Study Summary

Driver Performance and Acceptance of Camera-Based Systems Relative to Conventional Mirror Configurations: Smart Road and Naturalistic Driving Study Results

November 16, 2020

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Summary & Key Findings

- **Project assessed the equivalency of Camera-based systems relative to conventional external (driver and passenger) Mirrors for light vehicles**
- **Study included 36 drivers and three Camera-based prototype systems evaluated under controlled and naturalistic driving environments**
  - Total of 90,880 miles (46,730 Mirrors, and 44,149 Camera); day and nighttime
- **System Designs & Specifications**
  - The prototype Camera-based systems evaluated here were independently developed by each OEM partner and varied aspects related to their design
  - The test vehicles evaluated under the current effort were prototypes; some technologies over 5 years old
  - Findings were sometimes variable and sensitive to differences across fleets, suggesting that design specifications for Camera-based systems can be refined or optimized to address performance-based concerns

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NHTSA Report Summary (Con't)

- **Study addresses some but not all of NHTSA concerns**
  - Mazzae, E.M, Bladwin, G.H.S., Andrella, A.T (2018). Examination of a Prototype Camera Monitoring System for Light Vehicle Outside Mirror Replacement. National Highway Traffic Safety Administration, Report Number DOT HS 812 582, Washington, D.C.
  - Docket No NHTSA-2019-0082

		Is the Issue Addressed By the Current VTTI Study (SONIC Project)?		
	NHTSA Issues	Issue Addressed	Partially	Notes
1	Do the "wider than required views" lead to increased eye glance durations away from the roward roadway, or present challenges for image quality and visibility?"	X		(Eye Glance Frequency and Duration) Naturalistic lane change data explored the frequency and duration of driver eye-glances under CMS and conventional Mirrors. Can determine if glance frequencies change, and if durations are longer under CMS compared to mirrors.
				(Image Quality) Last Comfortable Lane Change Judgements under Controlled Smart Road Tests examined driver ability to detect presence of vehicles, and their distance and closing speed relative to mirrors.
				(Visibility) Naturalistic lane changes allow for the identification of potential conflicts under mirror and CMS configurations.
2	Will drivers acclimate to the electronic displays?	X		Naturalistic driving data allows driver reliance on the CMS displays to be tracked over time and with experience (e.g., Lane change rates over time). Also gathered driver's subjective impressions.
3	Will display brightness at night annoy, distract, or impair a driver's ability to discern forward obstacles?		X	Best addressed (more efficiently) in a controlled setting to assess driver ability to detect forward obstacles and hazards at night. Also an issue with Mirrors (headlight glare). The vast majority of drivers did not comment on nighttime display brightness: between 8% and 17% of drivers (depending on fleet implementation) felt the displays were too bright or annoying at night. In some designs, nighttime performance was judged to be "about the same" or "better" than Mirrors by 66% of the drivers.
4	Can the night mode be improved to have lower display luminance?		X	System optimization issue. (See above comment)
5	Can image obscuration from water droplets be remedied?		X	System optimization issue. Also an issue with Mirrors. In some CMS designs, performance in the rain was judged to be "about the same" or "better" than Mirrors by 84% of the drivers.
6	Can following vehicle headlight blooming be reduced?		X	System optimization issue. Also an issue with Mirrors (headlight glare).
7	Is there an optimal downward viewing angle for such displays that maximize drivers' comfort and situational awareness?		X	System optimization issue. CMS designs in the study varied display location and Field of View (FOV).

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Summary & Key Findings

Driver Acclimation to Displays

- **Evidence suggests drivers can quickly acclimate to using camera-based systems**
  - Nearly all drivers (94%) reported acclimating to the Camera system after 2-week exposure period
  - Naturalistic data found lane change rates were initially lower than Mirror systems during the first 100 miles of travel, but approximated mirror usage after 300 miles of travel (or earlier)
    - Suggests drivers were sufficiently comfortable with the Camera-based systems following moderate usage and exposure to initiate and execute lane changes at rates comparable to conventional vehicles with Mirror systems

Summary & Key Findings

<u>Impact of Wider Field of Views: Lane Change Judgements</u>

- **Camera systems were found to significantly improve a driver's ability to detect the presence of vehicles when in the "Blind Spot" area**
  - Controlled Smart Road tests found the field of views afforded by Cameras can reduce the likelihood drivers would make a lane change when a vehicle was present in the blind spot area
- **However, *controlled tests* also found that some Camera configurations may increase a driver's propensity to accept smaller time gaps when making a lane change judgement <u>if relying on the display alone</u>**
  - Pattern was limited to daytime conditions
  - Results not necessarily universal, but sensitive to Camera configuration (location, FOV, magnification level, display size, etc.). Some Camera configurations were comparable to conventional Mirrors
  - *Concerns with small gap acceptance were not realized under naturalistic driving settings*; likely due to the fact that drivers typically use multiple information sources

Summary & Key Findings

<u>Impact of Wider Field of Views: Glance Behavior</u>

- **Driver's glance rates to support lane changes were not substantially changed, in general, by the introduction of camera-based systems**
- **Camera-based systems were comparable to conventional Mirror systems in terms of:**
  - <u>Percentage of time looking forward</u> when making a lane change.
  - <u>Reliance on mirrors/displays</u> when making a lane change. Percentage of lane changes with glances to the rearview mirror or outside mirror/display
- **Glance distributions found no evidence to suggest that driver's make excessively long glances to Camera-based displays when planning and executing signalized lane changes**
  - <u>Average single glance durations</u> were remarkably similar between Mirror and Camera conditions for glances to the "Outside Mirror/Display," "Over-The-Shoulder," and "Rearview Mirror" across all three fleets combined

Summary & Key Findings (Con't)

- **Driver Glance Behavior (Continued)**
  - Glance Frequencies
    - Overall trends suggest drivers are somewhat more reliant on the Rearview Mirror under the Camera condition; Camera condition yields slightly higher average number of glances to Rearview Mirror. Differences not statistically significant.
      - Performance with experienced Camera users compares with Mirrors
      - Some differences among fleets with some implementations leading to significantly more glances to rearview during initial learning (early exposure)
  - Glance Durations
    - Overall trends suggest comparable glance durations to external aids between Mirrors and Cameras. Some significant differences between fleets
      - Drivers in some fleets found to have significantly longer average glance durations to outside displays under the Camera condition, but not outside acceptable safety limits. (mean duration 0.56 sec vs 0.70 sec)

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Summary & Key Findings (Con't)

- **Driver Perceptions Related to Camera Systems**
  - Most feel safe (83%) using Camera-based displays, and 53% felt it improved safety over conventional Mirrors
    - Many drivers (28%) credited the Camera system as having "saved" them from a potential conflict
  - Camera systems perceived to increase FOV and eliminate blind spots, but some configurations were found to make it harder to judge distances and closing speeds
  - Performance in the rain judged to be the same or better than Mirrors by 72% of participants (some variability across fleets)
  - Overall, Camera performance perceived to be much worse at night than conventional Mirrors by 56% of participants (some variability across fleets)
- **Driver Perceptions: Concerns, Feedback and Improvements**
  - In general, areas of concern and improvement included
    - Nighttime glare, Camera failure, display brightness, display location and obstructed views, etc.
    - Optimization related issues
    - Some variability across fleets

Summary & Key Findings

- **No crashes observed. High-level hazard analysis indicates comparable lateral acceleration levels during lane changes**
  - Radar-based data from naturalistic lane change events are available, and additional reduction and analysis of this data is ongoing
- **Driver performance and acceptance of Camera-Based systems is sensitive to design characteristics**
  - Fleet vehicles included in this study varied with regard to system characteristics (e.g., Display location, size, magnification, etc.)

Summary Results Table

- **Results Key Measures, Overall and By Fleet**

	VEHICLE FLEET			
	All Combined (n=36)	**Fleet A (n=12)**	**Fleet B (n=12)**	**Fleet C (n=12)**
SETTING & MEASURE				
Controlled Tests				
Static Go/No Go				
Blind Spot Detection	Significantly Higher for Camera Daytime Only	Comparable	Comparable	Significantly Higher for Camera Daytime Only
Likelihood of "Go" at Low TTC	Significantly Higher for Camera Daytime Only	Comparable	Comparable	Significantly Higher for Camera Daytime Only
Dynamic Last Comfortable				
Time-To-Collision at Judgment (Left/Right Lane Changes Combined)	Significantly Lower TTC for Camera Daytime Only	Significantly Lower TTC for Camera Daytime Only	Comparable	Significantly Lower TTC for Camera Daytime Only
Naturalistic Driving				
Percentage Forward, Lane Change	Comparable	Comparable	Comparable	Comparable
Mean Glance Frequency				
Outside Mirror/Display	Comparable*	Comparable*	Comparable*	Comparable*
Rearview Mirror	Comparable*	Comparable*	Comparable*	Comparable*
Mean Glance Duation				
Outside Mirror/Display	Comparable*	Comparable*	Comparable*	Camera Significantly Longer*
Rearview Mirror	Comparable*	Comparable*	Comparable*	Comparable*

* Experienced Users, Left/Right Lane Changes Combined

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Study Objectives & Approach

Project Objectives

- **Gather data to support FMVSS111 rulemaking efforts related to Camera-based rear and side view systems**
- **Assess equivalency of Camera-based systems to conventional Mirror systems:**
  - Ability to locate and judge distances, including gap judgments
  - Time needed to acquire information and support decisions
  - Eye-glance patterns during search (frequency & duration of glances)
  - Conflicts with surrounding traffic
- **Explore learning, potential behavioral adaptations, or unintended consequences**
- **Assess influence of moderating factors**
  - Age, Gender, Environmental conditions (Day/night, rain, snow, cold, etc.), Experience, Direction of lane change/merge (left and right-hand maneuvers)

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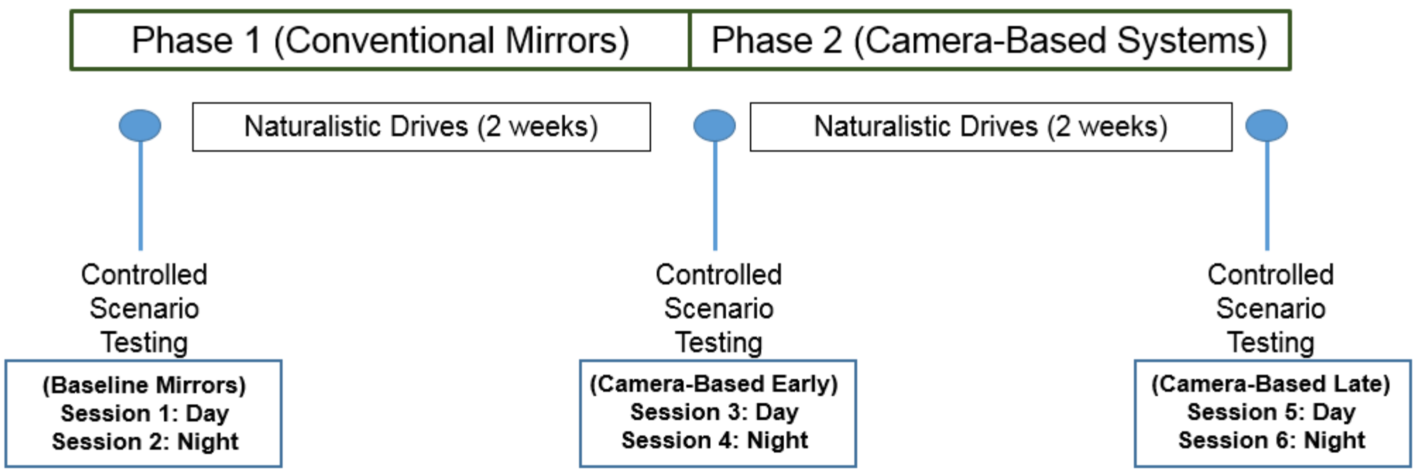
Approach

- **Study performed in Southwest, Virginia**
- **36 drivers (12 per vehicle platform)**
  - Drivers experienced both conventional Mirror and Camera-based versions
- **Vehicle Platforms**
  - Three OEM Camera-based prototypes, each with a conventional Mirror counterpart
- **Test Track & Naturalistic Driving components**
  - Controlled Test Track component
    - Captured performance under staged maneuvers
    - Forced reliance on external mirrors/displays
    - Performed under both day and nighttime sessions
    - Sessions repeated over time allowing learning impacts to be assessed with Camera-based systems
  - Naturalistic component
    - Drivers used vehicles as their daily driver
    - Recruited long-distance commuters (minimum 30 miles)

Approach (Con't)

- **Phase 1 (Baseline with Conventional Mirrors)**
  - Naturalistic Drives (Daily Driver); 2weeks
  - Controlled Scenario Testing, Both Day and Nighttime
- **Phase 2 (Camera-Based System)**
  - Naturalistic Drives (Daily Driver); 2weeks
  - Controlled Scenario Testing, Both Day and Nighttime
    - Tests Performed Early (Novice) and Late After Experience



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Study Vehicle & Configurations

- **Study included three Camera-based <u>prototype</u> vehicles: one from each of three OEM Fleets**
  - Prototype Camera-based vehicle's external Mirrors (driver and passenger-side) replaced with Camera-based equivalents
  - One fleet afforded a Camera-based Rearview Mirror, allowing all mirror surfaces to be replaced with Camera equivalents
  - Fleet vehicles included sedans and a truck
- **Also included three conventional Mirror- based vehicles matched to the prototype vehicles (equivalent model years and trim packages)**
- **All study vehicles instrumented with a Data Acquisition System to record kinematic data and camera views**

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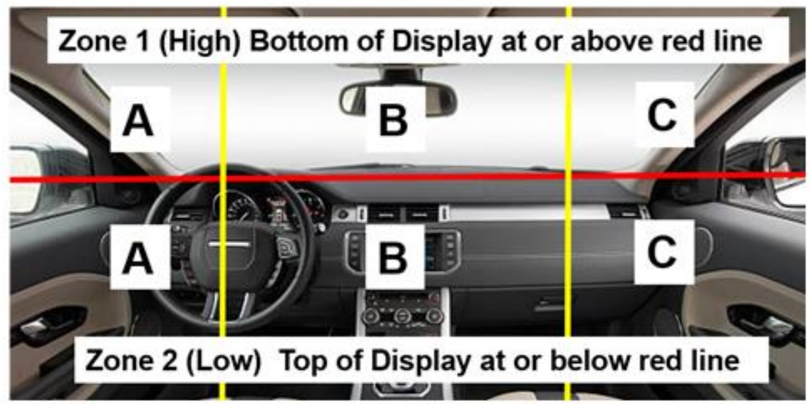
Vehicle Configurations

- Table specifies the range across the systems

Vehicle & System Characteristics	**Fleet A**	**Fleet B**	**Fleet C**
Camera System Specifications			
Field of View (FOV)	Driver: 31 to 42 degrees (horizontal) Passenger: 20 to 42 degrees (horizontal)		
Display Zone Location	Zone 1 (A & C)	Zone 1 (A & C)	Zone 2 (A & C)
			
Display Size	5.6 to 7.0 inches		
Magnification	Driver: 0.31x to 0.37x Passenger: 0.22x to 0.25x		

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Study Sample

- 36 drivers participated
  - 15 Females (42%), 21 Males (58%)
  - Ages 25 to 63 years
    - 33% Younger (25-39 yrs.)
    - 47% Middle-Aged (40-54 yrs.)
    - 19% Older (55+ yrs.)
- Mean age 44 years
- All drivers Virginia Tech Staff (Non-technical, administrative)
- All long-distance commuters; minimum 30 miles one-way
- All drivers passed driving record safety check via DMV

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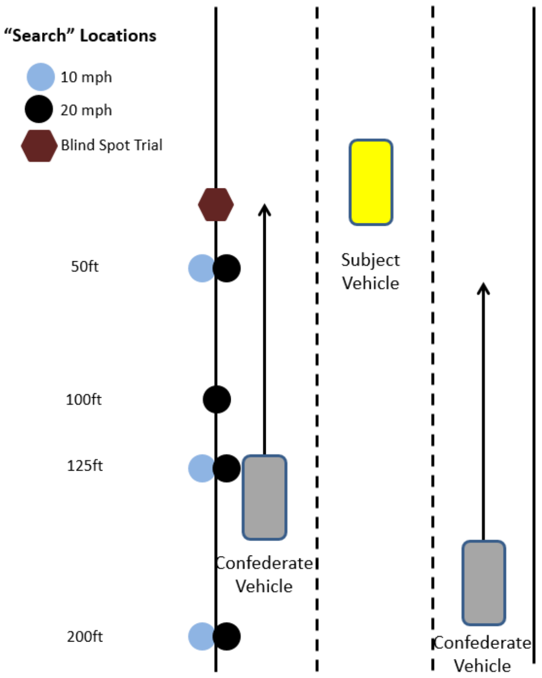
Controlled Smart Road Testing

Go/No Go Static Judgements

- **Assesses how well drivers can detect the presence, location, and closing speed of approaching vehicles in a single brief glance**
  - Stages an overtaking vehicle situation, and requires drivers to make lane change decisions
  - Mimics a brief glance to a mirror/display (vehicle is parked, drivers eyes closed)
- **Driver's cued to glance to mirror/display and make go/no go decision (make lane change or not)**
  - Based on what they first see
  - Only rely on external Mirrors/Camera (not rearview)
- **Test varies Confederate vehicle's distance, closing speed, and lane change direction**



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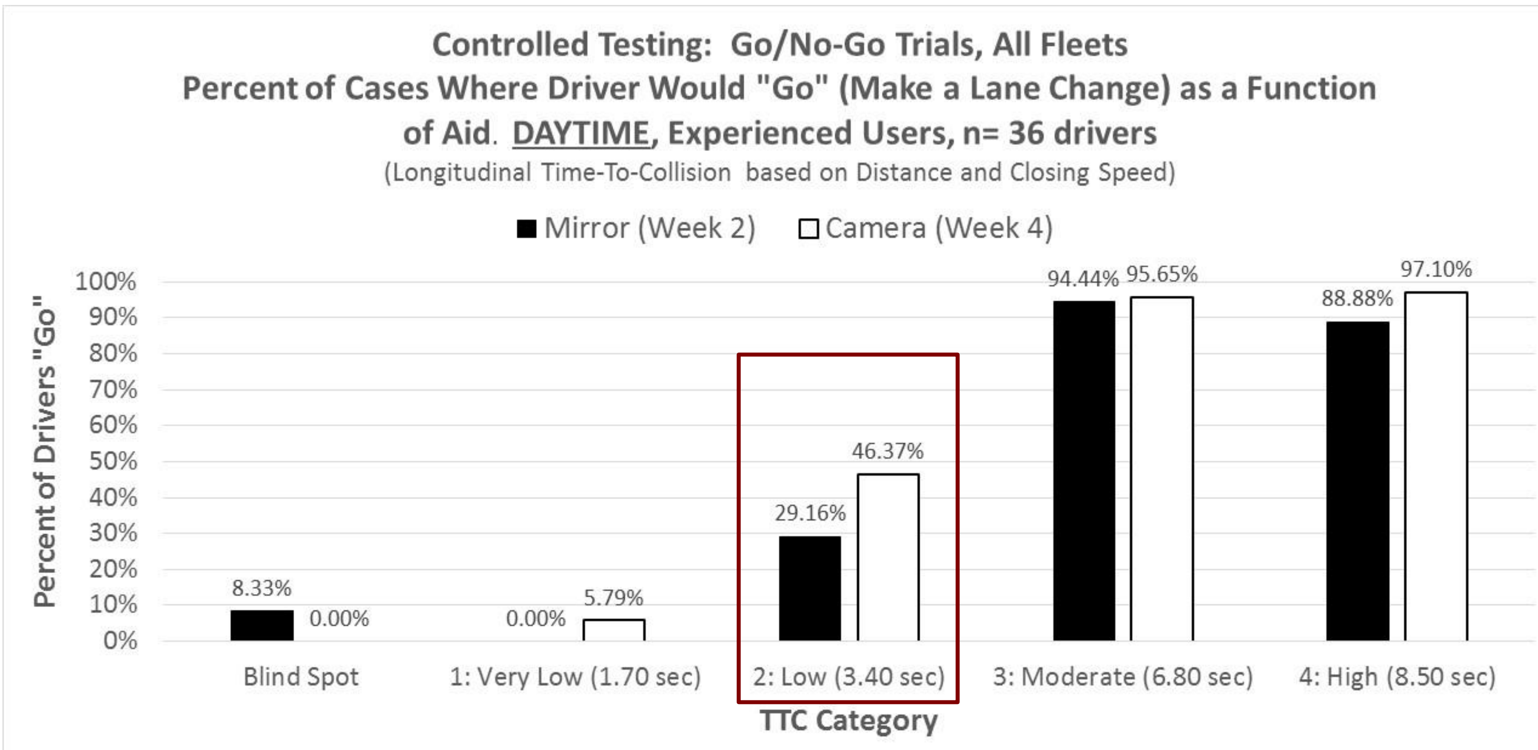
ALL FLEETS COMBINED

