Understanding hands-off behaviors while using Tesla Autopilot

Joonbum Lee[1], Pnina Gershon[2], Josh Domeyer[3], Bruce Mehler[2], and Bryan[2] Reimer

[1]University of Wisconsin-Madison, [2]MIT AgeLab, [3]Toyota CSRC

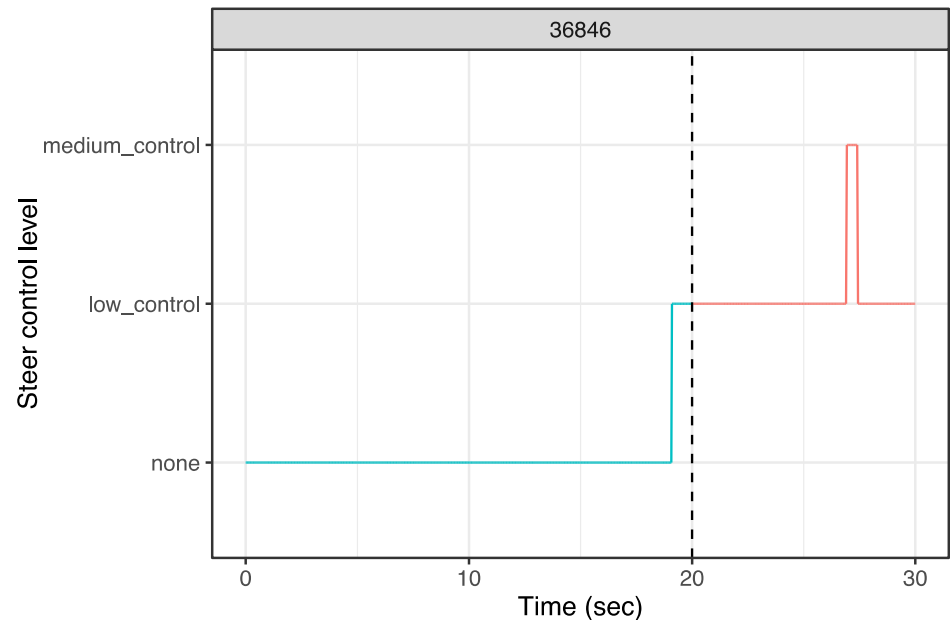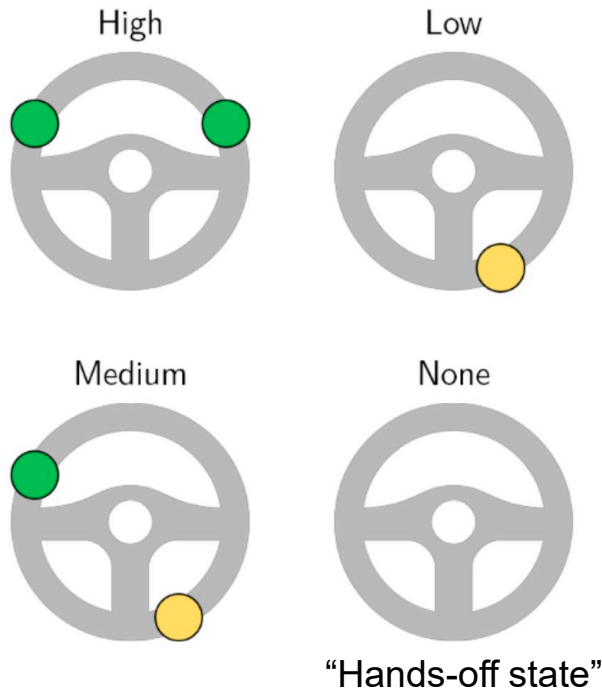# Understanding implications of hands-off behaviors

RQ 1. Is there a relationship between hands-off behavior and glance behavior?

RQ2. Do individual differences exist in the relationship between hands-off and forward glances?

RQ3. How are individual differences associated with hands-off behavior?

Data overview

- MIT AVT FOT TOC Dataset (V 1.0)*
    - 290 non-critical, driver-initiated Autopilot (AP) disengagements to manual control
    - 19 drivers (4 females) across 192 unique trips
    - Highways, daylight
    - 30s long segment (20s before and 10s after the disengagement)

High   Low

Medium   None

"Hands-off state"

*Morando, Gershon, Mehler, and Reimer (2020).

