



10<sup>th</sup> International Conference on

**RSS2026**  
Road Safety & Simulation

23-26 June 2026, Naples, Italy

# Characterising driver drowsiness in automated driving : A machine learning analysis of naturalistic driving data

Paper ID : 55

Ajay Iyer<sup>a</sup>, Amir Pooyan Afghari<sup>a</sup>, Eleonora Papadimitriou<sup>a</sup>

<sup>a</sup>Faculty of Technology, Policy, and Management, Delft University of Technology, Delft Netherlands



## ABSTRACT

This study identifies physiologically defined drowsiness episodes in naturalistic driving data and links them to risky driving behaviour patterns.

- Naturalistic driving data were analysed using IBI signals, vehicle kinematics, and ADAS signals across four intervention phases.
- A multi-stage **IBI-based protocol** detected drowsiness episodes, and dynamic time warping (**DTW**) **time-series clustering** characterized related risky driving behaviours.
- The analysis found **59 drowsiness episodes** and **three temporal archetypes** marked by harsh acceleration, cornering and braking.
- These findings support the need for context-aware in-vehicle countermeasures for driver monitoring systems (DMS).

## INTRODUCTION AND OBJECTIVES

Drowsiness is a major road safety hazard associated with reduced vigilance, poorer decision-making, and increased risky driving.

- Prior naturalistic studies have used physiological signals to detect and predict driver sleepiness, but far fewer have examined how risky driving behaviour develops during physiologically defined drowsy episodes.
- Most naturalistic driving studies use heart-rate variability (HRV) to monitor or classify drowsiness, but mainly as an input to detection or prediction algorithms rather than to analyse detailed on-road behaviour.
- Cardiac markers such as inter-beat interval (IBI) provide a validated temporal indicator of drowsiness, especially when interpreted relative to driver-specific baselines.
- This study introduces a multi-stage IBI filtering protocol, grounded in sleep research and automotive signal standards, and combines it with DTW-based clustering to reveal time-varying behavioural archetypes of risky driving during drowsiness.

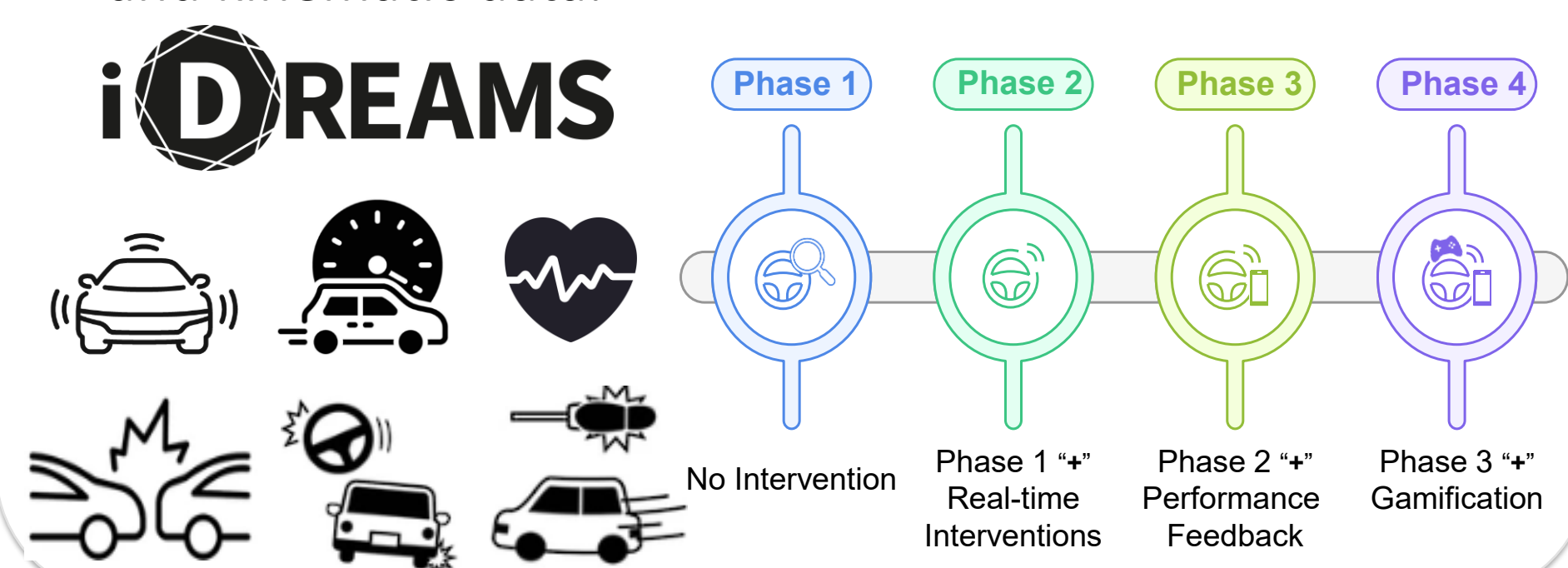
### Research Questions:

