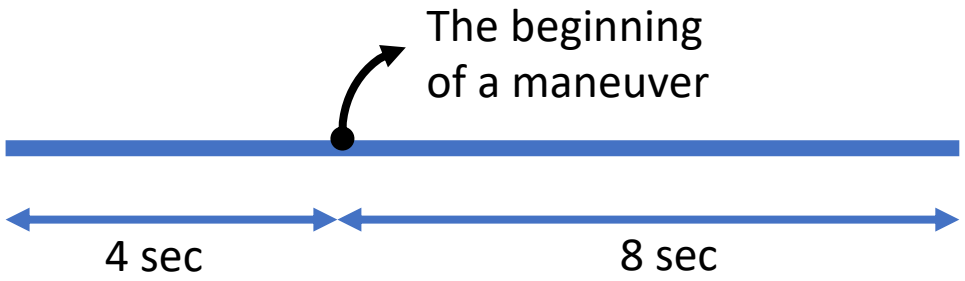
EDA signal decreases quickly during Intersection Passing, Left Turn, and Right Turn

Experimental Analysis– Maneuver-based Analysis

- **Physiological Signals in terms of Maneuvers**
  - Maneuvers:
    - Right turn (RT)
    - Left turn (LT)
    - U turn (UT)
    - Intersection passing (LP)
    - Left lane change (LLC)
    - Right lane change (RLC)
  - Physiological data:
    - HR, BR, EDA
    - Z-normalized, instead of using raw data

$$z = \frac{x - \mu}{\sigma}$$

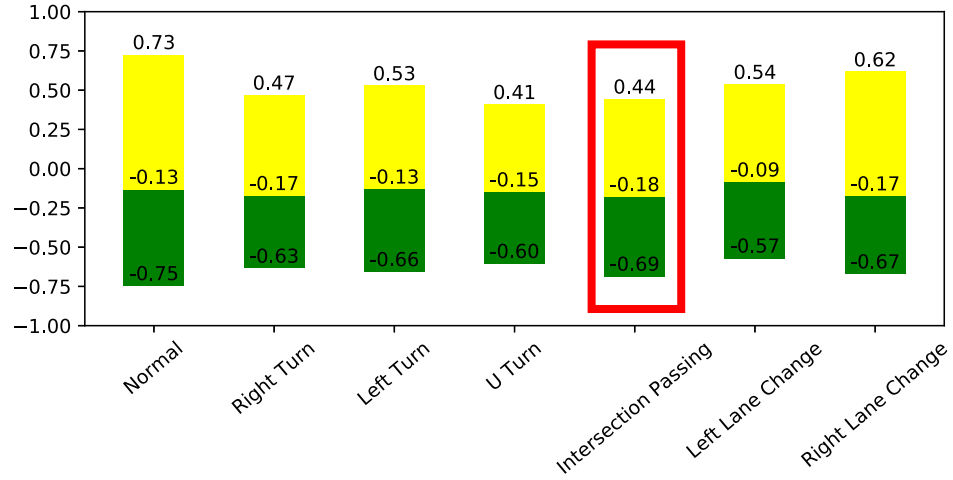
  - Analysis window
    - 12 seconds
    - 4 sec before and 8 sec after the beginning of the maneuvers



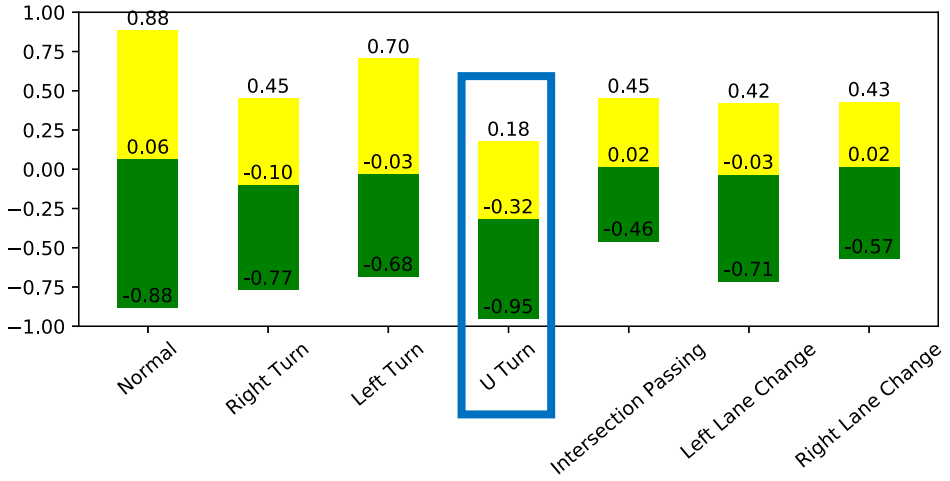
Experimental Analysis– Maneuver-based Analysis