Go/No-Go, Daytime: All Fleets

- **TTC Category (based on Longitudinal Distance and Closing Speeds)**
- **Data from 36 drivers, Experienced Users (Weeks 2 & 4)**
- **Likelihood of making a lane change when a vehicle is in the Blind Spot is higher with Mirrors, but not significantly**
- **Camera condition significantly increases likelihood of making a lane change at a "Low" TTC (3.40 sec)**



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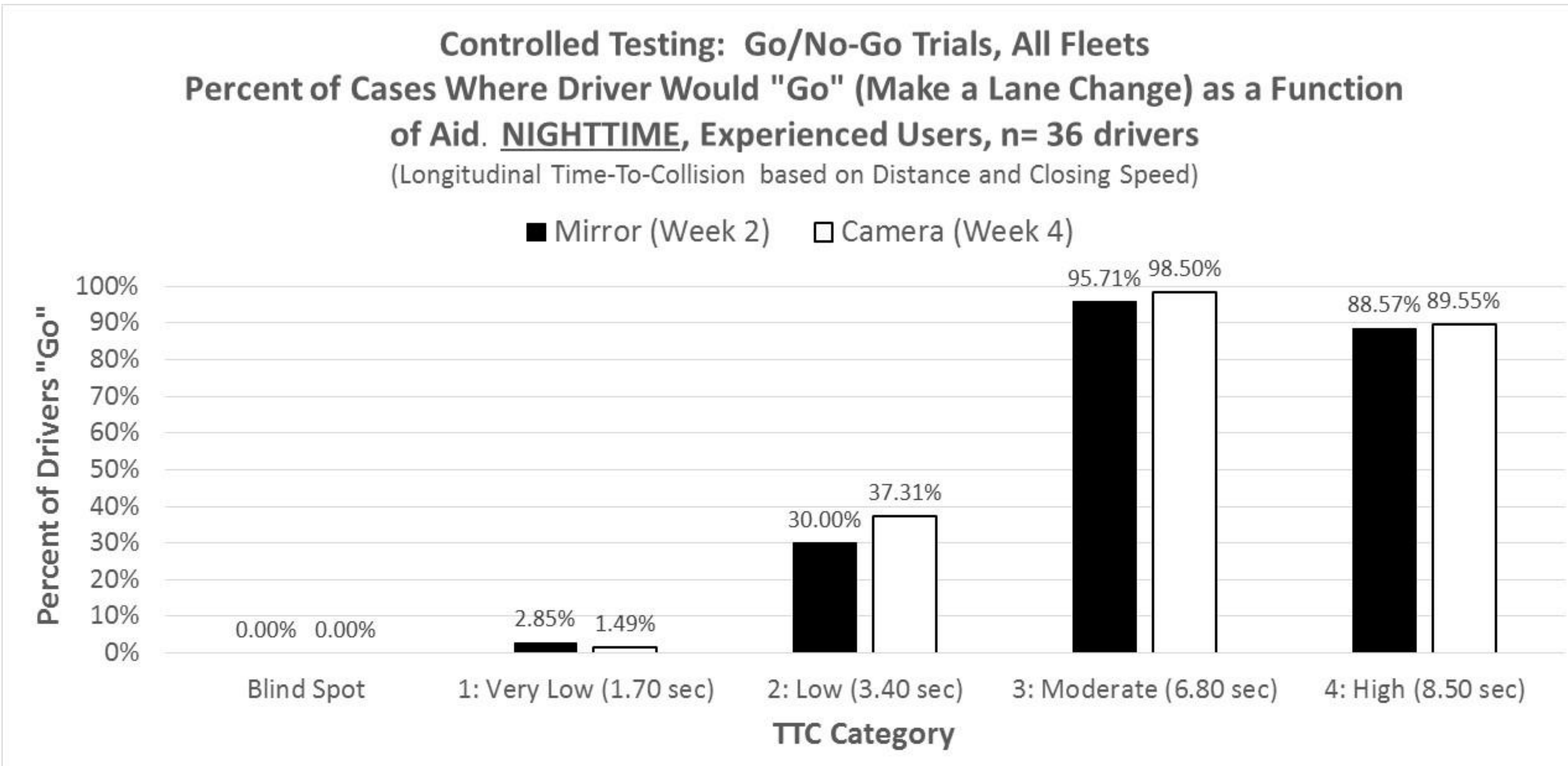
Go/No-Go, Nighttime: All Fleets

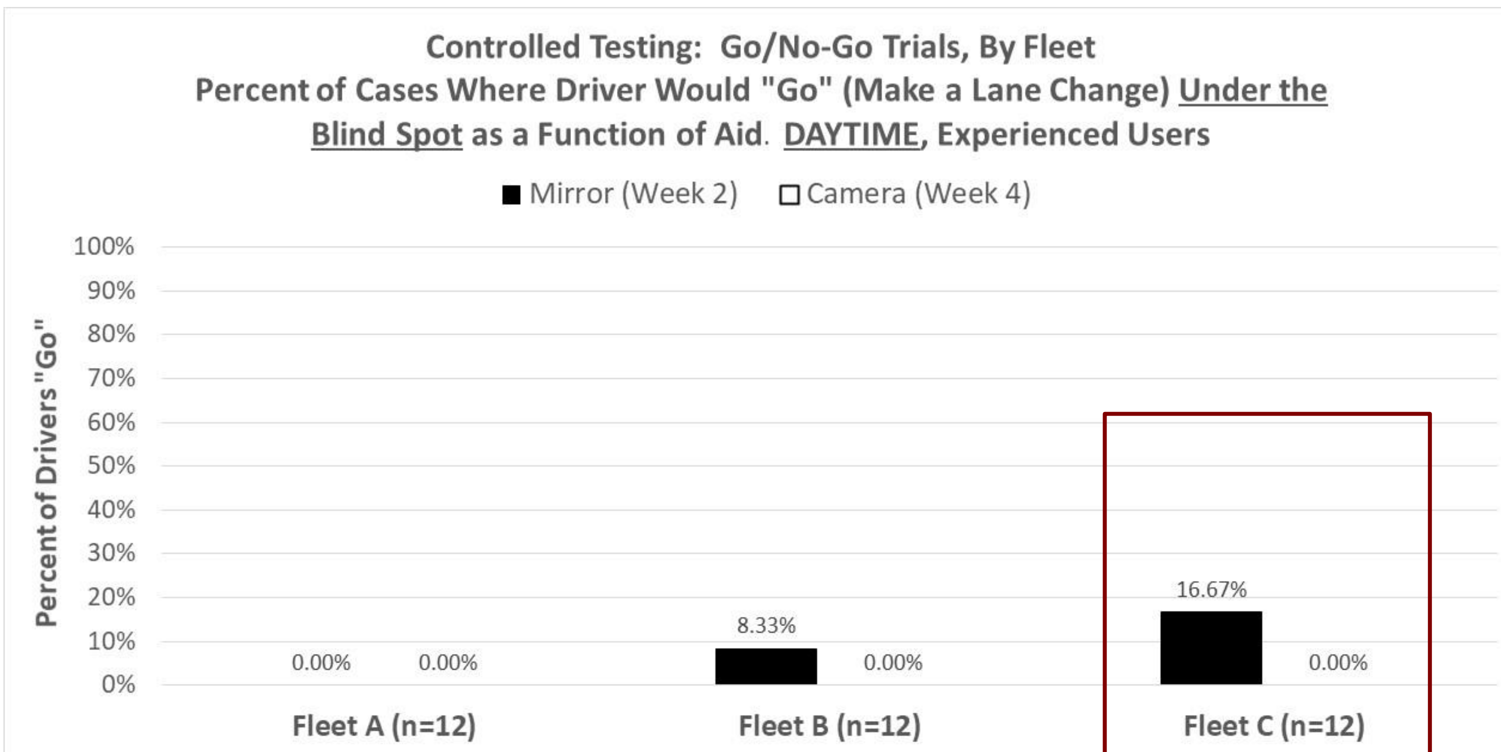
- **TTC Category (based on Longitudinal Distance and Closing Speeds)**
- **Data from 36 drivers, Experienced Users (Weeks 2 & 4)**
- **Comparable "Go" rates between Aid conditions at night**



PERFORMANCE BY FLEET

By Fleet, Daytime ("Blind Spot")

- **Static Go/No Go lane change judgments**
- **Data from 36 drivers, Experienced Users (Weeks 2 & 4)**
- **Percentage of drivers who would "Go" when a vehicle in Blind Spot**
- **Only Mirror conditions led to "Go" decisions**
  - Fleet C significant (two of 12 drivers)



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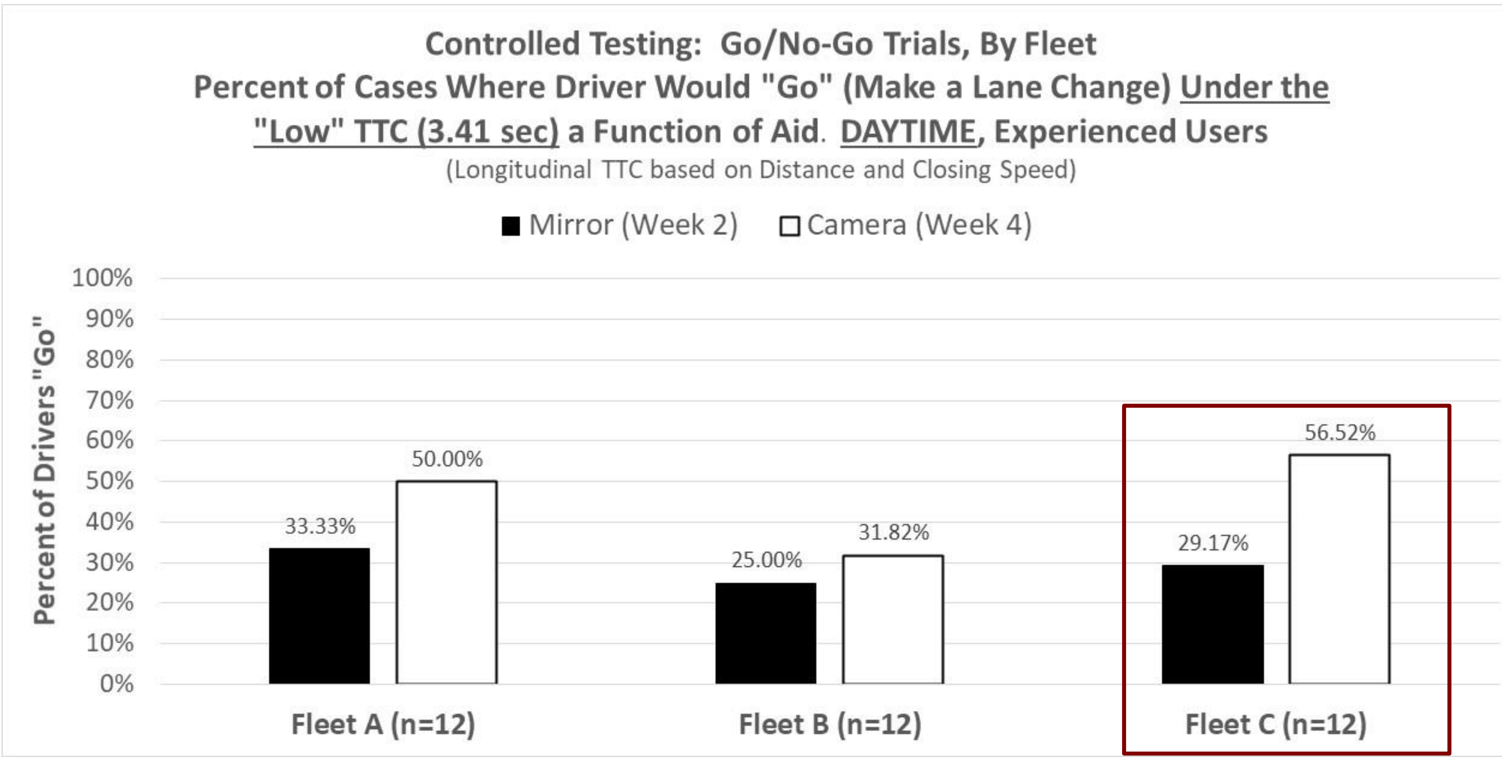
By Fleet, Daytime ("Low" TTC)

- **Static Go/No Go lane change judgments**
- **Data from 36 drivers, Experienced Users (Weeks 2 & 4)**
- **Percentage of drivers who would "Go" under "Low" TTC Category**
  - Longitudinal TTC = 3.40 sec (100ft @20 mph closing speed)
- **Cameras tended to increase "Go" judgments under this condition. Only significant difference under Fleet C**



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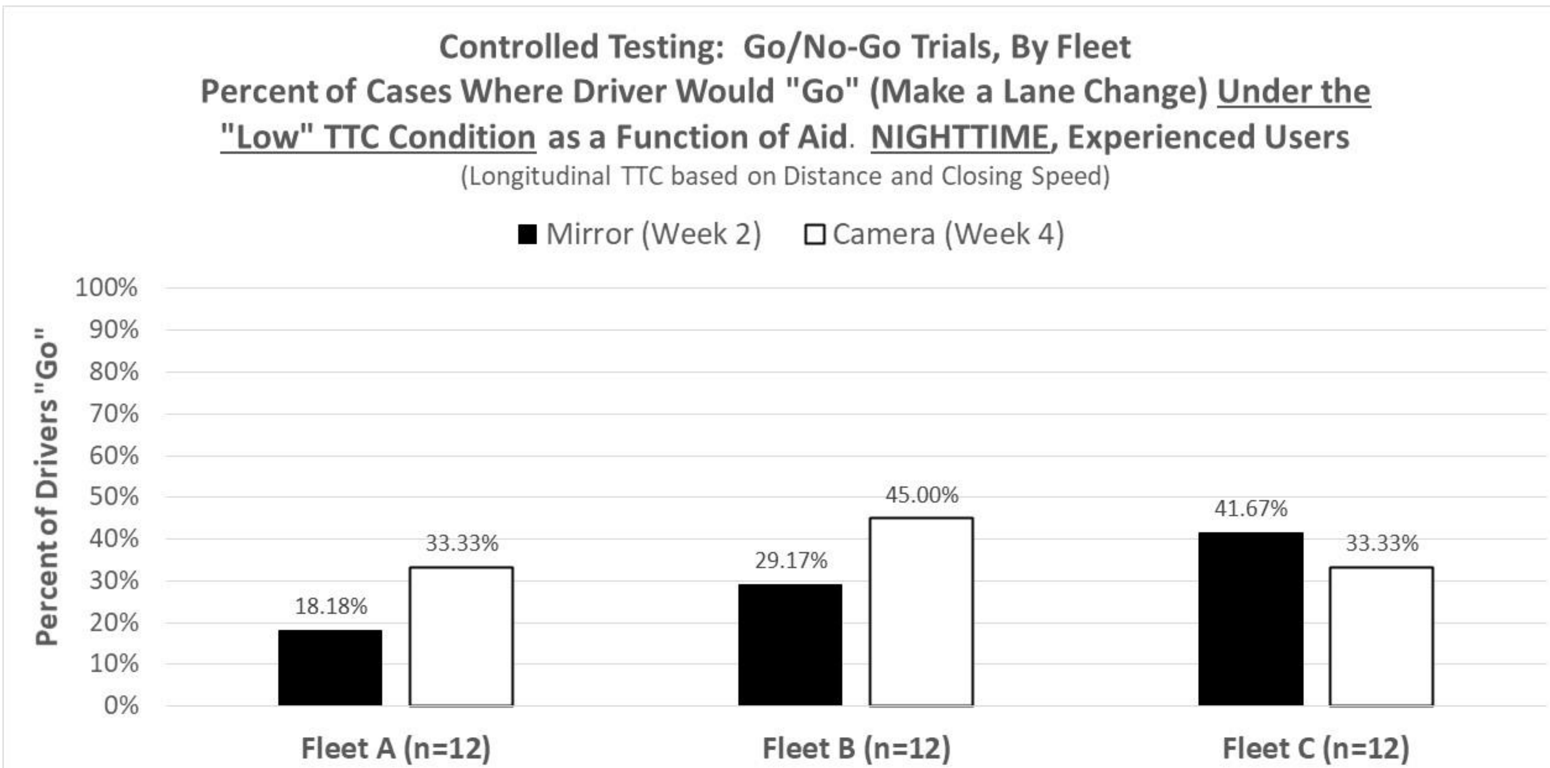
By Fleet, Nighttime ("Low" TTC)

- **Static Go/No Go lane change judgments**
- **Data from 36 drivers, <u>Experienced Users</u> (Weeks 2 & 4)**
- **Percentage of drivers who would "Go" under "Low" TTC Category**
  - Longitudinal TTC = 3.40 sec (100ft @20 mph closing speed)
- **No significant difference in aid condition for any fleet**
  - Judgments under the Camera for Fleet B had highest "Go" rates



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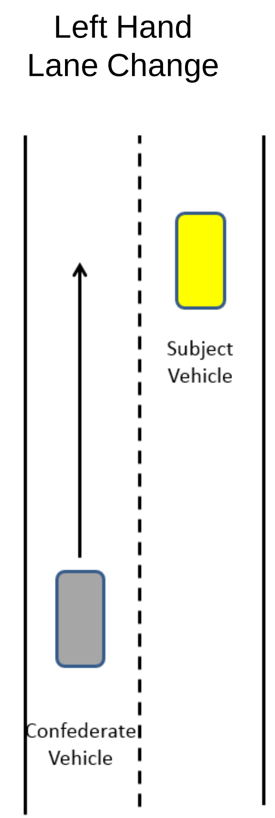
Dynamic Tests, Last Comfortable

- **Assess how well drivers can use the aids to make lane change judgments**
  - Exercise both outside mirrors
- **Last Comfortable Lane Change Point**
  - Drivers signal "Last comfortable point" judgement using turn signal indicator
  - Last point where they can change lanes without causing a conflict or requiring the approaching vehicle driver to react harshly
- **Two staged maneuvers:**
  - Left-Hand Lane Change
  - Right-Hand Lane Change
- **Trials performed under:**
  - 2 closing speed conditions: 10 and 20 mph
  - Both Left and Right Lane Change directions



