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NHTSA’s Research on Impairment – Lane Departure Characteristics under Different Impairment Types

SAE Government Industry

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Lane Departure Crashes

- Roadway departures a factor in 19,195 fatalities, 51% of all fatalities between 2016-2018 (FARS)
- Drowsiness a factor in 15-21% of fatalities, 6-10% of all crashes (AAA Foundation for Traffic Safety)
- Distraction a factor in 3,275 fatalities in 2023. (NHTSA)
- Alcohol a factor in 12,429 fatalities in 2023, 30% of fatalities. (NHTSA)
- Cannabis impairs motor skills, lane tracking, cognitive functions, multitasking. Crash risk not understood well enough.

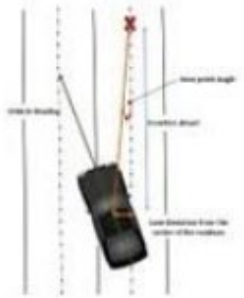
Objectives

Identify and Reduce Simulator Datasets

- Drowsy
- Alcohol, Drug
- Distraction

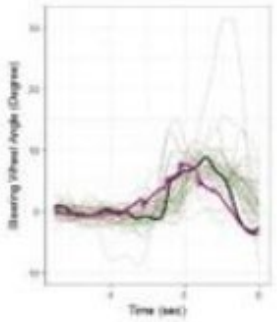
Characterize Lane Departures and Recovery

- Departure Characteristics
- Recovery Characteristics
- Context & Other Factors



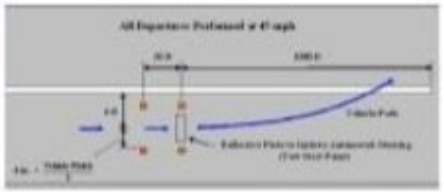
Compare Lane Departures and Recovery

- Departure Characteristics
- Recovery Characteristics
- Drowsy, Distracted, Alcohol, Cannabis



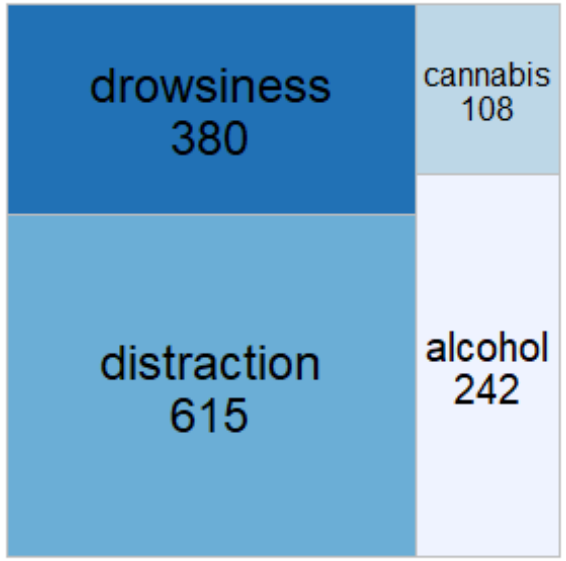
Provide Recommendations

- Test Parameters
- Speed, Departure Angle, Road Characteristics

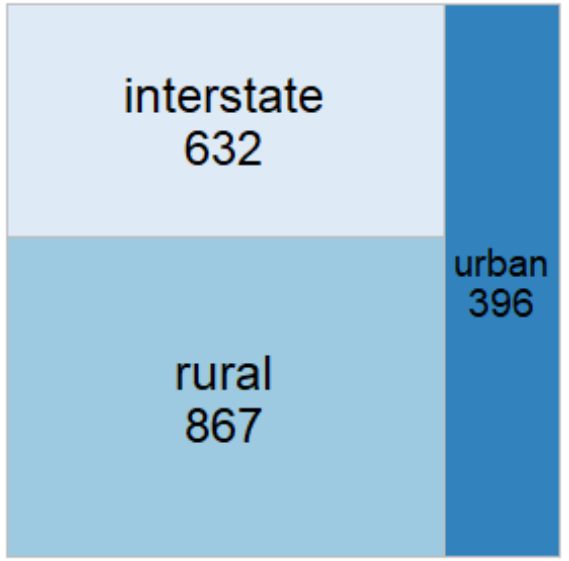


Simulator Datasets with Impaired Driving

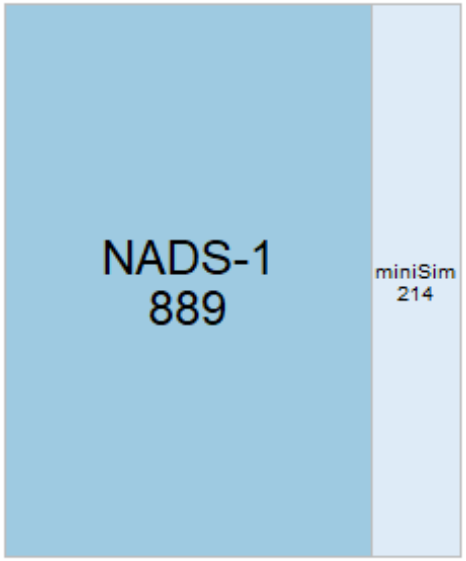
- 14 studies
- 1103 participants
- 4 impairment types
  - Drowsiness
  - Distraction
  - Alcohol
  - Cannabis
- Variety of scenarios, road types
- 2 simulators



Impairment types
(# participants)



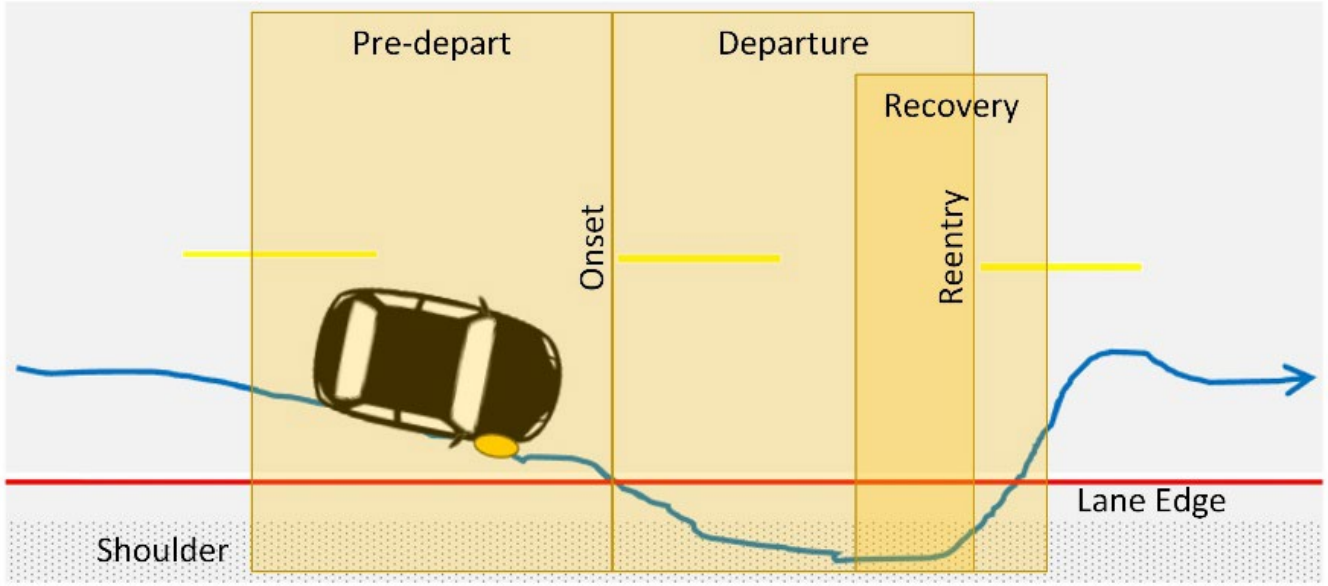
Road types
(# participants)



Simulator types
(# participants)

Anatomy of a Lane Departure

- Split lane departures into 3 phases and 2 transition points
- Phases
  - Pre
  - Departure
  - Recovery
- Transitions
  - Onset
  - Reentry

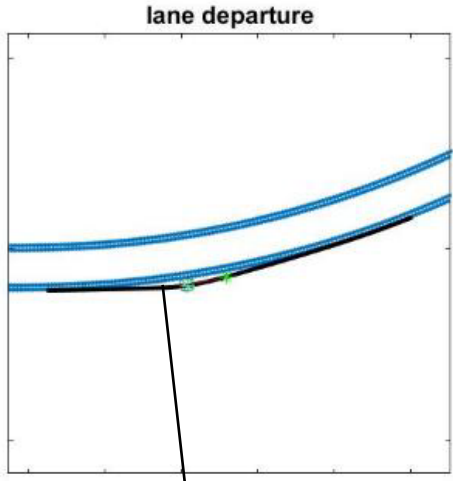


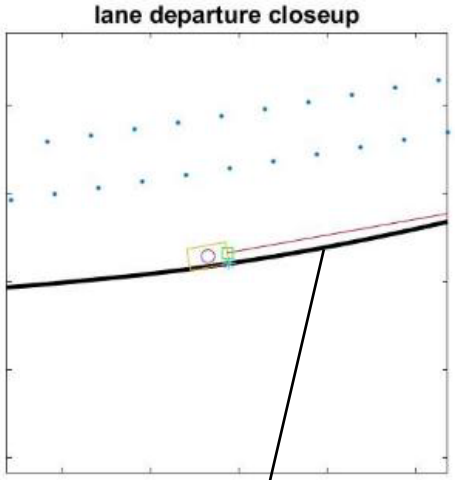
- Beginning and end of event when center of vehicle is 0.5 ft away from lane center

Lane Departure Example #1

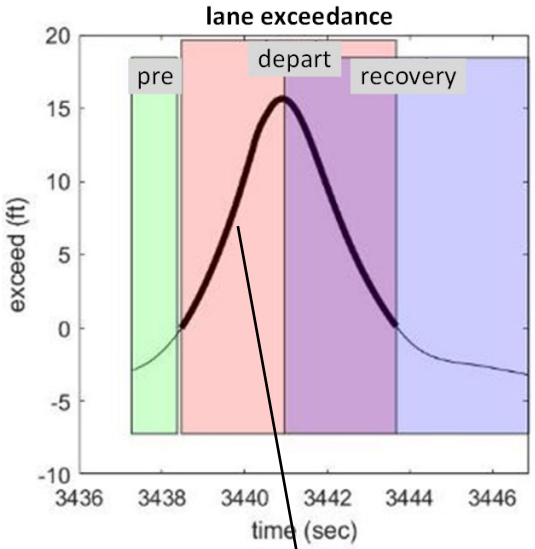
- 4 lane divided highway curve
- Single road departure to the right

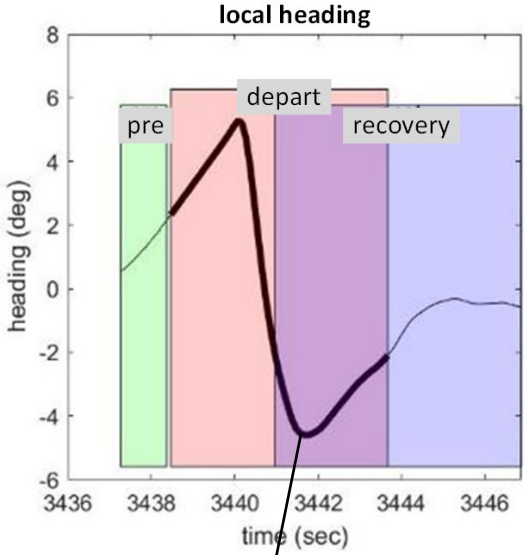
Pre-depart begins when center of vehicle exceeds 0.5 ft from lane center
Recovery ends when center of vehicle is within 0.5 ft from lane center