RQ1. Is there a relationship between hands-off behavior and glance behavior?

- Objective
    - To examine a relationship between percentage of hands-off and percentage of on-road glances

- Methods
    - Linear mixed effect model
    - Outcome variable: percentage of on-road glance
    - Predictors tested: **percentage of hands-off**, low control, medium control, high control, count of steer control changes
    - Random effect: drivers (intercept)

Percentage of on-road glance was negatively associated with percentage of hands-off during AP

- Higher percentage (or duration) of hands-off state is associated with lower percentage of on-road glances
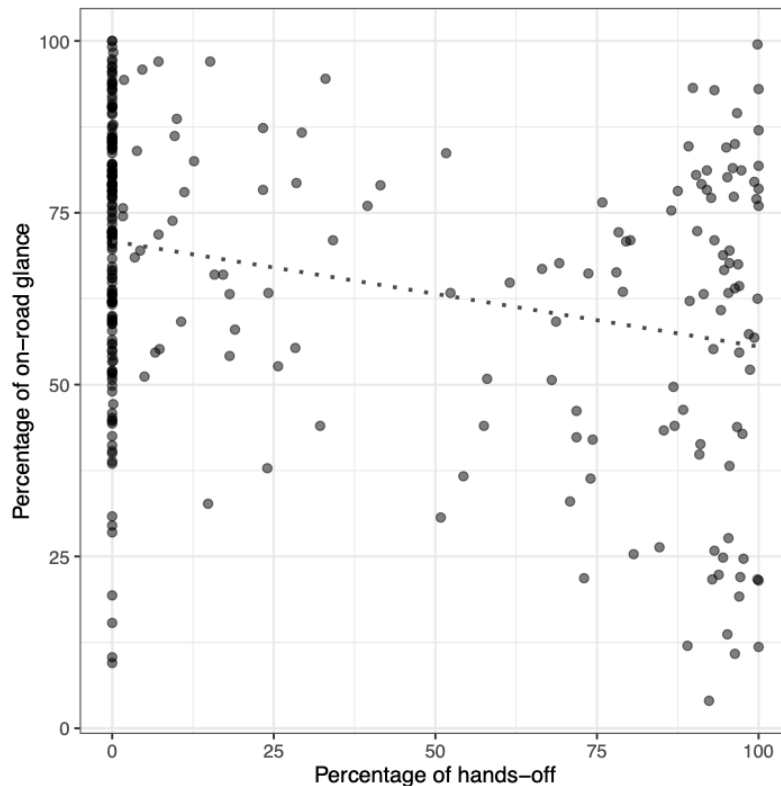

Predictors	percent_road			
	Estimates	CI	p	df
(Intercept)	73.33	68.72 – 77.93	**<0.001**	17.31
percent none	-0.14	-0.22 – -0.06	**<0.001**	125.76
Random Effects				
σ^2	390.13			
$\tau_{00 \ volunteer\_id}$	29.66			
ICC	0.07			
$N_{volunteer\_id}$	19			
Observations	290			
Marginal R^2 / Conditional R^2	0.074 / 0.140			

RQ1. Is there a relationship between hands-off behavior and glance behavior?

Bimodality in the percentage of hands-off behavior was observed, leading us to investigate RQ2 using a mixture model