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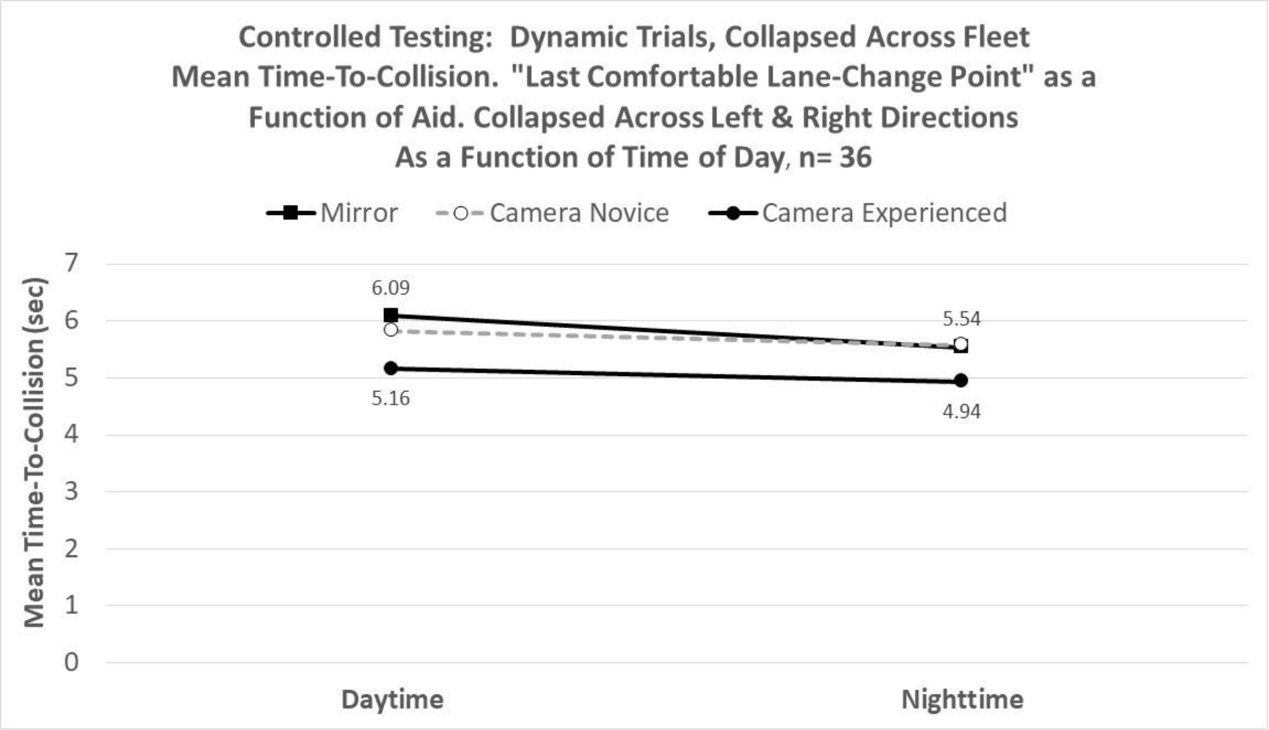
All FLEETS COMBINED

All Fleets: Mean TTC

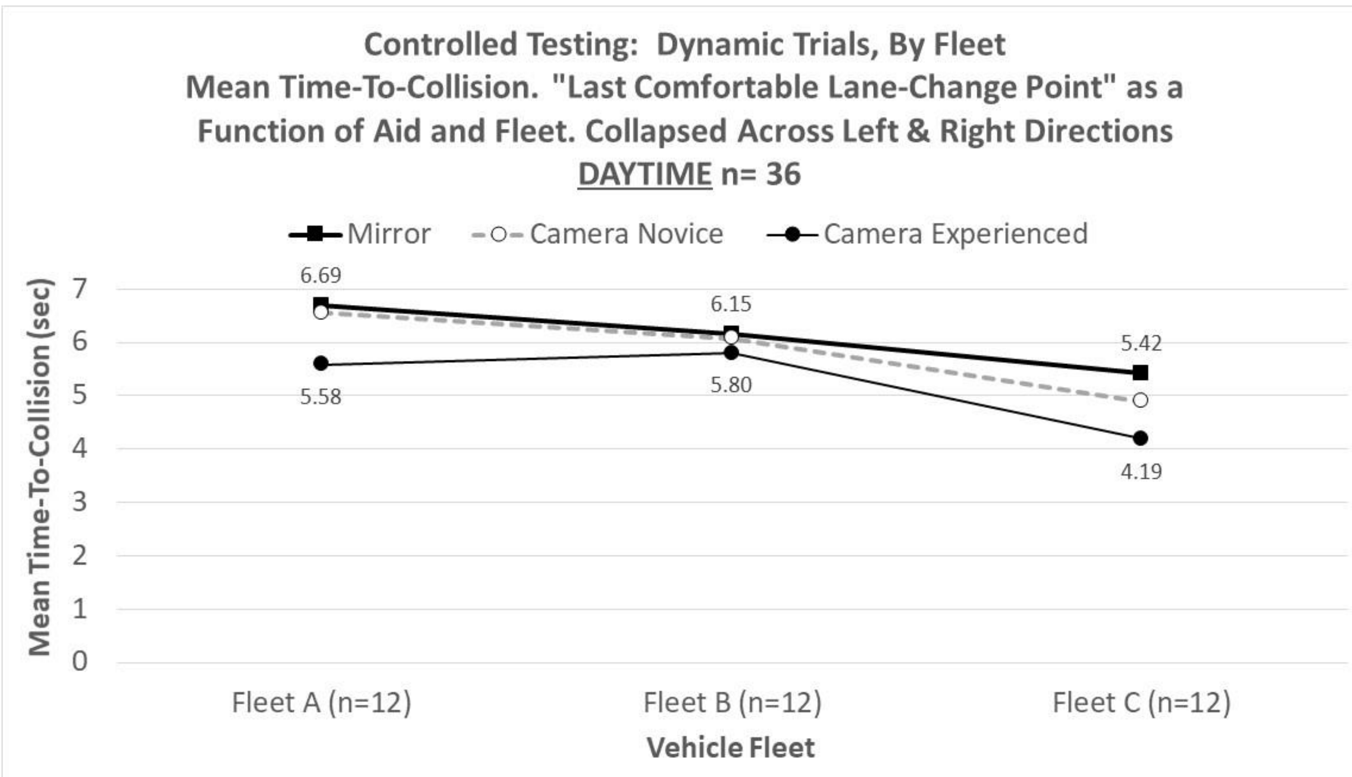
- **Mean Time-To-Collision at Last Comfortable Lane Change Judgment**
- **Collapsed Across All Fleets**
  - Forced Use. Collapsed Across Lane Change Direction
- **Camera condition yielded significantly lower average TTC judgements relative to Mirror condition under Daytime conditions (Suggests that sole reliance on Camera displays could lead to closer gap acceptance judgments)**
- **Nighttime TTC's tend to be lower than Daytime TTC judgements**
- **Mean TTC judgements over 4 seconds**



PERFORMANCE BY FLEET

By Fleet, Daytime

- **Mean Time-To-Collision at Last Comfortable Lane Change Judgment**
  - Daytime, Lane Change Direction, Mirror/Display, Forced Use.
- **(Experienced Users) With the exception of Fleet B, the Camera condition yielded lower average Mean TTC judgements relative to Mirror condition (Suggests Camera could lead to closer gap acceptance judgments)**
  - For experienced users, significant differences among Vehicle Fleet for both Mirror and Camera conditions. Fleet C significantly lower TTC judgements relative to other Fleets
  - Mean TTC's for some fleets lower under Camera, but still over 4 seconds on average



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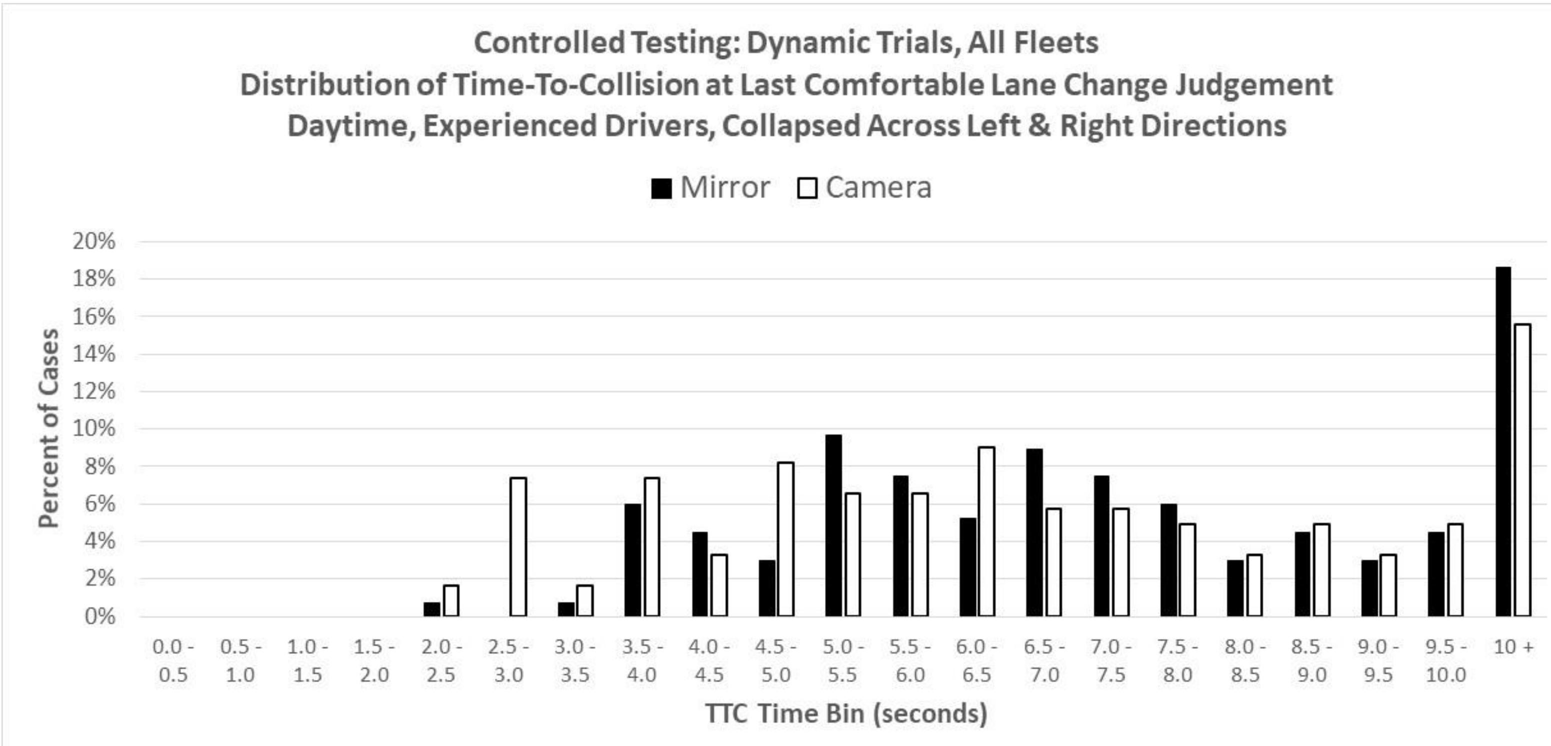
Distribution of TTC Judgments

- **Time-To-Collision at Last Comfortable Lane Change Judgment**
  - Daytime, Lane Change Direction, Mirror/Display, Forced Use.
- **Collapsed Across All Fleets**



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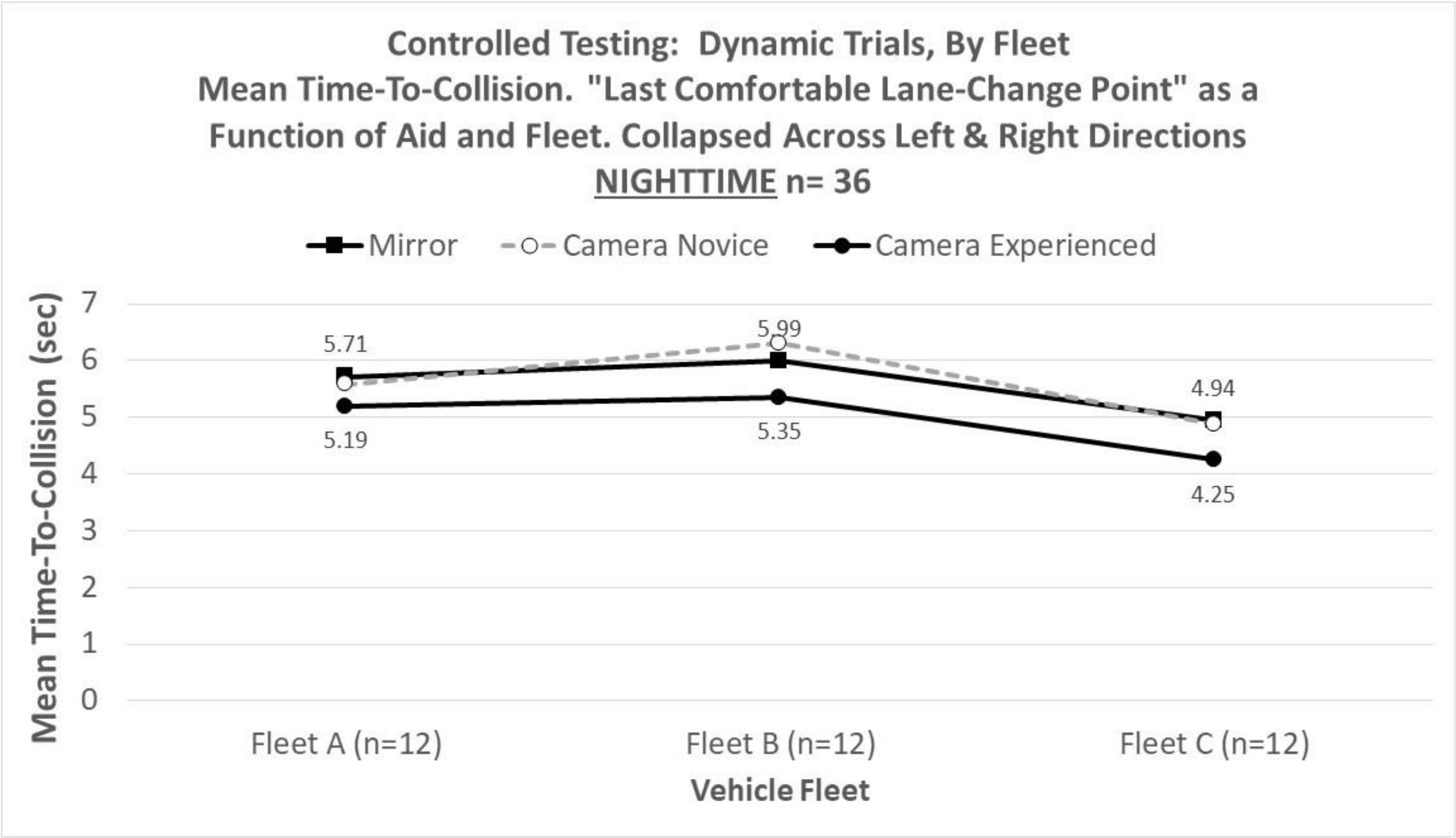
By Fleet, Nighttime

- **Mean Time-To-Collision at Last Comfortable Lane Change Judgment**
  - Daytime, Lane Change Direction, Mirror/Display, Forced Use. Experienced users
- **Camera condition yielded somewhat lower average Minimum TTC judgements (but not significantly lower) relative to Mirror condition**
  - No significant differences among Vehicle Fleet for either Mirror or Camera conditions.



Naturalistic Drives

Trip Summary (All Fleets)

- **Number Trips, Miles Traveled (all trips)**
- **Signalized Lane Changes (Speeds > 55 mph) for all 36 drivers**
- **Accumulated 90,880 miles and 25,655 Signalized Lane Changes**
  - Majority of lane changes occurred during daytime (Approximately 79%)

Overall, All Fleet Subjects (n= 36)	Overall (Total)	Phase 1: Conventional Mirror	Phase 2: Camera-Based Displays
Number of Trips	4,486	2,243	2,243
Total Miles Driven	90,880	46,730	44,149
Average Miles Per Trip	20.26	20.83	19.68
SIGNALIZED LANE CHANGES AT HIGHWAY SPEEDS (55 mph+)			
Total Aggregated Number of Signalized Lane Changes	25,655	12,960	12,695
Average Number of Signalized Lane Changes Per Trip			
Overall (All Trips)	5.71	5.78	5.66
Trips Over 20 Miles	14.14	14.43	13.85
Signalized Lane Change Rate Per 100 Miles			
Overall (All Trips)	21.69	16.24	16.93
Trips Over 20 Miles	31.50	30.97	32.03
Lane Change Direction (Signalized Lane Changes)			
Number Left-Hand Lane Changes	12,090	6,092	5,998
Number Right-Hand Lane Changes	13,565	6,868	6,697
Number of Signalized Lane Changes by Time of Day			
Day	20,382	10,633	9,749
Night	3,845	1,649	2,196
Twilight	1,428	678	750

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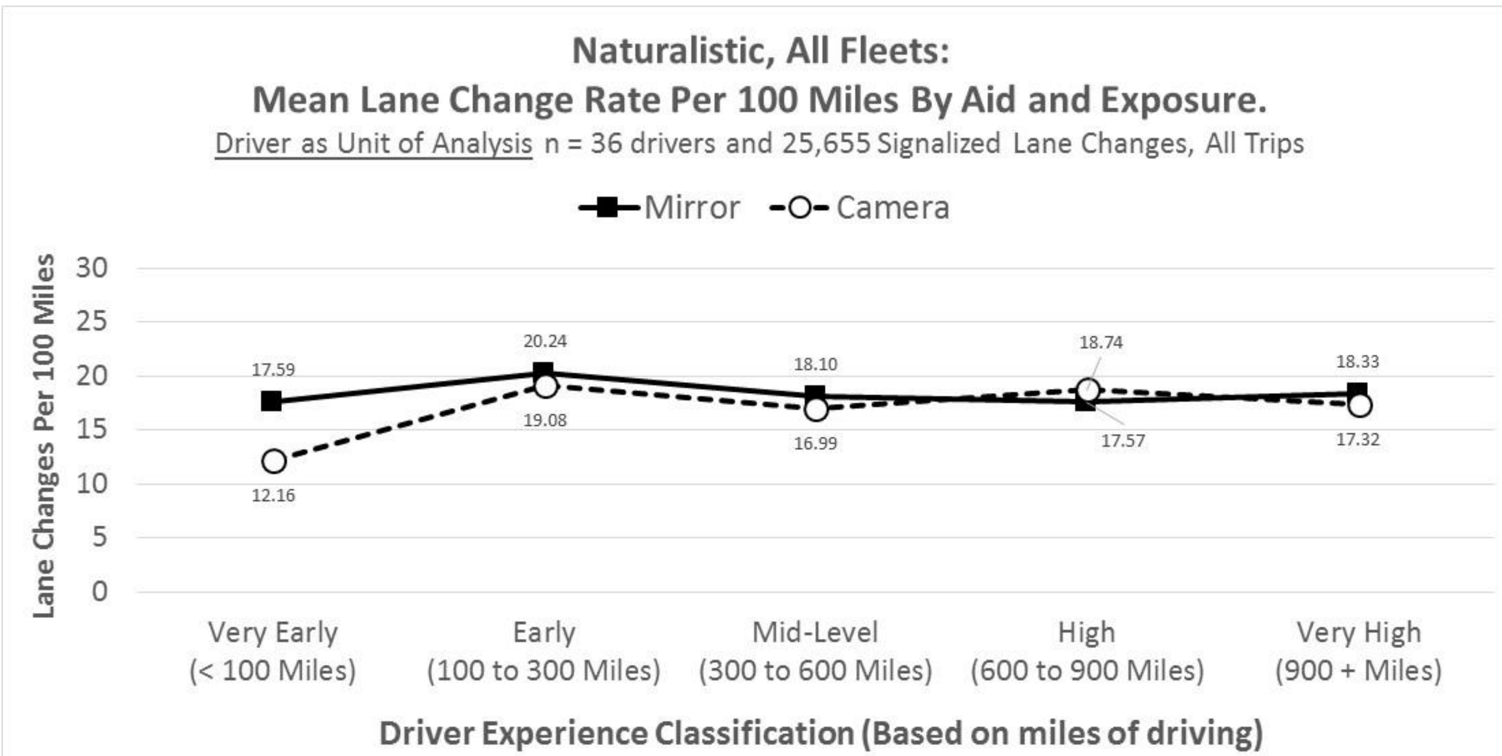
Driver Acclimation to Camera System

