Naturalistic Passenger Behavior: Postures and Activities

Technical Report

UMTRI-2020-2

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16. Abstract

Video cameras were installed in the passenger cabins of 75 vehicles to monitor the postures and activities of front-seat passengers. Video frames from a total of 2733 trips were coded for 306 unique front-seat passengers. During these trips, a total of 13638 frames were coded; each frame represents about four minutes of travel time. The median trip duration was 12.2 minutes and 5% of trips were longer than 54 minutes. The distribution of trip durations was similar to that for the general population of US travelers. The front seat passenger was female in 72% of frames and most often judged to be between 17 and 30 years of age. The seat belt was worn 97% of the time, with visibly poor fit (belt on belly or lateral to the clavicle) in about 30% of frames. The most common passenger interaction was talking with the driver, while interactions with hand-held devices (typically phones) occurred in 26% of frames. Phone use was associated with a downward pitched head. The head was rotated left or right in 33% of frames, and the torso was rotated left or right about 10% of the time and pitched forward in almost 10% of frames. The front of the thighs was lifted off the seat due to the feet being shifted rearward about 40% of the time and the legs were crossed in about 5% of frames.

Resting behavior was observed more frequently in longer-duration trips and when traveling at higher speeds, while phone use increased and talking with vehicle occupants decreased with increased sitting time. No seat position or seat back angle change was noted in 40 (53%) of vehicles. In the remaining 35 vehicles, seat back angle and seat position were observed to change only 16 and 61 times, respectively, so that the distributions of seat position and seat back angle on arrival were essentially unchanged during travel. The seat was positioned full-rear on the seat track about 23% of the time and rearward of the mid-track position in 81% of frames. The mean seat back angle was 25.4 degrees (standard deviation 6.4 degrees); seat back angle was greater than 30 degrees in 15% of frames and greater than 35 degrees in less than 1% of frames. Seat back angles greater than 30 degrees were more common on longer trips and associated with a greater likelihood of the head touching the seat, lower phone use, and slightly greater frequency of resting behavior. When a second-row passenger was present behind the front-seat passenger, the seat was 5 mm further forward and 1.4 degrees more upright, on average.

This study is the first to report distributions of seat positions and seat back angles for front-seat passengers and the first to provide details of passenger posture and activities from a large sample of individuals. The findings have implications for the design of current vehicles and also provide insight into the likely postures and activities of the occupants of future driverless vehicles.

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ABSTRACT

Video cameras were installed in the passenger cabins of 75 vehicles to monitor the postures and activities of front-seat passengers. Video frames from a total of 2733 trips were coded for 306 unique front-seat passengers. During these trips, a total of 13638 frames were coded; each frame represents about four minutes of travel time. The median trip duration was 12.2 minutes and 5% of trips were longer than 54 minutes. The distribution of trip durations was similar to that for the general population of US travelers. The front seat passenger was female in 72% of frames and most often judged to be between 17 and 30 years of age. The seat belt was worn 97% of the time, with visibly poor fit (belt on belly or lateral to the clavicle) in about 30% of frames. The most common passenger interaction was talking with the driver, while interactions with hand-held devices (typically phones) occurred in 26% of frames. Phone use was associated with a downward pitched head. The head was rotated left or right in 33% of frames, and the torso was rotated left or right about 10% of the time and pitched forward in almost 10% of frames. The front of the thighs was lifted off the seat due to the feet being shifted rearward about 40% of the time and the legs were crossed in about 5% of frames.

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This study is the first to report distributions of seat positions and seat back angles for front-seat passengers and the first to provide details of passenger posture and activities from a large sample of individuals. The findings have implications for the design of current vehicles and also provide insight into the likely postures and activities of the occupants of future driverless vehicles.

INTRODUCTION

The prospect of automated road vehicles has resulted in the development of many new concepts for vehicle interiors. When drivers become passengers in an automated vehicle, they will have the potential for a greatly expanded behavioral repertoire. Many new vehicle concepts include provisions for highly reclined postures to facilitate resting or sleeping, as well as support for a wide range of entertainment activities. This increased interest in passenger behaviors extends to the more near-term prospect of part-time drivers in vehicles that are capable of fully automated operation in certain domains, such as limited-access highways. What activities will these part-time drivers engage in, and how should the vehicle interior be designed to ensure that their comfort and safety are preserved or enhanced?

The current project is focused on quantifying the behaviors of front-seat passengers in current, human-operated vehicles, as the best-available predictor for the activities of future road-vehicle passengers. No previous studies of front-seat passenger postures and activities in road vehicles have been identified in the literature. Moreover, the distribution of front passenger seat positions and seat back angles in use has not previously been reported.

The methodology is adapted from many previous naturalistic studies of driver behavior. Drivers who reported regularly traveling with passengers were recruited from the local community. Their vehicles were instrumented with cameras and equipment to record location and vehicle kinematics. After approximately two weeks of using their vehicles as they usually would, the data were downloaded for analysis. Frames from videos of trips with passengers were manually coded using a custom, structured coding tool to identify postures and behaviors. A novel video-based system was used to estimate front-passenger seat position and seat back angle.

METHODS

Vehicles and Drivers

Seventy-five drivers of 2008 and later vehicles were recruited to participate in the study. All were at least 18 years of age with an unrestricted driver's license. The drivers were required to take at least 1 trip per day with a front-seat passenger and drive with passengers at least five days per week. In total, the vehicle pool included 31 sedans, 6 minivans, 1 full-size van, and 37 SUVs. Appendix A shows the list of vehicles**.**

Vehicle Instrumentation

Cameras

A camera with IR illuminators (KPC-EX20BH) was mounted to the windshield near the interior rear-view mirror with 3D printed adapter parts (Figure 1). The camera was connected to a data acquisition system in the trunk (Figure 2). The wide-angle lens was capable of visualizing the entire front row as shown in Figures 3. The infrared-sensitive camera with illuminators was able to produce useful images of the front row, including the retroreflective seat targets (see below) even in darkness (Figure 4).

Figure 1. Cabin view camera with IR illuminators mounted in vehicle

Figure 2. Data acquisition system (DAS) in the trunk of a vehicles

Figure 3. Examples of camera field of view in vehicles

Figure 4. Camera views in darkness.

Data downloaded from the vehicles were entered into a relational database that allows querying of linked records from all data channels along with the video. The primary unit of analysis is the “trip”, defined from key-on to key-off. Because the data acquisition system takes approximately 30 seconds to boot up, the first minute of each trip is not consistently recorded.

In-Vehicle Seat Position Documentation and Calibration Procedure

Arrival Position – When the vehicle arrived for camera installation, the initial position and angles of the of the seat were measured and markers applied so the seat could be returned to the same position after calibration. The first step was placing gaffer tape along the rocker panel trim and on the seat pan frame, then marking the fore-aft position of the seat and the height of the seat to the floor at the arrival position (Figure 5). The angle of the seat pan and seat back were also measured using a tool that approximates the angles measured by the SAE J826 machine (Huang et al. 2006). The dimensions of the tool were constructed so that on average the angles of the cushion and back components approximate SAE A27 (cushion angle) and A40 (manikin torso angle), respectively.

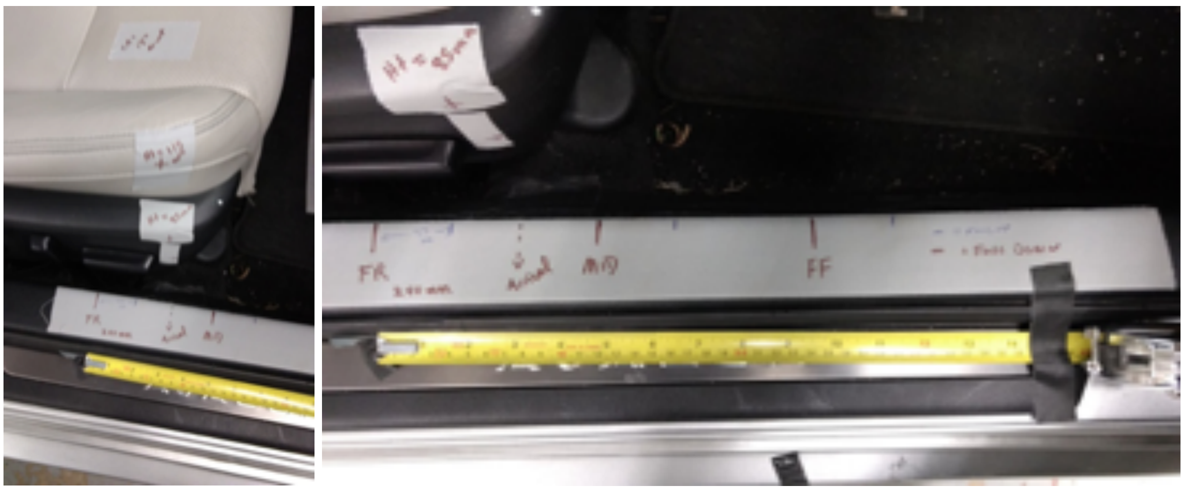


Figure 5. Tape on vehicle seat and frame to mark arrival position fore-aft and height and then move the seat through its range of track travel from full rear (FR in photo) and full forward (FF in photo).

Figure 6. Investigator measuring seat back angle (left) and seat pan angle (right) using tool (Huang and Reed 2006; Klinich et al. 2013) and inclinometer.

Seat Reference Markers – After marking the arrival position, the investigators super-glued fabric-backed retroreflective 8 mm diameter circles to matte black gaffer tape. The gaffer tape was then attached to a bigger piece of "no-residue duct tape" (3M 2425-HD). This layered approach was used due to residue left behind by gaffer tape on the leather and cloth seats of participants' vehicles during the summer heat and the no-residue tape being too reflective. Figure 7 shows these markers on a test vehicle seat.

A total of six retroreflective markers were placed on the seat as shown in Figure 8. Two markers were placed on the inboard margin of the head restraint, two markers on the inboard margin of the seat back with one near the top and one lower on the bolster, two on the seat cushion with one near the bight on the midline of the seat and one on the inboard margin on the bolster. Two markers were placed on the B-pillar as a static reference, and one marker was laced on the D-ring adjustment lever, or on another part of the D-ring trim that moved with the D-ring.

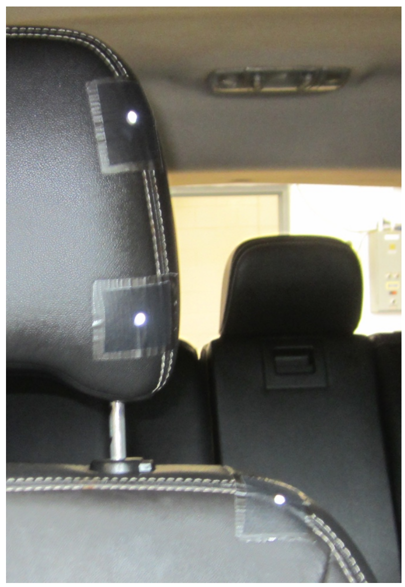


Figure 7. Retroreflective markers on a vehicle seat

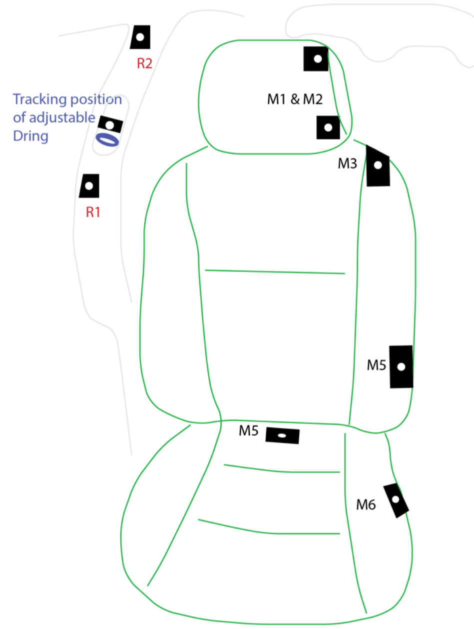


Figure 8. Retroreflective marker positions on vehicle seat, B-pillar and D-ring

Recording Calibration Frames – Video of the empty seat was recorded with the seat in a wide range of positions and seat back angles to provide data to establish the relationships between these variables and the optical target locations. The seat was placed in the full-down position (if the seat had up-down adjustment). The seat back angle was recorded from fully reclined to fully upright locked positions and then 5 angles distributed approximately evenly between these positions. The seat was then moved from full-rearward to full-full forward in 50 mm increments. This process was repeated at the full-up seat height for seats with vertical adjustment.