- Mixture model describes a dataset as a combination of multiple probability distributions (e.g., a mixture of different subpopulations)
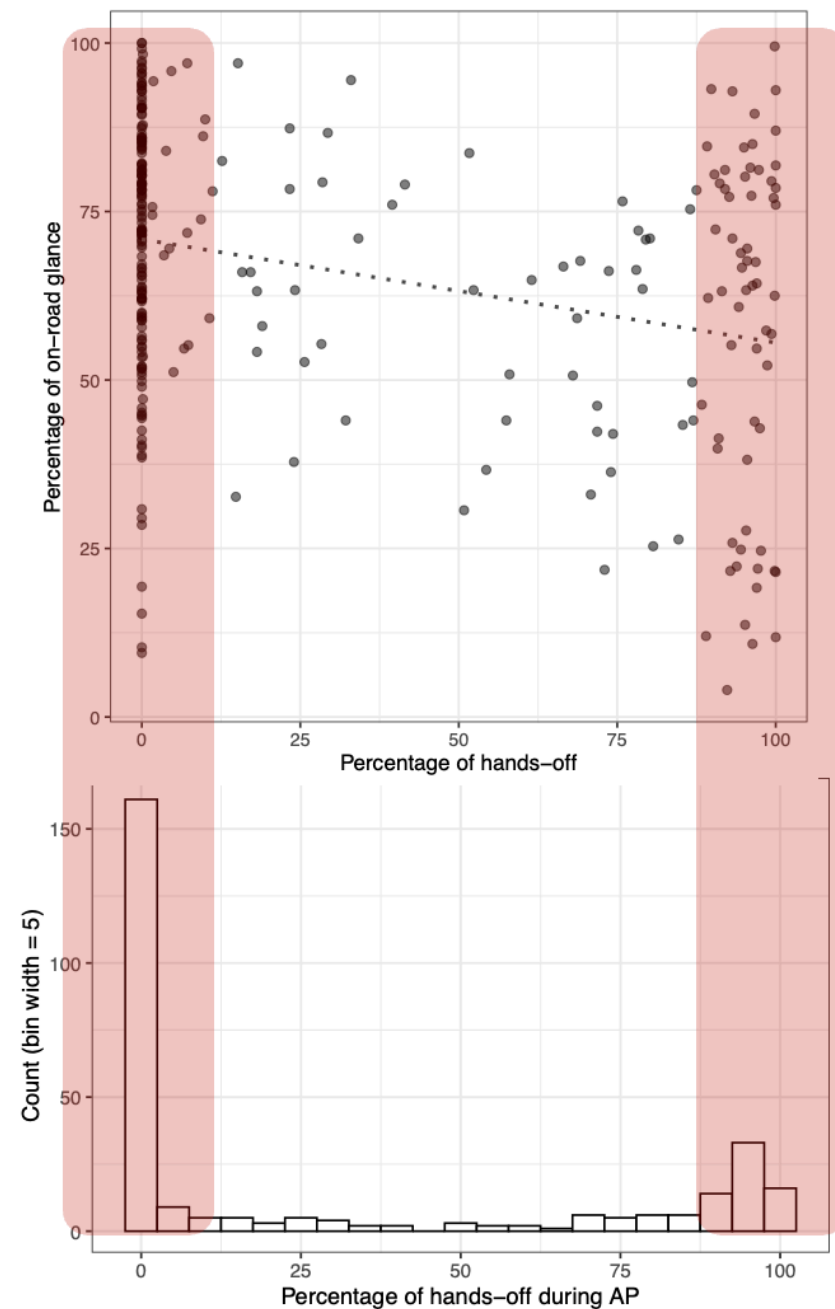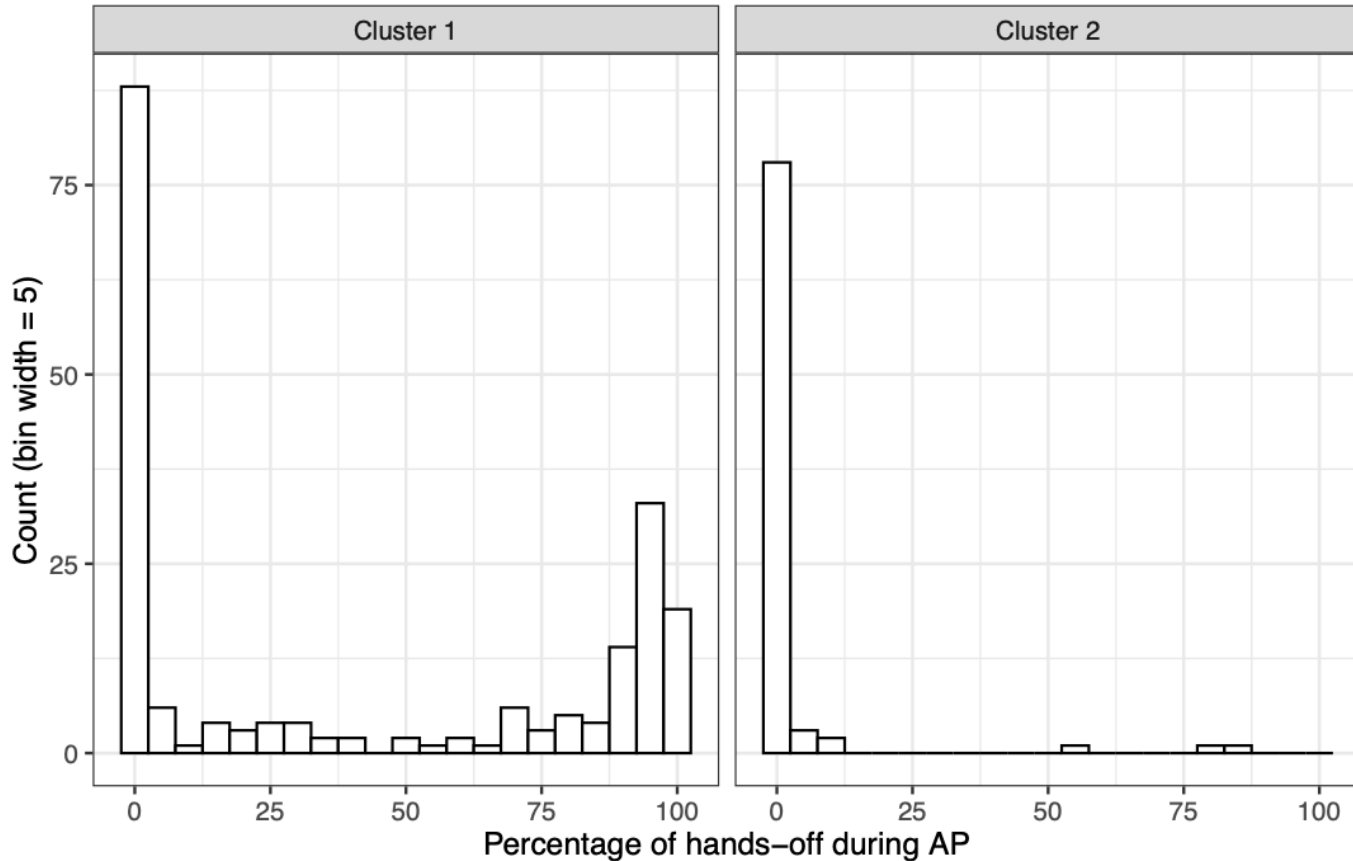