- How can physiologically defined drowsiness episodes be reliably identified from noisy, real-world IBI signals in a large naturalistic driving study?
- What time-varying patterns of risky driving behaviours (speeding, risky headway, harsh manoeuvres) emerge during these episodes?
- What are the implications of these patterns for context-aware Driver Monitoring Systems (DMS)?

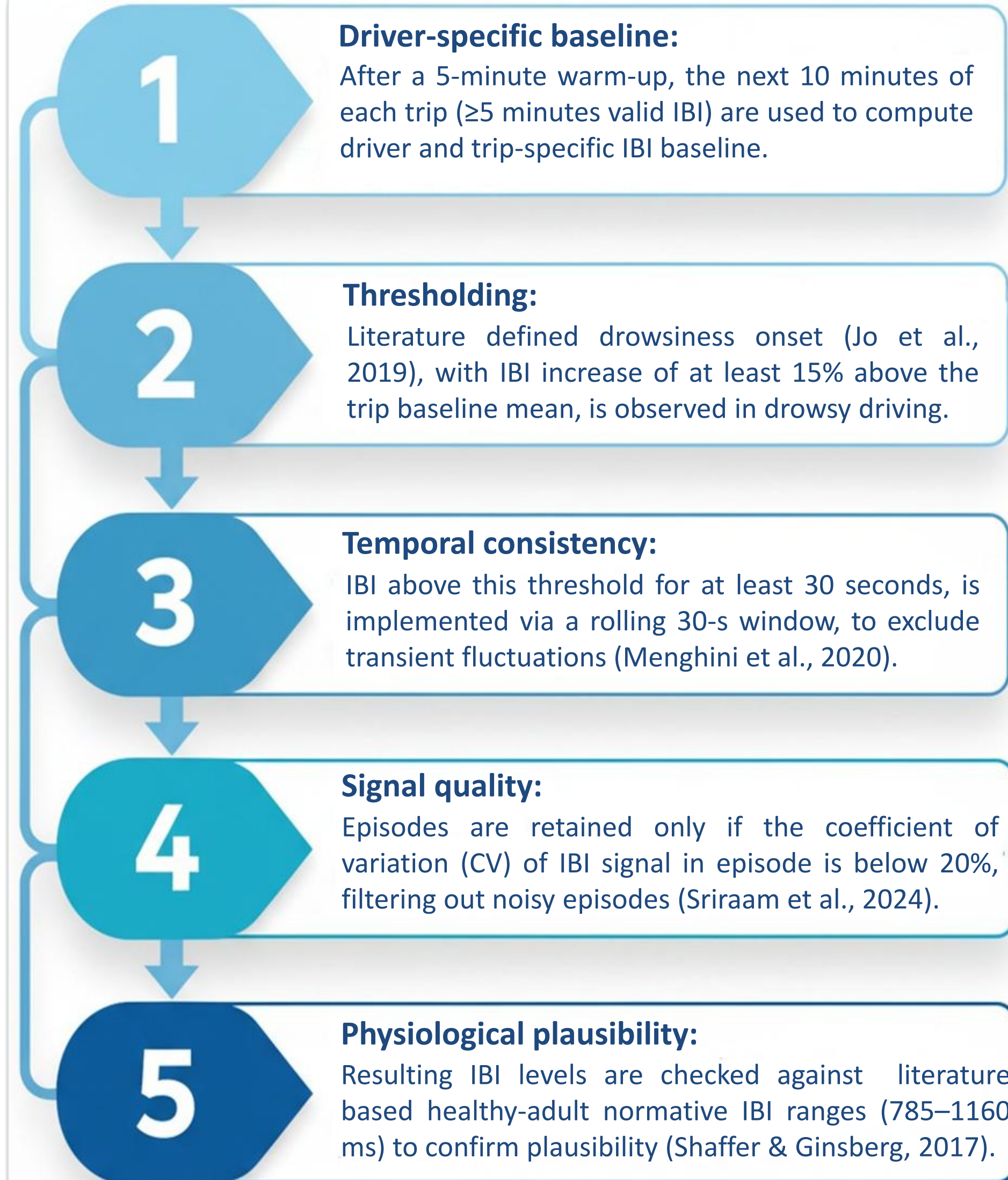
## DATASET AND VARIABLES

The analysis uses multimodal naturalistic driving data from the **iDREAMS** project.

- The EU Horizon study spans five countries and includes **250 drivers**, and **1.95 million** minutes of driving.
- This work focuses on **52 Belgian drivers** and **3,260 hours** of urban, rural, and highway driving.
- The sample was **63% male** and **37% female**, with a median driving experience of **22.5 years** (range: **1-55 years**).
- Vehicles provided IBI signals at 1,000 Hz through steering-wheel and wearable sensors, alongside ADAS and kinematic data.



## DROWSINESS EPISODE FILTERATION



## DROWSINESS EPISODE DESCRIPTION

Application of IBI-based protocol on the dataset identified:

- 59** distinct physiologically defined drowsiness episodes.
- Episode durations ranged from **30 to 466** seconds.