- **Physiological Signals and Maneuvers**
  - 25%, 50%, and 75% quantiles:

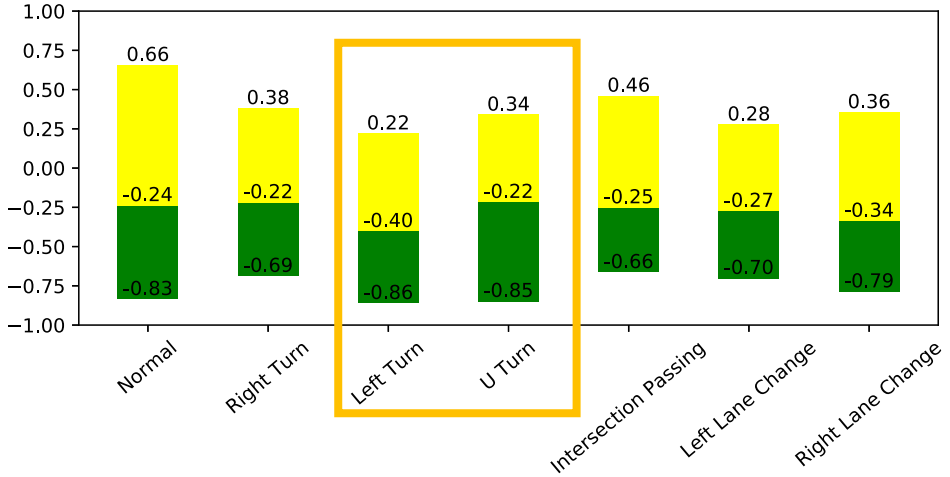
HR:



BR:



EDA:



  - One way analysis of variance (ANOVA)

    HR: F(6,10176) = 2.719, p = 0.012

    BR: F(6,10176) = 15.484, p = 0.0019

    EDA: F(6,10176) = 12.124, p = 0.0013

Experimental Analysis – Discriminant Analysis

- **Discriminant Analysis of Physiological Data**
  - Features:
    - 4 time domain features:
      Mean, Standard deviation,
      Maximum, and Minimum
    - 5 frequency domain features:
      The energy in the following frequency bands:
      [0-0.04 Hz], [0.04-0.15 Hz], [0.15-0.5 Hz], [0.5-4 Hz], [4-20 Hz]
  - Discriminant Models:
    - Support Vector Machine (SVM)
    - Random Forest

The number of annotations for each of the driving maneuver included in this study

	Number of
Normal	1245
Right Turn	1342
Left Turn	1155
U-Turn	131
Intersection Passing	5440
Left Lane Change	502
Right Lance Change	377

Random undersampling to balance classes

Experimental Analysis – Discriminant Analysis

- **Discriminant Analysis of Physiological Data**

	Support Vector Machine			
	HR [%]	BR [%]	EDA [%]	Combined [%]
Normal vs. RT	62.0	69.8	65.5	70.1
Normal vs. LT	41.8	53.4	65.7	66.9
Normal vs. UT	50.6	71.5	71.8	76.1
Normal vs. IP	61.4	74.3	66.5	74.8
Normal vs. LLC	46.3	60.5	53.7	65.0
Normal vs. RLC	39.2	62.6	47.0	64.1
Average	50.2	65.3	61.7	69.5
	Random Forest			
	HR [%]	BR [%]	EDA [%]	Combined [%]
Normal vs. RT	59.9	70.9	65.8	75.5
Normal vs. LT	53.4	65.1	67.6	74.2
Normal vs. UT	57.5	72.7	69.1	75.5
Normal vs. IP	53.3	71.9	60.6	73.8
Normal vs. LLC	53.8	63.4	56.9	70.5
Normal vs. RLC	47.9	62.6	54.8	67.4
Average	54.3	67.7	62.5	72.8

Discriminant analysis of physiological signal to recognize driving maneuvers (F1-score)

Observations:

- Physiological data provide valuable information about the driving maneuvers
- On average, the maneuvers can be detected with 72.8% (RF)
- Fusion leads to better performance

- Right turn (RT)
- Left turn (LT)
- U turn (UT)
- Intersection passing (LP)
- Left lane change (LLC)
- Right lane change (RLC)

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Conclusions

- **Conclusion**
  - Most of the segments with extreme values in the physiological data overlap with driving events
  - Considered six specific driving maneuvers:

    Right turn, *Left turn*, *U-turn*, *Intersection passing*, *Left lane change*, and *Right lane change*
  - These six driving maneuvers affects the physiological responses of the drivers
  - These six driving maneuvers can be recognized from normal recordings with an average classification F1-score of 72.8% (chances performance is 50%)
- **Future work**
  - Fuse driver's physiological data with vehicle's CAN-Bus data
  - Evaluate/develop non-invasive approaches to measure physiological signals

Any Questions?