RQ1. Is there a relationship between hands-off behavior and glance behavior?

RQ2. Do individual differences exist in the relationship between hands-off and forward glances?

- Objective
  - To identify subgroups of the drivers who showed different hands-off patterns

- Mixed effect mixture model
  - Number of clusters (k) = 2
  - Outcome variable: percentage of on-road glance
  - Predictor: percentage of hands-off
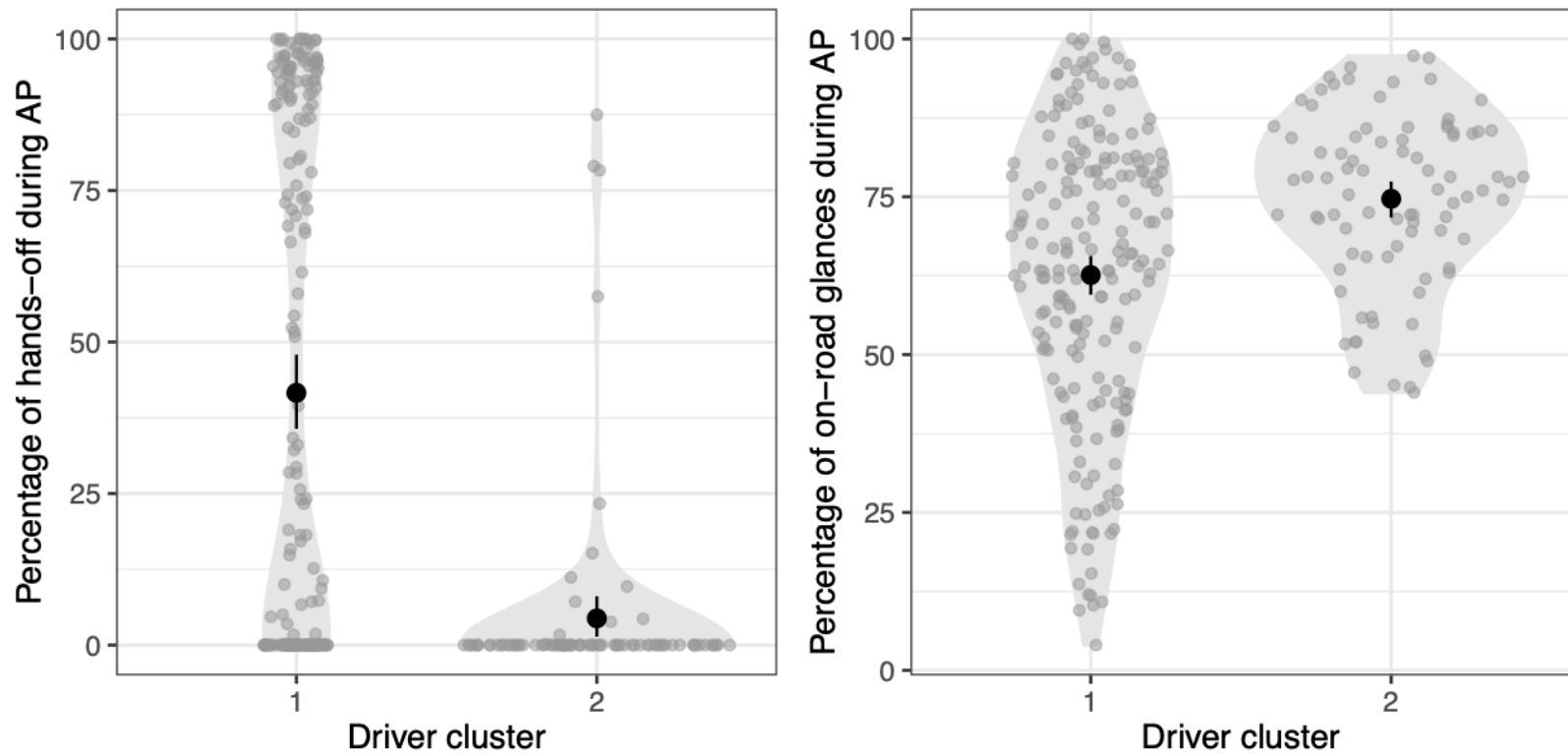 - Random effect: drivers (intercept)

Cluster 1 drivers maintain bimodality, while cluster 2 drivers peak at 0% hands-off

