# Upper-Extremity Postures and Activities in Naturalistic Driving

Final Report
UMTRI-2016-20

Matthew P. Reed
Sheila M. Ebert

Biosciences Group
University of Michigan Transportation Research Institute

*September 2016*

**UMTRI**
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# REPORT DOCUMENTATION PAGE

*Form Approved*
*OMB No. 0704-0188*

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. **PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.**

| 1. REPORT DATE *(DD-MM-YYYY)* | 2. REPORT TYPE | 3. DATES COVERED *(From - To)* |
|---|---|---|
| September 2016 | Final Report | |

| 4. TITLE AND SUBTITLE | 5a. CONTRACT NUMBER |
|---|---|
| Upper-Extremity Postures in Naturalistic Driving | 5b. GRANT NUMBER |
| | 5c. PROGRAM ELEMENT NUMBER |

| 6. AUTHOR(S) | 5d. PROJECT NUMBER |
|---|---|
| Reed, Matthew P. and Ebert, Sheila M. | 5e. TASK NUMBER |
| | 5f. WORK UNIT NUMBER |

| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) | 8. PERFORMING ORGANIZATION REPORT |
|---|---|
| University of Michigan Transportation Research Institute | UMTRI-2016-20 |

| 9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) | 10. SPONSOR/MONITOR'S ACRONYM(S) |
|---|---|
| Yanfeng Automotive Interiors | |
| | 11. SPONSOR/MONITOR'S REPORT NUMBER(S) |

**12. DISTRIBUTION / AVAILABILITY STATEMENT**

**13. SUPPLEMENTARY NOTES**

**14. ABSTRACT**
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**15. SUBJECT TERS**
Anthropometry, Body Shape

| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON M.P. Reed |
|---|---|---|---|---|---|
| a. REPORT | b. ABSTRACT | c. THIS PAGE | | 42 | 19b. TELEPHONE NUMBER *(include area code)* (734)936-1111 |

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

# ACKNOWLEDGMENTS

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## INTRODUCTION

Naturalistic driving studies (NDS) deploy instrumented vehicles to study many facets of the driving process. The University of Michigan Transportation Research Institute (UMTRI) has conducted many NDS over the past 20 years, studying advanced driver assistance systems and many facets of driving performance. The Connected Vechicle Safety Pilot Model Deployment (SPMD) study was focused on testing vehicle-to-vehicle and vehicle-to-infrastructure communication technologies (Bezzina and Sayer 2015).  As part of that study, 100 drivers who owned small sedans were recruited to have their vehicles instrumented. The vehicles were equipped with sensors to record a wide range of vehicle performance data.  Cameras were mounted on the vehicle to record the exterior scene, and one camera was mounted near the inside mirror to record the driver's activities.

The driver video provides a rich opportunity to quantify many aspects of driver behavior. The current analysis is focused on upper extremity activities, with a particular focus on resting postures. Video frames were sampled from a selection of trips with each equipped vehicle. A coding methodology was developed to categorize the upper extremity postures and activities, along with a few other aspects of driver behavior. The data were summarized to identify the distribution of behaviors as a function of driver and trip attributes.

## METHODS

### Database

The SPMD database contains a large amount of data that can be accessed by queries indexed by vehicle, trip, and many other variables. Figure 1 shows a sample video frame, demonstrating the typical view of the driver. The records span weeks of driving and dozens of trips for each vehicle. UMTRI has developed specialized software for viewing and analyzing naturalistic driving data, including video. In this study, this software was used to sample from within this large dataset and to manually code patterns of armrest usage from the video data.



Figure 1. Example of camera view from SPMD and software interface for viewing cabin videos

### Vehicles

One hundred vehicles were included in this study. All were passenger sedans from GM, Ford, and Honda. The vehicles included are listed in Table 1 and Figure 2 shows examples of interiors from vehicles of the same make, model and model year.

Table 1
Study Vehicles

| Make | Model | Year | Count |
|---|---|---|---|
| Chevrolet | Impala | 2007 | 2 |
| Chevrolet | Impala | 2008 | 2 |
| Chevrolet | Impala | 2010 | 2 |
| Chevrolet | Malibu | 2009 | 4 |
| Chevrolet | Malibu | 2010 | 2 |
| Chevrolet | Malibu | 2011 | 2 |
| Chevrolet | Malibu | 2012 | 4 |
| Chevy | Malibu | 2008 | 2 |
| Ford | Focus | 2012 | 3 |
| Ford | Focus | 2013 | 1 |
| Ford | Fusion | 2010 | 18 |
| Ford | Fusion | 2011 | 3 |
| Ford | Fusion | 2012 | 4 |
| Honda | Civic | 2006 | 8 |
| Honda | Civic | 2007 | 3 |
| Honda | Civic | 2008 | 9 |
| Honda | Civic | 2009 | 7 |
| Honda | Civic | 2010 | 4 |
| Honda | Civic | 2011 | 1 |
| Pontiac | G6 | 2006 | 1 |
| Pontiac | G6 | 2007 | 1 |
| Pontiac | G6 | 2008 | 2 |
| Pontiac | G6 | 2009 | 3 |
| Saturn | Aura | 2007 | 3 |
| Saturn | Aura | 2008 | 5 |
| Saturn | Aura | 2009 | 2 |
| Saturn | Aura | 2010 | 1 |
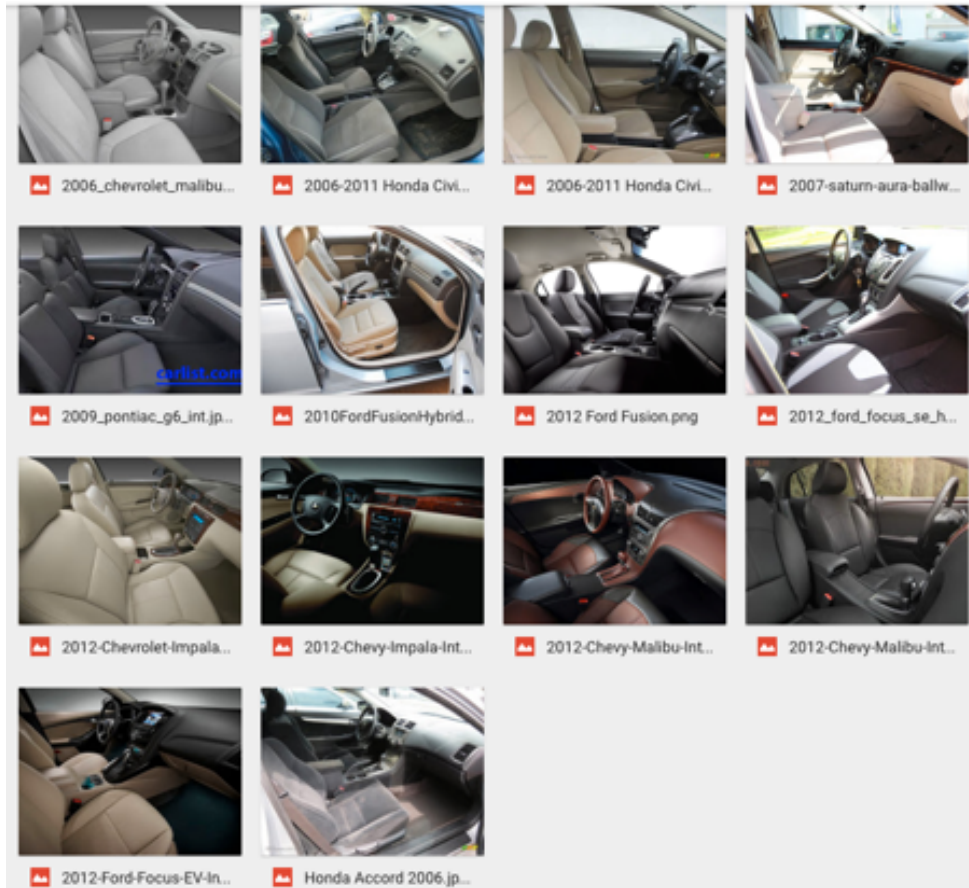
Figure 2. Examples of vehicle interiors (not necessarily representative of tested vehicles).