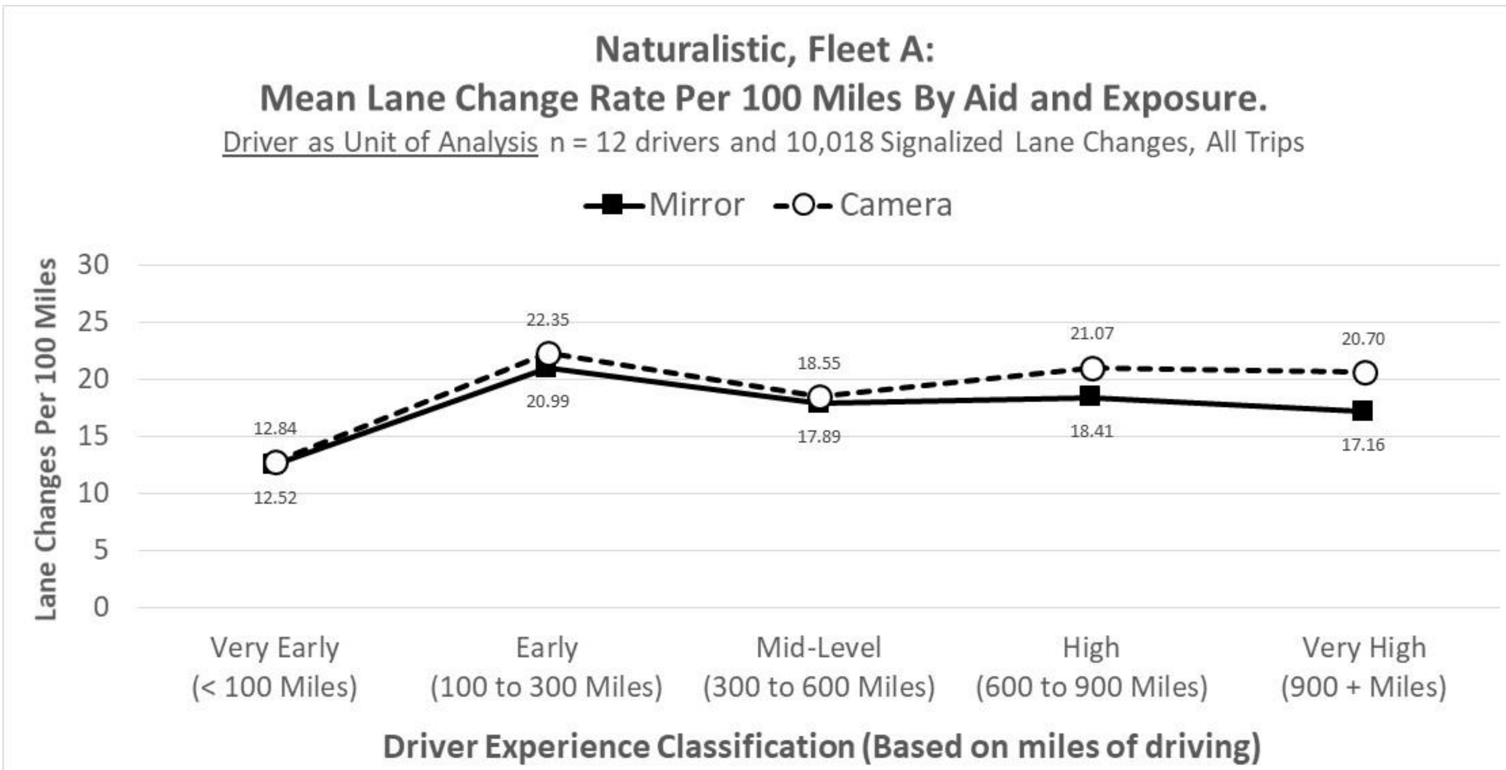
Lane Change Rates (All Fleets)

- **Signalized Lane Changes (Speeds > 55 mph) for 36 drivers**
- **Lane Change Rates Over Time and Experience (All Trips)**
  - Rates are initially significantly lower with "Very Early" exposure to the Camera, but quickly increases to approximate Mirror rates
  - Suggests early learning curve for Camera-based systems, but drivers quickly acclimate
  - Some differences observed across Fleets



Lane Change Rates (Fleet A)

- **Signalized Lane Changes (Speeds > 55 mph) for 12 drivers**
- **Lane Change Rates Over Time and Experience (All Trips)**
  - Comparable lane change rates over time between Camera and Mirror condition.
  - Drivers initially make fewer lane changes "Very Early" on under both Mirror and Camera condition.



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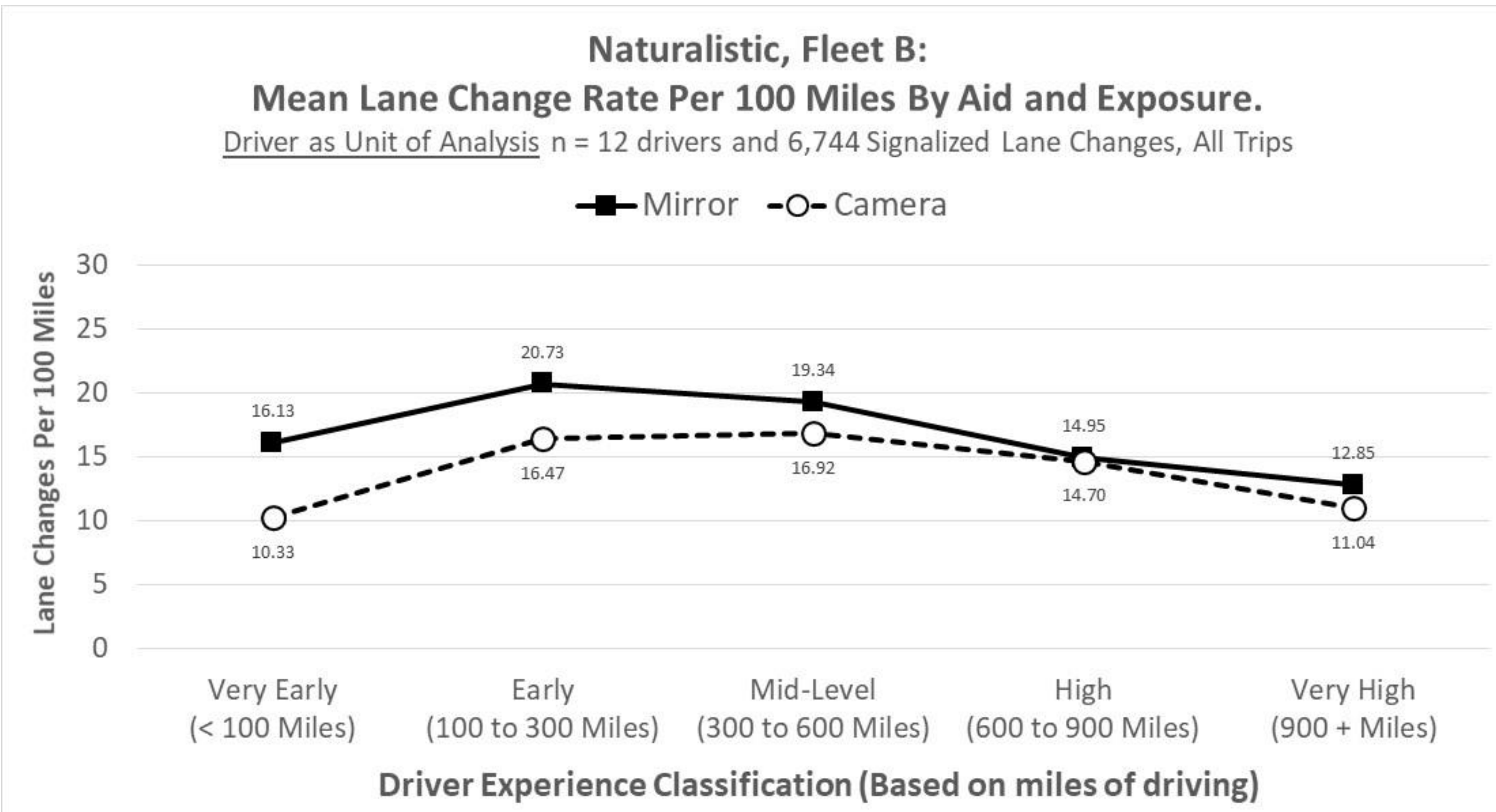
Lane Change Rates (Fleet B)

- **Signalized Lane Changes (Speeds > 55 mph) for 12 drivers**
- **Lane Change Rates Over Time and Experience (All Trips)**
  - Rates significantly lower for Camera for "Very Early" exposure level, then converges



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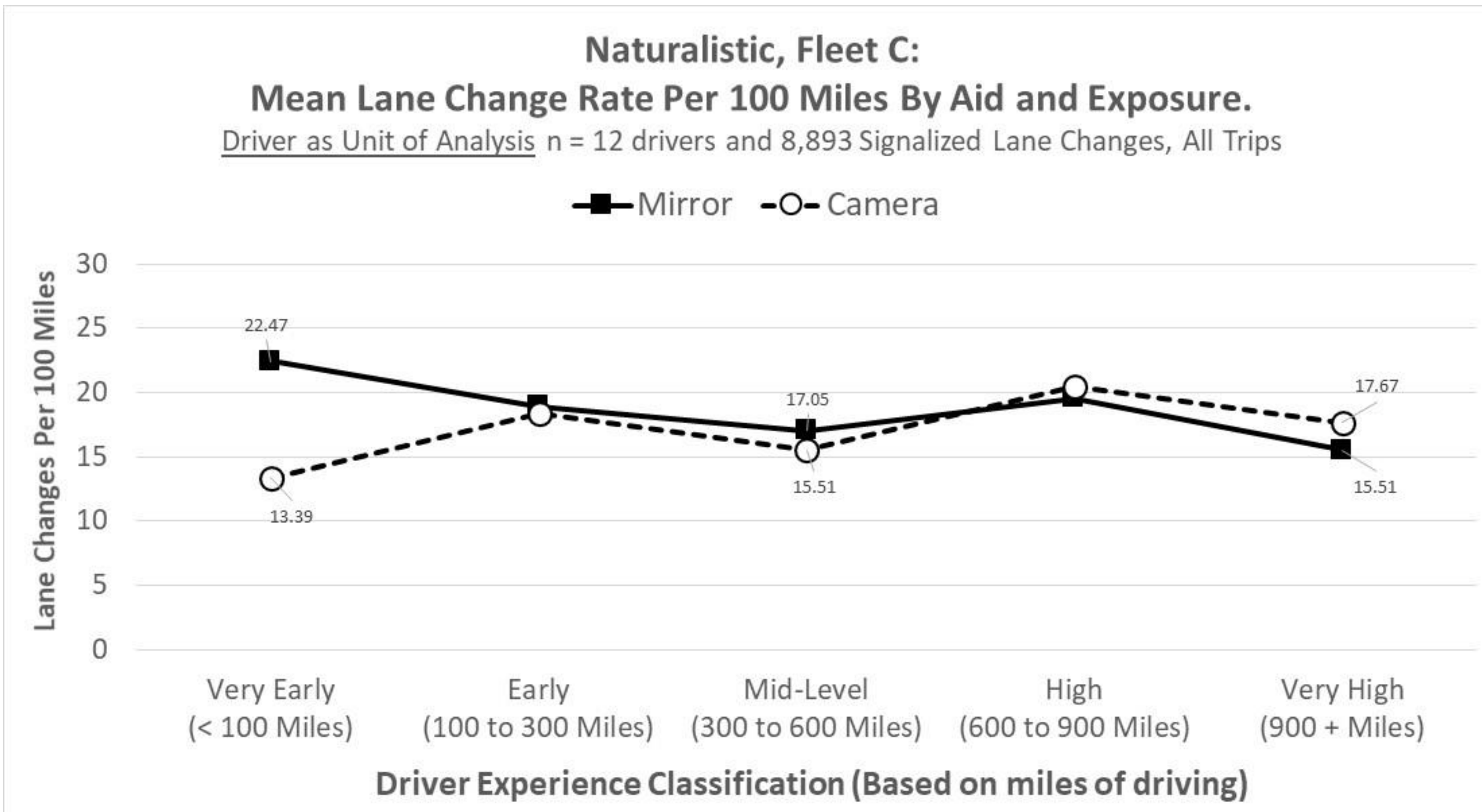
Lane Change Rates (Fleet C)

- **Signalized Lane Changes (Speeds > 55 mph) for all 12 drivers**
- **Lane Change Rates Over Time and Experience (All Trips)**
  - Drivers initially make fewer lane changes when first learning to use the Camera systems
  - Rates quickly approximate Mirror systems (this happens between 100 to 300 miles of usage) and remain comparable to Mirrors with increasing exposure



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Naturalistic Drives: Lane Change and Eye-Glance Reduction Protocols

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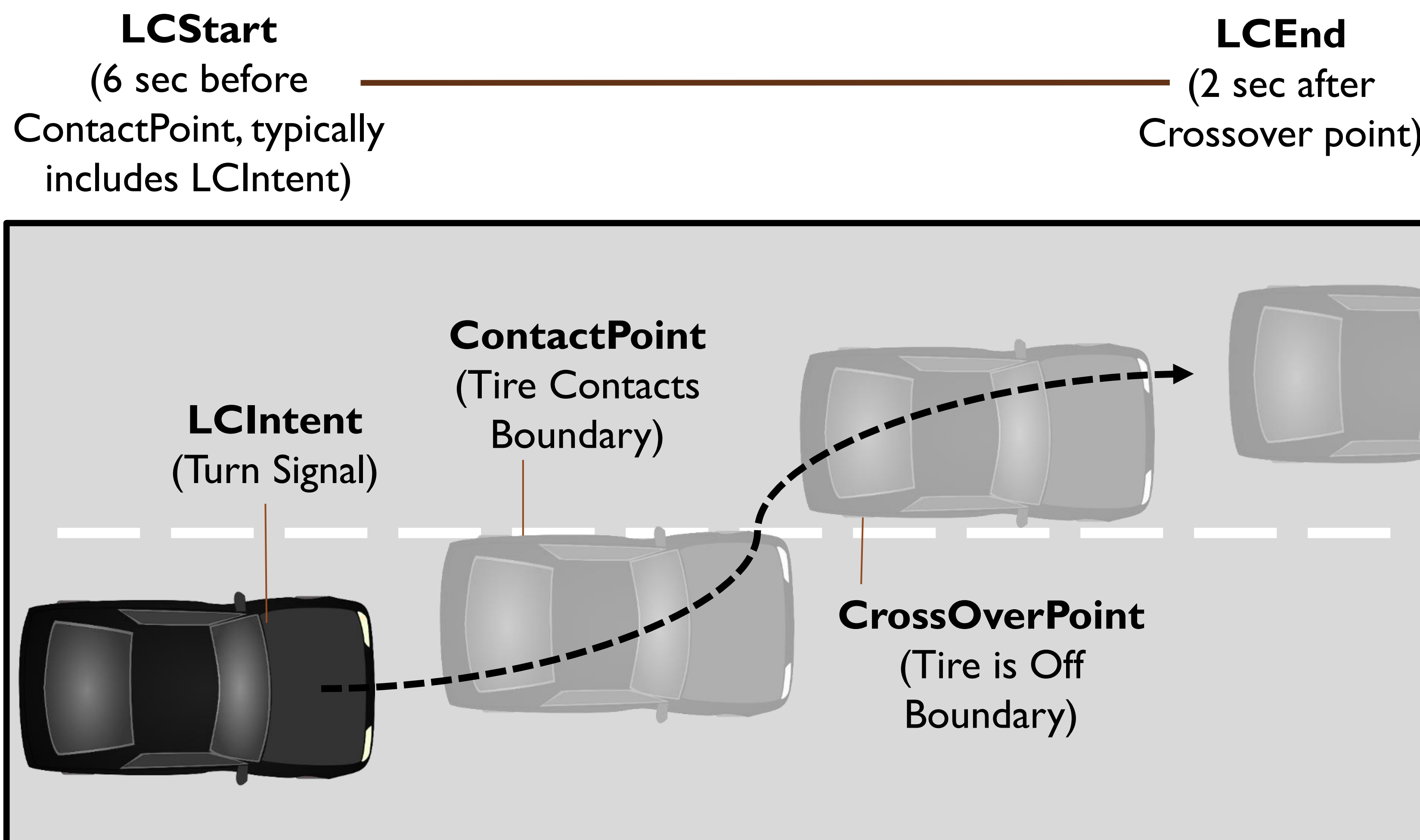
Signalized Lane Change Graphic