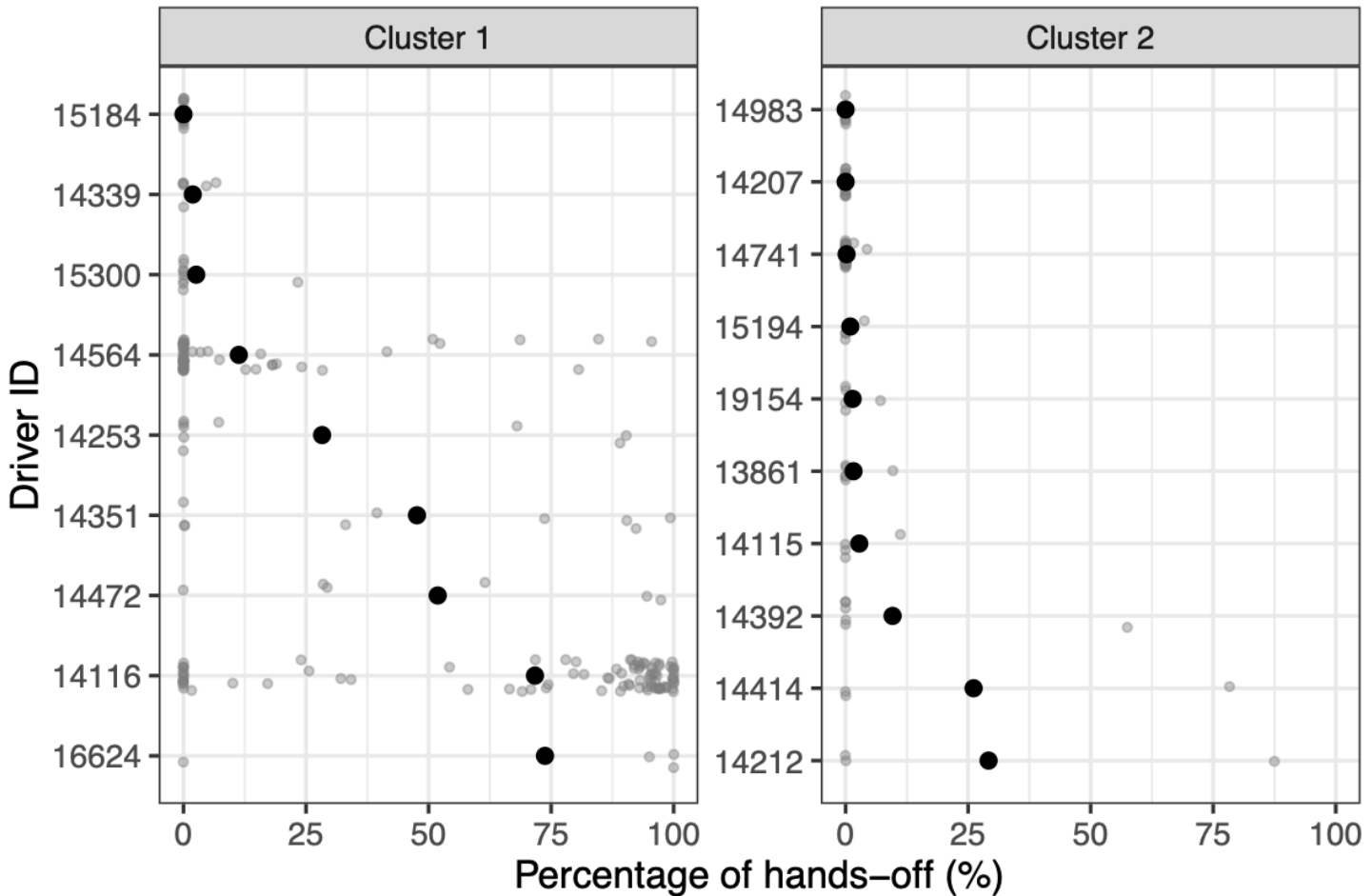Cluster 1: 9 drivers (no female), mean age = 45.8 (*SD* = 13.7)
Cluster 2: 10 drivers (4 female), mean age = 52.2 (*SD* = 14.5)

Clusters 1 and 2 exhibit distinct hands-off and forward glance patterns during AP

Does Cluster 1 include both low and high hands-off drivers, or do they maintain a bimodal distribution?

Survey data indicate that difference between clusters 1 and 2 might be explained by frequency of AP use

- Four questions were analyzed using the Wilcoxon test

Question	*W*	*p*
Frequency of AP use (5-point scale)	45	.06
Trust in technologies (10-point scale)	26.5	.75
Trust in AP (10-point scale)	33.5	.46
AP safety (10-point scale)	41.5	.16