Outside wheel path



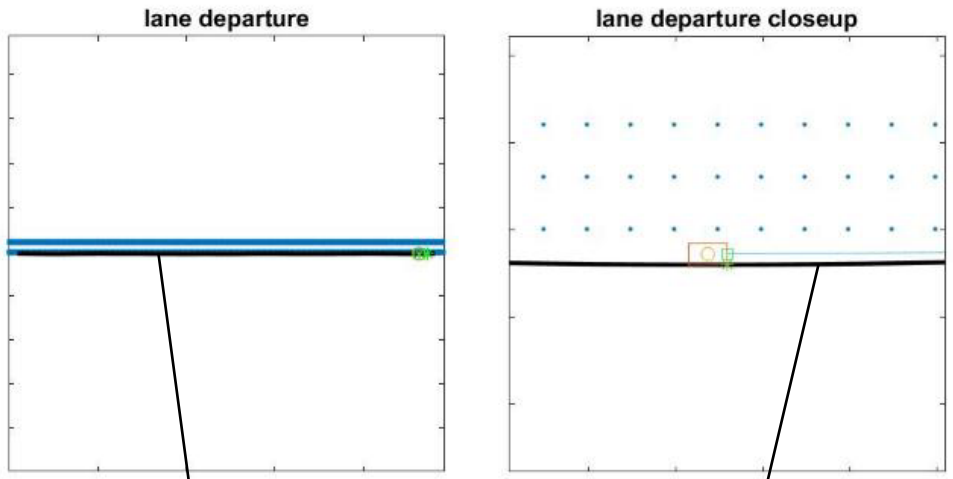


Exceedance and heading during departure

Lane Departure Example #2

- 6 lane divided highway straight
- Compound lane departure to the right

Compound lane departure: multiple departures that occur between pre-departure and recovery phases



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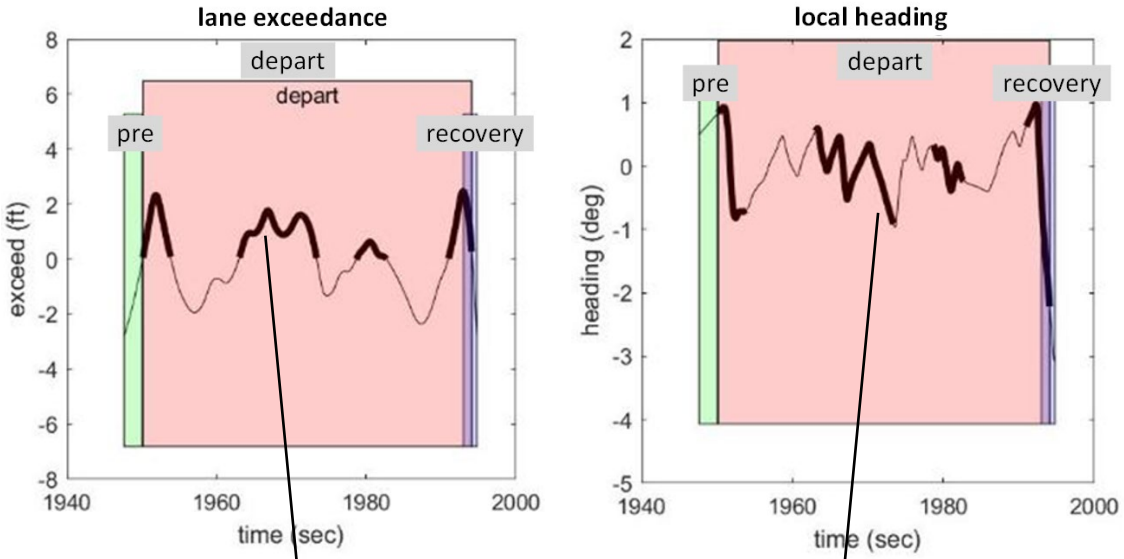


Exceedance and heading during departures

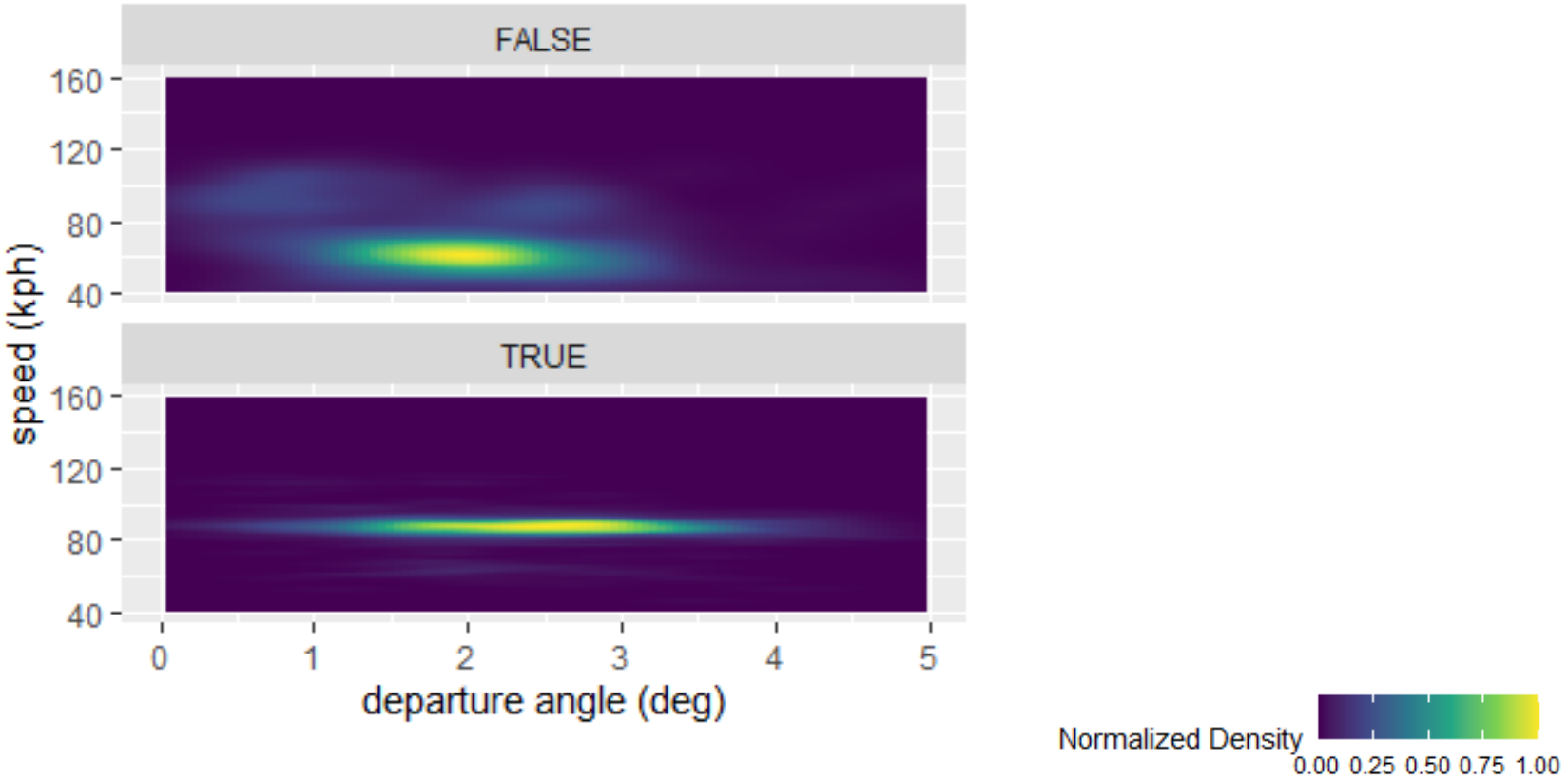
Lane Departure Summary

- In total, 12,920 lane departures were collected from simulator studies
- Impairment study category: Drowsy (6425), Distraction (3028), Alcohol & Cannabis (3467)
- Departure direction: Left (6394), Right (6526)
- Road curvature: Straight (9026), Curved (3899)
- Departures into an oncoming lane: 2562
- Compound departures: 2455

Limitations

- All data came from simulator studies on either the NADS-1 high-fidelity motion simulator or the non-motion miniSim™
  - Simulator environments are less cluttered and more forgiving, making recovery from lane departures easier
  - Simulator scenarios more controlled and do not have the range of environments and situations encountered in the real world
- Comparing lane departures across impairment types complicated by the fact they used different environments and routes
  - i.e. the effect of changing environment can be greater than the effect of the impairment
- Sequence analysis is geared towards using *combinations* of measures
  - Harder to answer a question like: how does angle of departure vary across level of each impairment?

Speed vs. Departure Angle (Distraction)