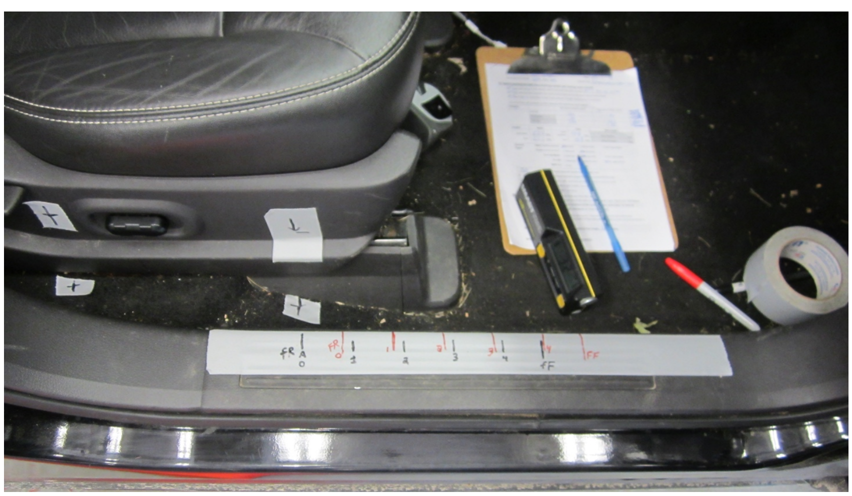


Figure 9. Tape on vehicle seat and frame to mark arrival position in vehicle with adjustable seat height

R + Finger count	Back angle	**Back Angle**	Pause along track at these locations and use fingers to indicate stop to the camera**							
		With Tool	0 Rear	1 (50)	2 (100)	3 (150)	4 (200)	5 (250)	6 (300)	FF
R0*	Fully Reclined									
R1	1/3 to R3									
R2	2/3 to R3									
R3	Halfway									
R4	1/3 to R6									
R5	2/3 to R6									
R6	Fully Upright									
Arrival	**Arrival**		**Arrival**							

Figure 10. Table from calibration form showing the combination of track positions and seat back angles set in the vehicle, recorded with the video camera, and digitized on the video frames.

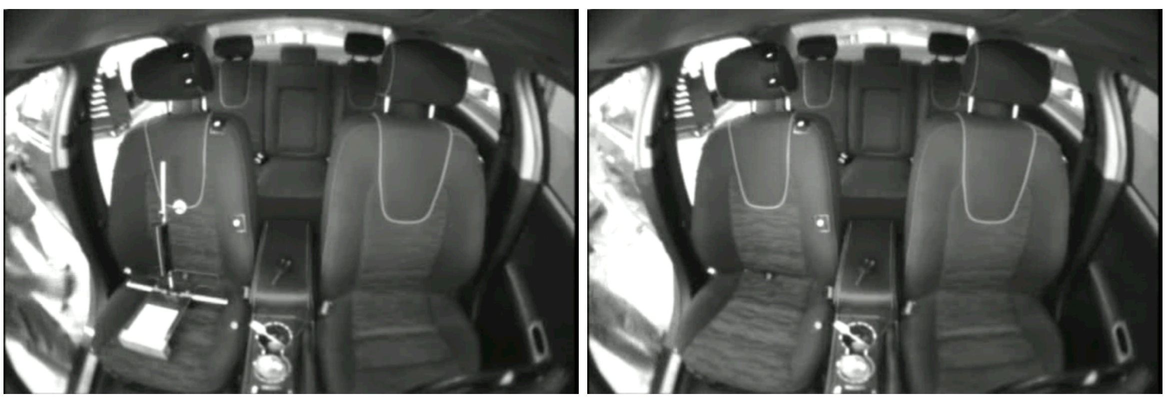


Figure 11. Vehicle seat set to a particular track position and recline angle (left) and then marker locations in a frame with the seat set to the known location digitized (right)

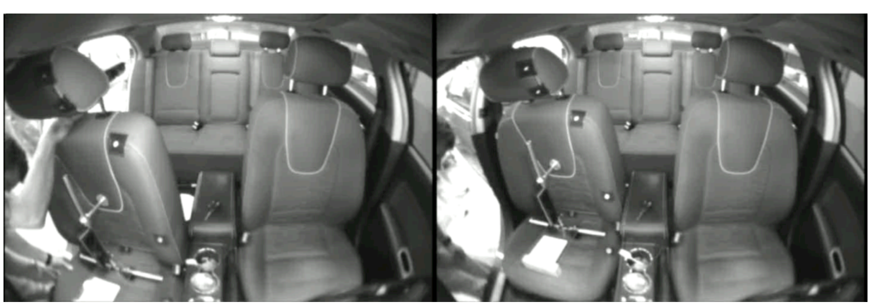


Figure 12. Investigator using the angle tool to set the seat back angle

Digitizing Calibration Frames

An investigator viewed the seat calibration videos and selected a frame for each of the back angle and seat track location combinations. The investigator then extracted the frames and digitized the center of each marker on the vehicle frame, seat back, and seat pan. The values represented the pixel locations in the 780 x 460 video frame. The average number of calibration frames for a seat was 42 for seats without adjustable seat height and 84 for seats with adjustable seat height. Figure 13 shows a screen capture of a calibration frame as it was being digitized.

Figure 13. Screen capture of a seat calibration frame being digitized.

Quantifying Seat Movements During Travel

The videos for all of the vehicle trips (with and without passengers) were viewed from beginning to end by investigators who logged seat occupancy windows, seat belt fit of the passengers, and any movement of the front passenger seat. Additionally, a video frame from the start, middle and end of each trip was extracted. Transparencies of the start and middle frames were overlaid on the end frame. Investigators then viewed all of these composite images, searching for changes in marker locations or a shift in the leading edge of the seat cushion if the markers on the seat cushion were not visible. Figures 14 and 15 show example of the extracted frames from trips along with examples of seat movements detected.

Changes in seat position between trips were also noted. For all trips with seat position changes, an investigator viewed the video again and digitized the locations of all the visible markers in a frame immediately after the movement and in a frame before the seat movement. The digitizing method was identical to that used during seat calibration. If there was an occupant in the seat and markers were occluded, the investigator also located and digitized frames before and after the movement in which the seat was unoccupied and more markers were visible. If the seat was moved more than once during a trip, the investigator repeated this process for each movement.

Two vehicles were excluded from the analysis of seat position and seat back angle due to inaccurate data. The calibration data was insufficient for one; in the other, the seat was removed by the participant and ultimately replaced with a different seat during the data collection period.

Figure 14. Video frames from start, middle and end (top row, left to right) of a trip with seat movement and transparency of the start frame overlaid onto end frame and middle frame onto end frame (middle, left to right). The bottom row shows overlaid images colorized and with the differences highlighted.

Figure 15. Examples of seat movements detected by overlaid images.

Calculating Seat Position and Seat Back Angle

A regression analysis was used to calculate the relationships between the seat landmark locations in the video frame (pixel coordinates) and seat position (forward of full-rear, mm) and seat back angle (degrees with respect to vertical). After experimenting with several different combinations of landmark locations, the final version used a linear function of the XY locations of the two headrest markers and the upper seat back marker.

For seat position, the adjusted R^2 values for the calibration fits averaged 0.97 (range 0.87 to 0.99). The mean root-mean square error (RMSE) was 11 mm (ranged 3 to 21 mm). For seat back angle, the adjusted R^2 values averaged 0.99 (range 0.84 to 0.99), with a mean RMSE value of from 1.0 degrees (range 0.3 to 3.0 degrees).

The calibration functions were applied to the digitized coordinates from all of the frames that were selected to quantify changes in seat position and seat back angle. Each of these frames was identified by vehicle, trip number, and time stamp within the trip. These values were then used to establish seat positions and seat back angles for all of the coded video frames. For vehicles in which no seat movements were noted, the arrival settings were used for all frames. For vehicles with seat movements, the current state of the seat at the time of the coded frame was used. Due to the residual variance in the calibrations, the calculated seat position was occasionally 10-20 mm rearward of the rear of the seat track (negative calculated seat position). In these cases (approximately 5% of frames), the seat position was set to zero. For most of these frames, the arrival seat position was zero and the visually observed change was a change in seat back angle.

Passenger Classification and Belt Fit Coding

The video from each trip was analyzed to determine passenger presence. Note that passengers often entered and exited the vehicles at various times during a trip, so the number of passenger trips differs from the number of vehicle trips. For purposes of this analysis, a passenger trip is the journey of a unique passenger from the time of entry to the vehicle (or the first available video for that trip) until the time of exiting from the vehicle (or the latest available video, if the system recording stopped before the passenger exited the vehicle).

For trips less than 5 minutes in duration, a single frame near the middle of the trip was coded (Table 1). For trips between 5 and 15 minutes, frames were selected from the first minute, last minute, and approximately at the midpoint of the trip. For trips longer than 15 minutes, additional frames were added so that the maximum duration between frames was 5 minutes.

Table 1
Frame Sampling

Trip Duration	Frames	Total Frames
<5 mins	1 near middle of trip	1
5 – 15 mins	First minute, last minute, midpoint	3
15	First minute, last minute, midpoint + five-minute increments	5+

Passenger Classification

Investigators viewed all the trips identified as having passengers. Each person who rode as a passenger in a vehicle was given an identification number and a screen shot of them was taken so that they could be tracked through all of their rides. The start and stop times of their rides for each passenger within each trip and their seating positions within the vehicle were recorded. The presence of rear seat passengers and their position was noted. The apparent gender, age, and approximate body dimensions of each passenger were estimated from the videos. Due to the imprecision of this method, age and body dimensions were coded as ordinal categories. Age was coded using the six categories listed in Table 2 and weight estimates used the three categories in Table 3. Sitting shoulder height was estimated by comparison of the videos to images of passengers with known sitting shoulder height seated in vehicles during a different study. These heights were evaluated relative to the top of the vehicle seat back and placed into one of 6 height categories (3 male and 3 female). The reference images and category descriptions are in Figure 18.

Table 2
Passenger Age Bins

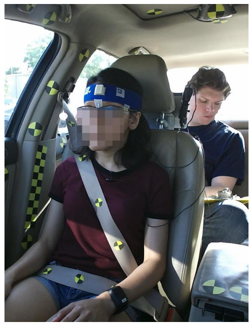
Group (years)	**Description**
<2	baby or toddler (should be in CRS with harness)
3-10	school aged (may be in booster seats)
11-16	tweens and young teens
17 to 30	younger adults
30-60	middle aged adults
>60	adults who appear more senior

Figure 16. Screen capture of example passengers from toddler to senior (top- left to bottom-right)

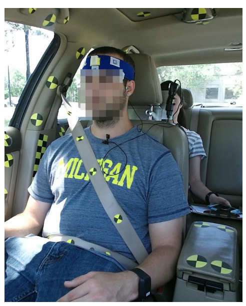
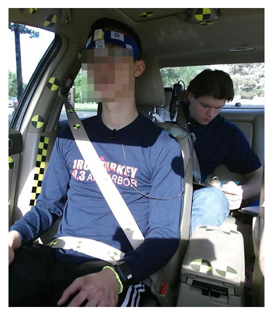
Table 3
Passenger Weight Bins

Weight Group	Description
Lean	thin to proportional weight (~BMI up to 25)
Heavy	bigger build, not lean but not highly obese
Obese	obviously obese, panniculus present (~BMI >35)

Figure 17. Examples of people coded as lean, heavy and obese (left to right)

Coding group:	Female-Short	Female-Medium	Female-Tall
Sitting height:	507 mm	Shoulder height: 557 mm	Shoulder height: 607 mm
Shoulder rel. top of seat:	*Very below*	*Well below*	*Just below*
	(4-6 inches)	*(2-3 inches)*	*(an inch or so)*

Coding group:	Male-Short	Male-Medium	Male-Tall
Sitting height:	Shoulder height: 553 mm	Shoulder height: 605 mm	Shoulder height: 638 mm
Shoulder rel. top of seat:	*Well below*	*Just below*	At or above
	(2-3 inches)	(an inch or so)	(0 or above)

Figure 18. Front seat passenger sitting height category criteria (images from another study). Note that female-medium is approximately the same as male-short and female-tall is approximately the same as male-medium.

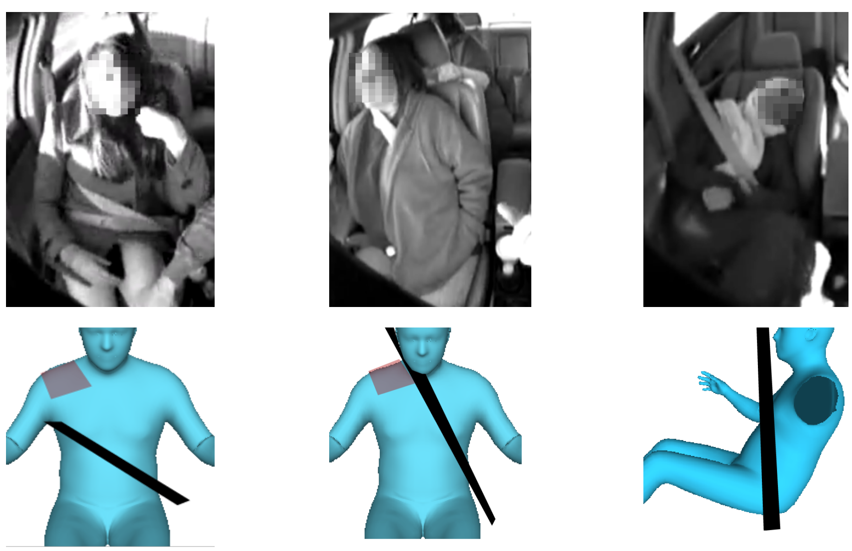
Belt Fit

Shoulder and lap belt fit were coded using the criteria shown in Figures 19 and 20. The investigators coded the belt fit for each passenger for each trip.