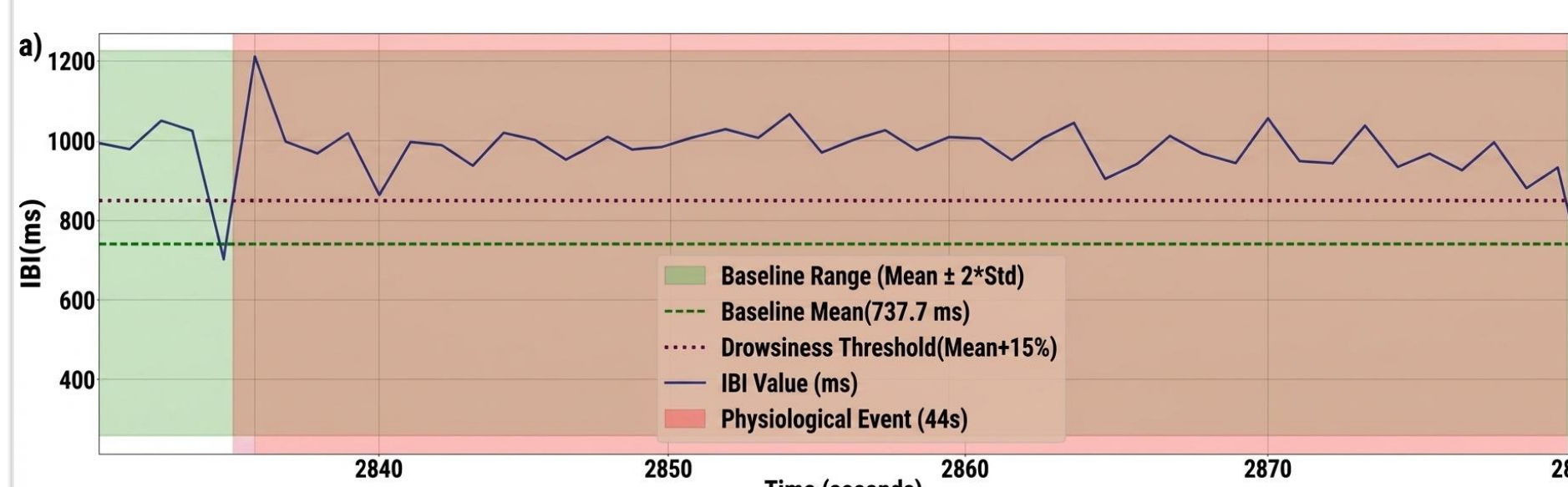


Fig. 1. (a) IBI protocol generated drowsy episode example

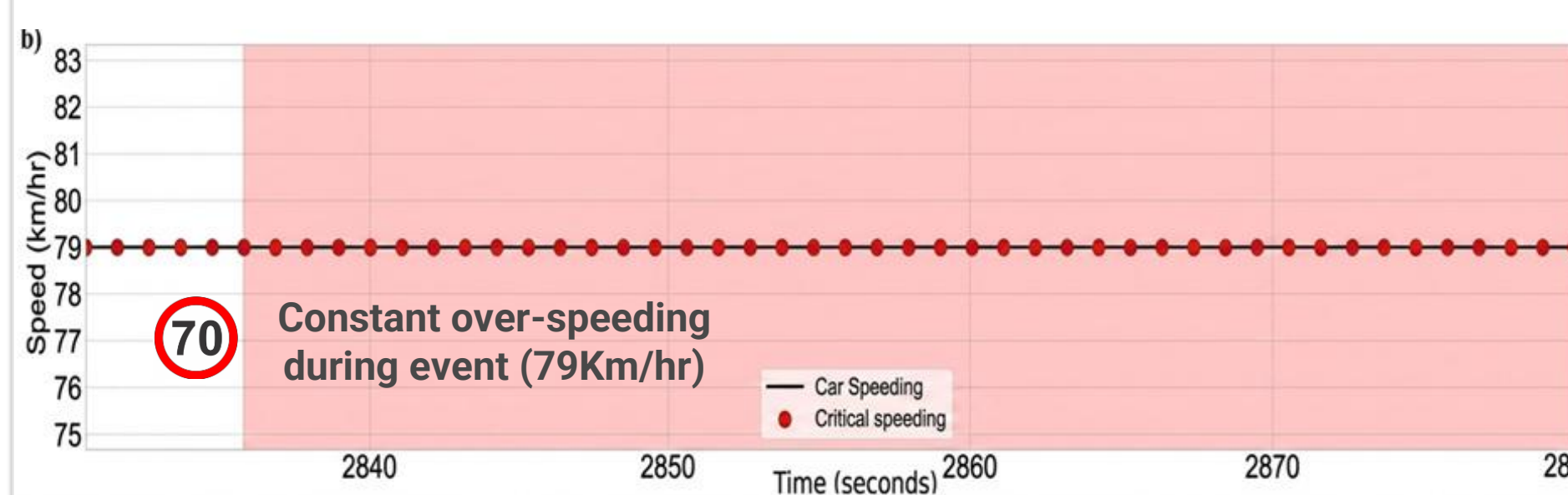


Fig. 1. (b) Constant critical speeding during episode

Statistical Variables	Values
Number of episodes found	59
Mean	1101.50ms
Std	175.28ms
Min	1061.19ms
Max	1508.4ms

Table. 1 Descriptive statistics of IBI values in drowsy episodes

## DTW CLUSTERING AND STATISTICAL ANALYSIS

**DTW temporal clustering** and within-subject statistical testing were used to analyse risky driving behaviour during drowsiness episodes.

- A multivariate time series was created for each episode using risky headway, speeding, harsh acceleration, harsh braking, and harsh cornering.
- DTW** clustering grouped episodes with similar temporal risk patterns, and the elbow method was used to choose the optimal number of clusters.
- Wilcoxon Signed-Rank** tests compared the median rate per second of each risky behaviour during drowsy episodes with matched non-drowsy segments from the same drivers and trips.
- Statistical significance was assessed at  $p < 0.05$  using a within-subject non-parametric approach suited to sparse, binary, and non-normal event data.