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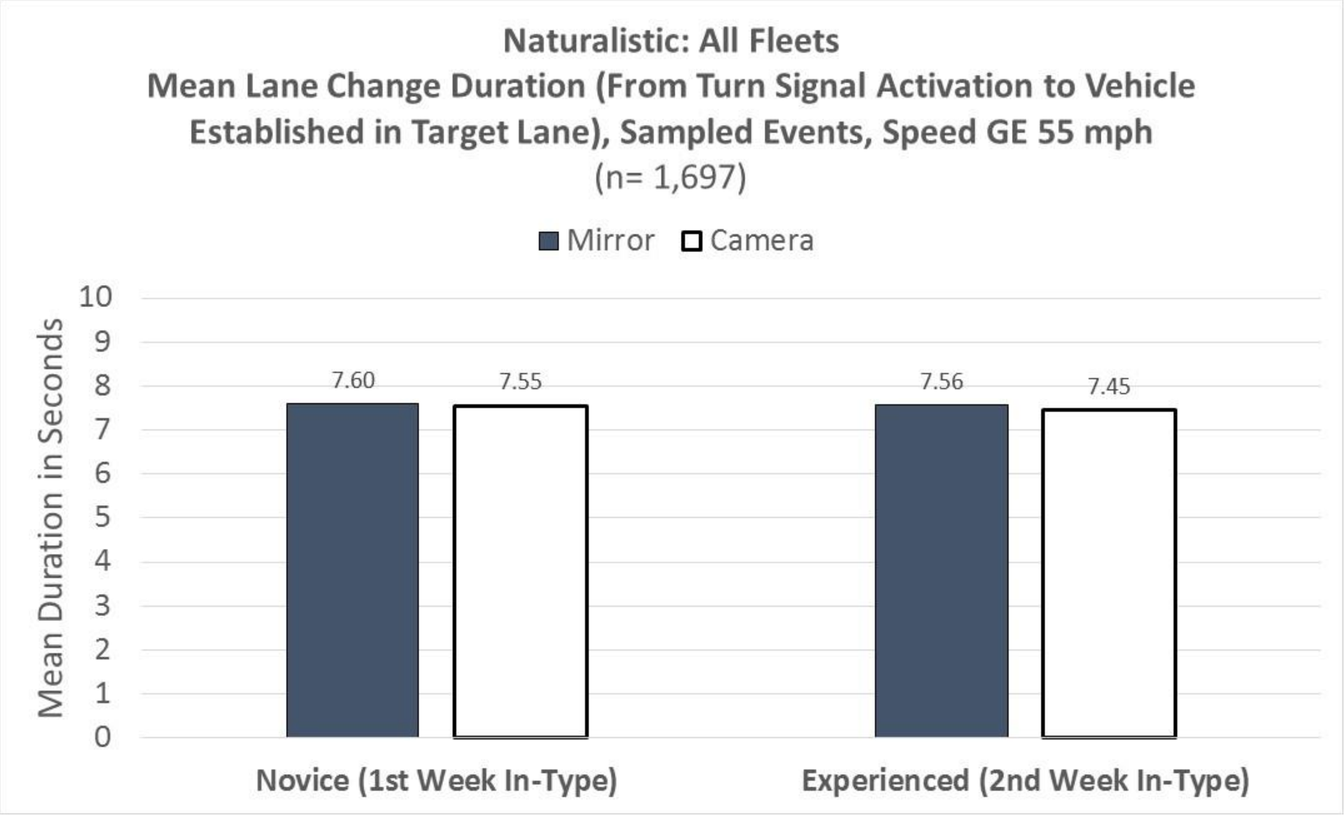
Data Sampled For Analysis

- **Sampled over 2,500 signalized lane change events**
- **Stratified sampling, each driver…**
  - 72 lane change events per driver
    - 36 events under Mirror and 36 under Camera conditions
    - Stratified across study week (18 events per week)
    - Half left and half right lane change events
- **Sampled lane change cases submitted for analysis**
  - Some samples not able to be reduced (did not meet lane change criteria, missing or hard to see camera views, etc.)
  - Total of 1,697 cases successfully reduced; Analyzed an average of 47 lane change events per driver
- **Reduced Lane Change events correspond to:**
  - High speed lane changes (Vehicle Speed GE 55 mph)
  - Single Lane Change (No multiple, back-to-back lane changes)
- **Analysis used these lane change cases to generate eye-glance measures**
  - Analysis used "Driver" as unit of analysis so each driver contributed equally

Naturalistic Drives: Lane Change Duration

Lane Change Duration By Aid and Exposure

- Mean time to perform a lane change. From onset of the turn signal to the vehicle established in the target lane
- For Sampled Signalized, Left & Right Lane Change Events. Same sampled cases as used for eye-glance reduction
- Comparable lane change times



Naturalistic Drives: Glance Behavior (Percentage of Lane Changes With Glances)

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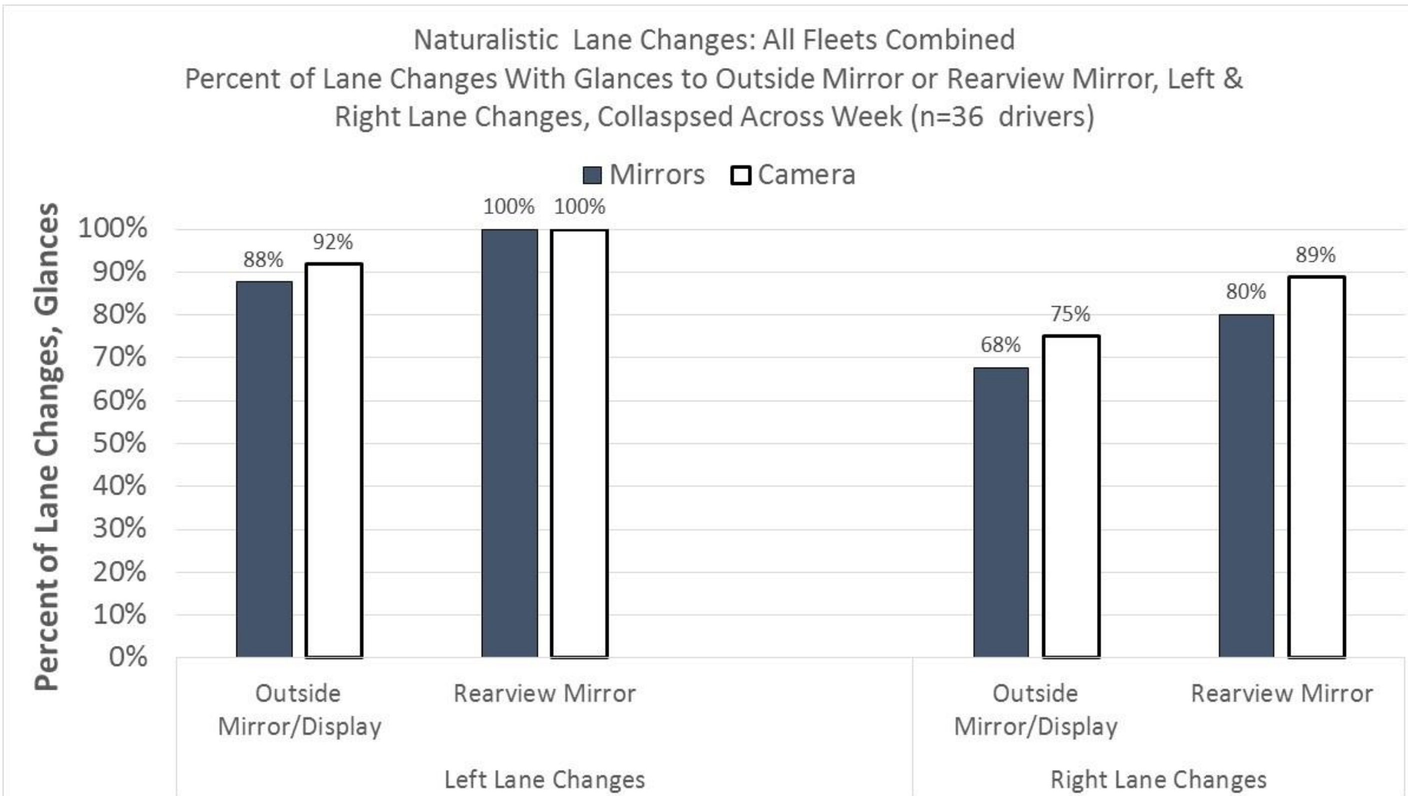
Percentage of Lane Changes With Glances

- Collapsed Across All Fleets (All Combined)
- Percentage of Lane Change Cases Where Drivers Checked (at least once) the Outside Mirror/Display or Rearview Mirror. For Signalized, Left & Right Lane Change Events, Collapsed Across Exposure
- Patterns are comparable for both Mirrors and Camera conditions
  - Much lower reliance on Outside Mirrors/Display when making Right Lane changes



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Naturalistic Drives: Glance Frequency & Duration (Means & Distribution)

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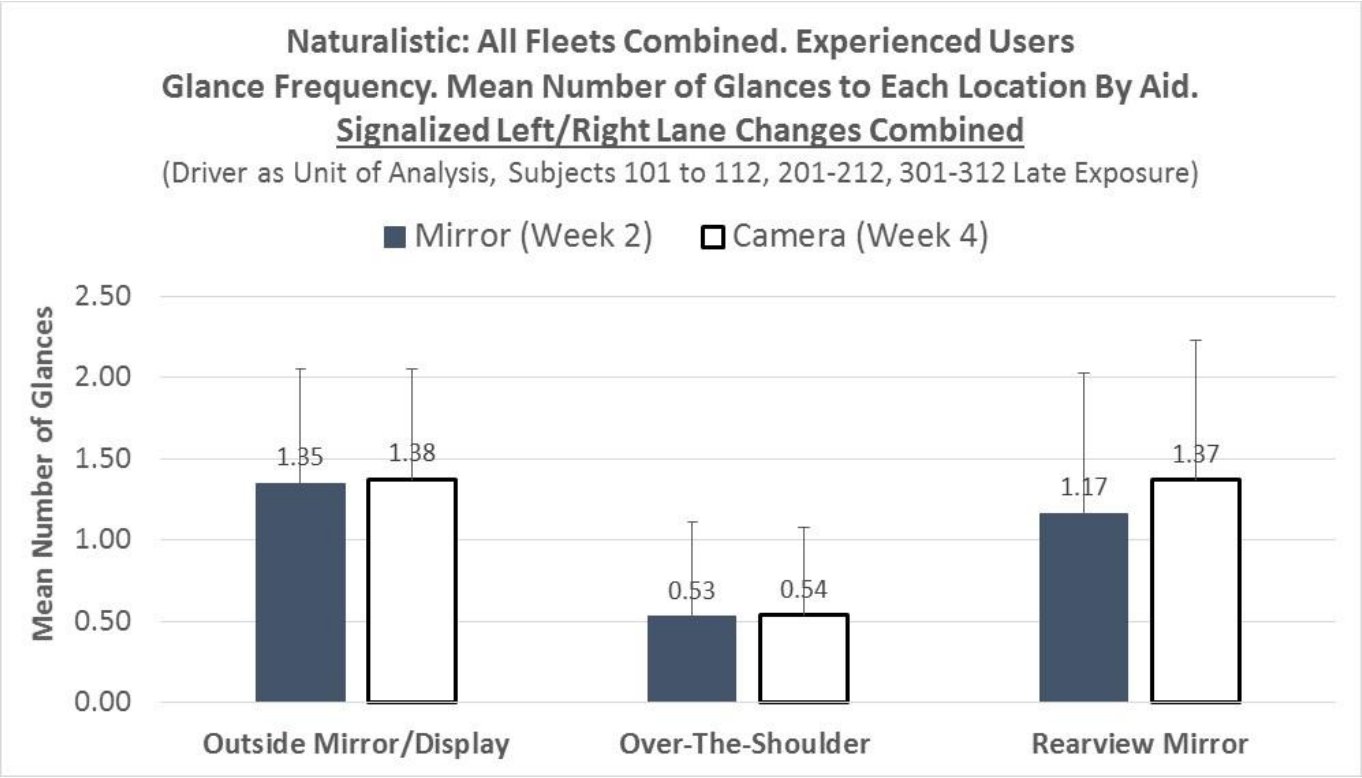
Glance Frequencies: All Fleets Combined

- Mean Number of glances to each location by Aid
- For Signalized, Left & Right Lane Change Events, Driver as Unit of Analysis
- Late Exposure for both Mirror and Camera (2nd week In-Type): Experienced Users
- No statistically significant differences between conditions



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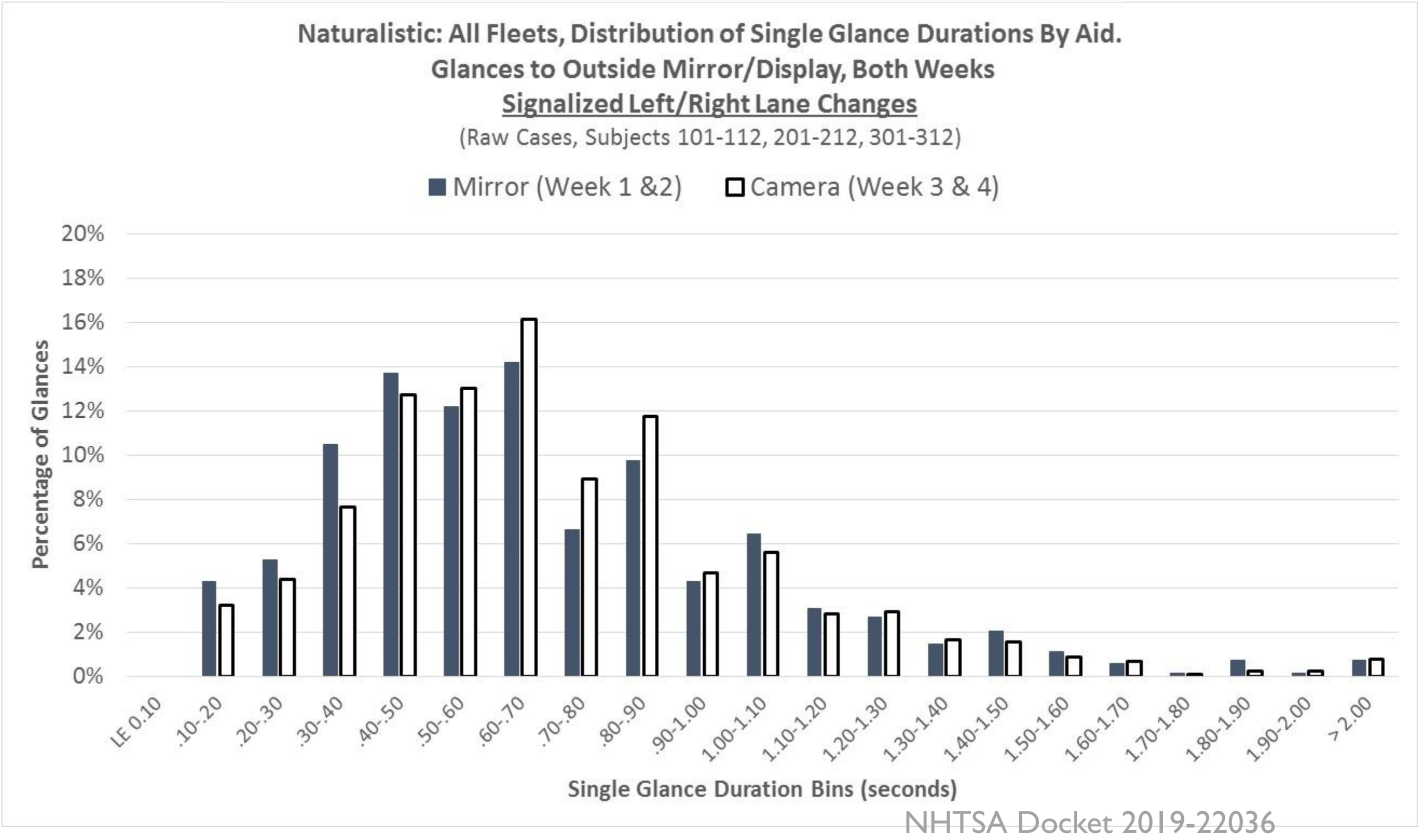
Glance Durations: Outside Mirrors (All Fleets)

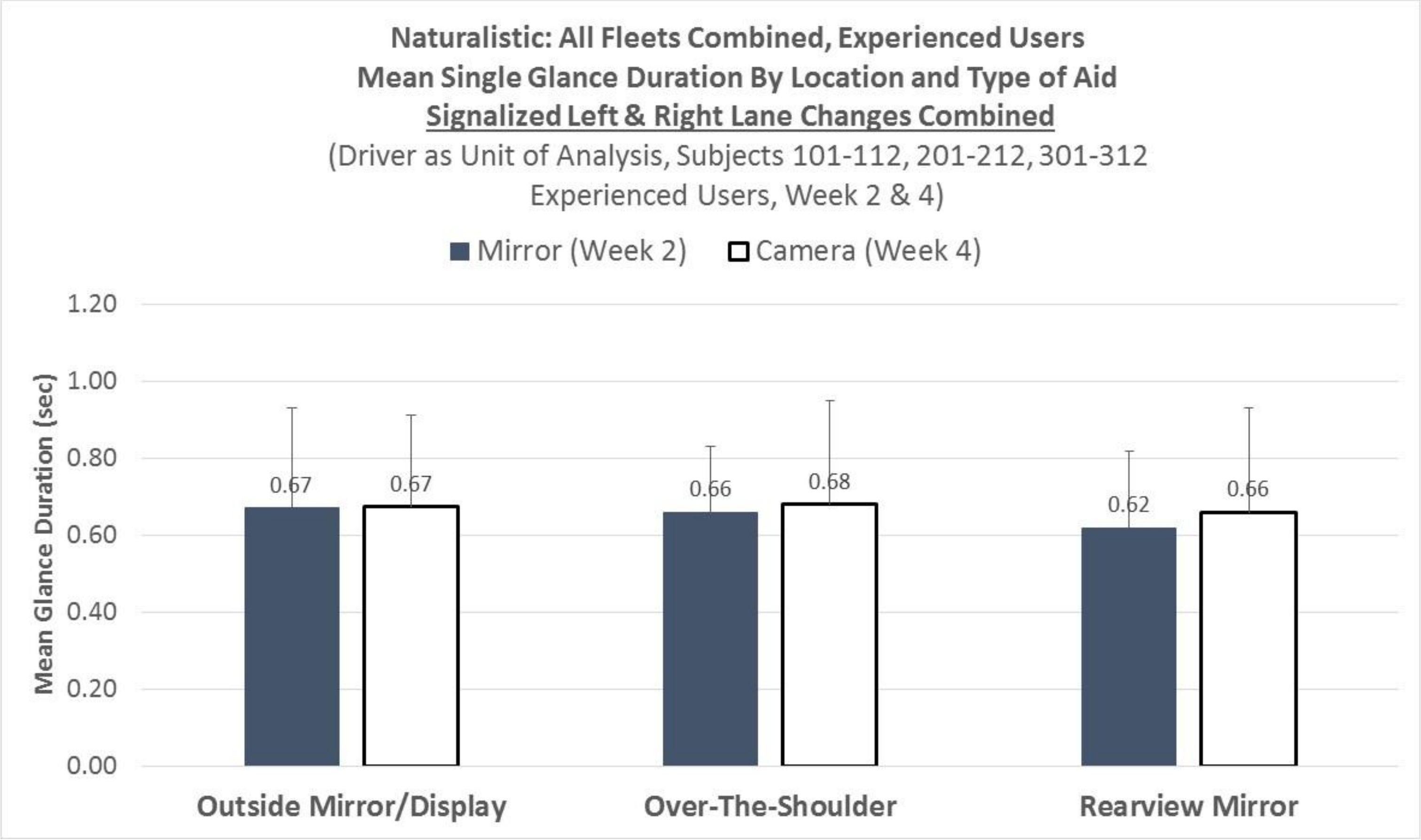
- Distribution of Glance Durations by Aid: Driver and Passenger-Side Mirrors/Display
- For Signalized, Left & Right Lane Change Events, Collapsed by Exposure (All Weeks)
- Distributions are comparable for Aid condition

Analysis Variable : Duration Duration									
Aid	N Obs	N	Mean	Minimum	Maximum	Mode	50th Pctl	75th Pctl	95th Pctl
Camera	1342	1342	0.7089255	0.1320000	3.1840000	0.5360000	0.6680000	0.8720000	1.3400000
Mirrors	1238	1238	0.6952326	0.1040000	2.9840000	0.5360000	0.6040000	0.8720000	1.4080000



Glance Duration: All Fleets Combined

- Mean glance duration to each location by Aid. For Signalized, Left & Right Lane Change Events. Driver as Unit of Analysis, Late Exposure for both Mirror and Camera (2nd week in-type)
- No statistically significant differences by Aid