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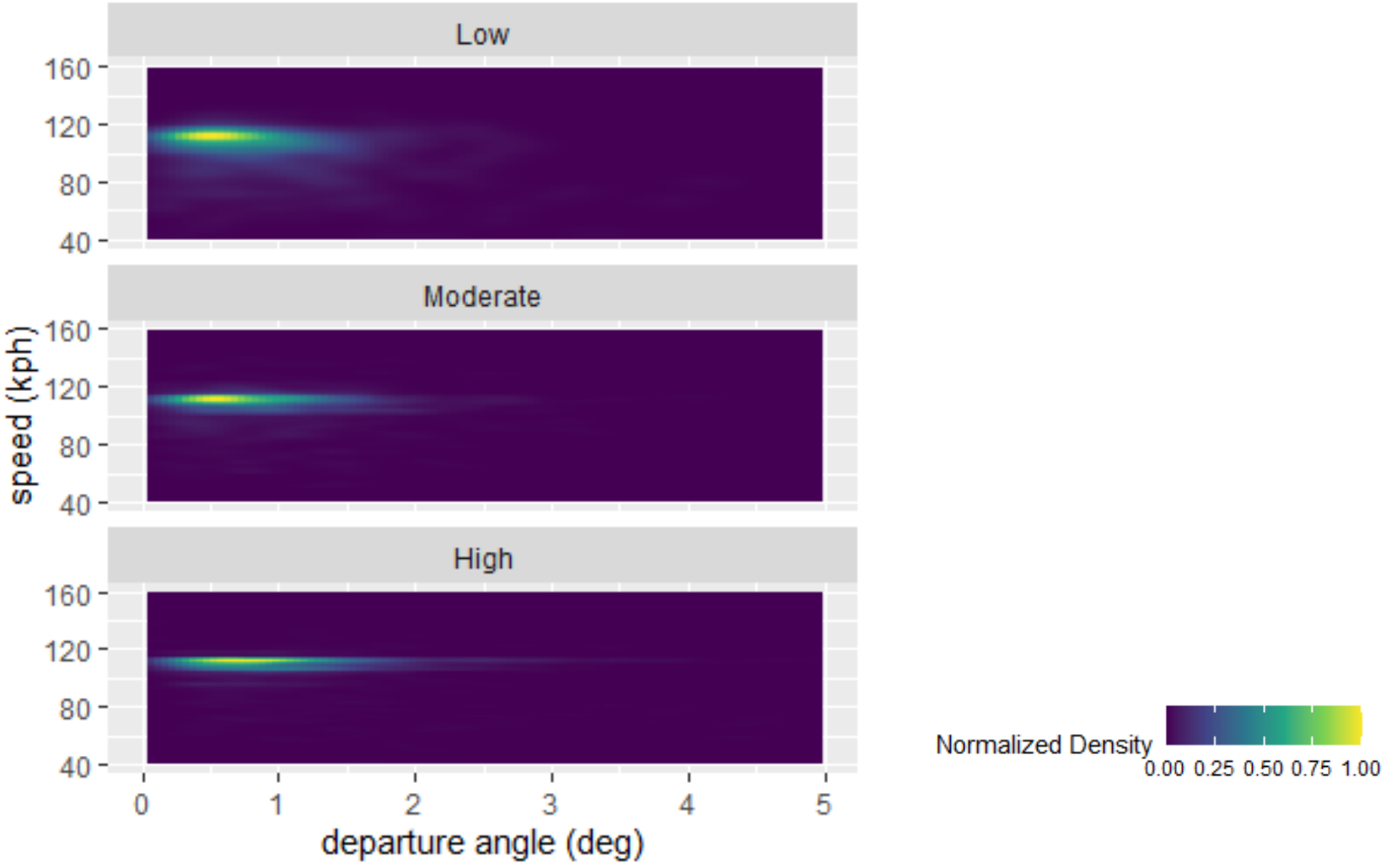
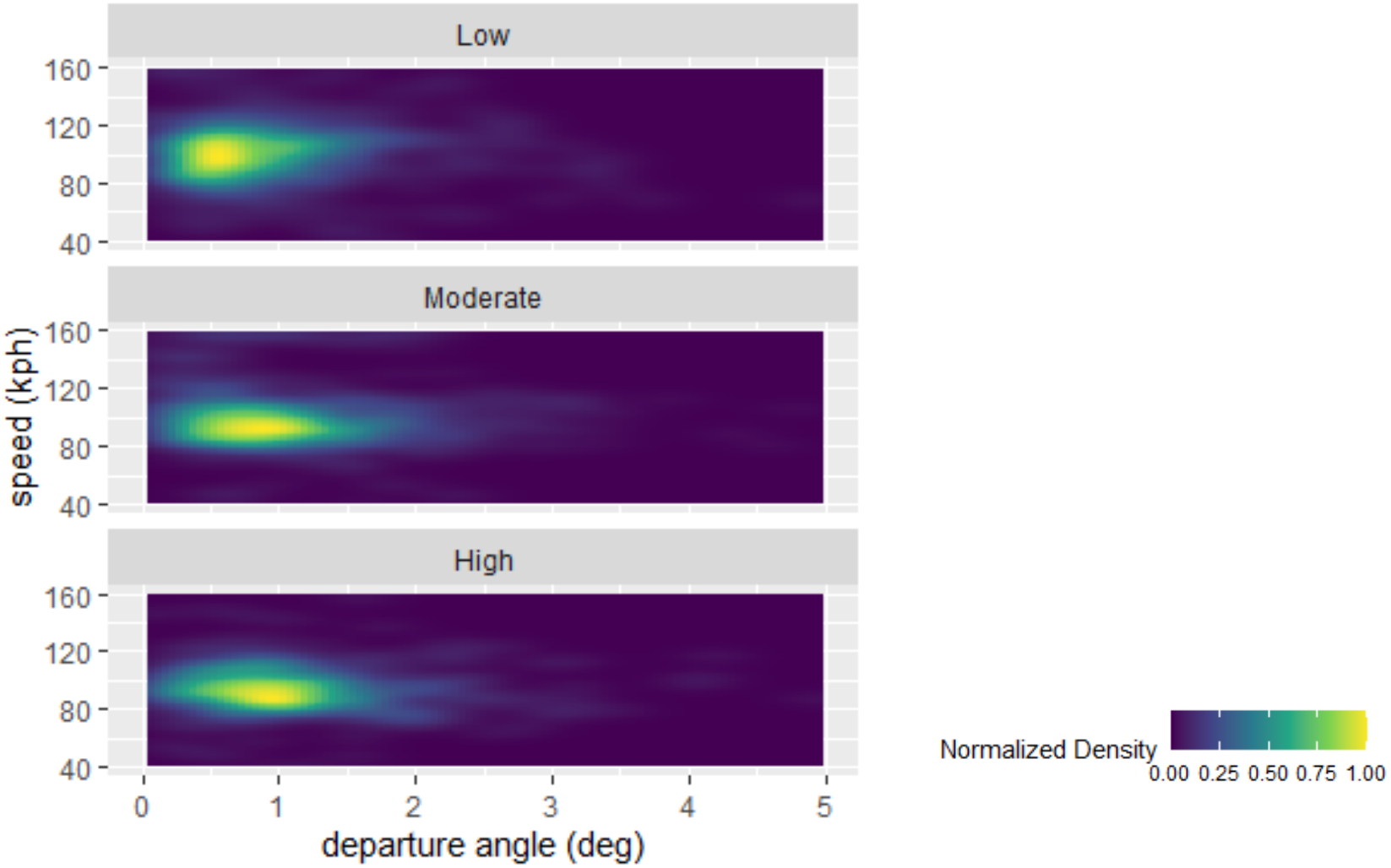
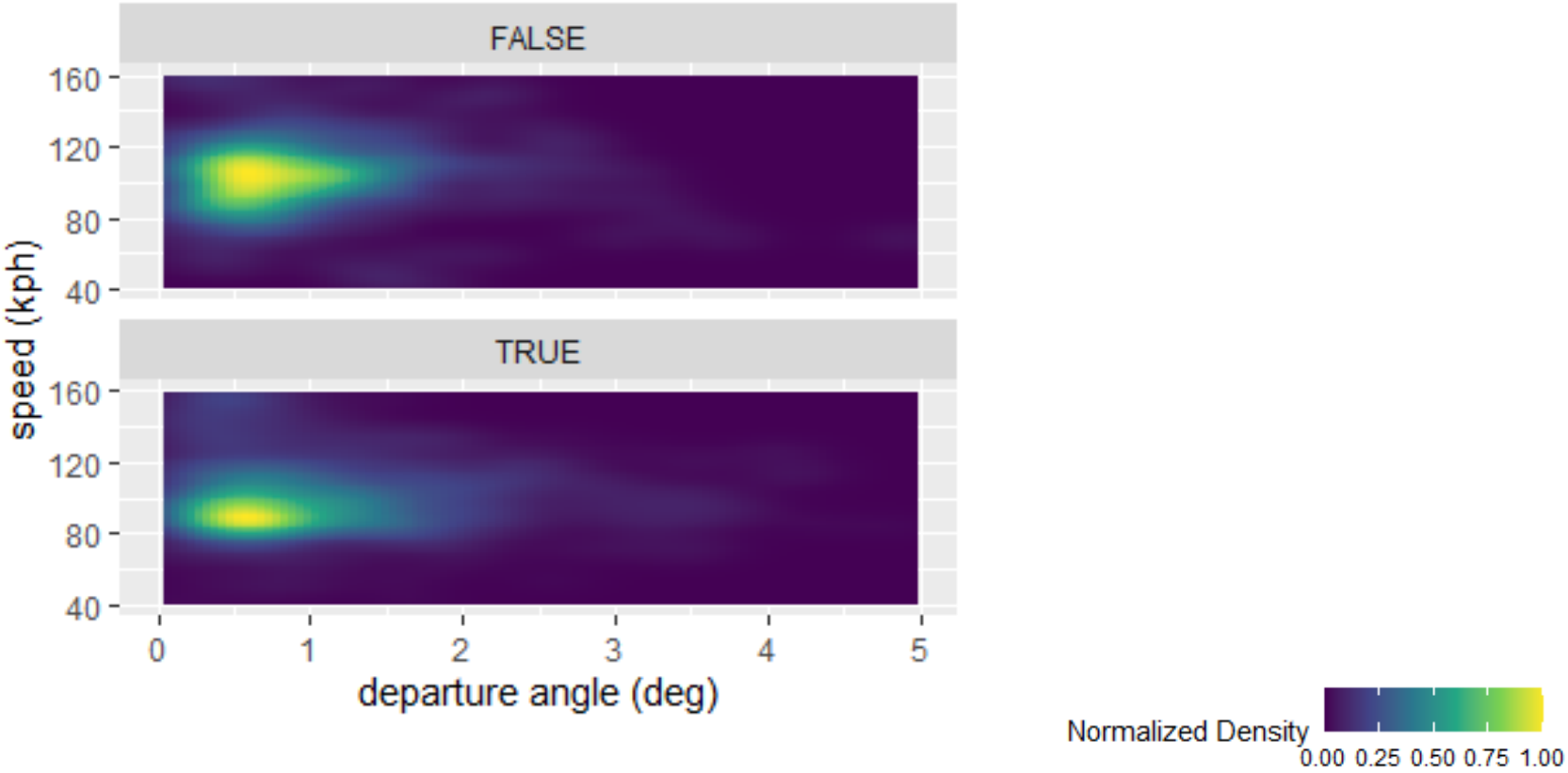


Speed vs. Departure Angle (Alcohol)

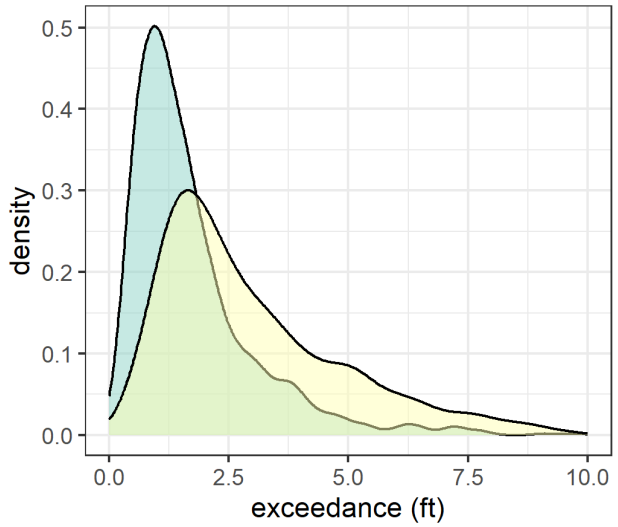


Speed vs. Departure Angle (Cannabis)

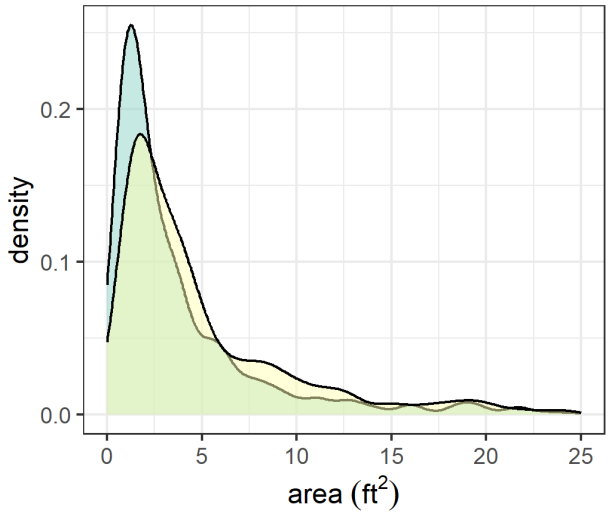


Lane Departure Severity

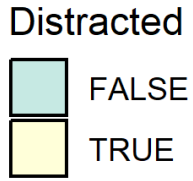
- Distracted drivers had more severe lane departures that exceeded the lane line by a greater distance



(a)



(b)



Sequence Analysis

Transition Sequences

Dependent Measures

Phases (3)	Transitions (2)	Measure
✓	✓	Steer angle (deg)
✓	✓	Throttle (0-1)
✓	✓	Brake (lbf)
✓	✓	Speed (mph)
✓		Distance (ft)
✓	✓	Lateral speed (ft/sec)
✓	✓	Lateral acceleration (ft/sec/sec)
✓	✓	Heading (deg)
✓		Steer angle standard deviation (deg)
✓		Throttle standard deviation (0-1)
✓		Brake standard deviation (lbf)
✓		Speed coefficient of variation (mph)
✓		Lateral speed standard deviation (ft/sec)
✓		Lateral acceleration standard deviation (ft/sec/sec)
✓		Heading standard deviation (deg)