## RESULTS

DTW clustering partitioned the **59** drowsiness episodes into **three archetypal patterns**.

- Cluster 0 (n = 31), Cluster 1 (n = 15), Cluster 2 (n = 13)** represents a composite risky driving profile over the episodes.

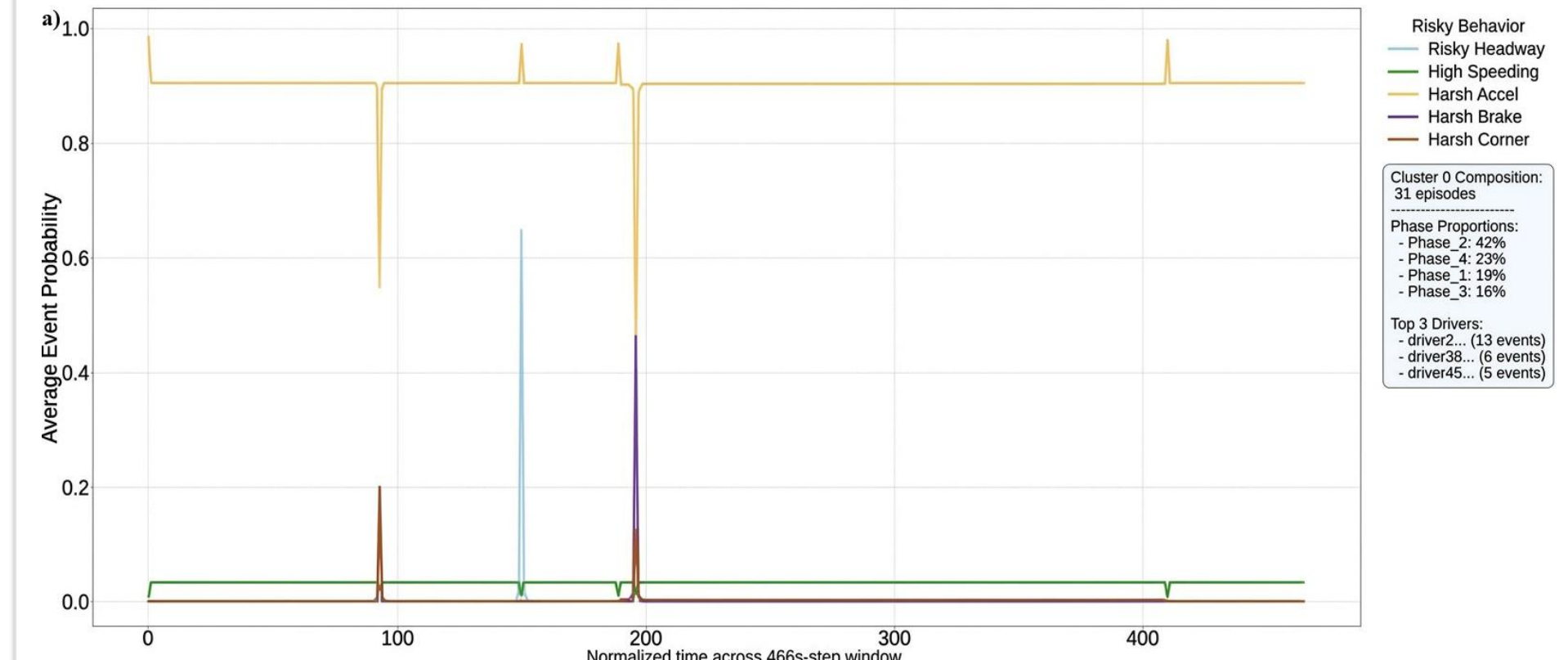


Fig. 2. a: Most common archetype reflecting reactive longitudinal control and abrupt corrective braking