None
Not wearing any belt or shoulder belt behind back

Middle of Clavicle
(good fit)

Lateral of Clavicle
(poor fit)

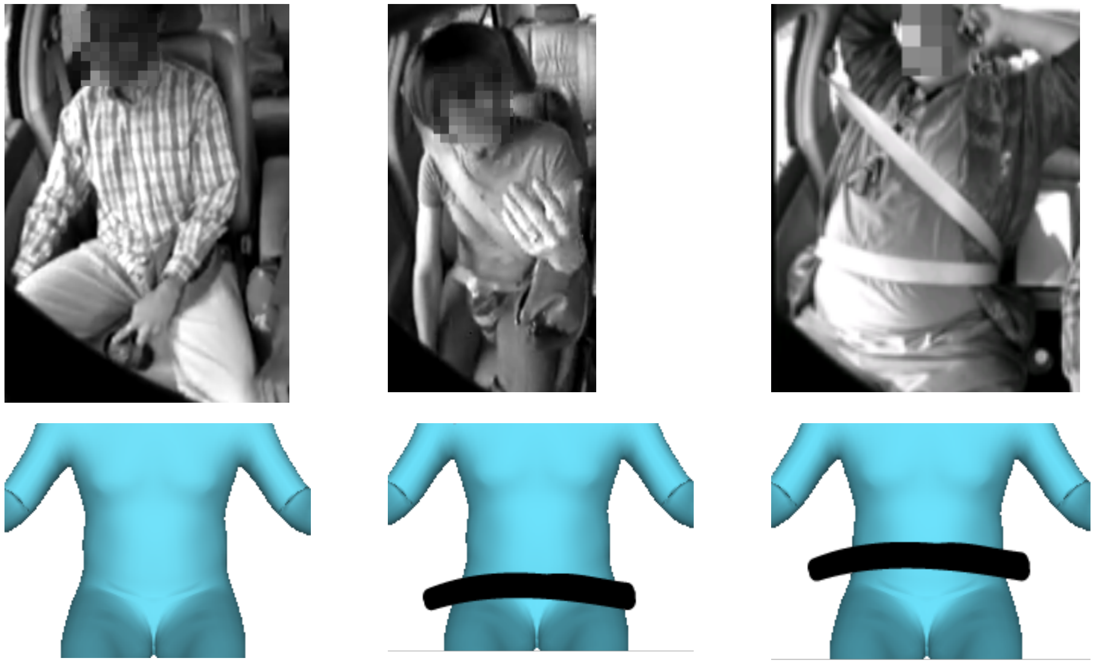


Under Arm
under outboard arm

On Neck
laying across neck

Forward of Body
belt forward of clavicle (not touching)

Figure 19. Shoulder belt fit coding categories



None - Not wearing any lap belt

On Lap - Good fit, low on abdomen, touching thighs

On Belly - Lap belt is high on abdomen, not touching thighs

Figure 20. Lap belt fit coding categories

Video Coding Tool

Figure 21 shows the main input dialog of the software coding tool developed for this study. All investigators were given written instructions similar to the descriptions in this report and an in-person training session that included practice coding frames with the trainer and independently.

The coding tool was divided into two major sections. The top section shown in Figure 21 codes the front seat passenger's physical characteristics and clothing level. The three coding levels are shirt (or less), sweater/jacket (a lighter extra layer) or coat (heavy extra layer or two bulking lighter layers that equal a coat). There was also a multiple checkbox area for general behavioral interactions during the frame and in the minute after the frame. This included resting eyes (eyes closed for the duration), talking with people in the vehicle, using the phone, eating, drinking, or just riding (i.e. just "passenging"/ "nothing").

The larger second section is used for coding front seat passenger body part positions, postures and interactions with the vehicle, other passengers, and items in the passenger's occupant space. A text box was used for additional coding of postures and behaviors not covered by the options on the form.

Figure 21. Main page of video coding tool

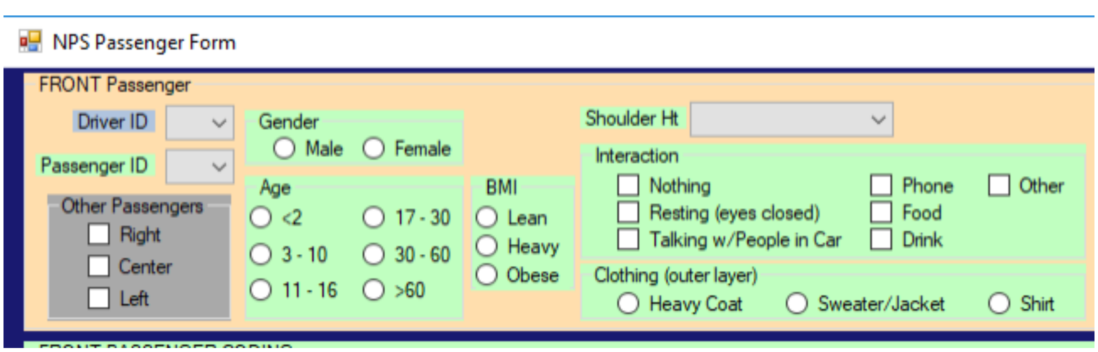


Figure 22. Section of coding tool for passenger physical characteristics and behavioral interactions

Upper Limb Position and Interactions

Examples of the coding sections in the tool for the upper limbs are shown in Figure 23, and the options are listed in Tables 4-6. Figure 24 shows how the regions of the arm were defined. Figure 25 shows screen captures of upper limb orientations.

Figure 23. Section of coding tool for upper limb position and interactions

Table 4
Elbow, Forearm, and Hand Vehicle Contact Coding Options

Interface	Option	Definition
Check boxes (select all that apply)	Armrest	Any area on top or alongside the armrest
	Window/Beltline	Anywhere around the margin of the window on the trim
	Lower Extremity	Touching the lap, thigh, or calf
	Torso	Any part of the torso above the lap
	Nothing	Touching nothing, (out in space)
	Center Stack (for hand only)	The center area of the instrument panel including the area where the radio and climate controls are located
	Other	Some other part of the vehicle (excluding the passenger seat) not listed. *A text entry is required if checked.*
	Can't Tell	Not possible to see or infer

Table 5
Hand Height Options Coding Options

Interface	Option	Definition
Check boxes (select all that apply)	On/slightly Above Lap	On or slightly above the lap area
	Chest to Neck	Above the lap, somewhere in the chest area, but below the neck
	Neck /Head	At the height of the neck or head
	Other	At some other height not listed. *A text entry is required if checked.*

Table 6
Hand Interaction Coding Options

Interface	Option	Definition
Check boxes (select all that apply)	Phone	Phone in the hand (does not need to be using it)
	Food	Includes all food stuffs
	Drink	Any drink
	Center Stack	Doing something with the center stack, not just resting upon it
	Other	Interacting with something in the vehicle (the vehicle itself, an object, or person). *A text entry is required if checked.*

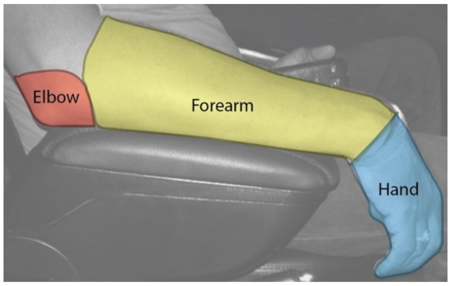


Figure 24. Arm regions

Figure 25. Screen shots of examples of arm locations and interactions

Lower Limb Position and Interactions

The coding sections of the tool for the thighs are shown in Figure 26, and the options are listed in Tables 7 and 8. The instructions indicate that this is the orientation of just the thigh. The lower leg and foot might have a different orientation, but they are not coded in this section. Figure 27 shows screen captures of some thigh orientations. Figure 28 illustrates lifted and not-lifted postures.

Figure 26. Section of coding tool for coding thigh position

Table 7
Right Thigh Orientation Coding Options

Interface	Option	Definition
Dropdown menu (select one)	Straight	Femur in line with hip
	Lateral	Leg splayed outward
	Medial	Leaning inward a lot, crossing torso centerline
	Can't Tell	Not possible to see or infer
Check boxes (select all that apply)	Lifted	Not all of the thigh touching the seat due to the feet being rearward (usually can tell due to thigh flesh not being spread out on the seat)
	Crossed Over Left	Right leg over the top of the left leg
	Crossed Under Left	Right leg under of the left leg
	Can't Tell	Not possible to see or infer

Table 8
Right Thigh Vehicle Contact Coding Options

Interface	**Option**	**Definition**
Check boxes (select all that apply)	Console	including any of the area that separates the passenger and driver compartment
	Knee Bolster	The padded area in front of the passenger. If they have their knee or other part of the leg touching above the glovebox use "other"
	Other	Some other part of the vehicle (excluding the passenger seat) not listed here. *A text entry is required if checked.*
	Can't Tell	Not possible to see or infer

Figure 27. Examples of thigh postures

Figure 28. Thighs not lifted (top) and lifted (bottom) off the seat cushion

Head Posture Relative to Torso and Face Orientation

The coding sections of the tool covering head orientation relative to the torso and which direction the face of the passenger was oriented are shown in Figure 29, and the options are listed in Tables 9-11. Figure 30 illustrates the orientation directions. Figure 31 shows examples.

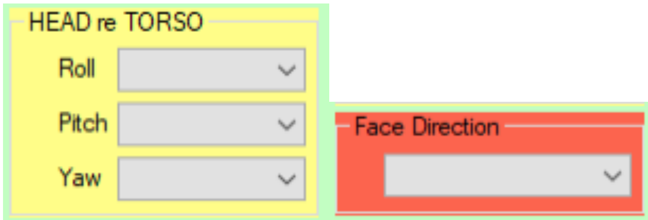


Figure 29. Section of coding tool for coding head and face

Table 9
Head Roll (Side-to-Side Tilt) Coding Options

Interface	Option	Definition
Dropdown menu (select one)	Neutral	Not tilted to either side relative to the torso
	Tilt Right	Leaning to the right relative to the torso (neck lateral bend right)
	Tilt Left	Leaning to the left relative to the torso (neck lateral bend left)
	Can't Tell	Not visible (even by scrubbing forward-backward several frames)
	Other	*A text entry is required if checked.*

Table 10
Head Pitch (Nod) Coding Options

Interface	Option	Definition
Dropdown menu (select one)	Neutral	Not forward or back relative to torso
	Forward	Tilted down relative to the torso (neck flexion)
	Back	Tilted backward relative to the torso (neck extension)
	Can't Tell	Not visible (even by scrubbing forward-backward several frames)
	Other	*A text entry is required if checked.*

Table 11
Head Yaw (Rotation) Coding Options

Interface	Option	Definition
Dropdown menu (select one)	Neutral	Aligned with torso
	Rot Right	Rotated to right
	Rot Left	Rotated to left
	Can't Tell	Not visible (even by scrubbing forward-backward several frames)
	Other	*A text entry is required if checked.*

Table 12
Face Direction Coding Options

Interface	Option	Definition
Dropdown menu (select one)	Windshield	Forward in the vehicle, in the direction of the windshield (can be a bit to the left or the right)
	Passenger Window	In the direction of the side passenger window (right side)
	Driver	To the left side of the vehicle, in the general direction of the driver
	Behind	Toward the rear of the vehicle
	Lap	Down toward their lap or the floor
	Can't Tell	Not visible (even by scrubbing forward-backward several frames)
	Other	Face is oriented to a location not listed here (most likely ceiling). *A text entry is required if checked.*

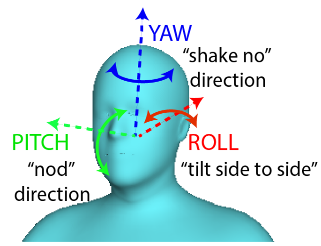


Figure 30. Head orientation directions

Figure 31. Face directions: out side window, lap, windshield, driver, ceiling (left-top to right-bottom)

Torso Position and Orientation Relative to Vehicle Seat

The coding section for torso orientation relative to the vehicle seat is shown in Figure 32 and the options are listed in Tables 13 and 14. Figure 33 illustrates the orientation directions. Figures 34-36 show examples.