**Data Acquisition System**

In addition to collecting video data of the cabin, the data acquisition system in the vehicles recorded the information in Table 2 at 10 Hz.  The vehicle's GPS position, speed, and heading were recorded as defined by the SAE J2735 standard (Bezzina & Sayer 2015).

Table 2
Participant information

| DAS Input | Description | Units |
|---|---|---|
| Data Time | Time in centiseconds since DAS started | csec |
| Accel Pedal | Accelerator pedal | % |
| Altitude | Height above the ellipsoid | m |
| Available Left | Mobil Eye left LDW availability | none |
| Available Right | Mobileye right LDW availability | none |
| X-axis | Longitudinal acceleration from Conti IMU | m/sec2 |
| Y-axis | Lateral acceleration from Conti IMU | m/sec2 |
| Boundary Left | Mobil Eye left lane type | none |
| Boundary Right | Mobil Eye right lane type | none |
| Brake | Brake light active | none |
| Cruise Engaged | Cruise control active | none |
| Distance | Trip distance | m |
| GPS Heading | GPS heading from Ublox GPS | degrees |
| Latitude | Latitude from Ublox GPS | degrees |
| Longitude | Longitude from Ublox GPS | degrees |
| Num Targets | Mobileye number of obstacles | none |
| Range | Mobileye Object 1 longitudinal position relative to the reference point. | m |
| Range Rate | Mobil Eye relative longitudinal velocity of object1 | m/sec |
| Turn Signal | Turn signal | none |
| Yaw Rate | Yaw rate from Conti IMU | degrees /second |
| Speed | Vehicle speed from transmission | m/sec |
| TOD Trip Start | Absolute date/time corresponding to test time = 0 in access date/time format based on computer clock | none |
| Odometer | Odometer | m |
| Local Time | GPS milliseconds in week from GPS | msec |

## Participants

The SPDM did not require the vehicle to be driven solely by the owner of the vehicle. Therefore, half the vehicles sampled had more than one driver, with twelve vehicles having three drivers, two vehicles having four drivers, and one having five drivers. A total of 165 drivers were observed (96 women and 69 men). Screen shot of each individual driver was taken (Figure 3) and stored with an assigned driver number. For each trip coded, the reviewers checked the photos to determine and record which driver was present in the video.

Front seat passengers were present in 18% of the frames coded. However, in some vehicles only the left side of the passenger's body was visible; gender and age were impossible to determine in most of those cases, a total of about 10% of passenger observations. Of the other frames, 60% of the front seat passengers were women and the remainder men.

The SPDM did not regularly record participant age, stature or weight. Therefore, the age and build of participants was estimated from video. Due to the imprecision of this method, age was grouped into three categories: less than 30 years, between 30 and 60 years and over 60 years. Tables 3 and 4 list the age distribution of the

drivers and passengers in the frames coded. Participant weight relative to stature was categorized as lean, heavy or obese, which would roughly correspond to a body mass inex (kg/m$^2$) of <25, 25 to 30 and >30 respectively.  Of the frames coded, the driver was categorized as lean in 65%, overweight in 30% and obese in 5%. This level of obesity is much lower than the population as a whole (approximately 30% of US adults are obese), so these values are likely to be skewed low. Of the frames with a front passenger present, the passengers were categorized as 67% lean, 24% overweight, and 2% obese.



Figure 3. Examples of diver screenshots used to determine which participant was driving

Table 3
Driver Age Distribution

| Age Category (years) | Number of Drivers | Percentage of Coded Trips (%) |
|---|---|---|
| <30 | 51 | 31 |
| 30-60 | 106 | 65 |
| >60 | 7 | 4 |

Table 4
Passenger Age Distribution

| Age Category (years) | Percentage of Coded Trips (%) |
|---|---|
| <30 | 30 |
| 30-60 | 46 |
| >60 | 16 |
| Unable to Categorize | 8 |

## Customized Video Coding Tool

Figure 4 shows a screenshot of the coding tool developed for this study. Radio buttons allowed only one response per question, and check boxes allowed multiple responses.  The details of the coding tool interface are described below.

*Driver and Passenger Physical Characteristics and Torso Orientation*

Figure 5 and 6 show the areas of the coding tool where investigators recorded information characterizing torso orientation and physical characteristics the driver and front passenger.  Torso orientation was referred to as "Torso Lean" to the right, left, forward or none.  Examples of the postures are in Figure 7.  Physical characteristics included gender (male, female or unknown in the case of some passengers), weight category (lean, heavy, obese), age (<30 years, 30-60 years, and >60 years), whether the driver was wearing sunglasses (yes or no) and hair color (dark or light) to help distinguish between different drivers and passengers within a car.

*Driver Upper Limb Location with Detailed Information on Armrest Usage*

Figure 8 and Tables 5 and 6 detail how the location and possible interactions of the elbow, forearm and hands of the driver and front passenger were recorded the coding tool.   The locations where the occupants touched the armrest was divided into three areas show in Figure 9, front, top and side. The zones of possible limb contact with the rest of the body are shown in Figure 10, and the elbow, forearm and hand was divided as shown in Figure 11. Figures 12-19 show examples of limb positions and object interactions.

Figure 4. Example observations recorded on the customized video coding tool

Figure 5. Part of the coding tool that records driver posture, gender, general hair color, whether wearing sunglasses, and weight and age category



Figure 6. Part of the coding tool that records front passenger posture, gender (if can be determined from the video), general hair color, and weight and age category



Figure 7. Examples of leaning left, right and forward (from left to right)

Figure 8. In the upper limb coding section of coding tool: blue and yellow columns are the right and left sides of the driver respectively and the black column is the left side of the front passenger if present. The rows from top to bottom are the body parts: elbow location, forearm location, hand location, and the most frequently objects which with the occupants interacted.