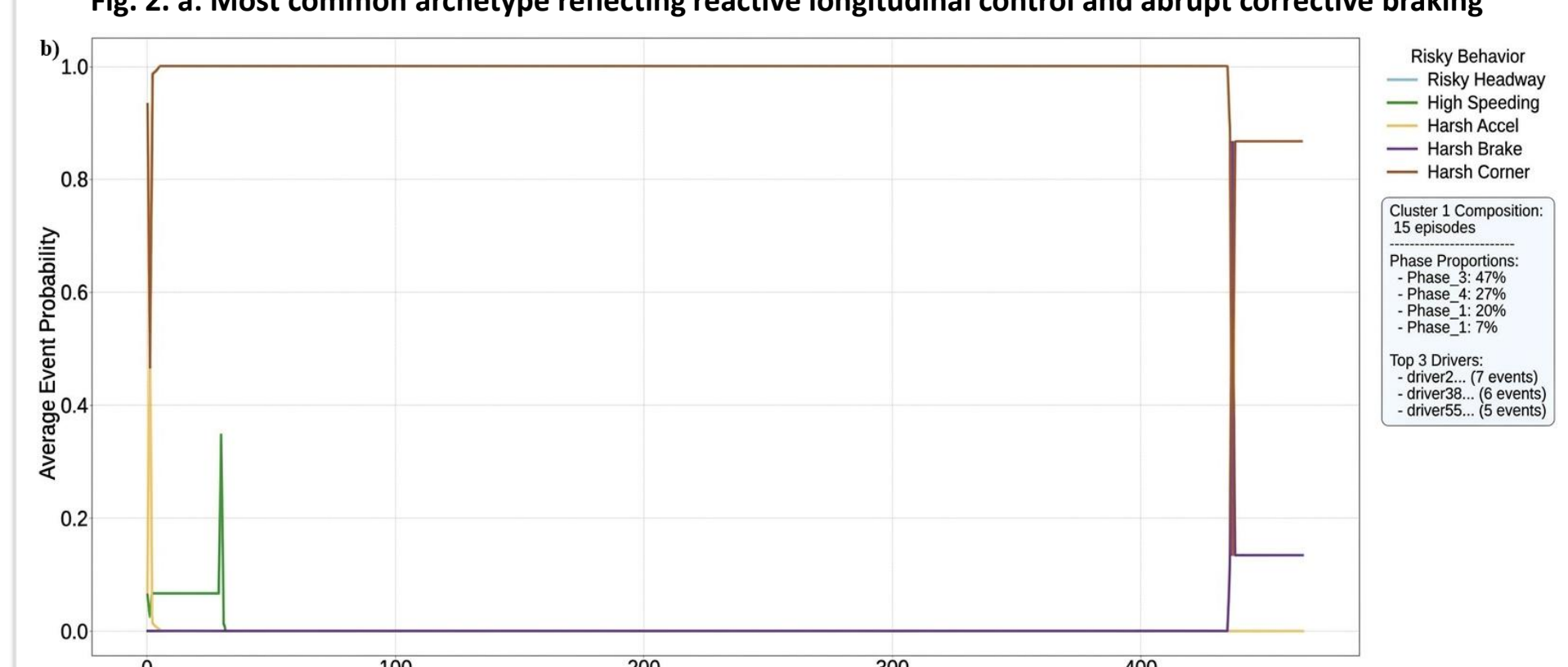


Fig. 2. b: Characterized by very high rates of harsh cornering, indicating jerky steering inputs