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PERFORMANCE BY FLEET

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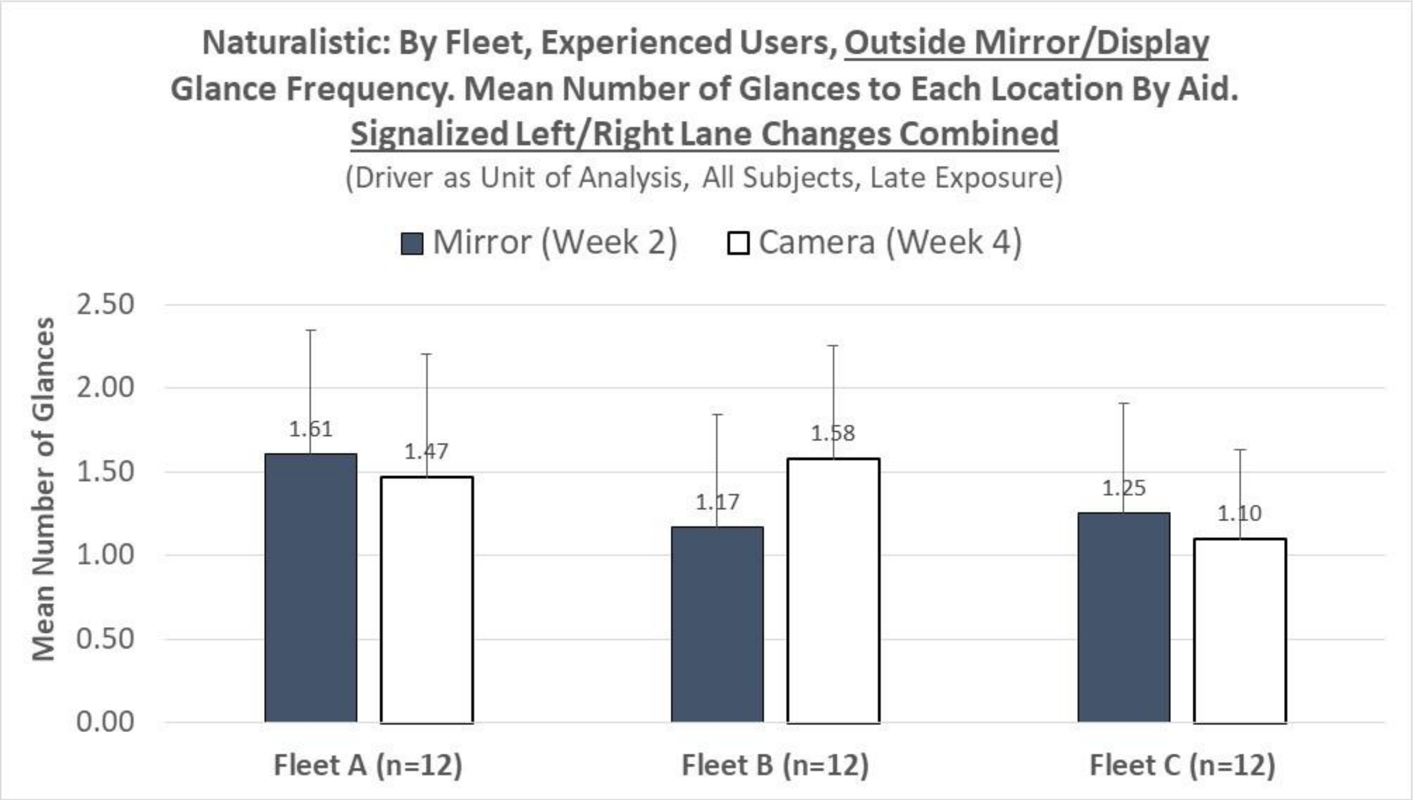
Glance Frequency By Fleet

- Outside Mirror/Display
- Mean glance frequency for Signalized, Left & Right Lane Change Events. Driver as Unit of Analysis, Late Exposure for both Mirror and Camera (2nd week in-type)
- No statistically significant difference for Aid or Fleet condition



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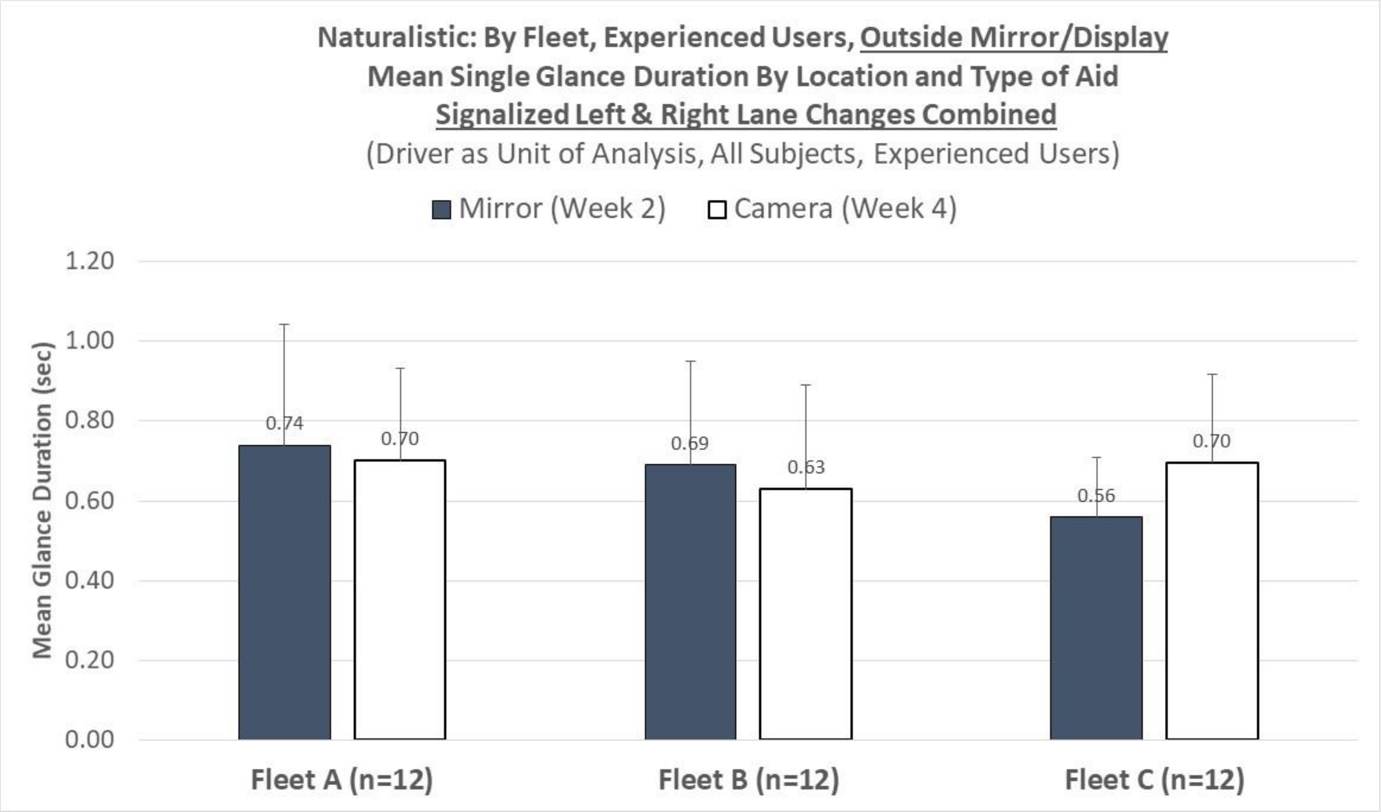
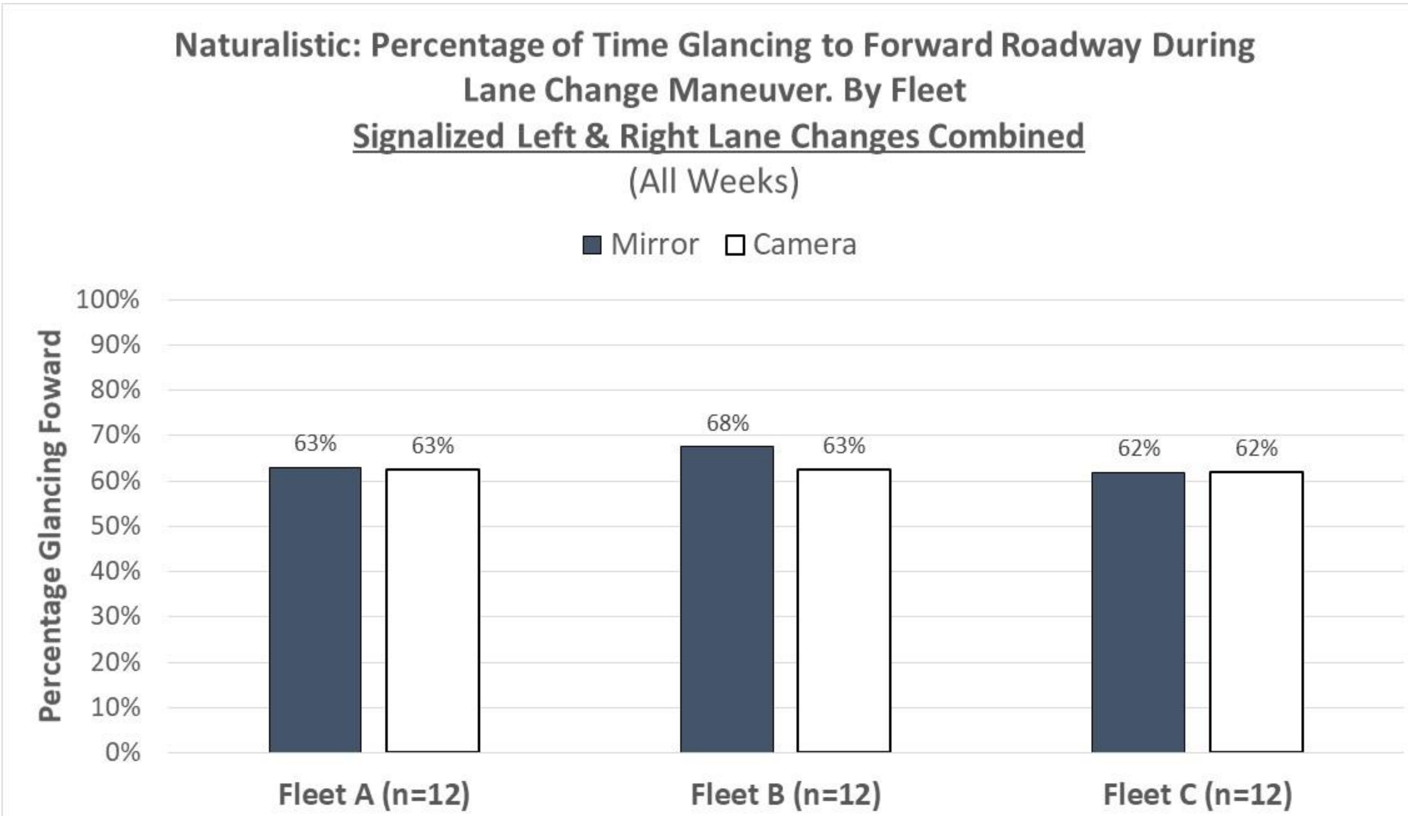
Glance Duration By Fleet

- Outside Mirror/Display
- Mean glance duration for Signalized, Left & Right Lane Change Events. Driver as Unit of Analysis, Late Exposure for both Mirror and Camera (2nd week in-type)
- Overall, no statistically significant difference for Aid or Fleet
  - Fleet C: Camera display was associated with significantly longer glance durations relative to Mirrors



Percentage Forward By Fleet

- Percentage of Time Glancing to Forward Roadway During Lane Change
- For Signalized, Left & Right Lane Change Events. <u>All Weeks</u>
- Comparable rates across fleets and Type of Aid
  - Fleet B had slightly higher rates under Mirror condition relative to other two Fleets



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Relationship Between Glance Frequency & Duration

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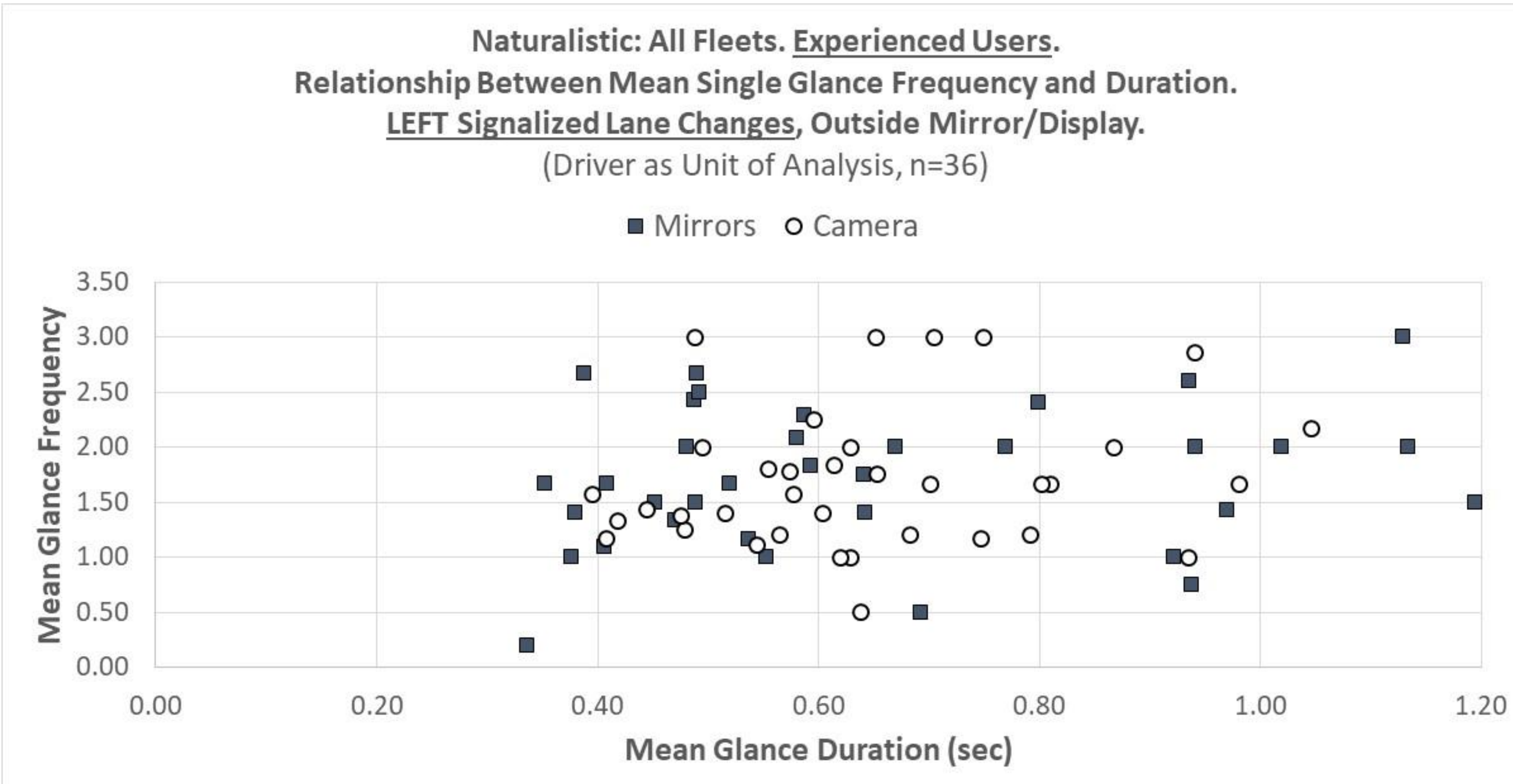
All Fleets: Outside Mirror/Display

- Left lane changes, Experienced users, Outside Mirror/Display
- No statistically significant differences between Aid conditions
- Each Point Reflects a Driver
- Maps Glance Frequency & Duration



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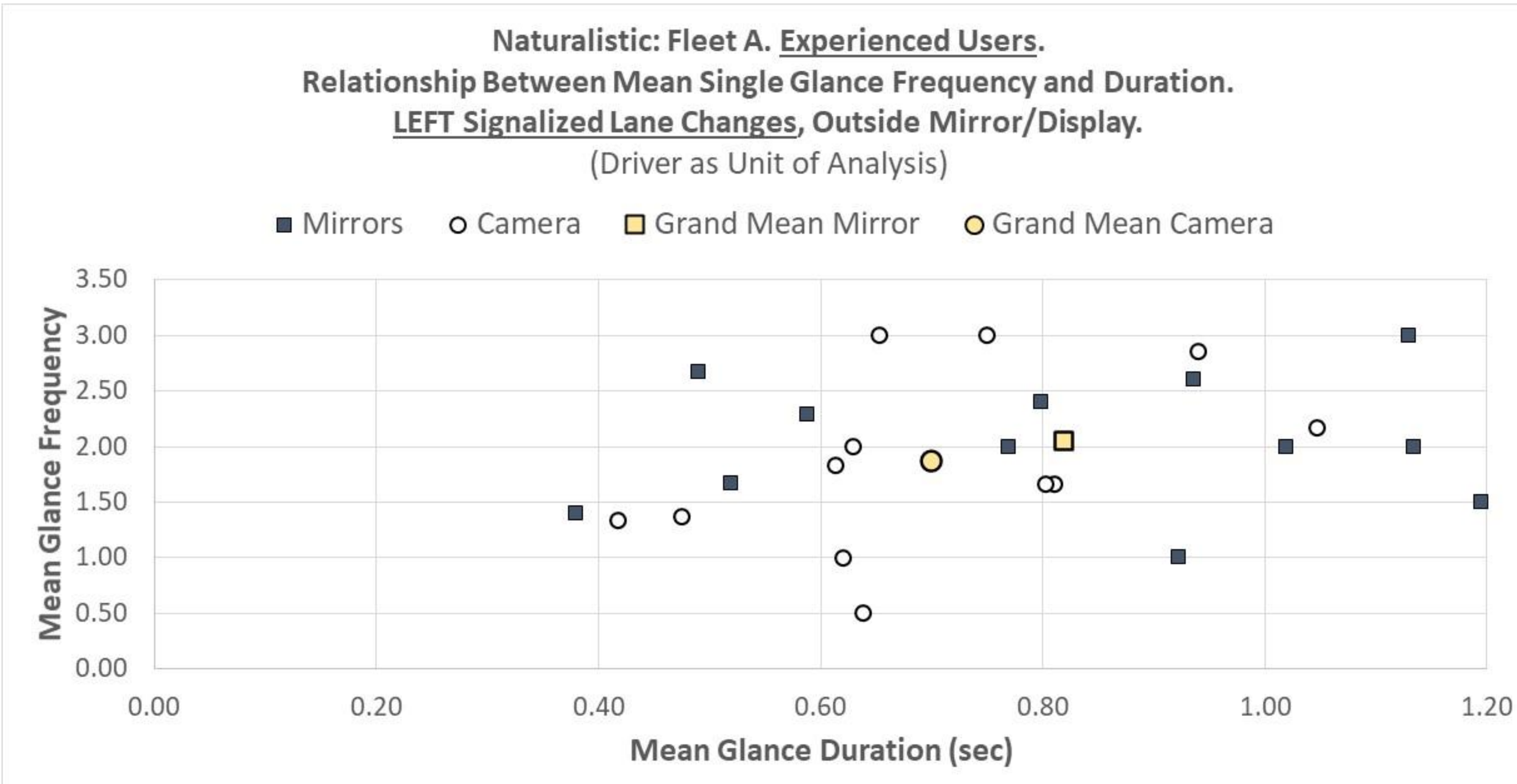
Fleet A: Outside Mirror/Display

- Left lane changes, Experienced users, Outside Mirror/Display
- No statistically significant differences between Aid conditions