Cluster 1 comprises more frequent AP users and fewer occasional users
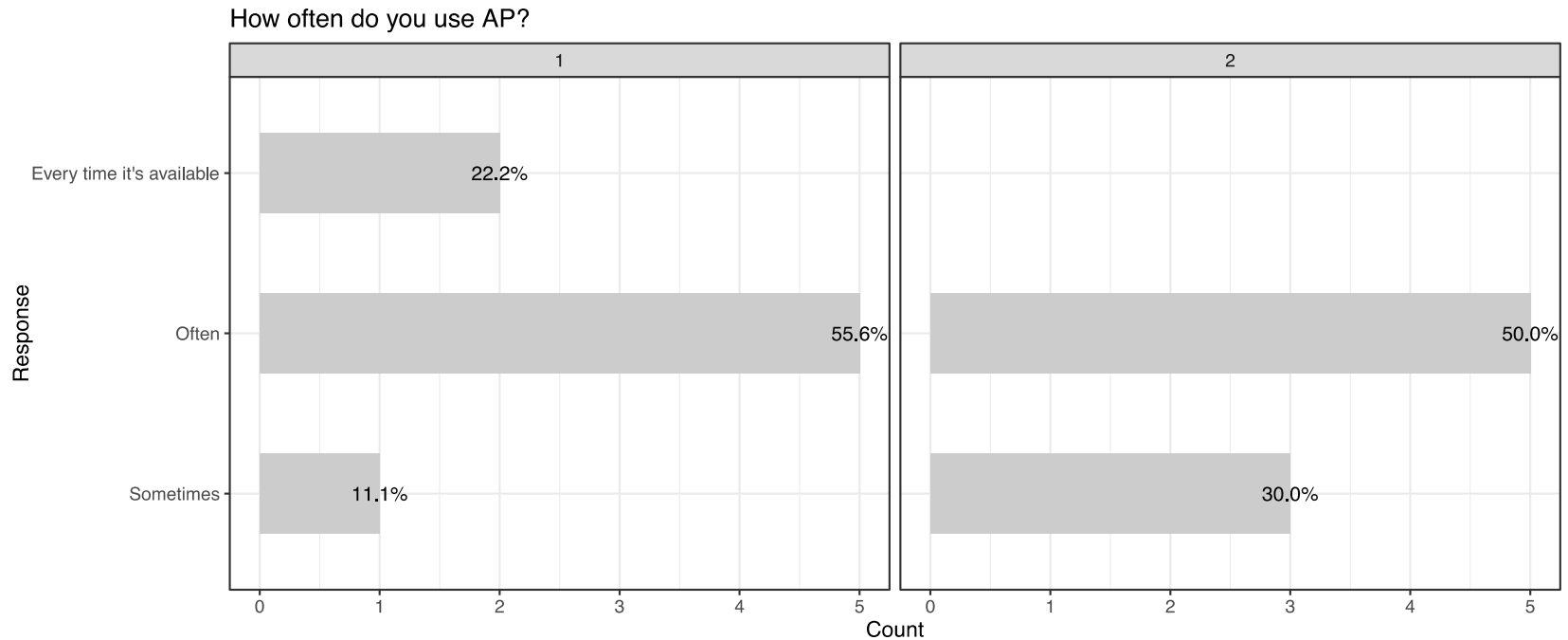
How often do you use AP?

Cluster 1: 9 drivers (no female), mean age = 45.8 (*SD* = 13.7)
Cluster 2: 10 drivers (4 female), mean age = 52.2 (*SD* = 14.5)

RQ3. How are individual differences associated hands-off behavior?

- Objective: To understand hands-off behavior and its relationship with individual differences

- Two-part mixed effect model
  - Hands-off data can be considered as discrete-continuous data
    - Discrete response (hands-off or not)
    - Continuous response (duration of hands-off)
  - Outcome variable: hands-off (response and magnitude)
  - Predictors: percentage of on-road glance
  - **Random effect: drivers (intercept)**
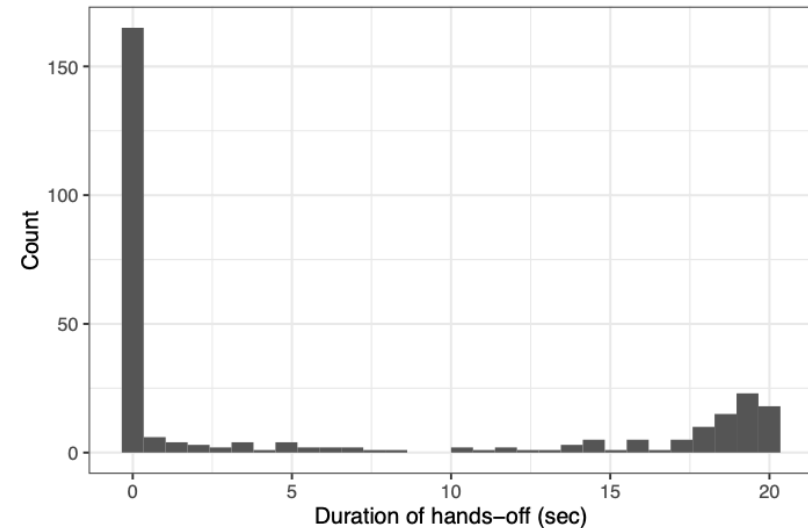
Individual difference is significant in magnitude but not in response