Table 5

Driver Arm Location and Object Interaction Checkboxes in Coding Tool

| Elbow, Forearm and Hand Locations (Left and Right) | | Additional Right Hand Locations | Left Hand Interaction Objects | Right Hand Interaction Objects |
|---|---|---|---|---|
| Armrest Front | Window/Beltline | Head | Drink | Drink |
| Armrest Side | Touching Nothing | Center Stack | Food | Food |
| Armrest Top | Not in Frame | Shifter | Phone | Phone |
| Torso (Self) | Cannot Tell | Object Interact | Grab Handle | Shifter |
| Lower Extremity (Self) | Other* | | Other* | Center Stack |
| Steering Wheel | | | | Other* |

*Requires rare events code

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Table 6
Front Passenger Arm Location and Object Interaction Checkboxes in Coding Tool

| Left Elbow, Forearm and Hand Locations | | Left Hand Interaction Objects |
|---|---|---|
| Armrest Front | Shifter | Drink |
| Armrest Side | Object Interact | Food |
| Armrest Top | Touching Nothing | Phone |
| Torso (Self) | Not in Frame | Shifter |
| Lower Extremity (Self) | Cannot Tell | Center Stack |
| Head (Self) | Other* | Other* |
| Center Stack | | |

*Requires rare events code
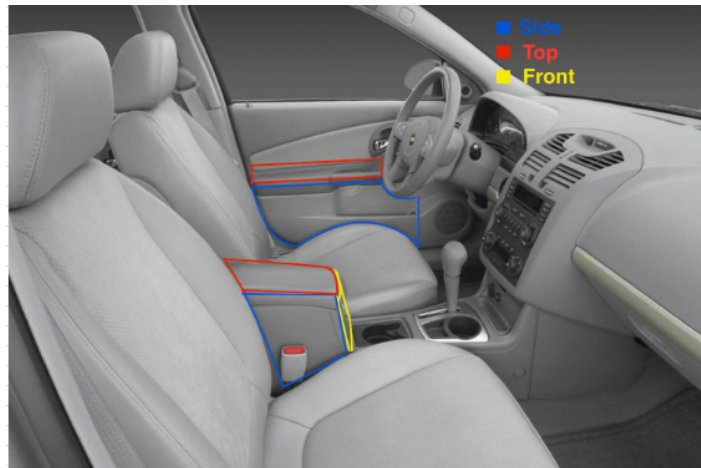


Figure 9. Armrest regions
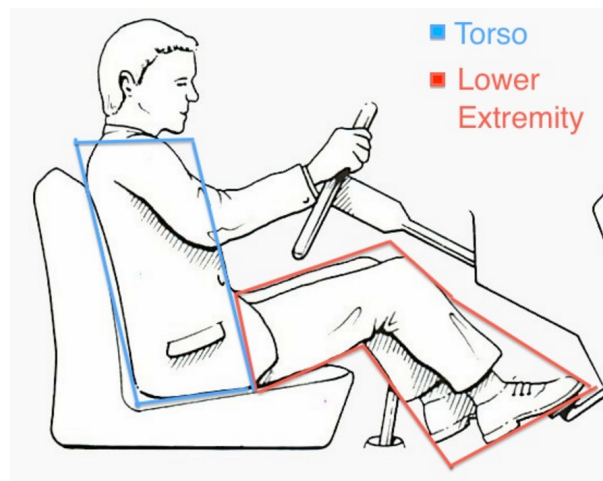


Figure 10. Body regions the arm might be coded to contact
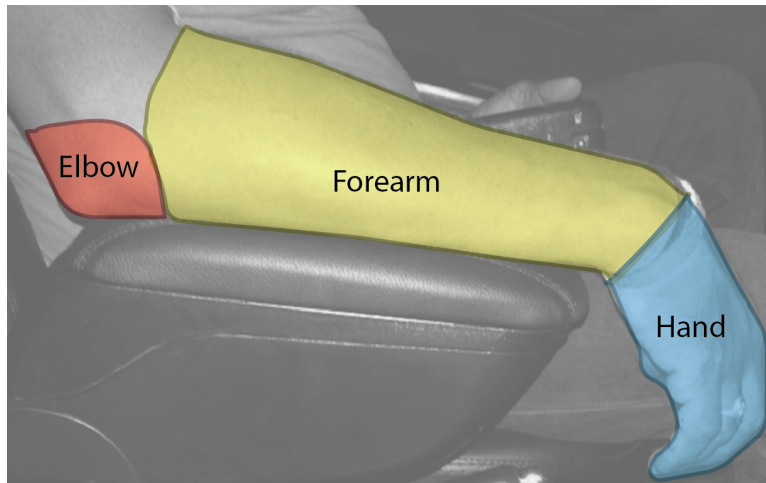
Figure 11. Arm regions



Figure 12. Example of right elbow on top of armrest, forearm touching nothing, right hand interacting with an object, left elbow on beltline/window, left forearm touching nothing, left hand on steering wheel, phone on lap and an unidentified object in cupholder

Figure 13. Example of right and forearm touching nothing, right hand on steering wheel, left elbow touching torso, left forearm touching nothing, and left hand touching lower extremity



Figure 14. Example of elbow and forearm (left) versus just the elbow touching the top of the armrest (right)

Figure 15. Example of driver with elbow in the beltline



Figure 16. Example of a passengers with elbow touching front of armrest (left), side of the armrest (middle), and of a passenger with elbow and forearm touching the top of the armrest (right)

Figure 17. Examples of phones in right hand and elbow on top of armrest



Figure 18. Examples of drink (left) and food (right) in right hand



Figure 19. Example of "Can't tell" on left, though reviewers were instructed to scrub forward or backward several frames to get more information to do the coding

*Rare Events*

To keep the form from being too crowded, rare events were entered in the notes area of the coding tool (Figure 20).  The wording of the rare events notes was standardized into a four-word pattern which included 1) the occupant position 2) the who, what or where 3) direction, side, or type of action and 4) the item, type of occurrence, duration or other descriptor.  The codes were organized into a spreadsheet that all coders used. Once a code was developed, it was copied and pasted into the coding tool for any following occurrences. Rare events coded are listed in Tables 7-9, with examples in Figures 21 - 22.
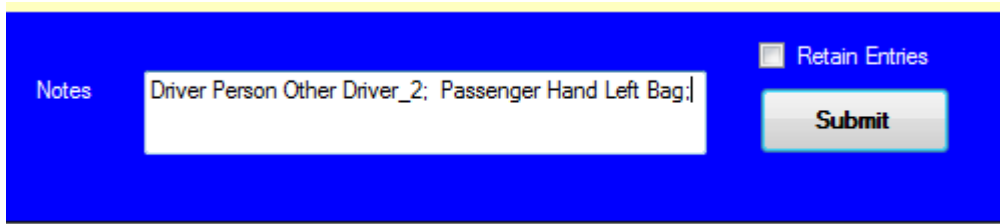


Figure 20. An example of entering rare events in notes area of coding tool in which the first entry indicates that it is "Driver 2" instead of  "Driver 1", and the second entry records that the left hand of the passenger is touching a bag.

Table 7
Driver Position Rare Events

| Right Hand Interaction | Left Hand Interaction | Other Body Parts Occurrences |
|---|---|---|
| Left Arm (Self) | Right Arm (Self) | Both Arms Crossed |
| Left Hand (Self) | Right Hand (Self) | Left Arm Outside |
| Cigarette | Cigarette | Shoulder Holding Phone |
| Console | Door | Left Knee Steering |
| Driver Floor | Driver Floor | Right Knee Steering |
| Rear Floor | Lotion | No One Steering |
| Lotion | Paper | Driver Eyes Down on |
| Money | Ponytail | Console |
| Paper | Sunglasses | |
| Pen | Sun Visor | |
| Ponytail | Front Seat Passenger | |
| Purse | | |
| Sun Visor | | |
| Passenger Seat | | |
| Rear Seat | | |
| Front Seat Passenger | | |
| Rear Seat Passenger | | |

Table 8
Objects in the Vehicle Rare Events

| Item on Center Console or Center Armrest | Items in Center Cup Holder | Location of Sunglasses Relative to Driver | Item in Lap of Driver | Seat Belt of Driver |
|---|---|---|---|---|
| Cup Phone Purse Pet Object* | Cup Cups Food Phone Purse Sunglasses Object * | Removing sunglasses Sunglasses top of head Sunglasses in mouth | Pet Phone Purse Object* | Donning while driving Donning while stopped Not using Adjusting Location |