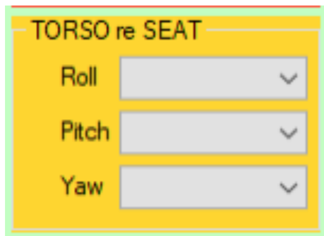


Figure 32. Section of coding for torso posture

Table 13
Torso Roll (Side-to-Side) Coding Options

Interface	Option	Definition
Dropdown menu (select one)	Neutral	Not tilted to either side relative to the seat
	Tilt Right	Leaning to the right relative to the seat
	Tilt Left	Leaning to the left relative to the torso
	Can't Tell	Not visible (even by scrubbing forward-backward several frames)
	Other	*A text entry is required if checked.*

Table 14
Torso Pitch (Leaning Forward or Backward) Coding Options

Interface	Option	Definition
Dropdown menu (select one)	Neutral	Not leaning forward or backward relative to seat back (standard posture relative to seat)
	Forward	Leaning forward from the seat
	Backward	Leaning back in the seat more than would be in standard posture; this would be in conjunction with hips slide forward
	Can't Tell	Not visible (even by scrubbing forward-backward several frames)
	Other	*A text entry is required if checked.*

Table 15
Torso Yaw (Twist) Coding Options

Interface	Option	Definition
Dropdown menu (select one)	Neutral	Not twisted relative to the seat
	Rot Right	Twisted so the chest is more toward the person's right
	Rot Left	Twisted so the chest is more toward the person's left
	Can't Tell	Not visible (even by scrubbing forward-backward several frames)
	Other	*A text entry is required if checked.*

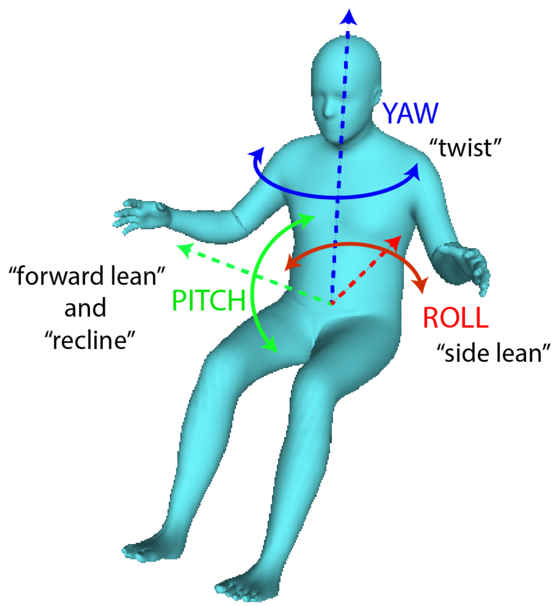


Figure 33. Torso directions

Figure 34. Examples of torso pitched forward (left), neutral (middle), backward (right)

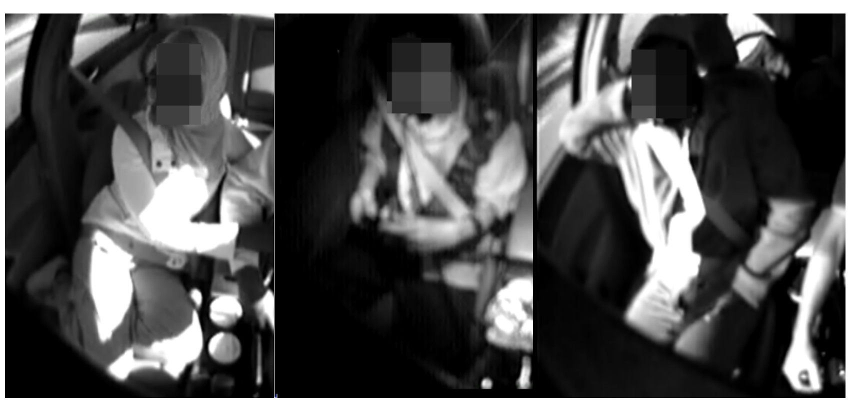


Figure 35. Examples of roll left (left), neutral (middle) and right (right)

Figure 36. Examples of rotation right and left

Pelvis Position and Orientation Relative to Vehicle Seat

The coding section for pelvis position and orientation relative to the vehicle seat is shown in Figure 37, and the options are listed in Tables 16-18. Figure 38 shows examples.

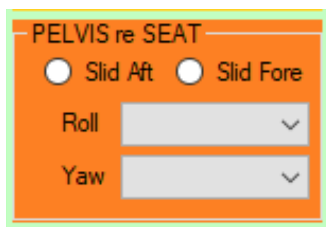


Figure 37. Section of coding for pelvis position and orientation

Table 16
Pelvis Fore-Aft Position Coding Options

Interface	**Option**	**Definition**
Radio Buttons (select one)	Slid Aft	*Normal* sitting position
	Slid Fore	Hips slid noticeably forward in the seat

Table 17
Pelvis Roll (Side-to-Side) Coding Options

Interface	**Option**	**Definition**
Dropdown menu (select one)	Neutral	Not tilted to either side relative to the seat
	Tilt Right	Tilted to the right; right hip lower in seat than left hip
	Tilt Left	Tilted to the left; left hip lower in seat than right hip
	Can't Tell	Not visible (even by scrubbing forward-backward several frames)
	Other	*A text entry is required if checked.*

Table 18
Pelvis Yaw (Twist) Coding Options

Interface	Option	Definition
Dropdown menu (select one)	Neutral	Not twisted
	Rot Right	Right hip noticeably more rearward in the seat than the left hip
	Rot Left	Left hip noticeably more rearward in the seat than the right hip
	Can't Tell	Not visible (even by scrubbing forward-backward several frames)
	Other	*A text entry is required if checked.*

Figure 38. Examples of pelvis postures in seat.

Contact Between the Midline of the Body and the Vehicle Seat

The coding section for the contact between the head, neck, upper back and lower back with the vehicle seat is shown in Figure 39, and the options of "yes", "no" or "can't tell" (CT) were coded (Tables 19). Figures 40 and 41 show examples.

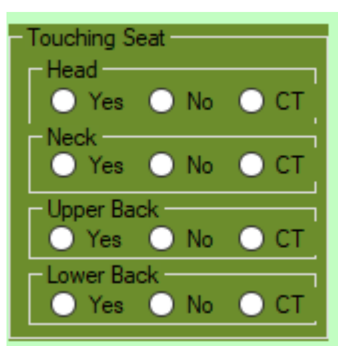


Figure 39. Section of the coding tool for head and trunk contact with seat surface

Table 19
Body-Seat Surface Contact Regions

Interface	Option	Definition
Radio Buttons for Yes, No or Can't Tell (CT)	Head	Any area of the head
	Neck	Any part of the neck
	Upper Back	Shoulder area (~T4 and up); when passengers are in an alert/neutral posture this part of the back is usually not touching the seat back
	Lower Back	Mid back and inferior; usually in contact when passengers are in a neutral posture, usually not in contact when passenger is slouched in seat and pelvis slid forward

Figure 40. Examples of head touching and not touching

Figure 41. Upper back not touching seat back in a standard posture (left), touching seatback in a slouched posture (center), and touching the seatback in a reclined posture (right)

Additional Coding

To keep the form from being too crowded, events that were less common were entered in the notes area of the coding tool (Figure 42). The wording of these notes was standardized into a four-word pattern that 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 another descriptor (see Appendix B). 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. A section of this spreadsheet is shown in Figure 43.

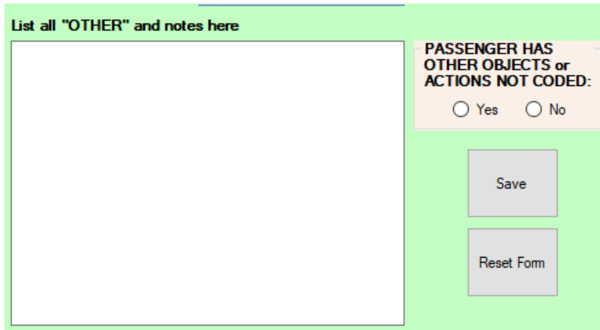


Figure 42. Notes area of the coding form.

A	B	C	D	E	F
Category	Who/What/Where	Direction/Action/ Location	Item/Occurance /HowLong/Descriptor		
WORD 1	**WORD 2**	**WORD 3**	**WORD 4**	**As Typed or Copied (EXACTLY)**	***Additional information***
Consol	Top	Center	Purse	Consol Top Center Purse;	*Purse placed on consol*
Consol	Top	Center	Pet	Consol Top Center Pet;	*Pet is on consol*
Consol	Top	Center	Object	Consol Top Center Object;	*A different object (can't tell what it is) is on the*
Consol	Top	Center	Phone	Consol Top Center Phone;	*A phone is on the consol*
Consol	Top	Center	Cup	Consol Top Center Cup;	*cup on console*
Cupholder	Inside	Center	Cup	Cupholder Inside Center Cup;	*Drink inside cupholder in center consol*
Cupholder	Inside	Center	Object	Cupholder Inside Center Object;	*An object that isn't a drink is in the cupholder*
Cupholder	Inside	Center	Phone	Cupholder Inside Center Phone;	*A phone is in the cupholder*
Cupholder	Inside	Center	Food	Cupholder Inside Center Food;	*Food is in cupholder*
Cupholder	Inside	Center	Purse	Cupholder Inside Center Purse;	*Purse in cupholder*

Figure 43. Examples of coding additional events.

RESULTS

Overview of Passengers and Trips

A total of 3085 trips with at least one passenger were coded. A total of 306 unique front-seat passengers were observed across 2733 trips, for an average of 8.9 trips per passenger. During these trips, a total of 13638 frames were coded, for an average of 5 frames per trip.

Although the distribution of frames across trip duration is not uniform, as noted above, the frames are sufficiently distributed that they can be considered to represent approximately uniformly sampled passenger time. The coded trips represented a total of 51128 minutes of passenger time, so each frame represents an average of 3.7 minutes of travel time.

Passenger Classifications and Belt Fit

Figure 44 shows the distribution of front-passenger trip duration. Table 20 lists selected percentiles of the trip-duration distribution. Half of trips are 12.2 minutes or less; 90% are less than 38.5 minutes, and 95% are less than 54.2 minutes. For comparison, Table 20 also lists the corresponding percentiles from the National Household Travel Survey (Klinich et al. 2019). Note that the NHTS data are based on self-report in a phone survey and show a strong bias toward increments of 5 and 15 minutes. However, the trend is similar, with the current data representing slightly shorter trips (although more accurately reported). The percentiles are within 6 minutes for trips longer than 30 minutes, including at the 99th percentile trip duration of 132 minutes (vs. 125 minutes in NHTS).

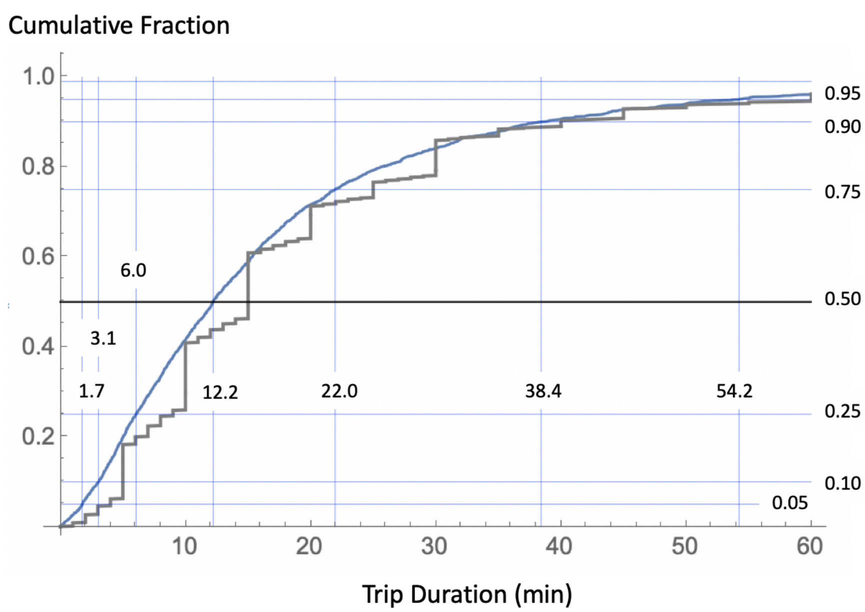


Figure 44. Cumulative distribution and selected quantiles of front passenger trip duration (smooth blue curve). Data from the 2017 National Household Travel Survey for all passenger vehicle trips is plotted for comparison.

Table 20
Quantiles of the Front-Seat Passenger Trip Duration Distribution

Percentile	Duration (minutes)	NHTS Duration (minutes)
5	1.7	4
10	3.1	5
25	6.0	9
50	12.2	15
75	22.0	25
90	38.4	40
95	54.2	60
99	131.5	125

Table 21 lists the number of trips per passenger position and the total count of different individuals in each position. The number of trips per passenger varied from 1 to 75, and drivers also varied in the number of trips with passengers and the number of passengers. Among front-passenger trips, 70% were taken during daylight conditions. (Note that the data were collected at about 42˚ north latitude between June and December, with most data collected in September through December.)

Most passengers were women**;** most of them had a lean body type and plurality had a medium sitting height (Table 22). The seat belt was observed to be used in about 97% of frames. When the belt was worn, the belt was most commonly on the lap and clavicle rather than in any of the identified positions associated with poor fit (Table 23). However, the lap belt was coded as "on the belly" in 12% of frames, and the shoulder belt was coded as lateral to the clavicle in 22% of frames.