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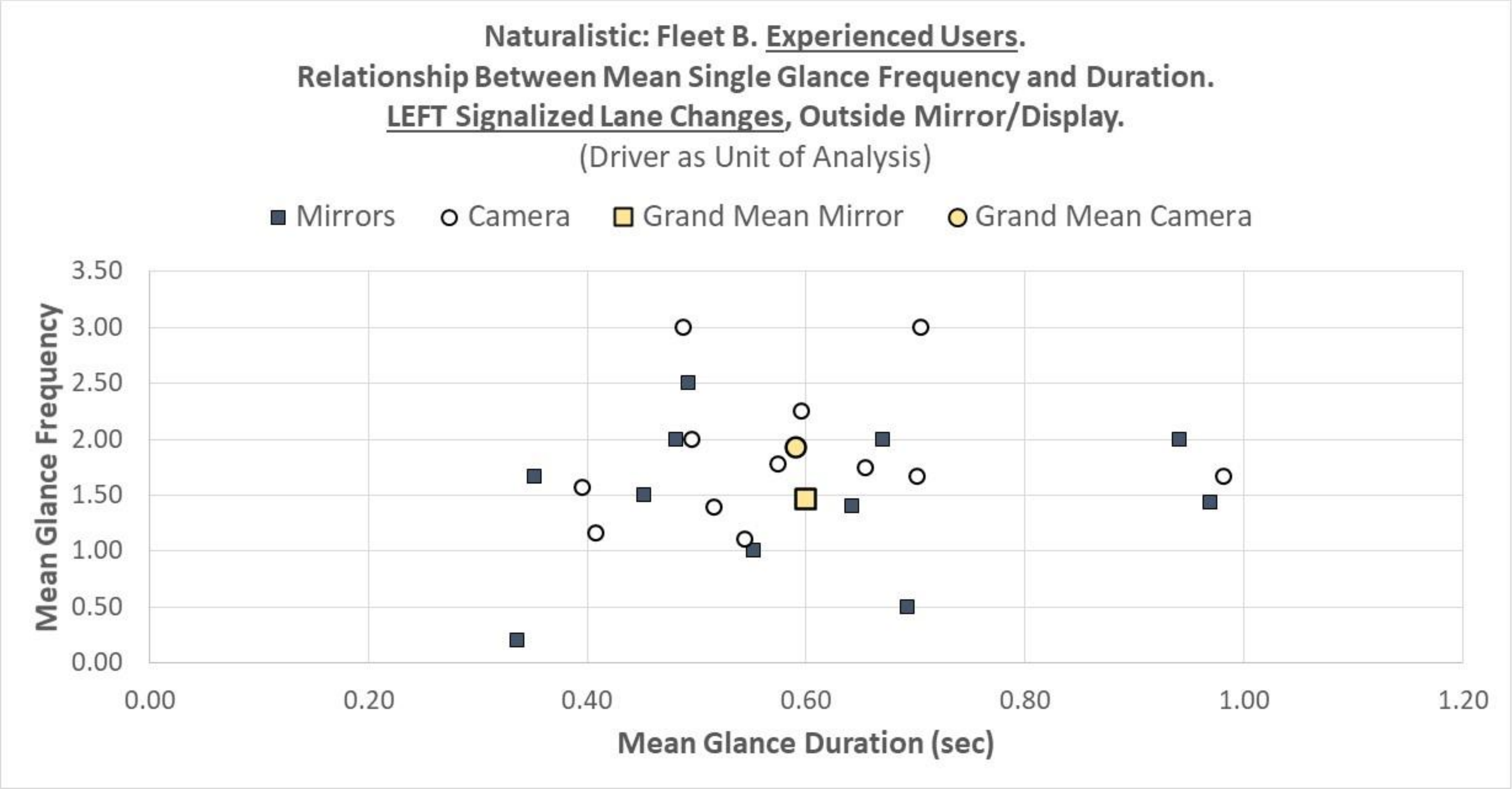
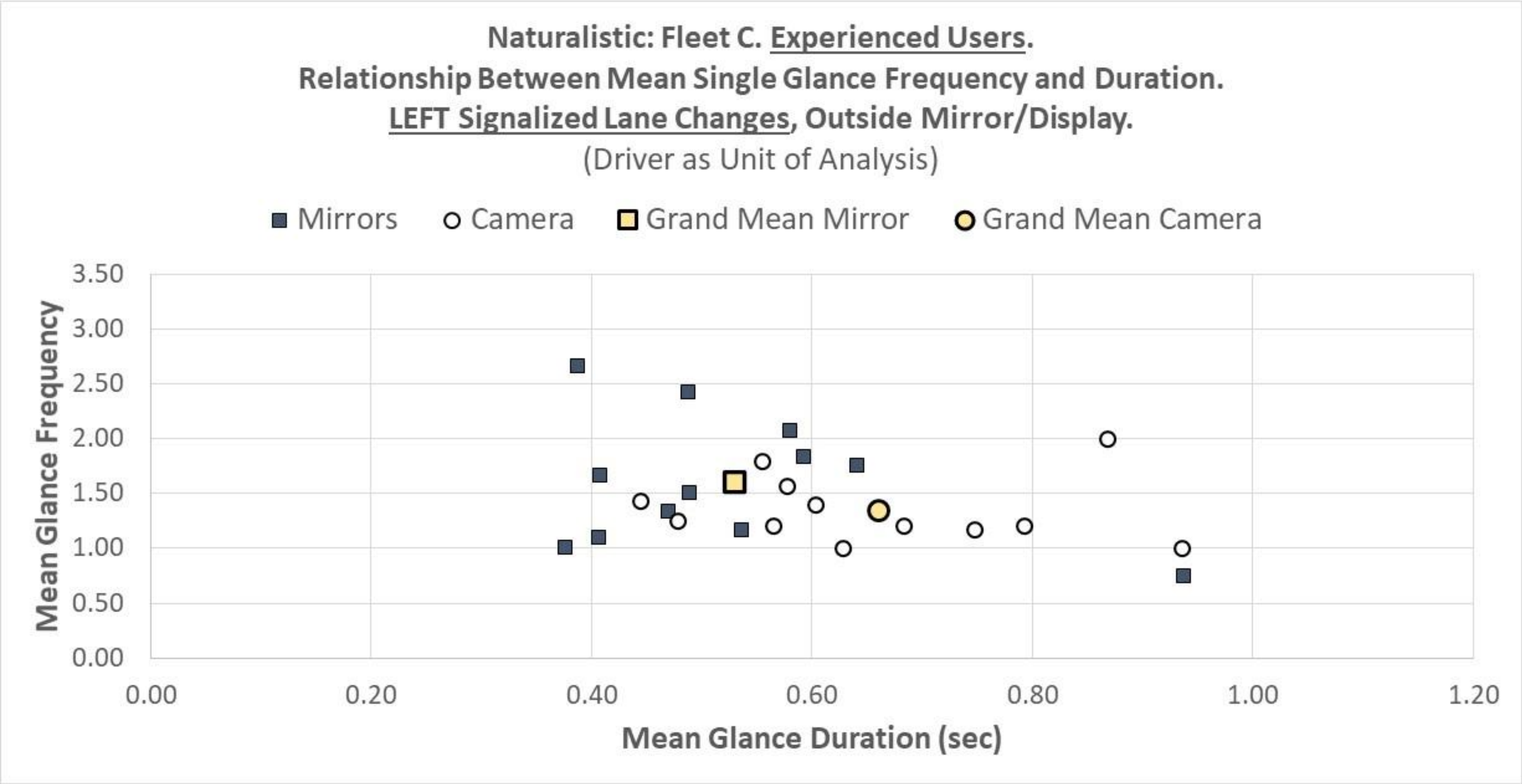
Fleet B: Outside Mirror/Display

- Left lane changes, Experienced users, Outside Mirror/Display
- No statistically significant differences between Aid conditions



Fleet C: Outside Mirror/Display

- Left lane changes, Experienced users, Outside Mirror/Display
- No statistically significant differences between Aid conditions



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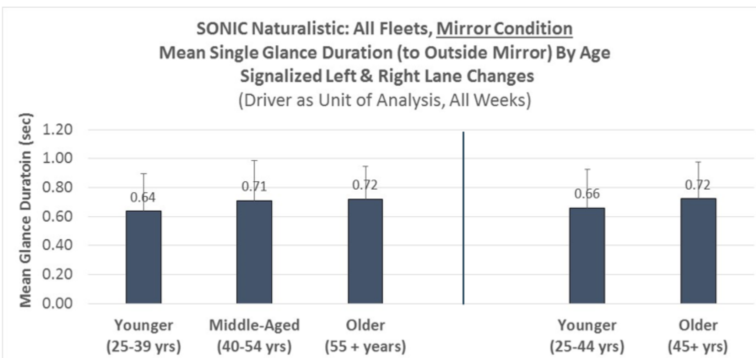
Driver Age

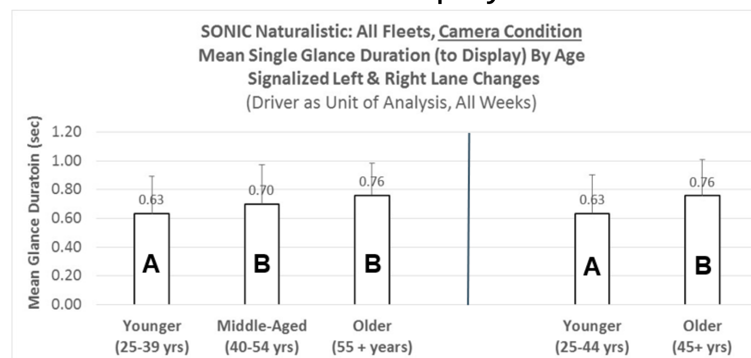
Summary Age-Related Results

- **Glance durations to outside mirrors/display tend to increase with age for both Mirrors and Camera conditions**
- **In general, no significant high-level age-related differences between Mirrors and Cameras (All Fleets Combined)**

Conventional Mirror



Camera Display



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Driver Perceptions: Post-Drive Questionnaire

(Gathered at the end of the study)

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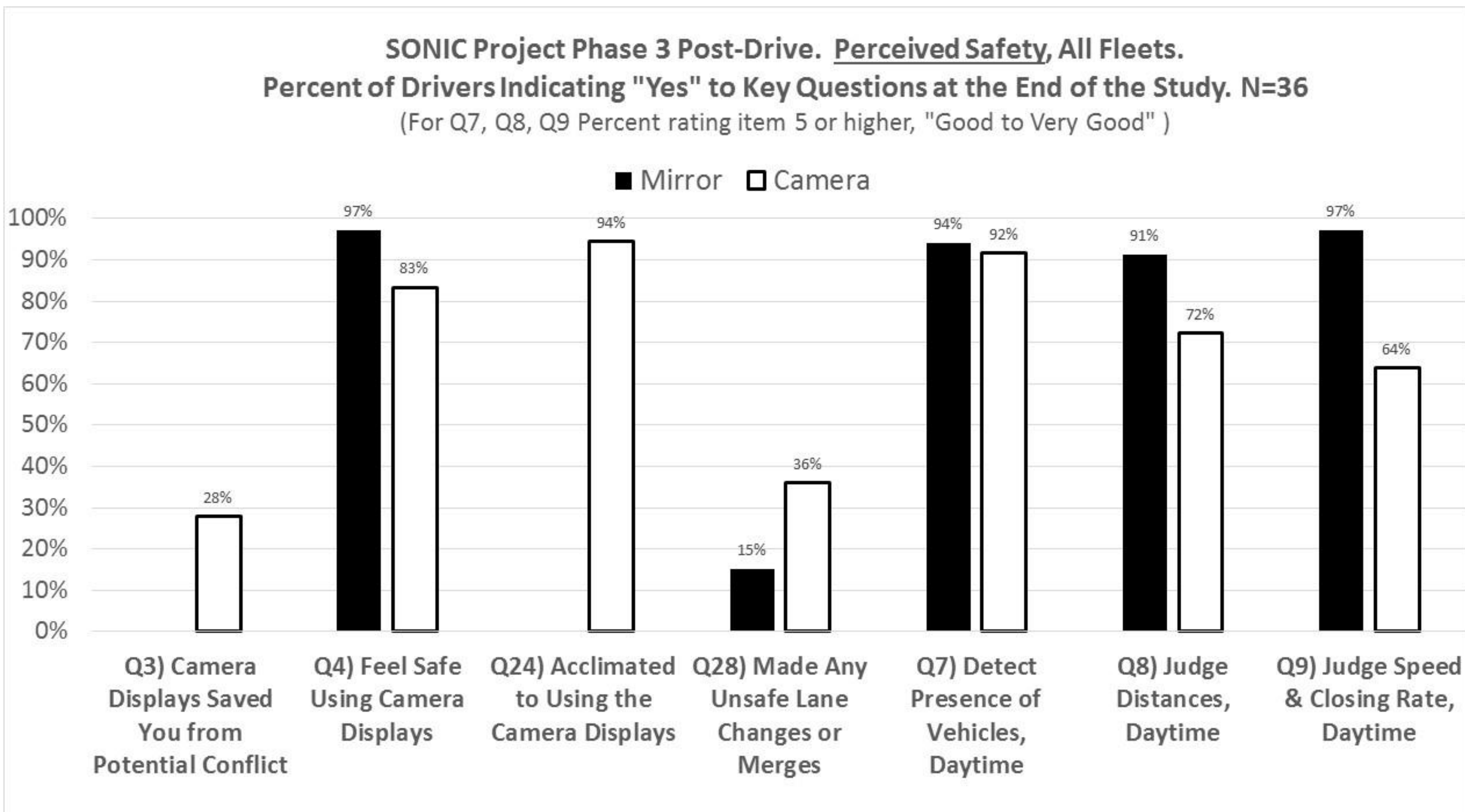
ALL FLEETS COMBINED

Perceived Safety: All Fleets

- Nearly all drivers (94%) reported acclimating to the Camera system
- Cameras perceived to be harder to judge distances, closing speeds (Some variability across fleets- see next chart)
  - 36% felt they made an unsafe lane change with the Camera system compared to 15% under conventional Mirrors. Yet, 28% reported the Camera system "saved" them from a potential conflict



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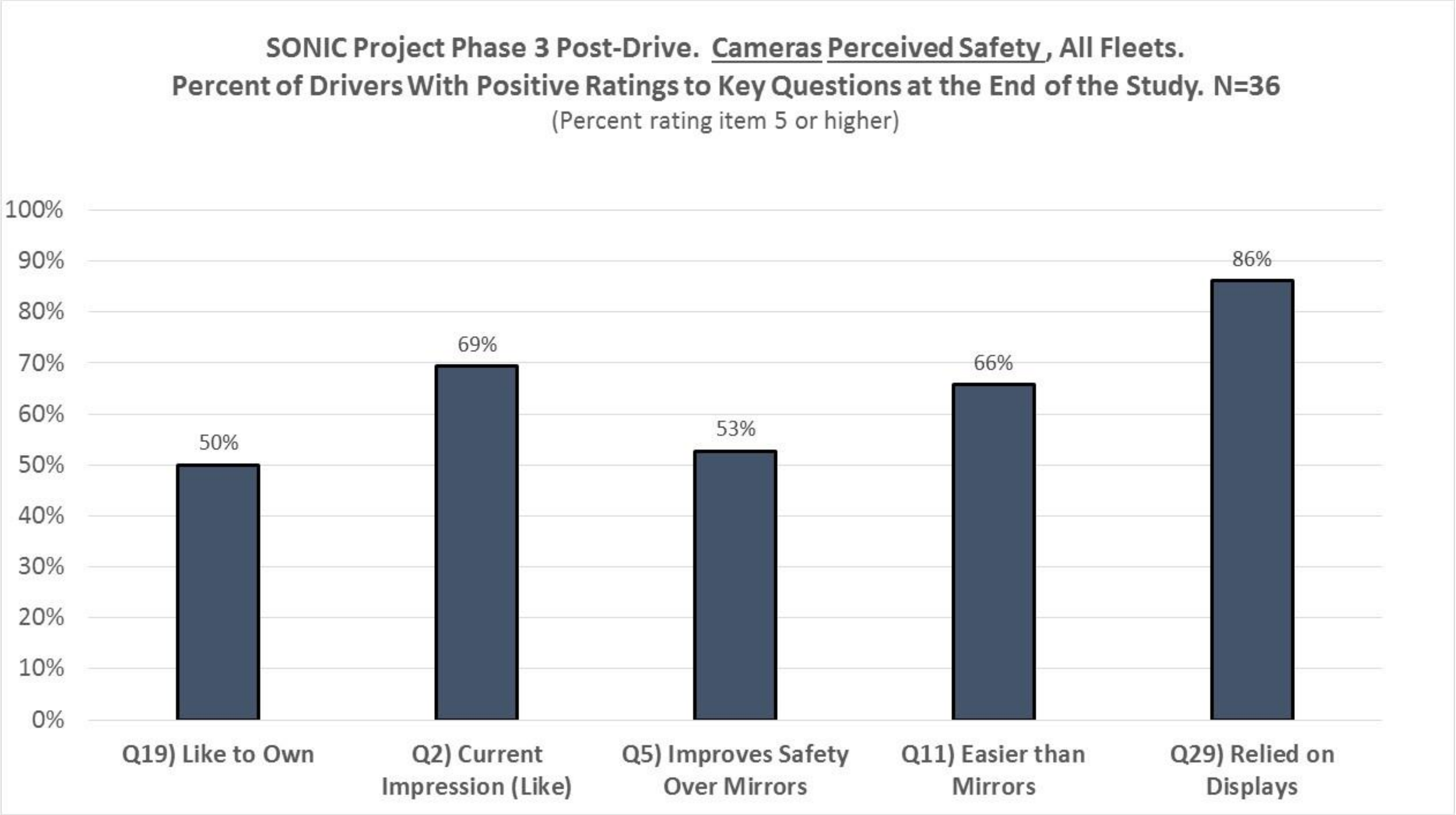
Perceived Safety: Judging Distances

- Variation across fleets in driver's perceptions related their ability to judge distances to vehicle and objects with Camera-based systems
  - Fleets A and B were rated higher in comparison to Fleet C

Perceived Safety (Con't): All Fleets

- Majority of the drivers liked the Camera-based displays (69%), and found them easier to use than Mirrors (66%), and more than half (53%) felt it improved safety over Mirrors
  - About half the sample (50%) indicated they would like to own a system
- Most drivers (86%) relied on the displays heavily