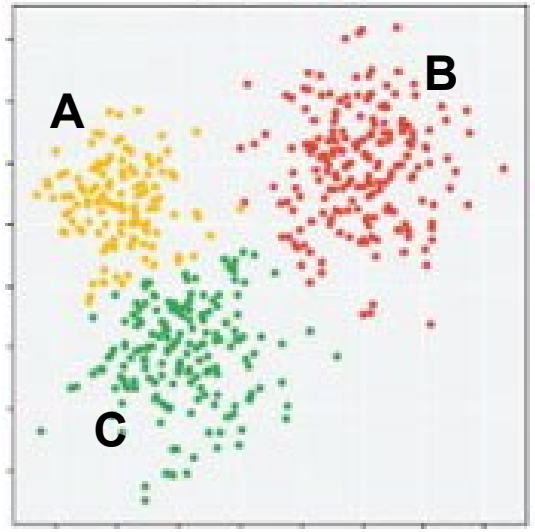
Phases:
- Pre
- Departure
- Recovery

Transitions:
- Onset
- Reentry

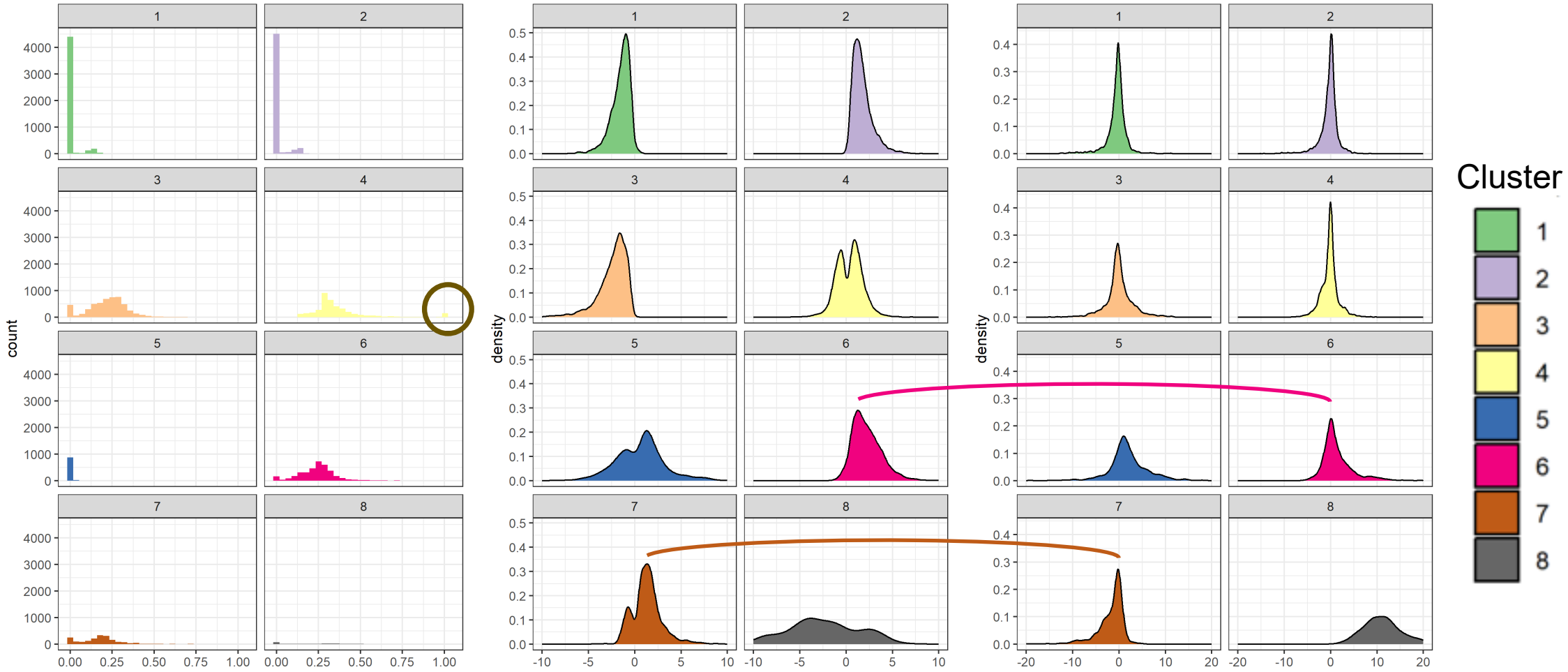
Sequence Analysis

- Clusters are letters
- Sequences are words
  - Order of letters matters!
- Phase sequence
  - Pre => Departure => Recovery
- Transition sequence
  - Onset => Reentry
- Sequence edit distance
  - Uses rules from natural language processing
  - CAT, HAT, CAR are ‘similar’ 3-letter words
  - DO, FO, DI are ‘similar’ 2-letter words

Clusters (example)

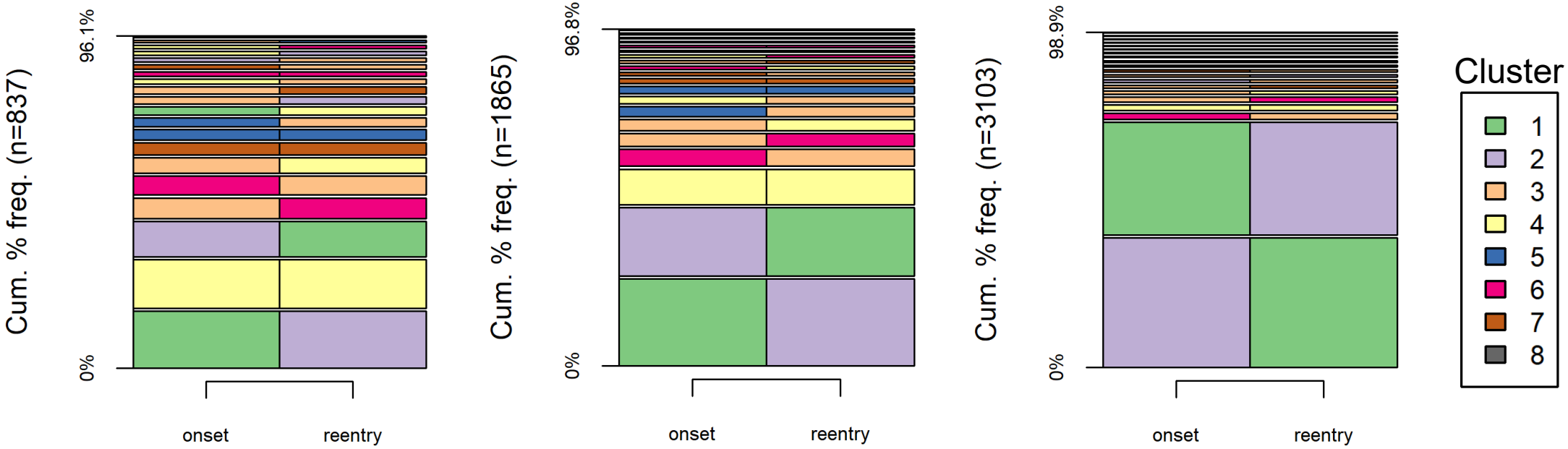


Clusters and Dependent Measures



Drowsiness

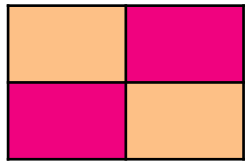
- Higher speeds, lower throttle, more prevalent with drowsiness
- Greater range of speed, full throttle, more prevalent with alertness

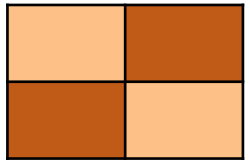


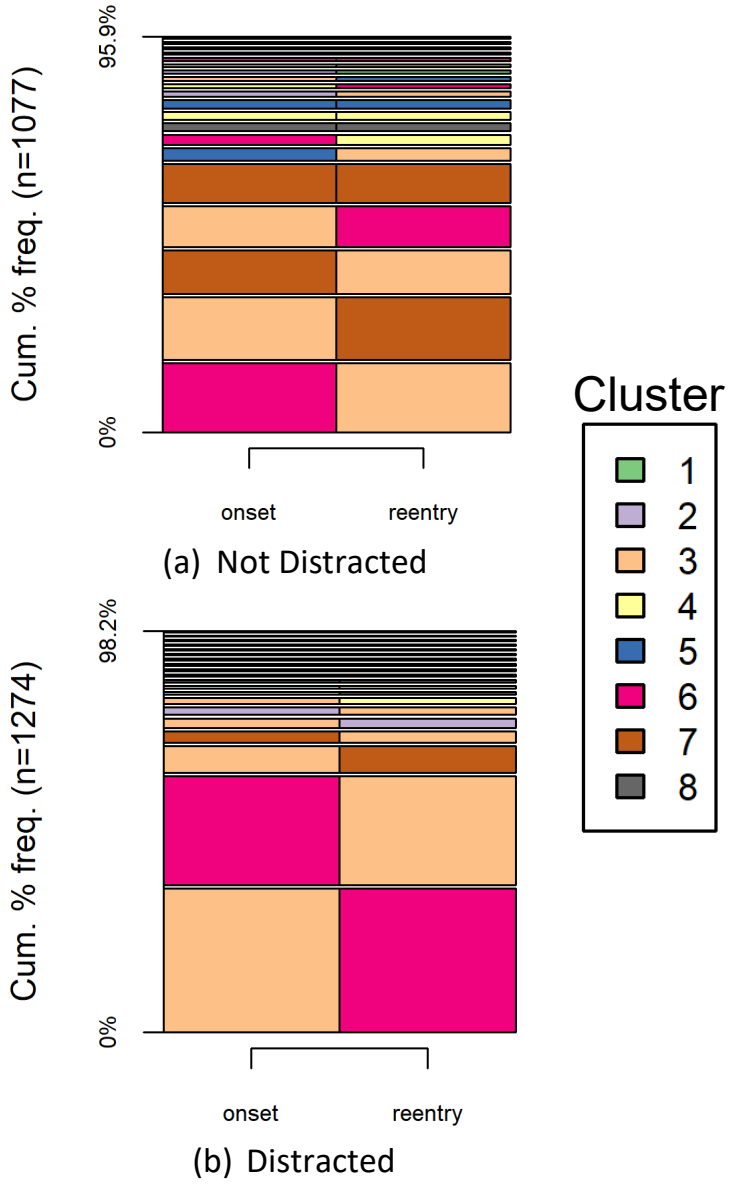
(a) Low Drowsiness (b) Moderate Drowsiness (c) High Drowsiness

Distraction

- More aggressive/abrupt lateral movement increased with distraction
- More conservative lateral movement increased with alertness (acceleration/steering acted to counter lateral speed)







Conclusions

- Different characteristics observed with driving impairment
  - Drowsy lane departures characterized by less input from steering, throttle, and braking. Low drowsiness had more active driver inputs
  - Distracted lane departures were more severe and had more aggressive lateral movement
  - Moderate BrAC (0.05-0.08) was associated with more active throttle and steering. Both low (<0.05) and high BrAC (>0.08) had less
    - Why? We think there's an interaction between intoxication and drowsiness
  - Least compelling differences observed with and without cannabis dosing
    - Different dosing protocols across cannabis studies made it very difficult to achieve common ground truth

Conclusions (cont.)