Table 21
Number of Trips in Database with Occupants

	Front	Right Rear	Center Rear	Left Rear
Total Trips Taken with Passengers	2733	914	168	700
Number of Different People in Passenger Position	306	173	66	138

Table 22
Front-Seat Passenger Characteristics (percent of frames)

Gender

%	Value
72.0%	F
27.6%	M
0.4%	Missing

BMI

%	Value
63.8%	lean
28.4%	heavy
7.4%	obese
0.4%	Missing

Age

%	Value
1.5%	3-10
16.2%	11-16
33.5%	17-30
37.4%	30-60
10.8%	>60
0.4%	Missing

Stature

%	Value
33.8%	short
44.6%	medium
21.2%	tall
0.4%	Missing

Table 23
Belt Fit (percent of frames)

ShoulderBelt

%	Value
71.5%	MidClavicle
21.5%	LatClavicle
2.7%	None
2.7%	OnNeck
0.8%	ForwardofBody
0.7%	UnderArm
0.1%	Missing

LapBelt

%	Value
85.0%	OnLap
12.4%	OnBelly
2.1%	None
0.3%	Can't Tell
0.3%	Missing

Table 24 lists the distribution of passenger interaction activities. Note that more than one activity could be coded per frame. The passenger was talking to other vehicle occupants in in 46% of frames and interacting with a phone in 27% of frames. (Note that phone interactions could include talking on the phone.) “Resting” was observed in only 2.2% of frames. Table 25 lists distributions of head posture. Passengers were most often looking out the windshield (55% of frames). Looking out the passenger window (13%), at their lap (23 %) and at the driver (8%) were also common gaze directions. The head was pitched down (forward toward the lap) in 29% of frames. The head was rotated right or left in about 33% of frames.

Table 26 lists the distribution of torso and upper-extremity postures. The passenger’s torso was tilted left or right about 14% of the time and pitched forward in almost 10% of frames. In about 10% of frames, the passenger’s pelvis was coded as having slid forward on the seat.

Table 24
Passenger Interaction Frequencies (percent of frames)*

Percent	**Behavior**
46.0%	Talking to Other Occupants
26.4%	Phone
25.9%	Nothing
5.7%	Other
3.2%	Food
2.2%	Resting
1.6%	Drink

* More than one activity could be coded per frame.
.

Table 25
Head Posture (percent of frames)

HeadRoll		**HeadYaw**	
%	Value	%	Value
84.9%	Neutral	65.4%	Neutral
10.1%	Tilt Right	19.1%	Rotated Right
3.7%	Tilt Left	14.1%	Rotated Left
1.1%	Missing	1.1%	Missing
0.3%	Can't Tell	0.3%	Can't Tell
HeadPitch		**FaceDir**	
67.1%	Neutral	55.0%	Windshield
28.6%	Down	22.5%	Lap
3.0%	Back	13.2%	Pas Window
1.1%	Missing	7.5%	Driver
0.2%	Can't Tell	1.2%	Missing
		0.5%	Can't Tell
		0.2%	Behind

Table 26
Torso and Lower Extremity Posture Variables (percent of frames)

TorsoRoll	Value
84.6%	Neutral
7.5%	Tilt Left
6.7%	Tilt Right
1.1%	Missing
0.1%	Can't Tell

TorsoPitch	Value
85.6%	Neutral
9.6%	Forward
3.6%	Backward
1.1%	Missing

TorsoYaw	Value
88.5%	Neutral
5.5%	Rotated Right
4.8%	Rotated Left
1.2%	Missing
0.1%	Can't Tell

PelvisPos	Value
89.3%	Slid Aft
9.5%	Slid Fore
1.2%	Missing

PelvisRoll	Value
93.0%	Neutral
4.4%	Tilt Left
1.1%	Missing
0.8%	Tilt Right
0.7%	Can't Tell

PelvisYaw	Value
86.4%	Neutral
8.6%	Rotated Right
3.2%	Rotated Left
1.2%	Can't Tell
0.5%	Missing

RtLeg_Orientation	Value
44.2%	Lateral
36.1%	Straight
13.1%	Medial
5.4%	Can't Tell
1.2%	Missing

LtLeg_Orientation	Value
39.1%	Straight
37.0%	Lateral
18.3%	Medial
4.5%	Can't Tell

Table 27
Seat Contacts

TouchingSeat_Head	Value
85.7%	N
13.0%	Y
1.1%	Missing
0.2%	Can't Tell

TouchingSeat_Neck	Value
89.3%	N
9.3%	Y
1.2%	Missing
0.2%	Can't Tell

TouchingSeat_UpBack	Value
70.0%	N
28.5%	Y
1.1%	Missing
0.4%	Can't Tell

TouchingSeat_LoBack	Value
84.4%	Y
14.2%	N
1.1%	Missing
0.3%	Can't Tell

Table 28
Upper Extremity Postures

ArmLt*

36.6%	Torso
30.3%	Nothing
19.2%	LowerExt
17.5%	Armrest
10.0%	Other
0.5%	Can't Tell
0.1%	WindowBeltline

ArmRt*

40.3%	Torso
33.8%	LowerExt
24.8%	Nothing
7.6%	Armrest
4.0%	Other
2.1%	WindowBeltline
2.1%	Can't Tell

ElbLt*

46.5%	Armrest
29.8%	Torso
15.2%	Nothing
11.8%	Other
1.4%	LowerExt
0.5%	Can't Tell
0.1%	WindowBeltline

ElbRt*

50.5%	Torso
20.6%	Nothing
17.1%	Armrest
5.5%	LowerExt
4.7%	WindowBeltline
2.4%	Can't Tell
1.5%	Other

HandLt* (Contact)

57.6%	Other
38.0%	LowerExt
9.9%	Nothing
6.5%	Torso
1.4%	Armrest
0.8%	Can't Tell
0.1%	0.3%
0.1%	WindowBeltline

HandRt* (Contact)

56.7%	Other
36.8%	LowerExt
8.2%	Nothing
5.0%	Torso
3.6%	Armrest
1.9%	Can't Tell
1.5%	WindowBeltline
0.1%	CtrStack

HandXLt* (Interaction)

40.7%	Nothing
29.7%	Phone
24.5%	Other
2.5%	Drink
2.4%	Food
0.3%	CtrStack

HandXRt* (Interaction)

40.4%	Nothing
30.8%	Phone
23.5%	Other
2.4%	Food
2.3%	Drink
0.1%	CtrStack

Hand Height Lt

68.1%	OnAboveLap
23.5%	ChestToNeck
6.5%	NeckHead
1.0%	Other

Hand Height Rt

67.8%	OnAboveLap
22.3%	ChestToNeck
7.1%	NeckHead
1.6%	Other

* More than one value could be coded per frame.

Table 29
Lower Extremity Postures

LtLeg*		RtLeg*	
48.5%	None	46.2%	None
37.9%	Lifted	39.7%	Lifted
6.6%	Can't Tell	7.0%	Can't Tell
3.4%	CrossedUnder	3.8%	CrossedOver
2.3%	CrossedOver	2.4%	CrossedUnder

LtLegTouch*		RtLegTouch*	
59.4%	Nothing	55.3%	Nothing
27.1%	Other	23.3%	Other
8.2%	Console	17.6%	Door
5.1%	Can't Tell	6.1%	Can't Tell
0.2%	KneeBolster	0.1%	KneeBolster

* More than one value could be coded per frame.

Covariate Effects

The data were examined to assess the extent to which the distribution of categorical outcomes differed based on a variety of covariates. Chi-square analysis was conducted to assess if the observed differences were likely to be to chance. All results reported here are statistically significant with $p<0.001$. However, because of the large sample size, some statistically significant results are quite small and may not be of practical importance.

Table 30 shows that the gender of the passenger is strongly associated with the gender of the driver. When the driver is female, the passenger is male over 40% of the time. In contrast, when the driver is male, the front passenger is female 83% of the time. Table 31 shows that female passengers are somewhat more likely than male passengers to be interacting with a phone and slightly less likely to be categorized as doing “nothing”. Table 32 lists the coded age distribution of male and female passengers. Female passengers were more likely to be judged to be over age 60 years and between 17 and 30 years, while male passengers were more likely to be age 30-60 years. Passengers younger than 11 years and older than 60 years were less like to be interacting with a phone (Table 33).

Table 30
Effect of Driver Gender on Passenger Gender

	Driver Gender	
Front Pass Gender	Female	Male
Female	59.3%	82.7%
Male	40.7%	17.3%
	100.0%	100.0%

Table 31
Gender Effects on Passenger Interactions*

	F	M
Talking	45.9%	45.6%
Nothing	24.7%	29.4%
Phone	19.4%	16.0%
Other	3.6%	3.1%
Resting	2.2%	2.4%
Food	2.0%	2.0%
Missing	1.4%	0.7%
Drink	0.9%	0.7%
	100.0%	100.0%

* Only one interaction per frame was used for this table (compare with Table 24).

Table 32
Passenger Age by Gender

	F %	M %
3-10	0.6%	4.0%
11-16	15.3%	18.9%
17-30	36.7%	25.7%
30-60	34.6%	45.4%
>60	12.8%	5.8%
	100%	100%

Table 33
Passenger Interactions by Age Category

	Age (yrs) 3-10	11-16	17-30	30-60	>60
Talking	48.8%	31.7%	49.4%	48.5%	46.0%
Nothing	19.0%	32.4%	25.6%	22.2%	31.9%
Phone	10.0%	25.4%	16.9%	20.0%	9.1%
Other	10.4%	4.2%	2.4%	2.5%	8.0%
Food	4.7%	2.6%	1.5%	2.2%	1.3%
None	1.4%	0.6%	0.5%	2.1%	1.2%
Resting	5.7%	1.8%	2.9%	1.8%	1.7%
Drink	0.0%	1.3%	0.8%	0.6%	0.9%
	100%	100%	100%	100%	100%

The ambient light condition was classified as daylight in 70% of trips. Table 34 shows the age distribution for passengers by daylight vs. darkness. Passengers 3-10 years and over 60 years of age were more frequently observed during daylight, but those ages 17-30 years were most often in darkness.

Table 34
Daylight by Age

	Age (yrs) 3-10	11-16	17-30	30-60	>60
Darkness	14.7%	25.5%	37.0%	29.0%	17.1%
Daylight	85.3%	74.5%	63.0%	71.0%	82.9%
	100%	100%	100%	100%	100%

Table 35 shows the passenger interaction categories by quantiles of trip duration. Phone use and resting were more common activities on longer trips, with resting observed more in longer trips, including 7% of frames on trips with duration greater than 38 minutes (90^{th} percentile of trip duration).

Table 35
Interactions by Trip Duration Percentile (see Table 20)

Trip Duration Category	<25 %	25-50 %	50-75 %	75-90 %	>90 %	>95 %
Durations (min)	<6.0	6.0-12.2	12-22	22-38	>38	>54
Frames (%)	3407 (25%)	3405 (25%)	3403 (25%)	2033 (15%)	703 (5.1%)	638 (4.9%
Talking	50.7%	48.1%	47.3%	44.1%	29.9%	25.6%
Nothing	28.1%	27.3%	24.0%	24.3%	19.6%	29.7%
Phone	14.6%	17.4%	19.6%	18.1%	31.5%	26.2%
Other	2.5%	2.8%	2.5%	4.3%	6.9%	8.0%
Resting	0.4%	1.2%	2.3%	4.4%	7.1%	5.3%
Food	1.5%	1.5%	2.1%	1.9%	3.8%	4.1%
None	1.0%	1.1%	1.6%	1.9%	0.2%	0.0%
Drink	1.1%	0.5%	0.7%	0.9%	1.1%	1.1%
	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Figure 45 shows how interactions change over time. At each time interval, the fraction of frames involving the five most common interactions are shown. The lines plot the fraction of interactions for passenger travel time *longer* than the specified time. For example, the lines at 60 minutes show the distribution of activities for video frames in which the passenger had been traveling for more than 60 minutes. For reference, the plot also shows the fraction of travel time that is of longer duration. The passenger has been sitting at least 60 minutes during approximately 10% of travel time. The data show that resting becomes increasingly common up to about one hour of travel time, then tapers off. (Note that this is a between-passenger observation, because most passengers were not observed sitting for an hour or more.)

Figure 46 shows the same data in 10-minute bins of travel time (Table 36 shows the number of frames per bin used to calculate the values in Figure 46). The lines are less smooth at longer travel times due to smaller sample size. In this plot, talking and phone interactions are fairly constant for the first hour, after which talking decreases and phone and resting increase, with resting reaching about 10% of frames sampled between 80 and 90 minutes of travel time. Note that data for travel 80-90 minutes are from only 142 frames, about 1% of the sampled frames.