*reviewer is unable to identify what the object is

Table 9
Front Passenger Rare Events

| Left Hand Interaction | | Other Body Parts Occurrences | Lap | In Seat |
|---|---|---|---|---|
| Bag Belt Computer Console | Opening Console Driver (Person) Driver Seat Rear Seat | Elbow in driver seat Forearm on console while opening | Bag Pet Purse | Pet |



Figure 21. Rare events examples of right hand in rear seat area (left) and a cigarette in left hand (right)

Figure 22. Examples rare events of objects in vehicle: food in console area (left) and donning seat belt (right)

## Sampling Strategy

Vehicles in the SPMD dataset that had data from at least 100 separate trips and traveled over 1000 miles over the course of SPDM were included. In these vehicles, only trips that lasted longer than 5 minutes were included. Ten trips with duration of greater than 5 minutes were selected from each of the vehicles and 10 frames were coded for each trip. Within each trip the first coded frame was 10 seconds after the start of the video and the last frame was 5 seconds from end of video. The remaining 8 frames were equally spaced over the duration of the trip. The trips were then assigned to the reviewers and placed in an interactive table (Figure 23) from which they could click a link that brought the video up in the viewer at the frame to be coded.

Based on this sampling strategy, approximately 25% of the trips were at night (after sunset and before sunrise). Trip length ranged from 5 minutes to 2.5 hours with an average trip length of 16 minutes (Figure 24).

Figure 23. Example of table generated for each reviewer with list of frames to code and hyperlinks to the video frame (device is the vehicle code)
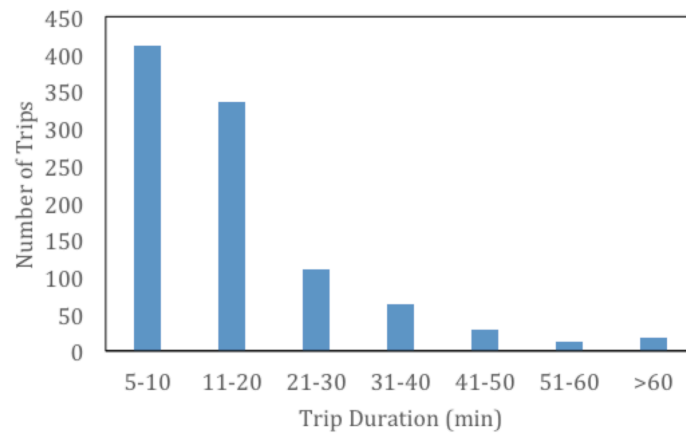


Figure 24. Frequency of trip lengths in data sampled

**RESULTS**

A total of 9856 video frames were coded. In less than 2% of these frames, driver data were not available, either due to obstruction of the camera view or the driver not being in the vehicle. All percentages reported below exclude those frames from the denominator.

The responses were tallied for each question and across all responses the notes field. The Appendix contains tallies for all responses. Tables 10 and 11 list summary statistics regarding the driver's upper extremity postures and actions. The driver's right elbow or forearm was in contact with the console armrest in 36% of frames, with the contact on the top of armrest more than three times as frequently as with the front. Elbow or forearm contact with other parts of the armrest observed in less than 1% of frames. The driver's right hand was in contact with any part of the armrest in less than 1% of frames. Drivers' right hands were in contact with the steering wheel in 45% of frames and interacting with an object in about 10% of frames, including in contact with a phone in 6% of frames.

Coding of the driver's left upper extremity was more challenging due to the camera angle, with the results indeterminate in about 10% of frames, depending on the body part. In about 10% of frames, the driver's left elbow was in contact with the door armrest and on the window/beltline in about 7% of frames. The driver's left hand was in contact with the steering wheel about twice as frequently as the right hand and interacting with objects, including phones, about half as frequently. Drivers had both hands on the steering wheel in about 28% of frames.

As noted above, passenger data were sparse. In about 8% of the frames, a passenger was present and had a forearm or elbow in contact with the top of the center console armrest.

Among the observations coded in the notes section of the input form, only a few were seen in 1% or more of frames. A cup or other beverage container was observed in the console cupholder in 12% of frames, although the cupholder was difficult to see in some vehicles. Some other object was observed in the cupholder about 2% of the time.

The Appendix contains tabulations of frequencies for each coded variable. For the notes section, the frequency of occurrence of each response from the coders is tabulated. Among the observations:

- in 60% of coded frames the driver was a woman,

- drivers were wearing sunglasses in 17% of frames,

- drivers were leaning appreciably left or right in less than 1% of frames, and

- the driver had a phone in his or her lap in about 2% of frames.

## Table 10
### Driver **Right** Upper-Extremity Posture and Actions

**Driver Right Elbow**

| | | |
|---|---|---|
| Touching Nothing | 5297 | 55.2% |
| Armrest Top | 2705 | 28.2% |
| Torso | 773 | 8.0% |
| Can't Tell | 589 | 6.1% |
| Armrest Front | 125 | 1.3% |
| Armrest Side | 42 | 0.4% |
| Other | 30 | 0.3% |
| Lower Extremity | 25 | 0.3% |
| Not in Frame | 17 | 0.2% |

**Driver Right Forearm**

| | | |
|---|---|---|
| Touching Nothing | 6923 | 72.1% |
| Armrest Top | 824 | 8.6% |
| Can't Tell | 763 | 7.9% |
| Lower Extremity | 559 | 5.8% |
| Torso | 392 | 4.1% |
| Not in Frame | 52 | 0.5% |
| Other | 41 | 0.4% |
| Armrest Side | 31 | 0.3% |
| Armrest Front | 16 | 0.2% |
| Steering Wheel | 2 | 0.0% |

**Driver Right Hand**

| | | |
|---|---|---|
| Steering Wheel | 4392 | 45.7% |
| Lower Extremity | 1285 | 13.4% |
| Object Interact | 943 | 9.8% |
| Not in Frame | 897 | 9.3% |
| Can't Tell | 822 | 8.6% |
| Touching Nothing | 352 | 3.7% |
| Head | 268 | 2.8% |
| Other | 180 | 1.9% |
| Shifter | 162 | 1.7% |
| Center Stack | 124 | 1.3% |
| Torso | 106 | 1.1% |
| Armrest Front | 41 | 0.4% |
| Armrest Side | 14 | 0.1% |
| Armrest Top | 11 | 0.1% |
| Window/Beltline | 6 | 0.1% |

**Driver Right Action**

| | | |
|---|---|---|
| No Action | 8601 | 89.6% |
| Phone | 628 | 6.5% |
| Drink | 126 | 1.3% |
| Other | 116 | 1.2% |
| Food | 112 | 1.2% |
| Shifter | 16 | 0.2% |
| Center Stack | 4 | 0.0% |

Table 11
Driver **Left** Upper-Extremity Posture and Actions

**Driver Left Elbow**

| | | |
|---|---|---|
| Touching Nothing | 5695 | 59.3% |
| Can't Tell | 1087 | 11.3% |
| Armrest Top | 1053 | 11.0% |
| Torso | 909 | 9.5% |
| Window/Beltline | 659 | 6.9% |
| Lower Extremity | 92 | 1.0% |
| Armrest Side | 64 | 0.7% |
| Not in Frame | 27 | 0.3% |
| Other | 15 | 0.2% |
| Steering Wheel | 1 | 0.0% |
| Armrest Front | 1 | 0.0% |