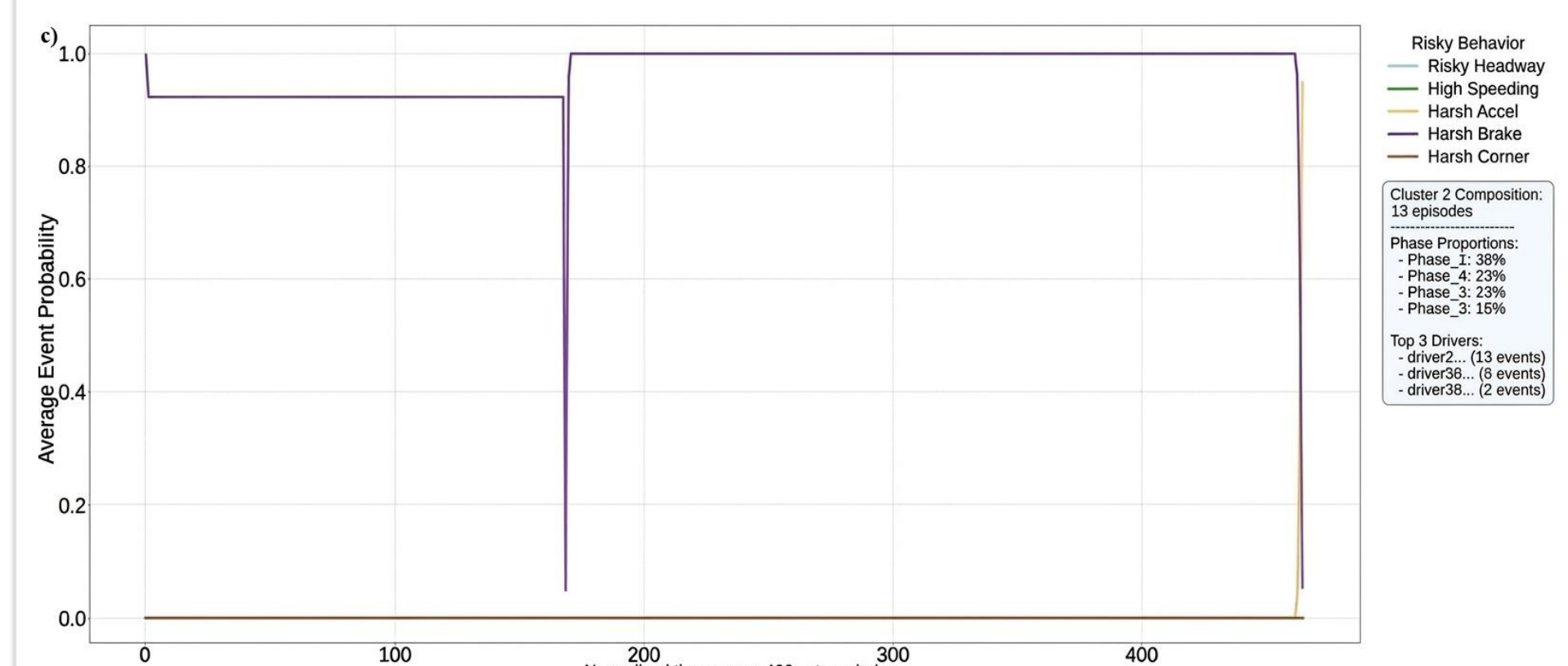


Fig. 2. c: Defined by high probability of harsh braking indicating repeated misjudgement of closing distances

Cluster N°	Behavior	P-Values
Cluster 0	Harsh Acceleration	0.0312
Cluster 1	Harsh Cornering	0.0002
Cluster 2	Harsh Braking	0.0020

Table. 2 Significant Wilcoxon Signed-Rank Test results

## CONCLUSIONS AND DISCUSSIONS

The proposed framework identified physiologically plausible drowsiness episodes and revealed distinct time-varying risky driving patterns.

- Main finding:** The IBI-based protocol and DTW clustering identified plausible drowsiness episodes and three risky driving archetypes.
- Interpretation:** Drowsy driving appears as dynamic behavioural modes rather than a single uniform decline in performance.
- Limitation:** The protocol cannot fully separate drowsiness from other reduced-vigilance states, and the findings are associative rather than causal.
- Implication:** Multimodal DMS combining IBI, kinematics, and visual cues may better capture emerging risk patterns than camera-only systems.
- Future work:** Future studies would integrate road conditions and gaze data and test the framework in other driver populations.

## ACKNOWLEDGEMENTS

This research received funding from the European Union's Horizon Europe research and innovation program under grant agreement No 101119590.

## CONTACT INFORMATION



aiyer@tudelft.nl