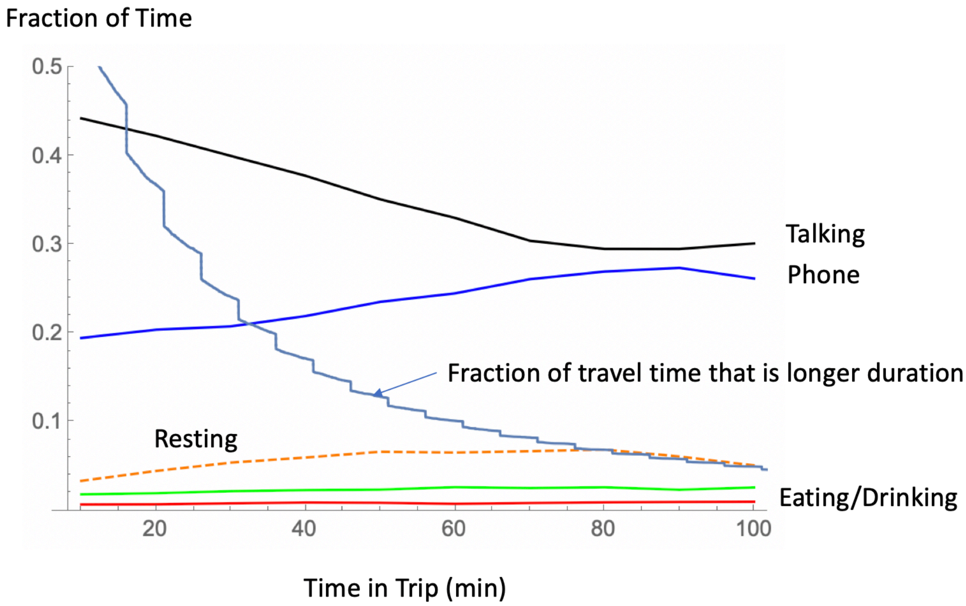


Figure 45. Passenger interactions for all trip time longer than the specified time.

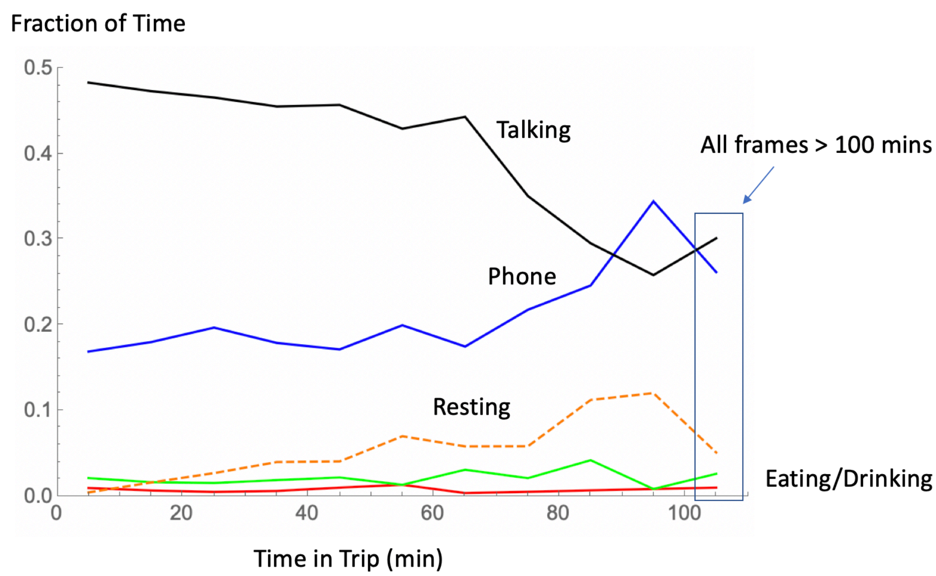


Figure 46. Passenger interactions in 10-minute bins (10-20, 20-30, …).

Table 36
Number of Frames per Time-in-Trip Bin (min)

Lower (min)	Upper (min)	Count
0	10	5418
10	20	3199
20	30	1729
30	40	948
40	50	588
50	60	370
60	70	257
70	80	188
80	90	142
90	100	116
100	316 (max)	683

Lower extremity posture was coded when visible, which was in about 90% of frames. Figure 47 shows examples of the posture categories: *neutral*, meaning lower extremities extending approximately straight forward and thighs engaged with the seat; thighs *lifted*, meaning the feet have been slid rearward to elevate the thighs; and *crossed*, either right-over-left or left-over-right.

Neutral Lifted Crossed

Figure 47. Examples of lower extremity postures.

Figure 48 shows leg postures across the range of travel time. The leg is "lifted" in about 40% of frames, independent of travel time. Postures with legs crossed over or under occur in about 8% of frames, although the coder was unable to ascertain the leg posture in up to 10% of frames.

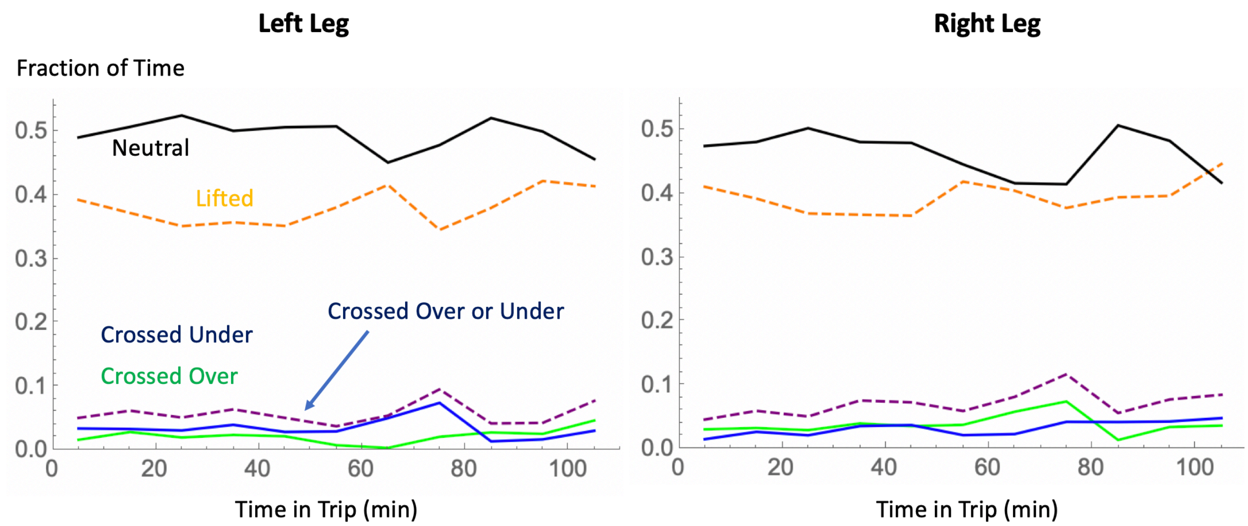


Figure 48. Leg postures across travel time.

Seat Position and Seat Back Angle

Arrival

The position of the seat and the angles of the cushion and back were measured when each vehicle arrived to be instrumented. Table 37 shows the means and standard deviations of these data, which are a good estimate of the distribution of front-passenger seat positions in the vehicle fleet. On average, the passenger seatback angle was 25.1 (5.0) degrees, with 95% less than 34 degrees (Figure 49). Seat cushion angles ranged between 9 and 20 degrees with a mean of 14.5 degrees. Seats were 60 mm forward of the full-rear position, on average, with a large standard deviation. With an average track length of 238 mm, the mean seat position was about 28% of the track length forward of full rear. The initial seat position was full rear for 23% of vehicles and rearward of the middle of the fore-aft adjustment range in 87% of vehicles (Figure 50).

Table 37
Front-Passenger Seat Positions on Arrival

Variable	Mean	SD
Seat Back Angle (deg)	25.1	5.0
Seat cushion angle (deg)	14.5	2.8
Seat Position forward of full rear (mm)	60	52
Seat Position above full down (mm)*	17	16
Seat track length (mm)	238	22

* For the 17 vehicles (23%) with height-adjustable passenger seats.

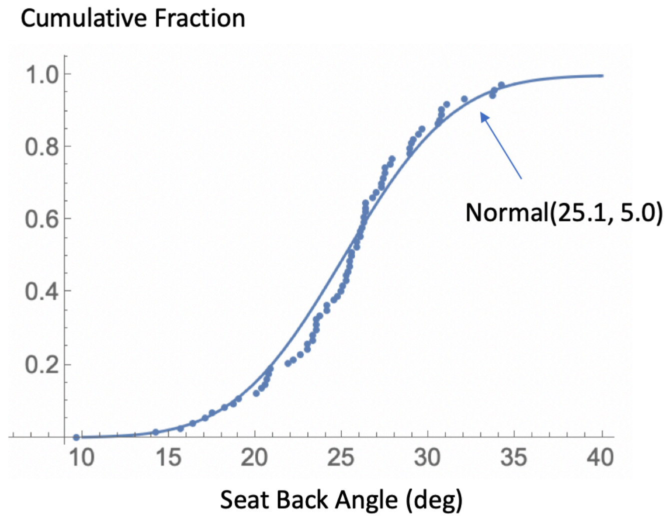


Figure 49. Cumulative distribution of seat back angle of vehicles on arrival along with approximating normal distribution.

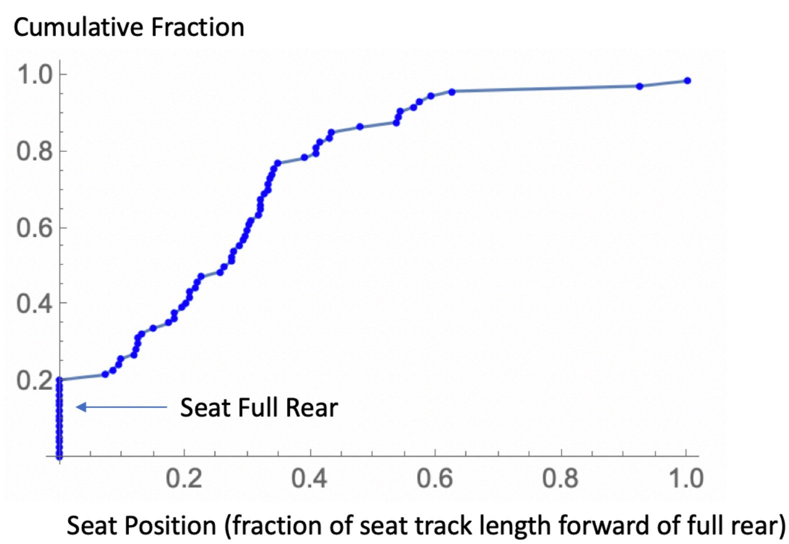


Figure 50. Cumulative distribution of seat position of vehicles on arrival, expressed as fraction of seat track length forward of full rear.

During Travel

In 40 of 75 vehicles (53%), no seat position or seat back angle movement was observed for the front passenger seat. For the 35 vehicles with observed movement, the fore-aft seat position was adjusted 16 times, and the seat back angle was adjusted 61 times. The passenger was observed to increase the seat back angle (recline) 45 times and to reduce the seat back angle (incline) 16 times. The seat position and/or seat back angle was adjusted between trips (i.e., the adjustment was not directly observed) 17 times.

As described in the methods section, the digitized landmark locations on the seat were used to estimate seat position forward of full rear and seat back angle relative to vertical for the associated frames. Note that because the first minute of a trip was not reliably recorded due to the time needed for the data acquisition to start up, some adjustments were not directly observed, but the seat positions used during coded frames were obtained from either the coded frames or from another frame in which the view of the seat was sufficient to digitize the optical targets.

Figure 51 shows the distribution of seat position for all frames. The seat was within 10 mm of full-rear in 23% of frames, and the median seat position was 53 mm (22%) forward of full-rear. The seat was aft of mid-track in 81% of frames.

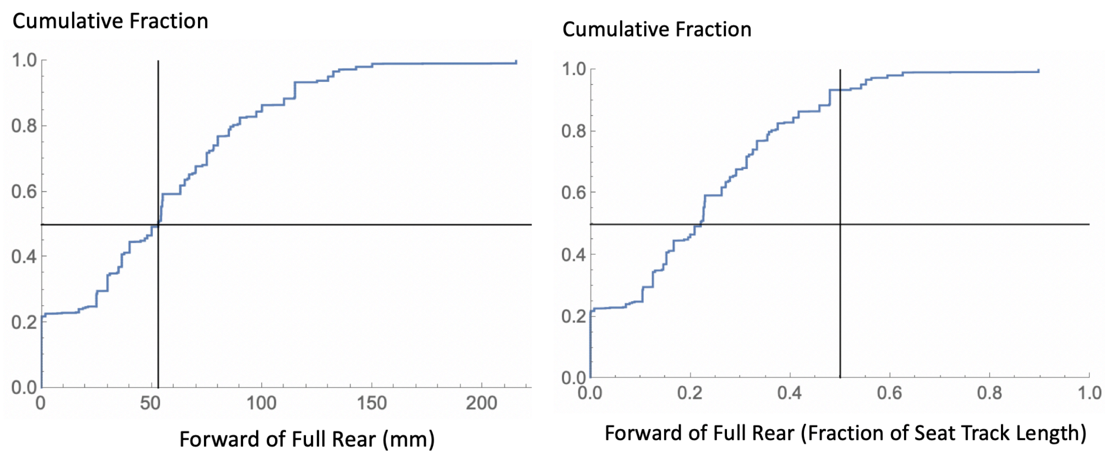


Figure 51. Distribution of passenger seat positions relative to full-rear.