- Simulators ideal for well-controlled and repeatable drives that focus on differences within and between drivers
- Aligning test procedures with known driver behaviors with and without impairment will help ensure the necessary range of test parameters are covered

Project Status

- Final report under review
- Final briefing in January
- Paper on Drowsy lane departures to be presented at 2026 Enhanced Safety of Vehicles

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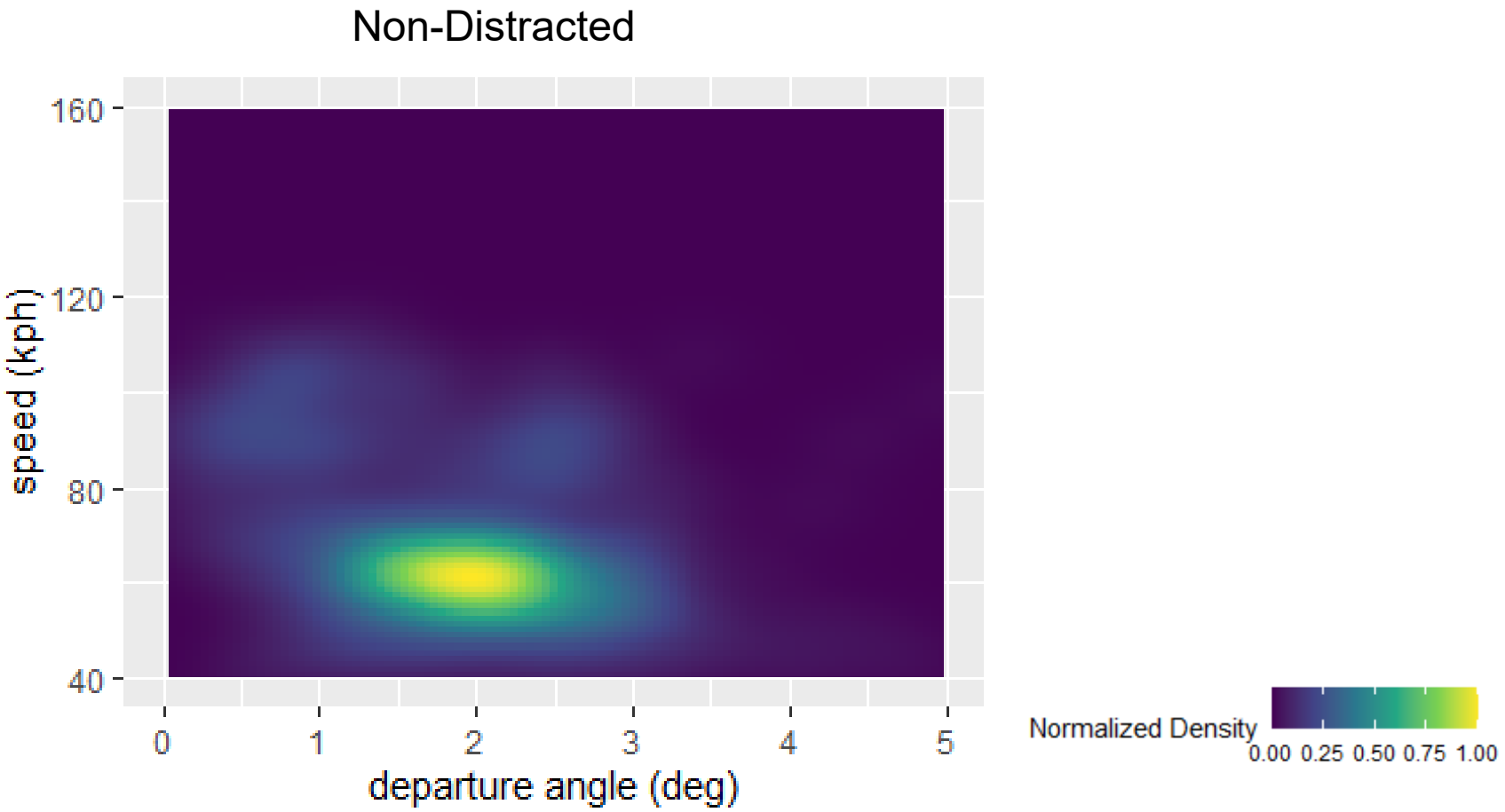
Questions?

Speed vs. Departure Angle (Distraction)



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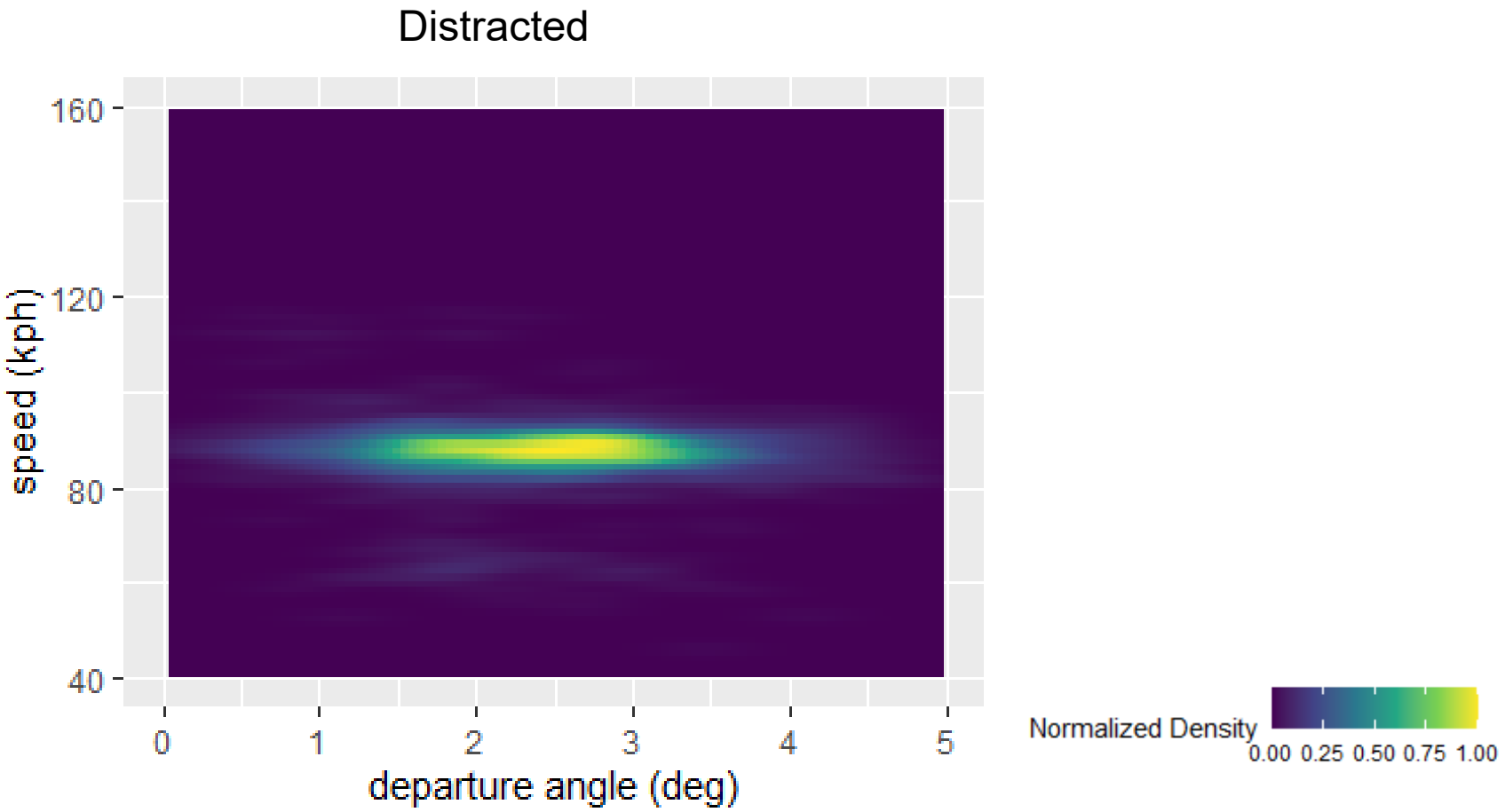
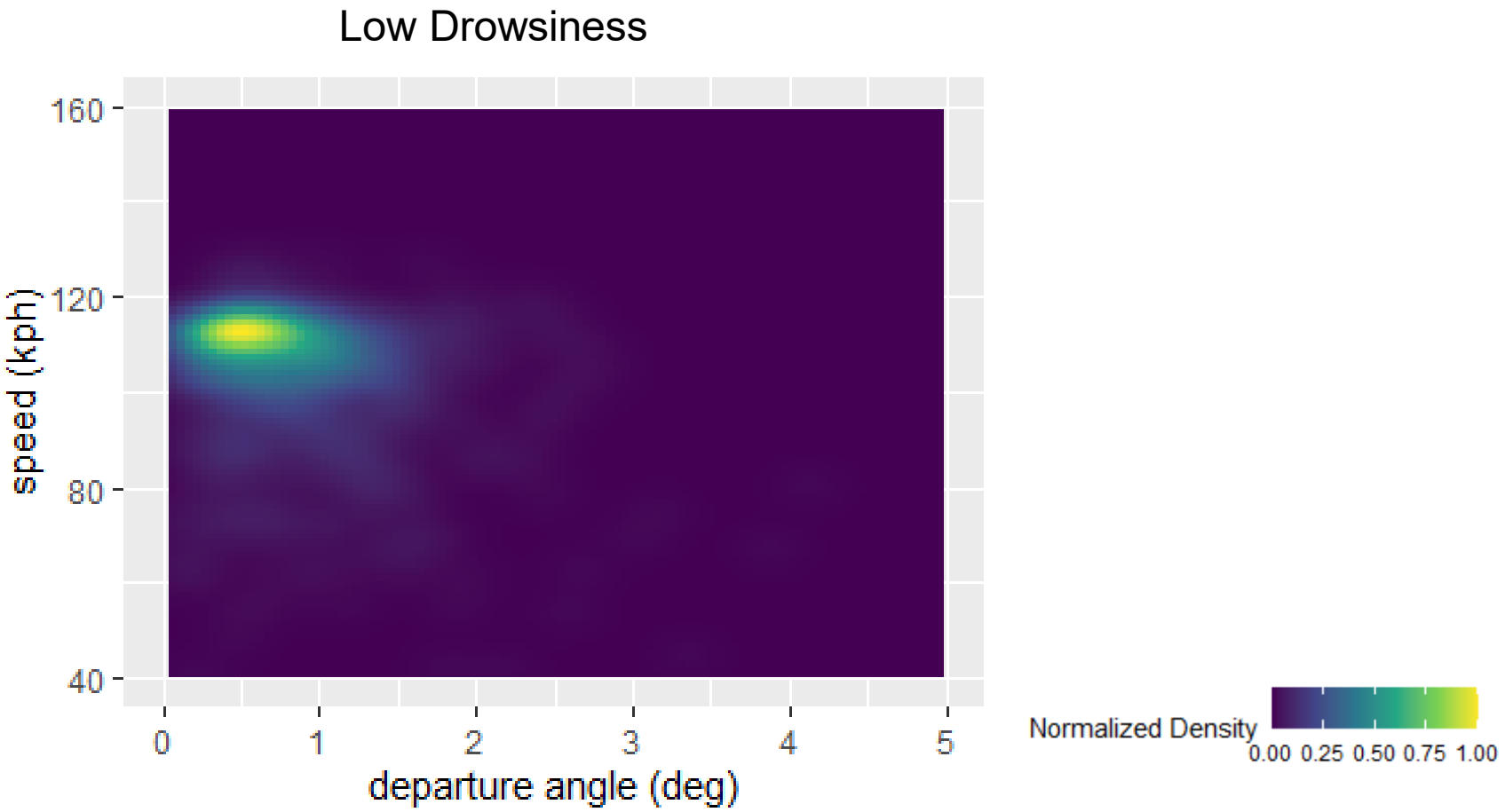
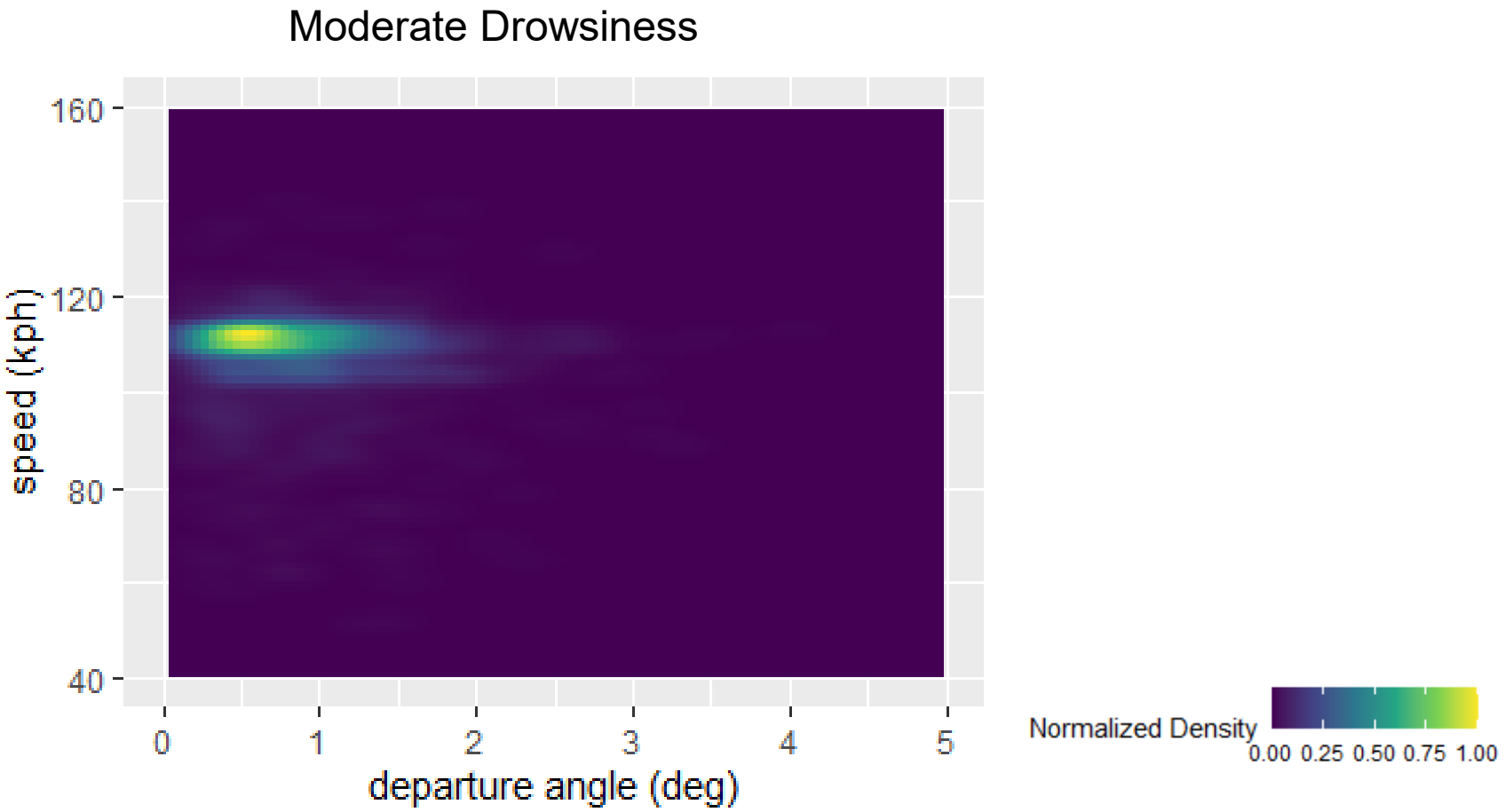