**Driver Left Forearm**

| | | |
|---|---|---|
| Touching Nothing | 6407 | 66.7% |
| Lower Extremity | 1276 | 13.3% |
| Can't Tell | 1131 | 11.8% |
| Torso | 302 | 3.1% |
| Armrest Top | 238 | 2.5% |
| Window/Beltline | 164 | 1.7% |
| Not in Frame | 45 | 0.5% |
| Other | 23 | 0.2% |
| Steering Wheel | 10 | 0.1% |
| Armrest Side | 7 | 0.1% |

**Driver Left Hand**

| | | |
|---|---|---|
| Steering Wheel | 6126 | 63.8% |
| Can't Tell | 1125 | 11.7% |
| Lower Extremity | 956 | 10.0% |
| Head | 435 | 4.5% |
| Object Interact | 381 | 4.0% |
| Touching Nothing | 213 | 2.2% |
| Other | 133 | 1.4% |
| Not in Frame | 81 | 0.8% |
| Window/Beltline | 55 | 0.6% |
| Torso | 46 | 0.5% |
| Armrest Top | 42 | 0.4% |
| Armrest Front | 8 | 0.1% |
| Armrest Side | 2 | 0.0% |

**Driver Left Action**

| | | |
|---|---|---|
| No Action | 9145 | 95.2% |
| Phone | 247 | 2.6% |
| Other | 108 | 1.1% |
| Drink | 73 | 0.8% |
| Food | 29 | 0.3% |
| Grab Handle | 1 | 0.0% |

## Covariate Effects

Chi-square analysis demonstrated that some aspects of upper-extremity posture were associated with driver and vehicle attributes. Male drivers were about 4 times as likely to rest their left elbow on the window/beltline than female drivers (12% vs. 3%). Men were also more likely than women to rest their elbows on the armrest (14% vs. 9%). Male and female drivers had their left hands on the steering wheel in approximately the same fraction of frames (61% vs. 65%).

Male drivers rested their right elbows on the top of center console armrest about twice as often as female drivers (40% vs. 20%). The ratio for forearm contact was similar (12% vs. 6%). Female drivers were more likely to be interacting with an object with the right hand (11% vs 7%) but the fraction of frames with the right

hand on the steering wheel was similar for men and women (42% vs. 48%). Female drivers were more frequently holding a phone in the right hand than male drivers (7.5% vs. 4.8%). Women were about twice as likely to wear sunglasses during the 75% of trips taken during the day (29% vs. 15%).

A potentially interesting relationship between vehicle model and console armrest use was observed. Table 11 shows tabulated observations for a binary variable indicating whether the right elbow was in contact with the top of the armrest. As noted above, women outnumber men in the sample, and women were less likely than men to use the console armrest. Only data from vehicle models for which at least 500 frames were coded and the data were collapsed across model years to obtain >500 samples per vehicle. The fraction of coded frames with male drivers varied across vehicles, from 70% in the Impala to 28% in the Civic. For women, the use of the armrest was similar across vehicles between 19% and 26% of frames. However, the usage rate for men was markedly different across vehicles, ranging from 69% in the Impala to a low of 25% in the Civic.

Table 11
Use of Console Armrest by Vehicle Model and Gender

| Elbow On Top | Aura | Civic | Fusion | G6 | Impala | Malibu |
|---|---|---|---|---|---|---|
| 0 | 711 | 2324 | 1776 | 513 | 269 | 809 |
| 1 | 360 | 656 | 675 | 182 | 331 | 495 |
| | | | | | | |
| 0 | 66% | 78% | 72% | 74% | 45% | 62% |
| 1 | 34% | 22% | 28% | 26% | 55% | 38% |
| Fraction Male | 47.2% | 28.0% | 51.0% | 23.7% | 70.0% | 36.4% |

MALE

| | Aura | Civic | Fusion | G6 | Impala | Malibu |
|---|---|---|---|---|---|---|
| 0 | 275 | 621 | 859 | 82 | 129 | 192 |
| 1 | 230 | 212 | 390 | 83 | 291 | 283 |
| | | | | | | |
| 0 | 54% | 75% | 69% | 50% | 31% | 40% |
| 1 | 46% | 25% | 31% | 50% | 69% | 60% |

FEMALE

| | Aura | Civic | Fusion | G6 | Impala | Malibu |
|---|---|---|---|---|---|---|
| 0 | 436 | 1703 | 917 | 431 | 140 | 617 |
| 1 | 130 | 444 | 285 | 99 | 40 | 212 |
| | | | | | | |
| 0 | 77% | 79% | 76% | 81% | 78% | 74% |
| 1 | 23% | 21% | 24% | 19% | 22% | 26% |

## DISCUSSION

This study is the first to look in detail at driver upper extremity postures in a large sample of naturalistic data. The data show that the inboard (console) armrest is used about twice as often as the outboard (door) armrest. Drivers had their left hands on the steering wheel more often than their right hands and interacted with other objects, including the vehicle console, more often with their right hands. The data showed some strong gender effects, with men more likely to use the armrests on both sides. This may be due in part to the armrests being fixed with respect to the vehicle while the seat moves fore-aft to accommodate drivers' body sizes. Women, who on average sit further forward, experience armrests that are on average further rearward relative to their body position.

The analysis by vehicle model showed some differences in male armrest use across vehicles, although the sample sizes are relatively small when looking at individual vehicle models. Nonetheless, these results suggest that it may be interesting to look at the extent to which armrest design affects driver's armrest usage patterns, and how the design interacts with driver body size. The current sample of vehicle models did not including any seat-mounted armrest designs, which would provide a more consistent experience independent of seat position.

Comparison data in the literature are sparse. Walton and Thomas (2005) reported drivers using two hands in 25% of on-road observations, consistent with the current study. However, that study was conducted in New Zealand using roadside observations rather than in-vehicle camera data.

This study is limited primarily by the sample size with respect to drivers and vehicle models. The data included 165 unique drivers in 100 vehicles; 50 or more frames were coded for 92 drivers. The relatively small number of drivers reduces the ability to assess the associations with drivers' attributes such as gender. The limited number of vehicles is also a substantial limitation. All were midsize sedans with front bucket seats. Vehicles from other market segments, such as pickup trucks and SUVs, may have produced different data. Future studies should examine upper-extremity activities across a wider range of vehicles. Improved camera coverage and higher video resolution would reduce the number of frames in which the activities could not be discerned.

# REFERENCES

Bezzina, D., & Sayer, J. (2015). Safety pilot model deployment: Test conductor team report. (Report No. DOT HS 812 171). Washington, DC: National Highway Traffic Safety Administration.