Figure 52 shows the distribution of seat back angle for all frames and Table 38 shows quantiles. The mean seat back angle was 25.4 (sd 6.4) degrees. The median seat back angle was 24.2 degrees and the distribution was approximately symmetrical around that value. Because the seat back angle was changed relatively few times and inclined approximately often as reclined, the seat position distribution during passenger travel frames is not meaningfully different from the arrival distribution. The seat back angle was greater than 30 degrees in approximately 15% of frames and greater than 35 degrees in only 84 frames (0.7%).

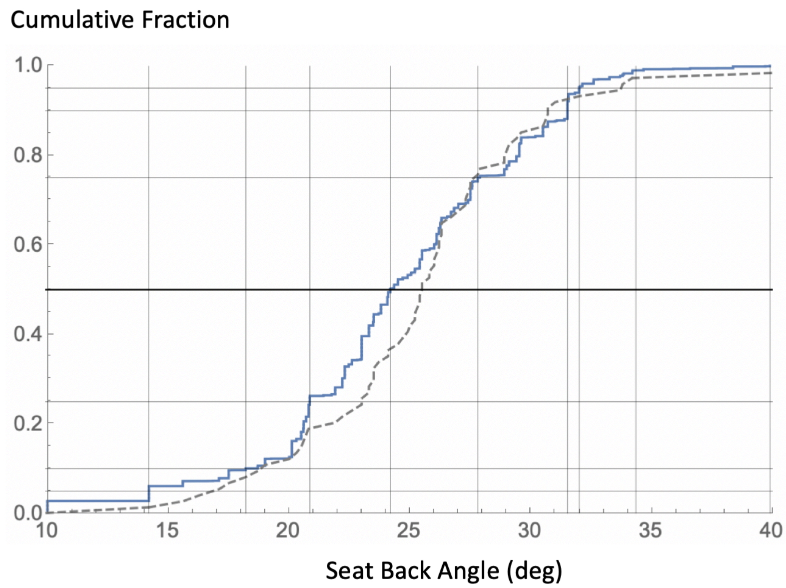


Figure 52. Seat back angle distribution (solid line). Arrival distribution is shown as a dashed line. Quantiles 0.05, 0.1, 0.25, 0.5, 0.75, 0.9, and 0.95 are shown.

Table 38
Seat Back Angle Quantiles

Quantile	Seat Back Angle (deg)
0.05	14.2
0.10	18.2
0.25	20.9
0.50	24.2
0.75	27.8
0.90	31.5
0.95	32.0
0.99	34.3
Max	39.9

Association with Covariates

Table 39 shows the association between seat position and selected covariates. Full-rear seat position was somewhat more common among female passengers, and placement of the seat forward of midtrack was slightly more common among male passengers, although this between-subjects finding is not likely to be generalizable. That is, different individuals were sitting forward and rearward, so the difference is likely due to these particular individuals rather than an effect of seat position. The seat was forward of midtrack more often when the passenger had been seated less than 30 or 60 minutes than during longer travel. Note that these comparisons are predominantly between vehicles and passengers, since seat movement was not common within vehicles and even less common for individual passengers or trips.

Table 40 shows the distribution of passenger interactions by seat position category. No important differences were observed, although resting was slightly more common in forward seat positions. Phone use was more common in both forward and full-rearward seat positions. Again, this probably reflects differences among passengers rather than effects of seat position.

Table 39
Association Between Covariates and Seat Position

Seat Position	F %	M %	**Time in Trip**	≤ 30 mins	> 30 mins
Forward of Full Rear	76.2%	80.3%	Rear of Midtrack	90.5%	95.6%
Full Rear	23.8%	19.7%	Forward of Midtrack	9.5%	4.4%
	100.0%	100.0%		100.0%	100.0%

	F %	M %		≤ 60 mins	> 60 mins
Rear of Midtrack	92.1%	90.9%	Rear of Midtrack	91.0%	98.2%
Forward of Midtrack	7.9%	9.1%	Forward of Midtrack	9.0%	1.8%
	100.0%	100.0%		100.0%	100.0%

Table 40
Association Between Passenger Interactions and Seat Position*

	Full Rear	<25%	26-50%	51-75%	75-100%
Num Frames	2707	4343	4054	681	94
% Frames	22.8%	36.6%	34.1%	5.7%	0.8%
Talking	41.7%	49.0%	45.2%	45.5%	77.7%
Nothing	24.5%	23.3%	26.9%	24.7%	6.4%
None	0.2%	0.6%	0.6%	14.4%	0.0%
Phone	22.3%	17.5%	19.5%	12.0%	7.4%
Resting	1.9%	2.5%	2.8%	1.0%	0.0%
Drink	0.8%	0.9%	0.6%	0.9%	4.3%
Food	1.8%	2.9%	1.2%	0.9%	4.3%
Other	6.9%	3.3%	3.2%	0.6%	0.0%

*Percent of seat track forward of full rear

Table 41 a passenger was seated in the second row behind the front seat passenger 23% of the time. As expected, the front seat was less likely to be full rear when someone was seated in the right rear, with the seat full rear only about 10% of the time when a rear passenger was present. The mean seat position with a rear passenger present was only about 5 mm further forward, however, and the mean seat back angle was only about 1.5 degrees more upright.

Table 41
Association Between Rear Passenger Presence and Seat Position and Back Angle

	No Rear Passenger	Rear Passenger
Not Full Rear	73.4%	90.0%
Full Rear	26.6%	10.0%
	100%	100%
Mean (SD) Seat Position (mm)	56 (50)	61 (46)
Mean (SD) Seat Back Angle (deg)	25.7 (6.8)	24.2 (4.9)

Table 42 shows the association between selected covariates and seat back angle. Seat back angle was not meaningfully associated with gender or darkness. Seat back angles greater than 30 degrees were slightly more common for time-in-trip less than 30 or 60 minutes, but as noted above, these trends are between vehicles and passengers.

Table 43 shows the distribution of passenger interactions by seat back angle category. Resting was slightly more common when reclined but remained under 3% even at back angles greater than 30 degrees.

Table 44 shows some differences in posture associated with seat back recline angles greater than 30 degrees. The head was about twice as likely to be touching the seat. Lower extremity postures with the thighs lifted (feet pulled rearward) were somewhat less likely with highly reclined seat back angles. Right leg crossed over left was also somewhat more common with more reclined seats.

Table 42
Association Between Covariates and Seat Back Angle

Seat Back Angle	F %	M %		**Time in Trip** ≤ 20 mins	> 20 mins
≤ 30 deg	83.9%	85.0%	≤ 30 deg	85.4%	81.7%
>30 deg	16.1%	15.0%	>30 deg	14.6%	18.3%
	100.0%	100.0%		100.0%	100.0%
	F %	M %		≤ 30 mins	> 30 mins
≥20 deg	88.2%	86.6%	≤ 30 deg	85.7%	78.8%
<20 deg	11.8%	13.4%	>30 deg	14.3%	21.2%
	100.0%	100.0%		100.0%	100.0%
	Darkness	Daylight		≤ 60 mins	> 60 mins
≤ 30 deg	82.3%	84.7%	≤ 30 deg	85.3%	73.1%
>30 deg	17.7%	15.3%	>30 deg	14.7%	26.9%
	100.0%	100.0%		100.0%	100.0%

Table 43
Association Between Passenger Interactions and Seat Back Angle

	BA ≤20 deg	BA >20 deg	BA ≤30 deg	BA >30 deg
Talking	45.2%	49.1%	44.8%	50.5%
Nothing	26.6%	20.1%	26.2%	24.1%
Phone	18.8%	15.8%	18.6%	17.1%
Other	3.2%	8.8%	4.2%	1.9%
Resting	2.1%	1.8%	1.9%	3.0%
Food	1.8%	2.8%	1.9%	2.0%
Missing	1.5%	0.4%	1.4%	0.9%

Table 44
Association Between Posture Variables and Seat Back Angle

	Seat Back Angle	
Head Touching Seat	≤ 30 deg	>30 deg
N	90.0%	81.1%
Y	9.8%	18.9%
Can't Tell	0.2%	0.0%
	100.0%	100.0%
Right Leg	≤ 30 deg	>30 deg
Neutral	44.9%	46.7%
Lifted	43.2%	33.6%
Can’t Tell	6.7%	11.0%
CrossedOver	3.1%	4.5%
CrossedUnder	2.1%	4.2%

Time of Day

Trips were recorded throughout the day but were most common during the late afternoon hours. Figure 53 shows a histogram of trip start times. Passenger activities varied with time of day, as shown in Figure 54. In particular, phone use was more common than talking in the early morning hours, whereas talking was more common the rest of the day. Table 45 shows that the probability of the seat back angle being greater than 30 degrees was also greatest in the early morning hours. However, these findings are based on a small number of trips between midnight and 5 AM, as shown in Figure 54.

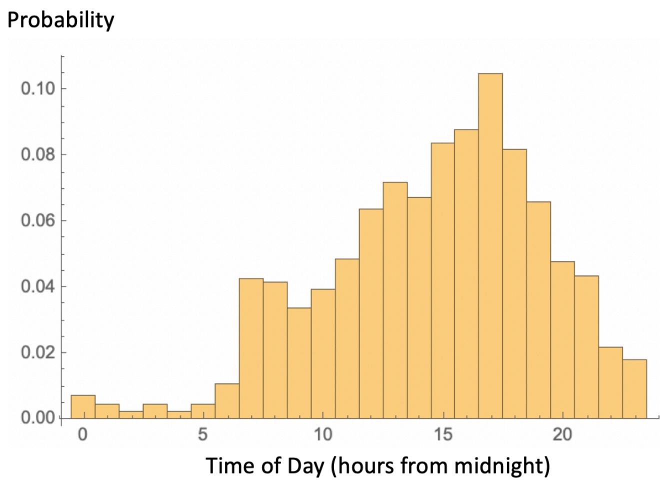


Figure 53. Histogram of trip start times.

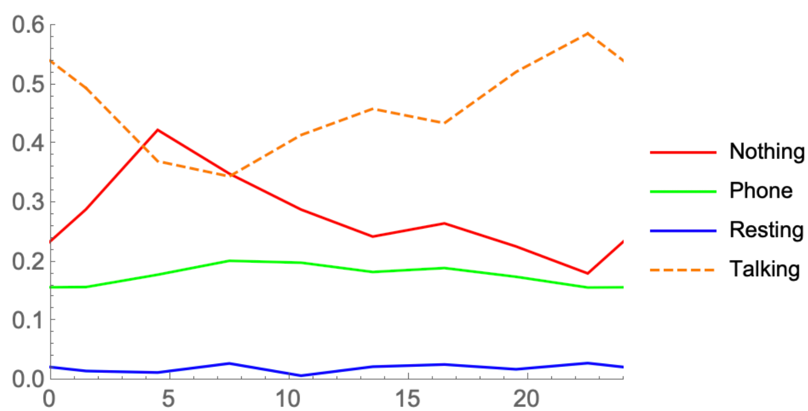


Figure 54. Passenger interaction activities by time of day, computed in three-hour bins. Passengers could be coded as engaging in more than one activity.

Table 45
Seat Back Angle by Time of Day

Time	<30 deg	≥30 deg
0-3:00	76.8%	23.2%
3-6:00	84.2%	15.8%
6-9:00	90.8%	9.2%
9-12:00	82.5%	17.5%
12-15:00	80.1%	19.9%
15-18:00	83.6%	16.4%
18-21:00	85.3%	14.7%
21-24:00	88.0%	12.0%

Vehicle Speed

The vehicle speed was recorded for each frame. Table 46 shows the percentage of frames across the range of speed categories. The prevalence of vehicle speed was essentially uniform across the range from zero to 80 mph. In 18% of frames, the vehicle speed was close to zero. The only salient difference in passenger interactions across speed categories (Table 47) was a greater prevalence of resting at highway speeds (>60 mph), although the prevalence of reclined seat back angles (≥30 deg) did not differ across speed categories.

Table 46
Distribution of Vehicle Speed

% of Frames	mph	kph
18.1%	<1	<1
21.1%	1-20	1-32
23.2%	21-40	33-65
17.3%	41-60	66-97
19.1%	61-80	98-130
0.9%	>80	>130
0.3%	Missing	Missing

Table 47
Passenger Interactions by Vehicle Speed (mph)

	Stopped	1-20 mph	21-40 mph	41-60 mph	61-80 mph	>80 mph
Talking	45.5%	51.1%	49.7%	46.6%	34.6%	41.1%
Nothing	22.9%	27.7%	27.3%	27.8%	23.9%	27.4%
Phone	21.4%	15.1%	15.9%	16.5%	24.9%	14.5%
Other	3.6%	2.5%	2.5%	2.8%	6.4%	3.2%
Food	2.6%	1.6%	1.7%	2.1%	2.2%	0.0%
None	2.3%	0.6%	0.7%	2.0%	0.8%	0.8%
Drink	0.9%	1.0%	0.7%	0.8%	0.7%	2.4%
Resting	0.8%	0.5%	1.6%	1.5%	6.5%	10.5%
SBA < 30˚	83.1%	85.8%	85.1%	84.7%	81.0%	85.2%
SBA ≥ 30˚	16.9%	14.2%	14.9%	15.3%	19.0%	14.8%

Additional Events

Events of interest that were not covered explicitly by the coding tool were entered using code words. Appendix B lists the frequency of these events that appeared in more than 0.5% of frames in several categories. Purses and other objects were placed on or adjacent to the passenger on the seat in about 7% of frames. The cupholder in the center console was in use more than 25% of the time; about 6% of the time it held a phone.