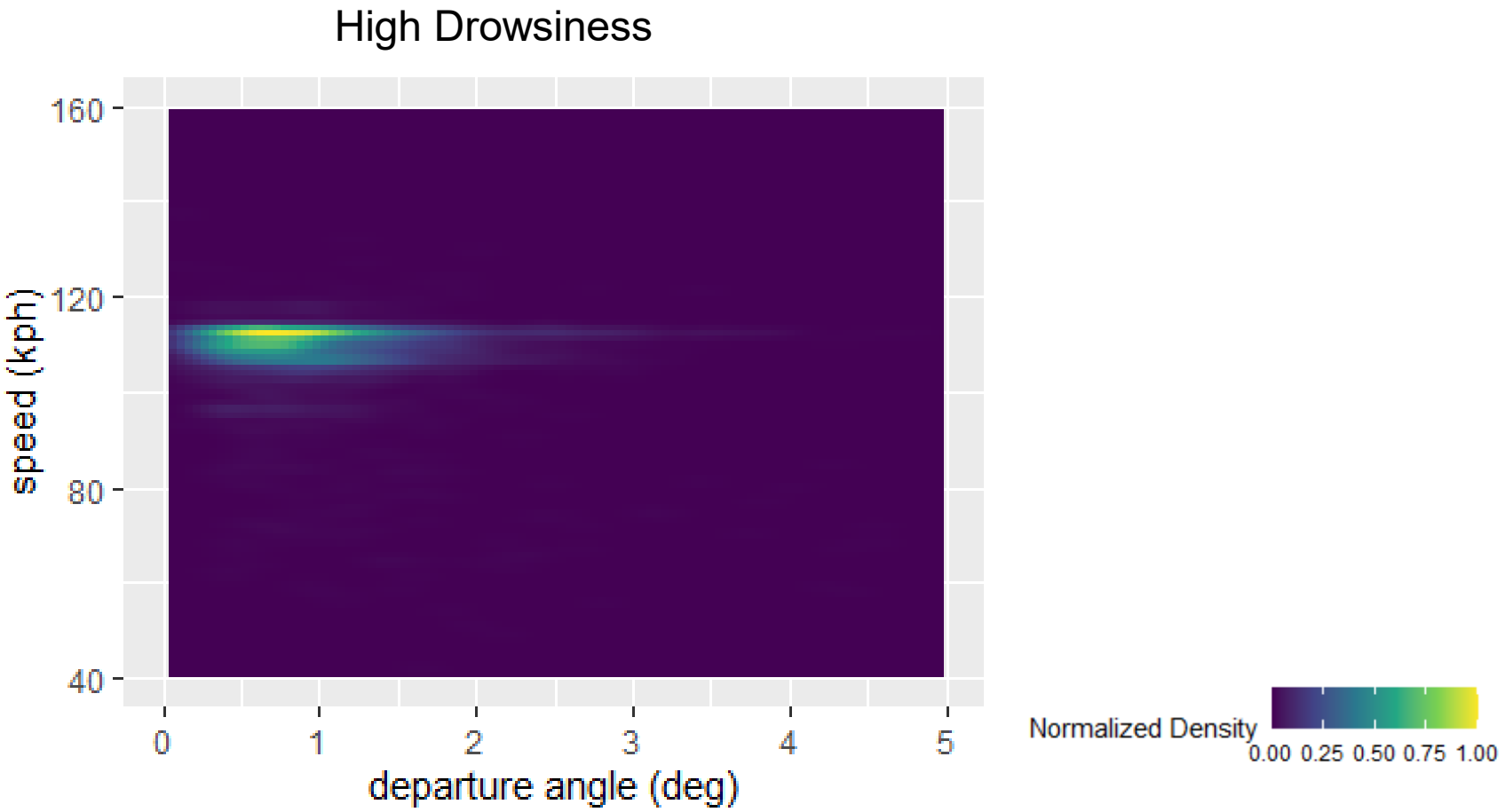
Speed vs. Departure Angle (Drowsiness)



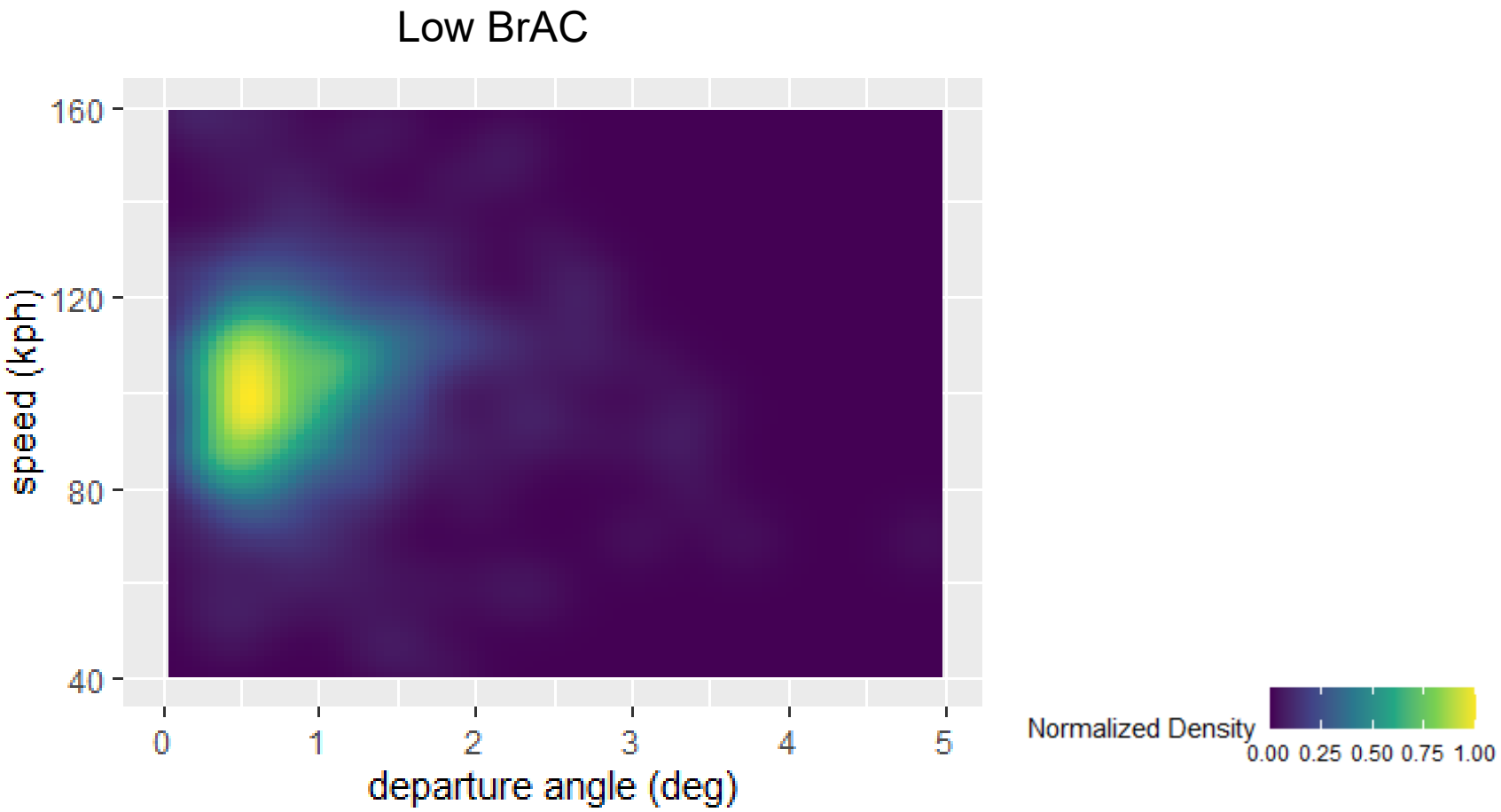
Speed vs. Departure Angle (Drowsiness)



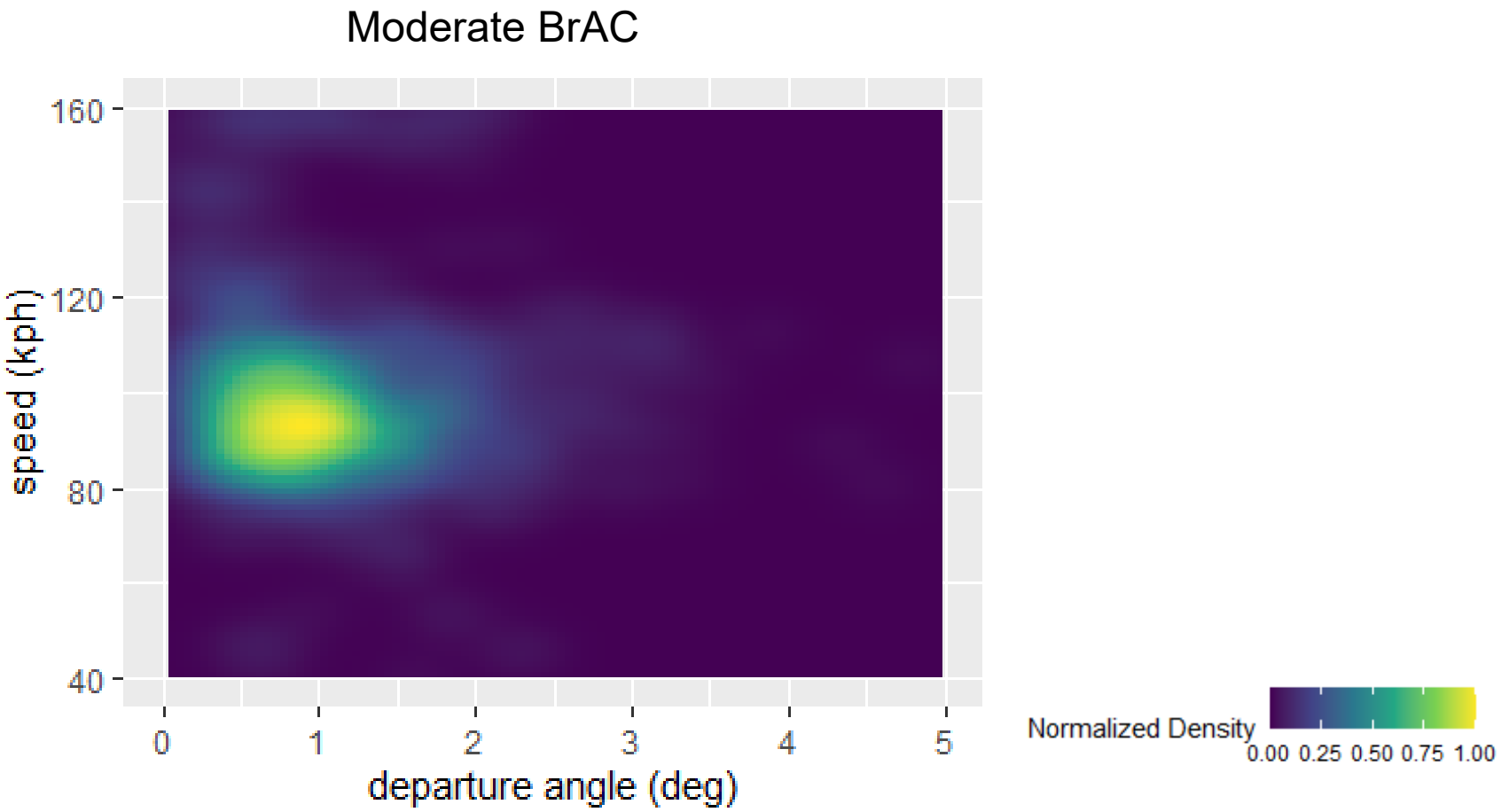
Speed vs. Departure Angle (Drowsiness)