Walton, D., and Thomas, J.A. (2005). Naturalistic observations of driver hand positions. *Transportation Research Part F*, 8:229–238

# APPENDIX

## Tabulated Data Tallies

| Dri_Gender | Count | Fraction | | Dri_Age | Count | Fraction |
|---|---|---|---|---|---|---|
| F | 5862 | 61.0% | | 3060 | 6608 | 68.8% |
| M | 3741 | 39.0% | | LT30 | 2316 | 24.1% |
| | | | | GT60 | 679 | 7.1% |
| Dri_Hair | | | | | | |
| Dark | 5914 | 61.6% | | | | |
| Light | 3689 | 38.4% | | Dri_Weight | | |
| | | | | Lean | 6263 | 65.2% |
| Dri_TorsoLean | | | | Heavy | 2918 | 30.4% |
| No | 9215 | 96.0% | | Obese | 422 | 4.4% |
| Forward | 184 | 1.9% | | | | |
| Left | 173 | 1.8% | | Dri_Sunglasses | | |
| Right | 31 | 0.3% | | N | 7961 | 82.9% |
| | | | | Y | 1642 | 17.1% |
| Pas_Present | | | | Pas_Gender | | |
| FALSE | 7759 | 80.8% | | Pas_Gender | | |
| TRUE | 1844 | 19.2% | | Null | 7758 | 80.8% |
| | | | | F | 1082 | 11.3% |
| Pas_Hair | | | | M | 602 | 6.3% |
| Null | 7998 | 83.3% | | Unknown | 161 | 1.7% |
| Dark | 1391 | 14.5% | | | | |
| Light | 214 | 2.2% | | Pas_Age | | |
| | | | | Null | 8040 | 83.7% |
| Pas_Weight | | | | 3060 | 859 | 8.9% |
| Null | 7885 | 82.1% | | LT30 | 565 | 5.9% |
| Lean | 1226 | 12.8% | | GT60 | 139 | 1.4% |
| Heavy | 452 | 4.7% | | | | |
| Obese | 40 | 0.4% | | Pas_TorsoLean | | |
| | | | | Null | 7836 | 81.6% |
| | | | | No | 1739 | 18.1% |
| | | | | Left | 19 | 0.2% |
| | | | | Right | 9 | 0.1% |

| Make | | | Model | | |
|---|---|---|---|---|---|
| Honda | 3024 | 31.5% | Civic | 2974 | 31.0% |
| Ford | 2823 | 29.4% | Fusion | 2423 | 25.2% |
| Chevrolet | 1895 | 19.7% | Malibu | 1296 | 13.5% |
| Saturn | 1071 | 11.2% | Aura | 1071 | 11.2% |
| Pontiac | 692 | 7.2% | G6 | 692 | 7.2% |
| Chevy | 98 | 1.0% | Impala | 597 | 6.2% |
| | | | Focus | 400 | 4.2% |
| Year | | | Malibu LTZ | 100 | 1.0% |
| 2010 | 2733 | 28.5% | Accord | 50 | 0.5% |
| 2008 | 1993 | 20.8% | | | |
| 2009 | 1577 | 16.4% | | | |
| 2012 | 1083 | 11.3% | | | |
| 2007 | 870 | 9.1% | | | |
| 2006 | 744 | 7.7% | | | |
| 2011 | 503 | 5.2% | | | |
| 2013 | 100 | 1.0% | | | |

| Dri_Lt_Elbow_1 | | | Dri_Lt_Elbow_2 | | |
|---|---|---|---|---|---|
| Touching Nothing | 5695 | 59.3% | Null | 9574 | 99.7% |
| Cant Tell | 1087 | 11.3% | Torso | 20 | 0.2% |
| Armrest Top | 1053 | 11.0% | Armrest Top | 3 | 0.0% |
| Torso | 909 | 9.5% | Armrest Side | 3 | 0.0% |
| Window/Beltline | 659 | 6.9% | Window/Beltline | 2 | 0.0% |
| Lower Extremity | 92 | 1.0% | Touching Nothing | 1 | 0.0% |
| Armrest Side | 64 | 0.7% | | | |
| Not in Frame | 27 | 0.3% | | | |
| Other | 15 | 0.2% | Dri_Lt_Forearm_2 | | |
| Steering Wheel | 1 | 0.0% | Null | 9593 | 99.9% |
| Armrest Front | 1 | 0.0% | Torso | 7 | 0.1% |
| | | | Touching Nothing | 2 | 0.0% |
| Dri_Lt_Forearm_1 | | | Lower Extremity | 1 | 0.0% |
| Touching Nothing | 6407 | 66.7% | | | |
| Lower Extremity | 1276 | 13.3% | Dri_Lt_Hand_1 | | |
| Cant Tell | 1131 | 11.8% | Steering Wheel | 6126 | 63.8% |
| Torso | 302 | 3.1% | Cant Tell | 1125 | 11.7% |
| Armrest Top | 238 | 2.5% | Lower Extremity | 956 | 10.0% |
| Window/Beltline | 164 | 1.7% | Head | 435 | 4.5% |
| Not in Frame | 45 | 0.5% | Object Interact | 381 | 4.0% |
| Other | 23 | 0.2% | Touching Nothing | 213 | 2.2% |
| Steering Wheel | 10 | 0.1% | Other | 133 | 1.4% |
| Armrest Side | 7 | 0.1% | Not in Frame | 81 | 0.8% |
| | | | Window/Beltline | 55 | 0.6% |
| Dri_Lt_Hand_2 | | | Torso | 46 | 0.5% |
| Null | 9472 | 98.6% | Armrest Top | 42 | 0.4% |
| Steering Wheel | 68 | 0.7% | Armrest Front | 8 | 0.1% |
| Object Interact | 49 | 0.5% | Armrest Side | 2 | 0.0% |
| Lower Extremity | 9 | 0.1% | | | |
| Head | 2 | 0.0% | Dri_Lt_Action_1 | | |
| Touching Nothing | 1 | 0.0% | Null | 9145 | 95.2% |
| Other | 1 | 0.0% | Phone | 247 | 2.6% |
| Armrest Side | 1 | 0.0% | Other | 108 | 1.1% |
| | | | Drink | 73 | 0.8% |
| Dri_Lt_Action_2 | | | Food | 29 | 0.3% |
| Null | 9603 | 100.0% | Grab Handle | 1 | 0.0% |

**Dri_Rt_Elbow_1**

| | | |
|---|---|---|
| Touching Nothing | 5297 | 55.2% |
| Armrest Top | 2705 | 28.2% |
| Torso | 773 | 8.0% |
| Cant Tell | 589 | 6.1% |
| Armrest Front | 125 | 1.3% |
| Armrest Side | 42 | 0.4% |
| Other | 30 | 0.3% |
| Lower Extremity | 25 | 0.3% |
| Not in Frame | 17 | 0.2% |

**Dri_Rt_Elbow_2**

| | | |
|---|---|---|
| Null | 9584 | 99.8% |
| Torso | 8 | 0.1% |
| Touching Nothing | 5 | 0.1% |
| Armrest Front | 4 | 0.0% |
| Armrest Top | 2 | 0.0% |

**Dri_Rt_Hand_1**

| | | |
|---|---|---|
| Steering Wheel | 4392 | 45.7% |
| Lower Extremity | 1285 | 13.4% |
| Object Interact | 943 | 9.8% |
| Not in Frame | 897 | 9.3% |
| Cant Tell | 822 | 8.6% |
| Touching Nothing | 352 | 3.7% |
| Head | 268 | 2.8% |
| Other | 180 | 1.9% |
| Shifter | 162 | 1.7% |
| Center Stack | 124 | 1.3% |
| Torso | 106 | 1.1% |
| Armrest Front | 41 | 0.4% |
| Armrest Side | 14 | 0.1% |
| Armrest Top | 11 | 0.1% |
| Window/Beltline | 6 | 0.1% |

**Dri_Rt_Action_2**

| | | |
|---|---|---|
| Null | 9596 | 99.9% |
| Other | 5 | 0.1% |
| Phone | 1 | 0.0% |
| Drink | 1 | 0.0% |

**Dri_Rt_Forearm_1**

| | | |
|---|---|---|
| Touching Nothing | 6923 | 72.1% |
| Armrest Top | 824 | 8.6% |
| Cant Tell | 763 | 7.9% |
| Lower Extremity | 559 | 5.8% |
| Torso | 392 | 4.1% |
| Not in Frame | 52 | 0.5% |
| Other | 41 | 0.4% |
| Armrest Side | 31 | 0.3% |
| Armrest Front | 16 | 0.2% |
| Steering Wheel | 2 | 0.0% |