DISCUSSION

Overview

This study provides the first detailed examination of front-seat passenger behaviors using a naturalistic dataset. Passengers were usually seated nominally, neither reclined or unusually upright, but non-nominal postures were also observed a substantial portion of the time. In particular, the passenger's head was turned left or right, or tilted down, more than 35% of the time. The torso was pitched forward or leaning to one side about 15% of the time. More research is needed to determine whether these posture deviations from nominal may influence injury risk in crashes.

Passengers were observed to be interacting with a phone (generically, a handheld electronic device – the specific device type could not be determined) about 26% of the time. Phone use influenced posture, with the head more likely to be pitched downward (toward the lap) when the passenger was interacting with a phone (82% vs. 13% of time when no interaction was noted).

Seat position and seat back angle changed infrequently during travel, with seat movement observed in fewer than half (35, 47%) of vehicles. The seat was full-rear about 23% of the time, and forward of the middle of the seat track adjustment range less than 9% of the time. Highly reclined seat back angles (>30 degrees, or more than 1 standard deviation greater than the mean) represented only about 85% of travel time. Seat back angles greater than 35 degrees were observed in fewer than 0.7% of frames. The seat was less likely to be full rear if a passenger was sitting behind the front seat passenger, but the effect of the second-row passenger on mean seat position was only 5 mm, and seat back angle was only 1.5 deg more upright with a rear passenger.

Safety Considerations

The data showed a high percentage of belt use but many instances of obviously poor belt fit. Of greatest interest from a safety perspective are the situations that differ from the typical crash-test scenario with an ATD normally seated with the seat in either the middle fore-aft seat position or full forward.

The data indicate that non-nominal torso and head postures are common (around 15% and 30% of the time, respectively). As noted above, highly reclined postures (seat back angles greater than 30 degrees) are fairly rare in this dataset. The mean seat back angle of 25 degrees is similar to the back angles typically used in crash testing. However, the seat positions observed in this study were usually in the rear half of the seat track, with about 23% of passengers sitting at the rearmost position. A more-rearward seat position could change load sharing among the components of the restraint system during a frontal crash, in particular increasing belt loading while decreasing loading from the airbag and knee bolster. More research is needed to assess the possible implications for restraint system performance.

The data show that objects, particularly phones, are commonly held or placed in areas that may result in interaction with the occupants during crashes. The frequent use by passengers of the cupholder and seat to temporarily store these objects suggests a need for readily accessed storage that is tailored to commonly accessed objects other than cups and bottles.

Limitations

As the first large-scale, detailed characterization of front-seat passenger postures and activities, these data are the best available for predicting the activities of passengers in future driverless road vehicles. However, the biggest limitation is seen in Table 24, which shows that passengers were conversing with the driver or another passenger 46% of the time. In the US, vehicles have a single occupant (the driver) 58% of the time, so replacing these trips with a driverless vehicle would create a single passenger in the vehicle without a physically present conversation partner. In this scenario, the already common interaction with handheld devices might replace some or all of the conversation time. This possibility is supported by the relatively low prevalence of conversation relative to phone interactions in early-morning trips (3-6 AM).

These data are also limited by the sample of drivers, which is drawn from individuals who volunteered for a university study. Data were gathered from over 3085 trips taken by 306 unique front-seat passengers with a wide range of age and body size. A larger sample from the same population would have revealed more unusual behaviors but would be unlikely to substantially change the overall distributions.

The data collection was conducted in a small US city (Ann Arbor, Michigan), which likely has different traffic patterns from other metropolitan areas. However, the distribution of trip durations compares favorably with the nationally representative NHTS sample. The relatively northern latitude (42 degrees) and time of year for data collection (June through December), influenced the distribution of daylight trips, although no important differences in driver postures and behaviors were noted between trips in daylight and darkness.

Differences would be expected if sampling was conducted from a different population. An earlier pilot study used data from a naturalistic driving study with drivers classified as “risky” (Reed et al. 2019). In that study of 959 passenger trips, 77% of the front-seat passengers were male and the seat belt use rate was only 66%. Talking was a more common activity and phone use was lower than in the current study (10% vs. 27%).

The passenger was female in approximately 72% of the sampled frames, whereas an analysis of data from the US General Estimates System indicates that front seat passengers are female approximately 62% of the time (Klinich et al. 2019). The reasons for this difference in findings are unclear, but may have been related to the sampling strategy, which included a requirement that drivers regularly travel with passengers. More research will be needed to determine if drivers who regularly have passengers are more likely to have female passengers.

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APPENDIX A

Table A1. Vehicles

Make	**Model**	**Year**	**Category**
Chevy	Cruze	2011	Sedan
Chevy	Express	2017	Van
Chevy	Impala	2015	Sedan
Chevy	Malibu	2009	Sedan
Chevy	Malibu	2010	Sedan
Chevy	Malibu	2010	Sedan
Chevy	Malibu	2011	Sedan
Chevy	Sonic	2013	Sedan
Chevy	Tahoe	2012	SUV
Chevy	Trail Blazer	2007	SUV
Chevy	Traverse	2015	SUV
Chrysler	Town and Country	2014	Minivan
Dodge	Journey	2012	Minivan
Ford	Edge	2007	SUV
Ford	Edge	2008	SUV
Ford	Edge	2016	SUV
Ford	Escape	2011	SUV
Ford	Escape	2013	SUV
Ford	Escape	2013	SUV
Ford	Escape	2017	SUV
Ford	Escape	2017	SUV
Ford	Escape	2019	SUV
Ford	Expedition	2017	SUV
Ford	Explorer	2016	SUV
Ford	Fiesta	2012	Sedan
Ford	Fiesta	2013	Sedan
Ford	Flex	2014	SUV
Ford	Flex	2019	SUV
Ford	Fusion	2009	Sedan
Ford	Fusion	2010	Sedan
Ford	Fusion	2011	Sedan
Ford	Fusion	2013	Sedan
Ford	Fusion	2015	Sedan

Ford	Fusion	2015	Sedan
Ford	Fusion	2017	Sedan
Ford	Fusion	2018	Sedan
Ford	Lincoln MKT	2010	SUV
Ford	Mountianer	2002	SUV
GM	Torrent	2009	SUV
Honda	Accord	2011	Sedan
Honda	Accord	2012	Sedan
Honda	Civic	2005	Sedan
Honda	Civic	2017	Sedan
Honda	Escape	2010	SUV
Honda	Odyssey	2008	Minivan
Honda	Odyssey	2019	Minivan
Hyundai	Santa Fe	2013	SUV
Kia	Sedona	2012	Minivan
Kia	Soul	2013	SUV
Kia	Soul	2013	SUV
Kia	Soul	2017	SUV
Mazda	CX5	2015	Sedan
Mazda	Mazda 3	2010	Sedan
Nissan	Altima	2014	Sedan
Nissan	Altima	2015	Sedan
Nissan	Murano	2017	SUV
Nissan	Pathfinder	2015	SUV
Nissan	Pathfinder	Missing	SUV
Nissan	Rogue	2018	SUV
Nissan	Rogue	2018	SUV
Nissan	Rogue Sport	2017	SUV
Nissan	Sentra	2017	Sedan
Nissan	Xterra	2007	SUV
Subaru	BRZ	2013	Sedan
Subaru	Forester	2016	SUV
Subaru	Forester	2017	SUV
Subaru	Forrester	2010	SUV
Toyota	Camry	2005	Sedan
Toyota	Camry	2013	Sedan
Toyota	Corolla	2006	Sedan
Toyota	Corolla	2008	Sedan
Toyota	Rav4	2014	SUV
Toyota	Rav4	2015	SUV

Toyota	Rav4	2016	SUV
Toyota	Sienna	2010	Minivan

Sedan	31
SUV	37
Minivan	6
Full-Size Van	1
Total	75

Appendix B

Additional Events Appearing in 0.5% or More of Frames

Table B1. Passenger Lap Events

Event	**N**	**Percent of Frames**
FrontPass Lap Center Phone	1018	7.5%
FrontPass Lap Center Purse	750	5.5%
FrontPass Lap Left Phone	409	3.0%
FrontPass Lap Center Bag	409	3.0%
FrontPass Lap Center Blanket	265	1.9%
FrontPass Lap Center OtherObject	214	1.6%
FrontPass Lap Center Backpack	172	1.3%
FrontPass Lap Center Book	164	1.2%
FrontPass Lap Center Pillow	159	1.2%
FrontPass Lap Center Jacket	155	1.1%
FrontPass Lap Left Charger	141	1.0%
FrontPass Lap Right Phone	135	1.0%
FrontPass Lap Center Paper	127	0.9%
FrontPass Lap Right Purse	119	0.9%
FrontPass Lap Center Food	115	0.8%
FrontPass Lap Center Wallet	110	0.8%
FrontPass Lap Left Bag	104	0.8%
FrontPass Lap Center Box	87	0.6%
FrontPass Lap Center Charger	87	0.6%
FrontPass Lap Left Purse	87	0.6%
FrontPass Lap Right Jacket	72	0.5%

Table B2. Passenger Hand Events

Event	N	%
FrontPass Hand Right HandLeftSelf	1139	8.4%
FrontPass Hand Left HandRightSelf	996	7.3%
FrontPass Hand Left Face	356	2.6%
FrontPass Hand Left Purse	305	2.2%
FrontPass Hand Right Face	259	1.9%
FrontPass Hand Right Purse	236	1.7%
FrontPass Hand Left Paper	213	1.6%
FrontPass Hand Left Phone	203	1.5%
FrontPass Hand Right Phone	185	1.4%
FrontPass Hand Left OtherObject	183	1.3%
FrontPass Hand Left DriverHandRight	160	1.2%
FrontPass Hand Right Paper	153	1.1%
FrontPass Hand Right OtherObject	144	1.1%
FrontPass Hand Left Bag	142	1.0%
FrontPass Hand Right Bag	134	1.0%
FrontPass Hand Right Book	106	0.8%
FrontPass Hand Right SeatPass	93	0.7%
FrontPass Hand Right UpperDoorHandle	88	0.6%
FrontPass Hand Right Pillow	85	0.6%
FrontPass Hand Left Seatbelt	82	0.6%
FrontPass Hand Left ForearmRight	78	0.6%
FrontPass Hand Right DoorHandle	75	0.5%

Table B3. Passenger Phone Events

Event	N	%
FrontPass Lap Center Phone	1018	7.5%
FrontPass Lap Left Phone	409	3.0%
FrontPass Hand Left Phone	203	1.5%
FrontPass Hand Right Phone	185	1.4%
FrontPass Thigh Left Phone	152	1.1%
FrontPass Lap Right Phone	135	1.0%
FrontPass Thigh Right Phone	98	0.7%

Table B4. Cupholder Events

Event	N	%
Cupholder Inside Center Cup	3367	24.7%
Cupholder Inside Center Bottle	1866	13.7%
Cupholder Inside Center Can	971	7.1%
Cupholder Inside Center Phone	794	5.8%
Cupholder Inside Center Object	762	5.6%
Cupholder Inside Front Drink	614	4.5%
Cupholder Top Center Object	392	2.9%
Cupholder Top Center Bottle	390	2.9%
Cupholder Inside Back Drink	383	2.8%
Cupholder Top Center Cord	234	1.7%
Cupholder Inside Center Paper	174	1.3%
Cupholder Top Center Phone	174	1.3%
Cupholder Top Center Bag	133	1.0%
Cupholder Top Center Paper	131	1.0%
Cupholder Inside Center Charger	96	0.7%
Cupholder Top Center Charger	94	0.7%
Cupholder Inside Left Drink	78	0.6%
Cupholder Inside Drink	74	0.5%
Cupholder Inside Right Drink	71	0.5%
Cupholder Inside Center Mug	69	0.5%

Table B5. Passenger Seat Events

Event	**N**	**%**
FrontSeat Pan Left Purse	402	2.9%
FrontSeat Pan Left Bag	153	1.1%
FrontSeat Pan Center Phone	137	1.0%
FrontSeat Floor Center Backpack	130	1.0%
FrontSeat Floor Center Bag	114	0.8%
FrontSeat Pan Left Object	107	0.8%
FrontSeat Pan Left Phone	107	0.8%
FrontSeat Floor Left Bag	95	0.7%
FrontSeat Floor Center Cane	86	0.6%