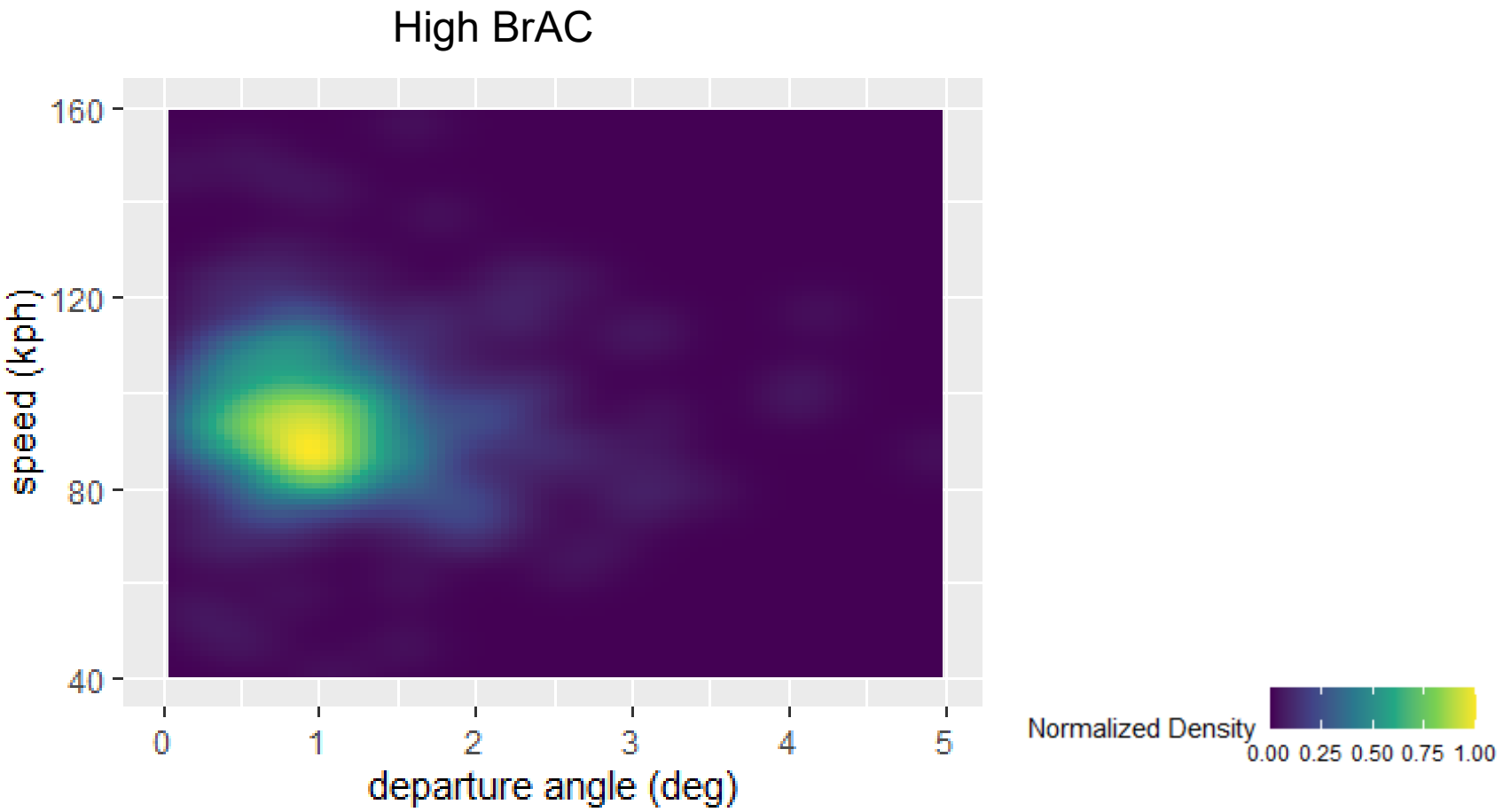
Speed vs. Departure Angle (Alcohol)



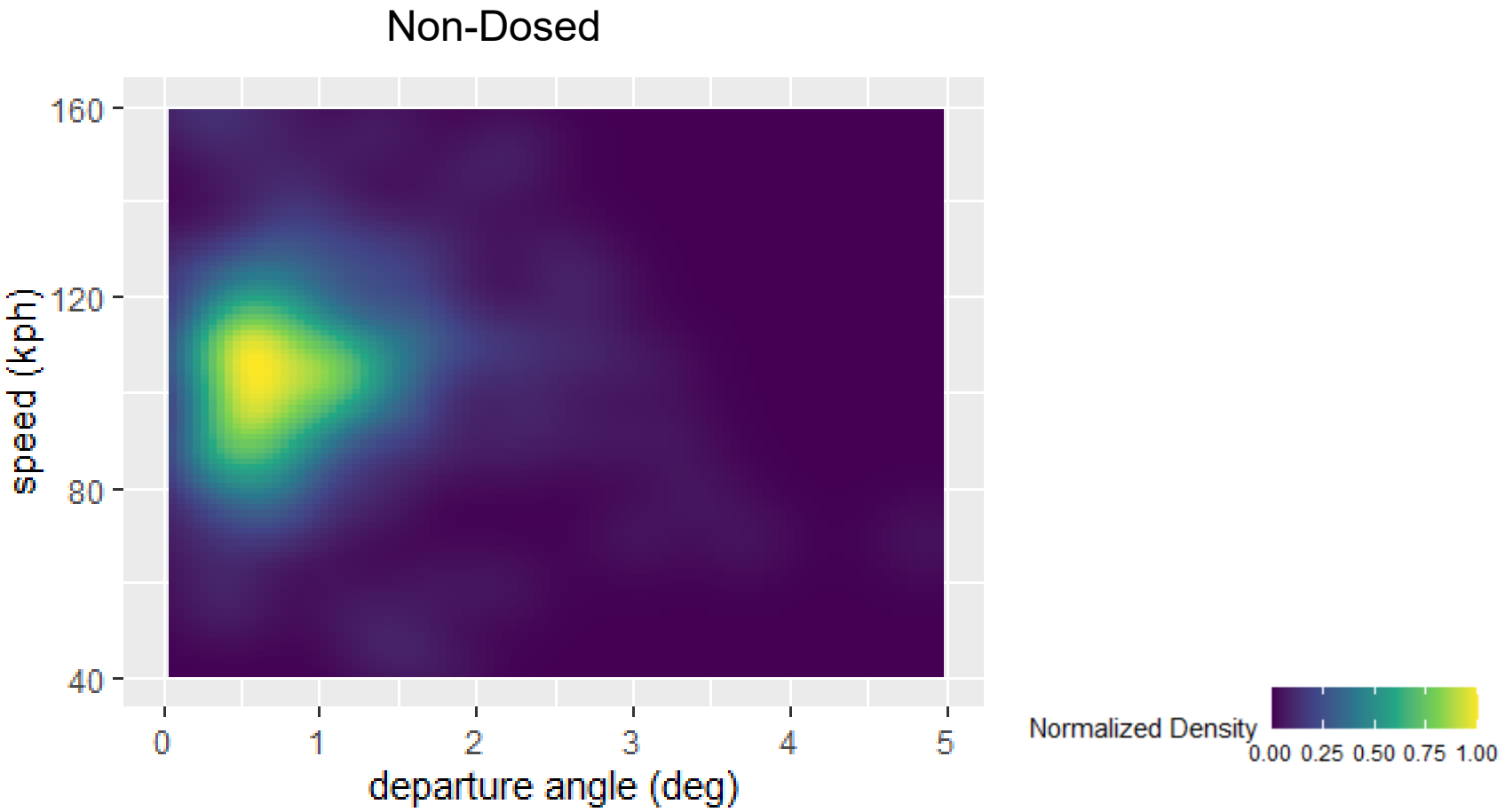
Speed vs. Departure Angle (Alcohol)



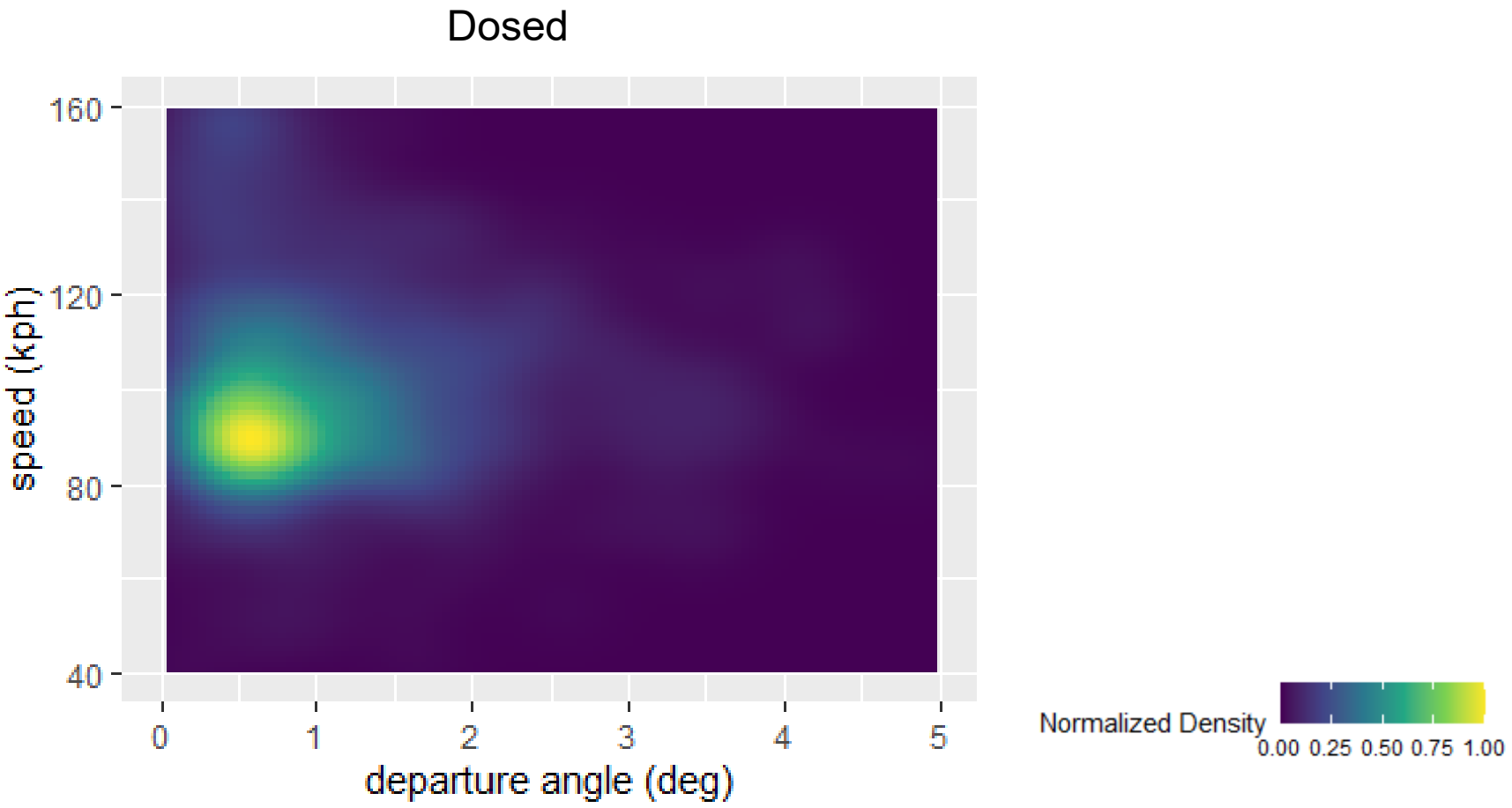
Speed vs. Departure Angle (Alcohol)