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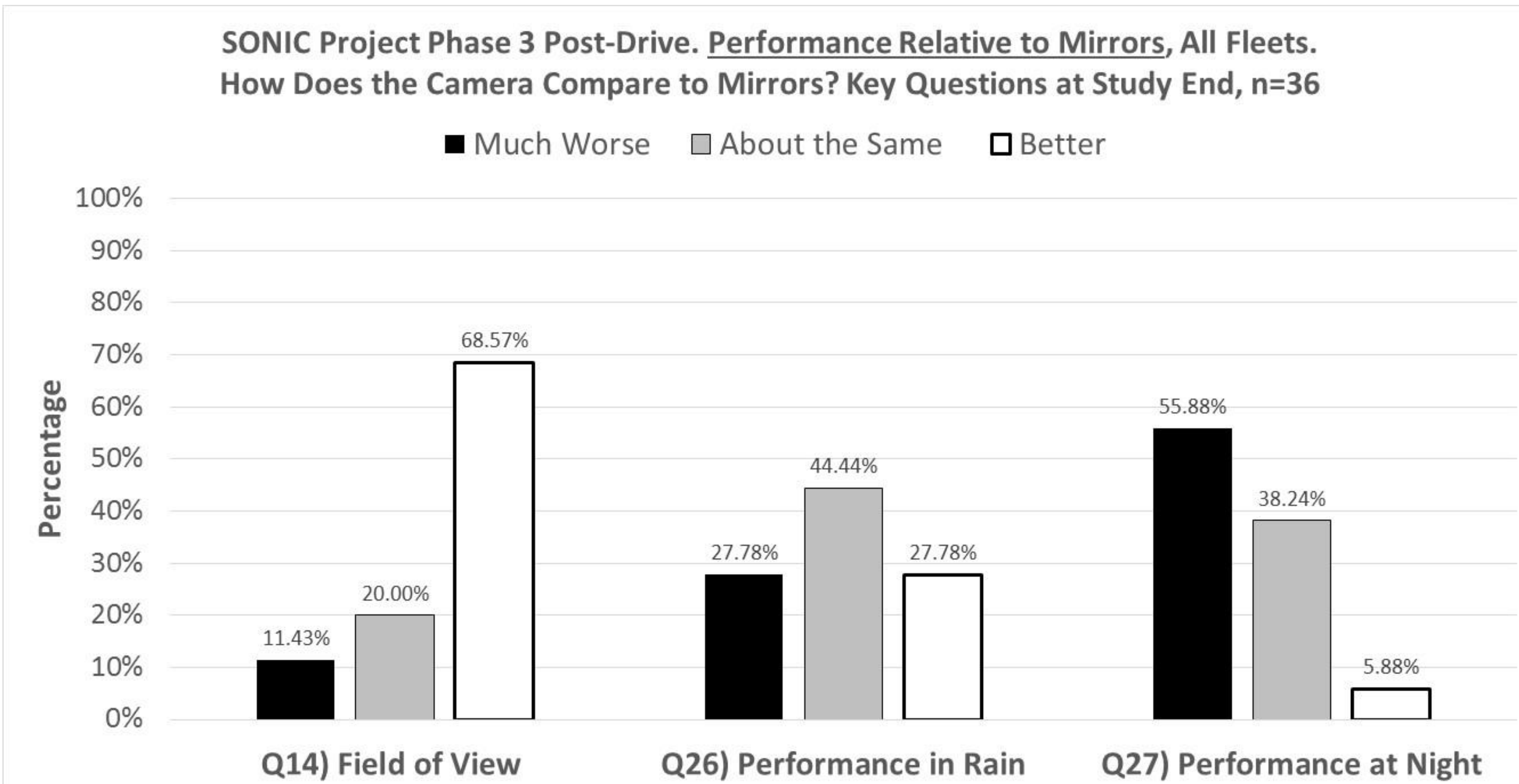
Impressions Relative to Mirrors: All Fleets

- Overall, Cameras judged to have better FOV, perform about the same as Mirrors in rain, but provide poorer performance at night
- Some variation across fleets (see next slide)



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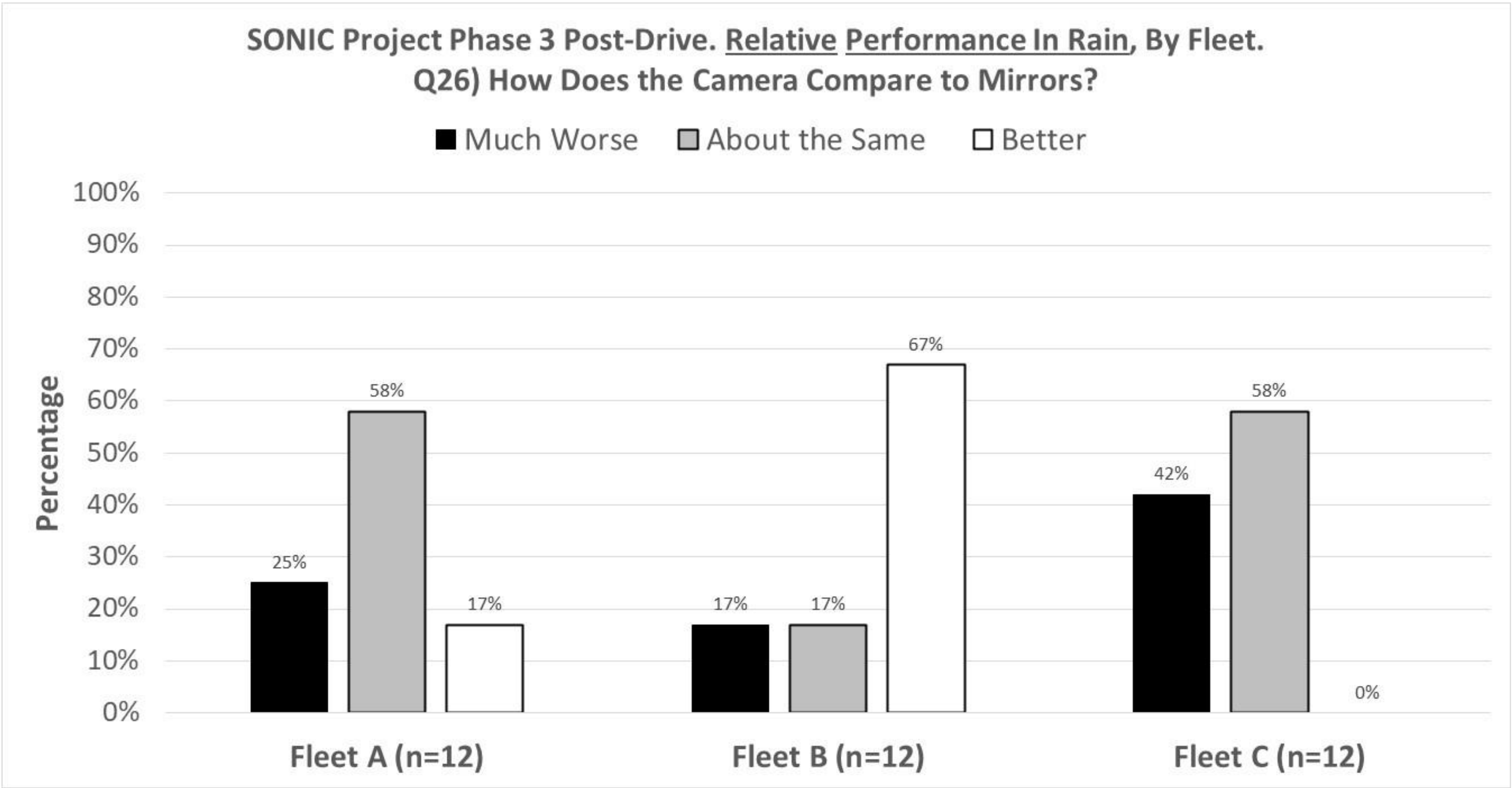
Relative Performance in Rain

- Considerable variation across fleet implantation regards driver's perceptions of the Camera system's performance in rain
  - For Fleet B, 84% of drivers rated the Camera systems performance in the rain as the same or better relative to conventional Mirrors
  - For Fleet C, 42% drivers perceived performance to be much worse



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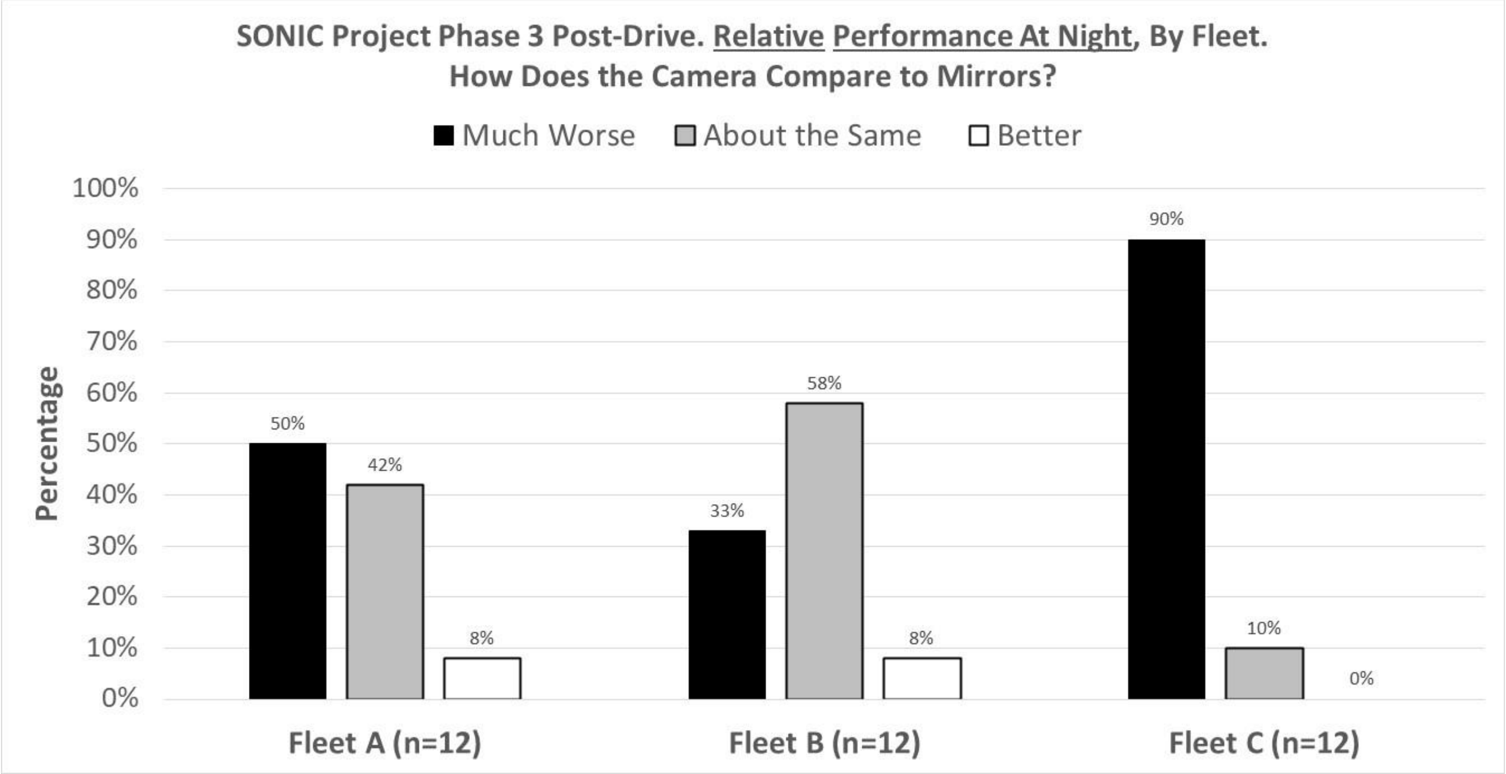
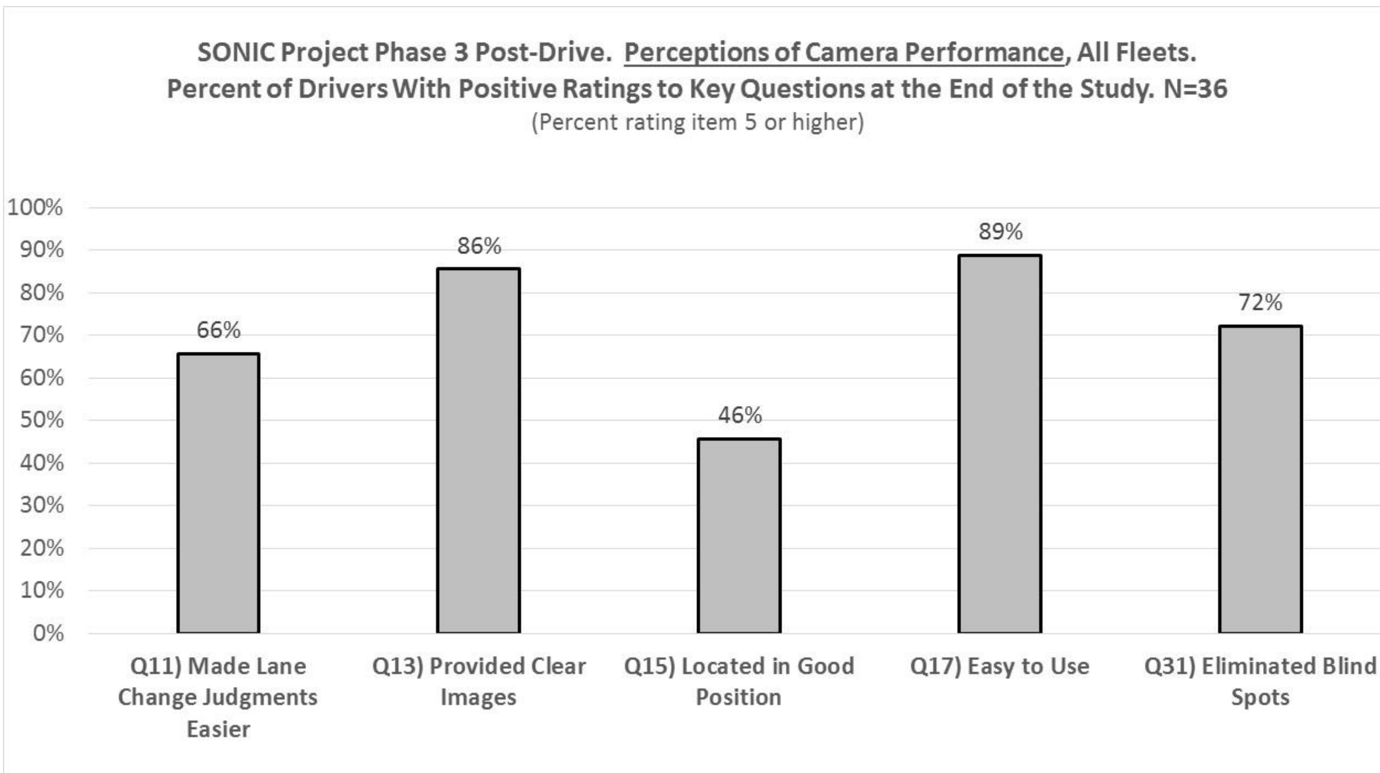
Relative Performance at Night

- Considerable variation across fleet implantation regards driver's perceptions of nighttime performance
  - For Fleet B, 66% of drivers rated the Camera systems nighttime performance as the same or better relative to conventional Mirrors
  - For Fleet C, most drivers perceived performance to be much worse



Camera Performance: All Fleets

- Drivers generally had favorable judgements about the Camera's performance and characteristics: clear images, easy to use, eliminates blind spots)
- The display's location was an issue. Overall, 46% of drivers liked its location (combined across all fleets).
  - Perceptions were strongly influenced by the specific OEM implementation, with percentages ranging from 33% to 67% across fleets



Hazard Analysis

Hazard Analysis

- **Assess equivalency of Camera-based systems to conventional Mirror systems:**
  - Lateral Acceleration
  - Ultimately assess conflicts with surrounding traffic
- **Apply existing risk algorithms to determine risks for drivers under the two different modes:**
  - Mirrors
  - Camera-Based Displays
- **Work is also underway to examine radar data surrounding real-world lane change events executed by drivers relying on both conventional mirror and camera-based systems**
  - Characterize driver gap acceptance under both aids

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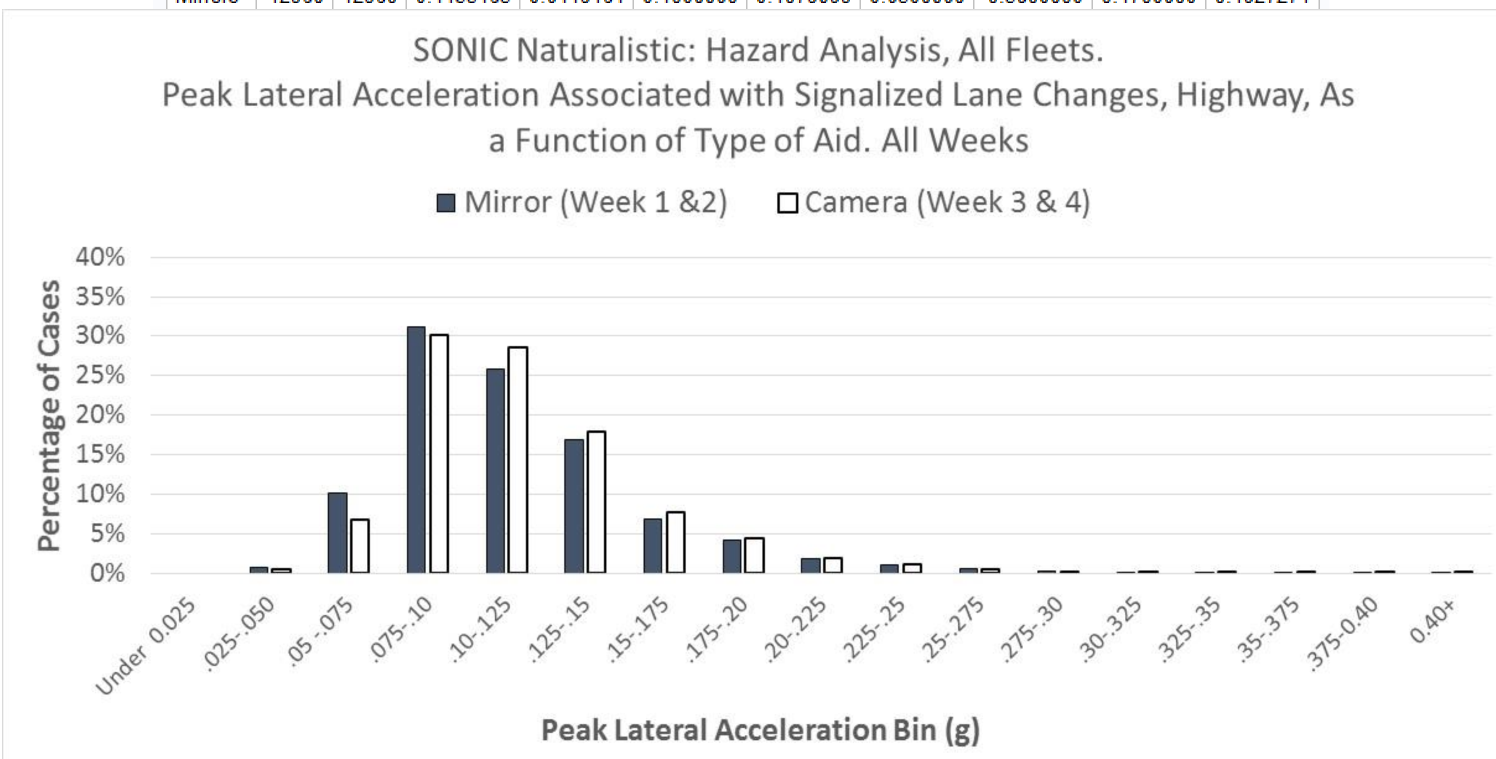
Lateral Acceleration By Aid

- All Fleets, Signalized Lane Changes, Highway
- No significant differences were observed in peak lateral acceleration under Mirrors & Camera conditions

Analysis Variable : PeakLatAccel										
Aid	N Obs	N	Mean	Std Dev	Mode	Median	Minimum	Maximum	90th Pctl	95th Pctl
Camera	12695	12695	0.1187865	0.0410917	0.1000000	0.1100000	0.0300000	0.4900000	0.1700000	0.1967768
Mirrors	12960	12960	0.1155165	0.0419464	0.1000000	0.1079099	0.0300000	0.5800000	0.1700000	0.1927271



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END

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