**Dri_Rt_Forearm_2**

| | | |
|---|---|---|
| Null | 9541 | 99.4% |
| Torso | 23 | 0.2% |
| Armrest Top | 21 | 0.2% |
| Lower Extremity | 7 | 0.1% |
| Armrest Side | 6 | 0.1% |
| Touching Nothing | 3 | 0.0% |
| Cant Tell | 1 | 0.0% |
| Armrest Front | 1 | 0.0% |

**Dri_Rt_Hand_2**

| | | |
|---|---|---|
| Null | 9535 | 99.3% |
| Object Interact | 31 | 0.3% |
| Steering Wheel | 28 | 0.3% |
| Lower Extremity | 4 | 0.0% |
| Head | 2 | 0.0% |
| Other | 1 | 0.0% |
| Not in Frame | 1 | 0.0% |
| Cant Tell | 1 | 0.0% |

**Dri_Rt_Action_1**

| | | |
|---|---|---|
| Null | 8601 | 89.6% |
| Phone | 628 | 6.5% |
| Drink | 126 | 1.3% |
| Other | 116 | 1.2% |
| Food | 112 | 1.2% |
| Shifter | 16 | 0.2% |
| Center Stack | 4 | 0.0% |

**Pas_LtForearm_1**

| | | |
|---|---|---|
| Null | 7878 | 82.0% |
| Armrest Top | 865 | 9.0% |
| Touching Nothing | 470 | 4.9% |
| Torso | 202 | 2.1% |
| Armrest Side | 89 | 0.9% |
| Cant Tell | 69 | 0.7% |
| Armrest Front | 11 | 0.1% |
| Other | 7 | 0.1% |
| Not in Frame | 7 | 0.1% |
| Lower Extremity | 5 | 0.1% |

**Pas_LtForearm_2**

| | | |
|---|---|---|
| Null | 9587 | 99.8% |
| Torso | 12 | 0.1% |
| Armrest Side | 2 | 0.0% |
| Touching Nothing | 1 | 0.0% |
| Armrest Top | 1 | 0.0% |

**Pas_LtHand_1**

| | | |
|---|---|---|
| Null | 7878 | 82.0% |
| Not in Frame | 599 | 6.2% |
| Lower Extremity | 507 | 5.3% |
| Touching Nothing | 199 | 2.1% |
| Cant Tell | 169 | 1.8% |
| Object Interact | 131 | 1.4% |
| Other | 40 | 0.4% |
| Head | 28 | 0.3% |
| Torso | 19 | 0.2% |
| Armrest Front | 11 | 0.1% |
| Armrest Top | 10 | 0.1% |
| Armrest Side | 9 | 0.1% |
| Center Stack | 3 | 0.0% |

**Pas_LtElbow_1**

| | | |
|---|---|---|
| Null | 7878 | 82.0% |
| Touching Nothing | 797 | 8.3% |
| Armrest Top | 355 | 3.7% |
| Lower Extremity | 229 | 2.4% |
| Torso | 151 | 1.6% |
| Cant Tell | 82 | 0.9% |
| Not in Frame | 52 | 0.5% |
| Other | 35 | 0.4% |
| Armrest Side | 14 | 0.1% |
| Armrest Front | 10 | 0.1% |

**Pas_LtElbow_2**

| | | |
|---|---|---|
| Null | 9577 | 99.7% |
| Torso | 9 | 0.1% |
| Lower Extremity | 6 | 0.1% |
| Armrest Top | 5 | 0.1% |
| Armrest Side | 3 | 0.0% |
| Touching Nothing | 2 | 0.0% |
| Armrest Front | 1 | 0.0% |

**Pas_LtHand_2**

| | | |
|---|---|---|
| Null | 9593 | 99.9% |
| Object Interact | 7 | 0.1% |
| Touching Nothing | 2 | 0.0% |
| Lower Extremity | 1 | 0.0% |

**Pas_LtAction_1**

| | | |
|---|---|---|
| Null | 9469 | 98.6% |
| Phone | 69 | 0.7% |
| Other | 40 | 0.4% |
| Drink | 16 | 0.2% |
| Food | 8 | 0.1% |
| Shifter | 1 | 0.0% |

# NOTES TALLIES

| N_Driver_Hand_Right_ArmLt | N | Y |
|---|---|---|
| **Count** | 9839 | 17 |
| **Fraction** | 99.8% | 0.2% |
| N_Driver_Hand_Right_Cigarette | N | Y |
| | 9849 | 7 |
| | 99.9% | 0.1% |
| N_Driver_Hand_Right_Consol | N | Y |
| | 9852 | 4 |
| | 100.0% | 0.0% |
| N_Driver_Hand_Right_FloorDr | N | Y |
| | 9851 | 5 |
| | 99.9% | 0.1% |
| N_Driver_Hand_Right_FloorRr | N | Y |
| | 9854 | 2 |
| | 100.0% | 0.0% |
| N_Driver_Hand_Right_HandLt | N | Y |
| | 9806 | 50 |
| | 99.5% | 0.5% |
| N_Driver_Hand_Right_Lotion | N | Y |
| | 9855 | 1 |
| | 100.0% | 0.0% |
| N_Driver_Hand_Right_Money | N | Y |
| | 9855 | 1 |
| | 100.0% | 0.0% |
| N_Driver_Hand_Right_Paper | N | Y |
| | 9855 | 1 |
| | 100.0% | 0.0% |
| N_Driver_Hand_Right_Pen | N | Y |
| | 9852 | 4 |
| | 100.0% | 0.0% |
| N_Driver_Hand_Right_Ponytail | N | Y |
| | 9855 | 1 |
| | 100.0% | 0.0% |
| N_Driver_Hand_Right_Purse | N | Y |
| | 9847 | 9 |
| | 99.9% | 0.1% |
| N_Driver_Hand_Right_Sunvisor | N | Y |
| | 9854 | 2 |
| | 100.0% | 0.0% |

| | N | Y | |
|---|---|---|---|
| N_Driver_Hand_Right_PassengerSeat | N | Y | |
| | 9820 | | 36 |
| | 99.6% | | 0.4% |
| N_Driver_Hand_Right_SeatFt | N | Y | |
| | 9838 | | 18 |
| | 99.8% | | 0.2% |
| N_Driver_Hand_Right_SeatRr | N | Y | |
| | 9855 | | 1 |
| | 100.0% | | 0.0% |
| N_Driver_Hand_Right_PassengerFt | N | Y | |
| | 9817 | | 39 |
| | 99.6% | | 0.4% |
| N_Driver_Hand_Right_PassengerRr | N | Y | |
| | 9854 | | 2 |
| | 100.0% | | 0.0% |
| N_Driver_Hand_Left_ArmRt | N | Y | |
| | 9836 | | 20 |
| | 99.8% | | 0.2% |
| N_Driver_Hand_Left_Cigarette | N | Y | |
| | 9810 | | 46 |
| | 99.5% | | 0.5% |
| N_Driver_Hand_Left_Door | N | Y | |
| | 9855 | | 1 |
| | 100.0% | | 0.0% |
| N_Driver_Hand_Left_FloorDr | N | Y | |
| | 9854 | | 2 |
| | 100.0% | | 0.0% |
| N_Driver_Hand_Left_HandRt | N | Y | |
| | 9855 | | 1 |
| | 100.0% | | 0.0% |
| N_Driver_Hand_Left_Lotion | N | Y | |
| | 9855 | | 1 |
| | 100.0% | | 0.0% |
| N_Driver_Hand_Left_Paper | N | Y | |
| | 9849 | | 7 |
| | 99.9% | | 0.1% |
| N_Driver_Hand_Left_PassengerFt | N | Y | |
| | 9853 | | 3 |
| | 100.0% | | 0.0% |
| N_Driver_Hand_Left_Ponytail | N | Y | |
| | 9855 | | 1 |
| | 100.0% | | 0.0% |