- Difference in individual drivers is only associated with the duration of hands-off, rather than whether they would hands-off or not (i.e., response)

Random intercept model
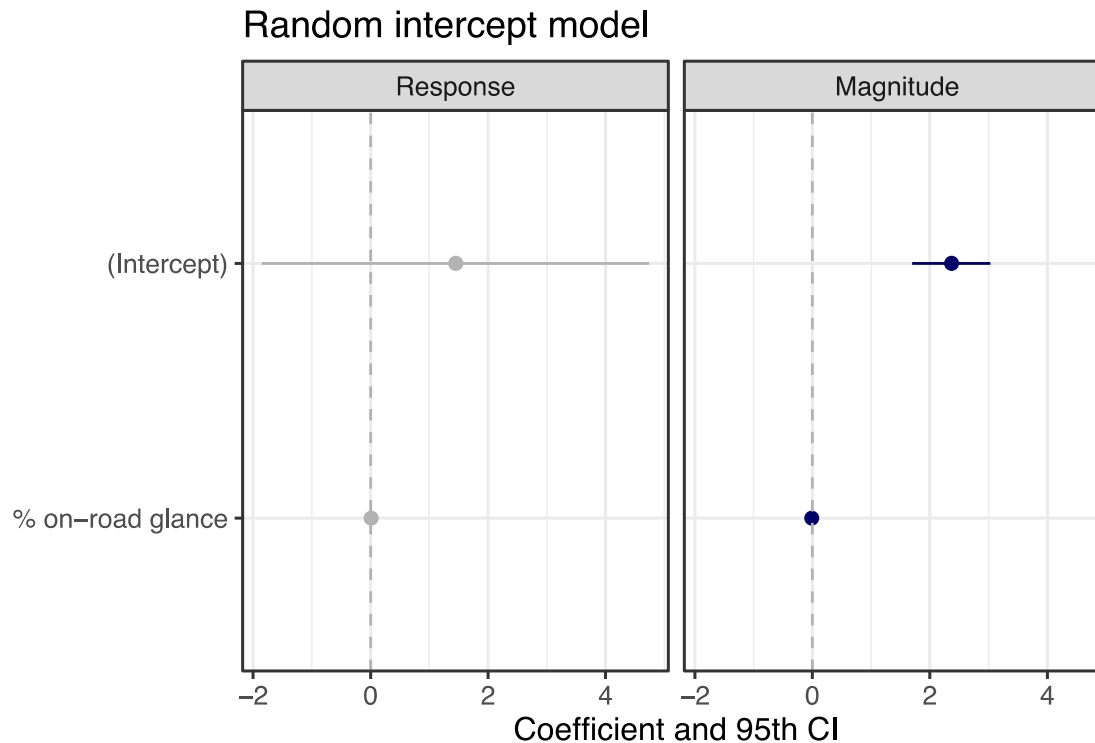
Model estimates and 95th percentile confidence intervals. The left column (Response) indicates hands-off events, while the right column (Magnitude) indicates the duration of hands-off periods. Dark-colored points indicate significance at the p < .05 level

Summary

- Research questions
    1. Is there a relationship between hands-off behavior and glance behavior?

    2. Do individual differences exist in the relationship between hands-off and forward glances?

    3. How are individual differences associated with hands-off behavior?

- Key findings
    1. Higher percentage (or duration) of the hands-off state is associated with a lower percentage of on-road glances
    2. Driver Clusters 1 and 2 exhibit distinct hands-off and forward glance patterns during AP
        1. Cluster 1 comprises more frequent AP users and fewer occasional users
        2. Cluster 2 comprises more female drivers
    3. Individual difference in hand-off behavior is significant in magnitude (duration of hands-off) but not in response (hands-off or not)