Speed vs. Departure Angle (Cannabis)



Speed vs. Departure Angle (Cannabis)



Analyses Conducted

- Sequence analysis. Clusters were trained from dependent measures and constructed into sequences. From the sequences, empirical observations were made and a statistical comparison, called discrepancy analysis, was performed
- Lane departure severity. Severity, measured by maximum lane exceedance and lane departure area, was compared across impairment levels using ANOVA
- Environmental variables. Other factors that describe lane departures were studied using a Chi-squared analysis. These included lane departure direction, departures into oncoming lanes, departures (partially) off the road, and departures on high or low curvature roads
- Sequence clusters. A second round of clustering on sequences help to reduce the set of sequences into distinct groups and summarize differences between the groups

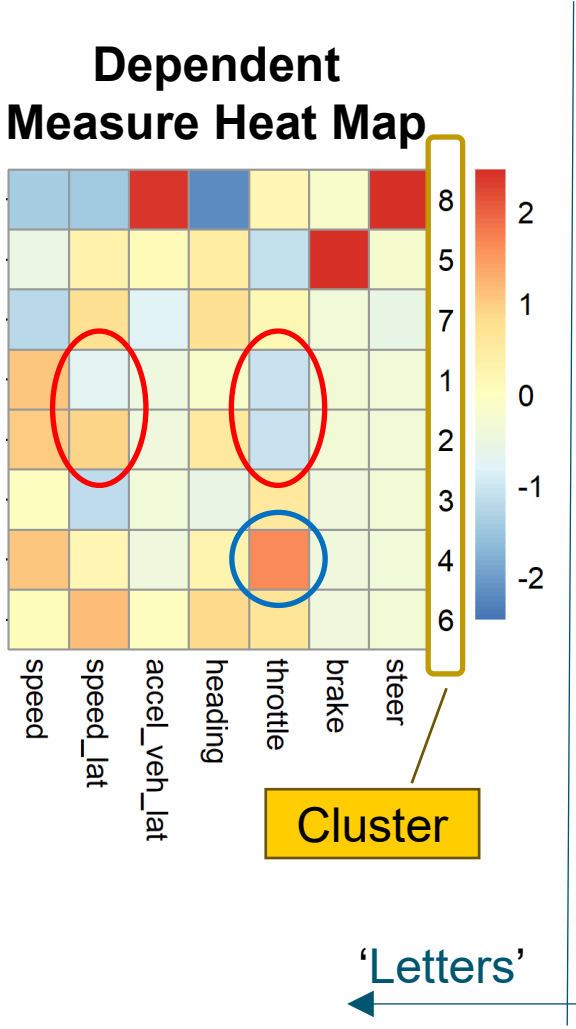
Environmental Factors

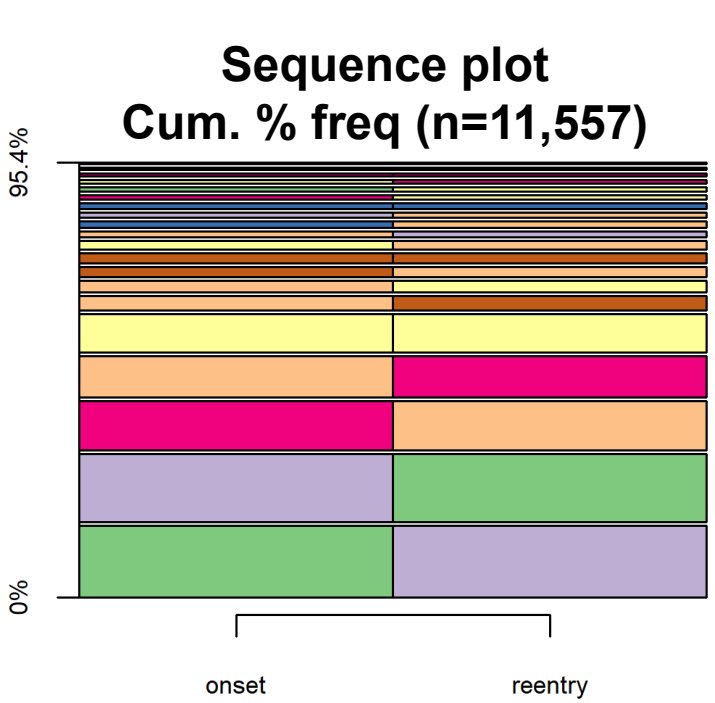
- In the presence of impairment, some environmental characteristics were apparent
  - E.g. lane departures into the oncoming lane were more common with distraction, alcohol, and cannabis, but not with drowsiness

	Direction	Oncoming	Offroad	Curvature
Drowsiness	Right	False	True	High
Distraction	Left	True	--	--
Alcohol	--	True	--	Low
Cannabis	Right	True	True	Low

Lane Departure Transitions

Cluster	Characteristics
1	60-75 mph, left, throttle modes (0, 0.12)
2	60-75 mph, right, throttle modes (0, 0.12)
3	25-75 mph, left, throttle modes (0, 0.25)
4	50-100 mph, balanced direction, throttle modes (0.3, 1.0)
5	15-65 mph, balanced direction, throttle modes (0), mild braking
6	40-70 mph, right, throttle modes (0, 0.25)
7	15-55 mph, center right, center left accel, center right heading, throttle modes (0, 0.2), center left steer
8	10-75 mph, center left, right accel, center left heading, throttle modes (0, 0.3), right steer

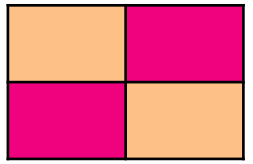


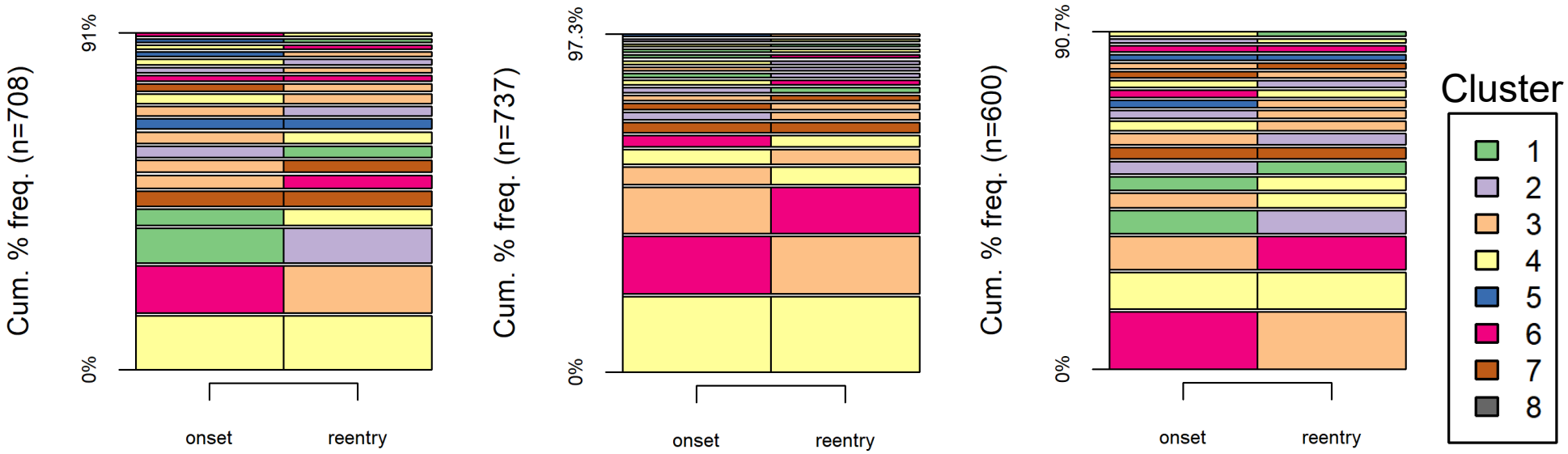


‘Letters’ ‘Words’

Alcohol

- More aggressive/abrupt lateral movement associated with moderate BrAC

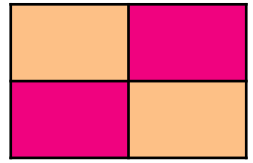




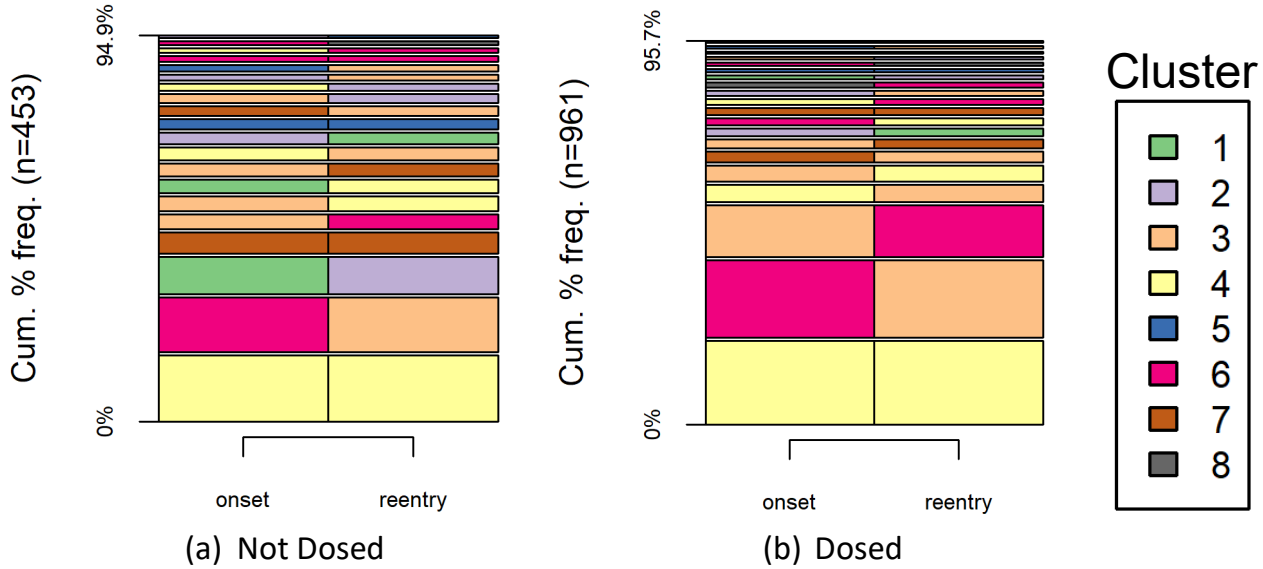
(a) Low BrAC (b) Moderate BrAC (c) High BrAC

Cannabis

- More aggressive/abrupt driver inputs increased with cannabis



- Highway speeds, low throttle use, more common without cannabis



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