| | N | Y |
|---|---|---|
| N_Driver_Hand_Left_Sunglasses | N | Y |
| | 9855 | 1 |
| | 100.0% | 0.0% |
| N_Driver_Hand_Left_Visor | N | Y |
| | 9855 | 1 |
| | 100.0% | 0.0% |
| N_Driver_Arm_Crossed_Both | N | Y |
| | 9855 | 1 |
| | 100.0% | 0.0% |
| N_Driver_Arm_Left_Outside | N | Y |
| | 9811 | 45 |
| | 99.5% | 0.5% |
| N_Driver_Arms_Both_Crossed | N | Y |
| | 9855 | 1 |
| | 100.0% | 0.0% |
| N_Driver_Shoulder_Holding_Phone | N | Y |
| | 9855 | 1 |
| | 100.0% | 0.0% |
| N_Driver_Knee_Left_Steering | N | Y |
| | 9853 | 3 |
| | 100.0% | 0.0% |
| N_Driver_Knee_Right_Steering | N | Y |
| | 9854 | 2 |
| | 100.0% | 0.0% |
| N_Passenger_Elbow_Driver_Seat | N | Y |
| | 9855 | 1 |
| | 100.0% | 0.0% |
| N_Passenger_Forearm_Left_ConsolOpening | N | Y |
| | 9855 | 1 |
| | 100.0% | 0.0% |
| N_Passenger_Hand_Left_Bag | N | Y |
| | 9847 | 9 |
| | 99.9% | 0.1% |
| N_Passenger_Hand_Left_Belt | N | Y |
| | 9855 | 1 |
| | 100.0% | 0.0% |
| N_Passenger_Hand_Left_Computer | N | Y |
| | 9855 | 1 |
| | 100.0% | 0.0% |
| N_Passenger_Hand_Left_Consol | N | Y |
| | 9854 | 2 |
| | 100.0% | 0.0% |

| | N | Y |
|---|---|---|
| N_Passenger_Hand_Left_Console Opening | | |
| | 9855 | 1 |
| | 100.0% | 0.0% |
| N_Passenger_Hand_Left_Driver | | |
| | 9845 | 11 |
| | 99.9% | 0.1% |
| N_Passenger_Hand_Left_SeatDr | | |
| | 9853 | 3 |
| | 100.0% | 0.0% |
| N_Passenger_Hand_Left_SeatRr | | |
| | 9855 | 1 |
| | 100.0% | 0.0% |
| N_Armrest_Top_Center_Object | | |
| | 9847 | 9 |
| | 99.9% | 0.1% |
| N_Consol_Top_Center_Cup | | |
| | 9852 | 4 |
| | 100.0% | 0.0% |
| N_Consol_Top_Center_Object | | |
| | 9821 | 35 |
| | 99.6% | 0.4% |
| N_Consol_Top_Center_Pet | | |
| | 9850 | 6 |
| | 99.9% | 0.1% |
| N_Consol_Top_Center_Phone | | |
| | 9838 | 18 |
| | 99.8% | 0.2% |
| N_Consol_Top_Center_Purse | | |
| | 9788 | 68 |
| | 99.3% | 0.7% |
| N_Cupholder_Inside_Center_Cup | | |
| | 8685 | 1171 |
| | 88.1% | 11.9% |
| N_Cupholder_Inside_Center_Cups | | |
| | 9846 | 10 |
| | 99.9% | 0.1% |
| N_Cupholder_Inside_Center_Food | | |
| | 9855 | 1 |
| | 100.0% | 0.0% |
| N_Cupholder_Inside_Center_Object | | |
| | 9628 | 228 |
| | 97.7% | 2.3% |

| | N | Y | |
|---|---|---|---|
| N_Cupholder_Inside_Center_Phone | N | Y | |
| | | 9798 | 58 |
| | | 99.4% | 0.6% |
| N_Cupholder_Inside_Center_Purse | N | Y | |
| | | 9851 | 5 |
| | | 99.9% | 0.1% |
| N_Cupholder_Inside_Center_Sunglasses | N | Y | |
| | | 9846 | 10 |
| | | 99.9% | 0.1% |
| N_Driver_Eyes_Down_Consol | N | Y | |
| | | 9855 | 1 |
| | | 100.0% | 0.0% |
| N_Driver_Consol_Remove_Sunglasses | N | Y | |
| | | 9855 | 1 |
| | | 100.0% | 0.0% |
| N_Driver_Head_Remove_Sunglasses | N | Y | |
| | | 9854 | 2 |
| | | 100.0% | 0.0% |
| N_Driver_Head_Top_Sunglasses | N | Y | |
| | | 9846 | 10 |
| | | 99.9% | 0.1% |
| N_Driver_Mouth_Center_Sunglasses | N | Y | |
| | | 9855 | 1 |
| | | 100.0% | 0.0% |
| N_Driver_Lap_Center_Object | N | Y | |
| | | 9843 | 13 |
| | | 99.9% | 0.1% |
| N_Driver_Lap_Center_Pet | N | Y | |
| | | 9855 | 1 |
| | | 100.0% | 0.0% |
| N_Driver_Lap_Center_Phone | N | Y | |
| | | 9687 | 169 |
| | | 98.3% | 1.7% |
| N_Driver_Lap_Center_Purse | N | Y | |
| | | 9782 | 74 |
| | | 99.2% | 0.8% |
| N_Driver_Lap_Right_Purse | N | Y | |
| | | 9853 | 3 |
| | | 100.0% | 0.0% |
| N_Passenger_Lap_Center_Bag | N | Y | |
| | | 9847 | 9 |
| | | 99.9% | 0.1% |

| | N | Y |
|---|---|---|
| N_Passenger_Lap_Center_Pet | | |
| | 9851 | 5 |
| | 99.9% | 0.1% |
| N_Passenger_Lap_Center_Purse | N | Y |
| | 9847 | 9 |
| | 99.9% | 0.1% |
| N_Passenger_Seat_Center_Pet | N | Y |
| | 9839 | 17 |
| | 99.8% | 0.2% |
| N_Driver_Belt_Don_Driving | N | Y |
| | 9855 | 1 |
| | 100.0% | 0.0% |
| N_Driver_Belt_Don_Stopped | N | Y |
| | 9854 | 2 |
| | 100.0% | 0.0% |
| N_Driver_Belt_Not_Used | N | Y |
| | 9854 | 2 |
| | 100.0% | 0.0% |
| N_Driver_Belt_On_Adjusted | N | Y |
| | 9853 | 3 |
| | 100.0% | 0.0% |
| N_Driver_Body_All_Outside | N | Y |
| | 9791 | 65 |
| | 99.3% | 0.7% |
| N_Driver_Car_Not_Moving | N | Y |
| | 8701 | 1155 |
| | 88.3% | 11.7% |
| N_Driver_Steering_No_Contact | N | Y |
| | 9801 | 55 |
| | 99.4% | 0.6% |