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ABSTRACT

Improvements in the accessibility and ease of use of seatbelts require an understanding of driver belt donning behavior. Participants in a study of driving posture were videotaped as they put on their belts in their own vehicles, either an SUV or a midsize sedan. The participants were unaware that the purpose of the videotaping was related to the seatbelt. Videos from 95 men and women were analyzed to identify several categories of belt-donning behavior and to analyze the influence of body dimensions. The results have applicability to seatbelt system design, including the use of human figure models to assess seatbelt accessibility.

INTRODUCTION

Seat belt accessibility and ease of donning are issues that may influence drivers' willingness to use seatbelts. In assessing potential improvements in seat belt accessibility, vehicle manufacturers are attempting to use digital human figure models to simulate belt donning. The movements of individual people donning belts are used to drive the movements of the figure model. The value of these simulations is substantially limited by a lack of information about the distribution of belt donning behaviors in the driving population. No previous publications address belt donning behavior quantitatively.

This paper reports the characteristics of belt donning behavior for people in their own vehicles who were participating in a study of driving posture. The overall sequence of belt donning is described, and differences in donning behavior are analyzed in relation to driver gender and body dimensions.

METHODS

Ninety-five participants in a study of driving posture were videotaped as they put on their belts in their own vehicles, either a sports utility vehicle (SUV) or a midsize sedan. (Table 1). The vehicles were the 2000-2001 Ford Taurus, and Mercury Sable, and the 1999-2001 Ford Expedition and Lincoln Navigator. The driver position in all vehicles had a three-point belt with a sliding latch-plate and an emergency locking retractor. The seats had fore-aft, vertical and cushion angle adjustment.

Table 1
Drivers by Category

	Vehicle Type		
	Cars	SUVs	Total
Men	19	19	38
Women	30	27*	57
Total	49	46	95

* Eight of the female SUV drivers did not own the vehicle in which they were observed.

The participants gave written informed consent after having the test procedures for the posture study explained to them and being informed that they would be video-taped entering their vehicles. The participants then drove their vehicles to an area in the testing facility where a stall for vehicle measurements was prepared. With the driver still in the vehicle, a platform supporting a FARO arm was placed under the edge of the vehicle and jacked up slightly to wedge the platform between the floor and the vehicle. Three-dimensional locations of the driver's shoulder and the pivot point of the seat belt D-ring were measured using the FARO along with other points important to the study of driver posture. A coordinate system for the FARO Arm measurements was established on the floor of the stall near the location of the vehicle front door.

The participant then exited the vehicle, and the investigator measured each participant's weight, erect sitting height and stature without shoes. The investigator listed the seat location, steering wheel tilt, headrest height, mirrors and D-ring height as possible adjustment options. This was the only time seatbelts were mentioned during the introduction.

Each participant was asked to enter the vehicle for a test drive and was reminded to adjust the seat and other components until comfortable. The video recorder was started as the driver prepared to enter the vehicle. If a participant did not don the seat belt during the course of preparing to drive, the investigator reminded them to do so, indicating that belt use is mandatory in Michigan and emphasizing driving safety.

RESULTS

The videos of belt donning behavior were scored using the questions in Appendix A and B. Twenty randomly selected videos were scored by one investigator twice and a second investigator once. The inter-observer and intra-observer reliability of the scored questions was evaluated by the percentage of questions that were coded the same way and by Cohen's kappa which takes chance matches into account (Sanderson and Fisher 1997). A percentage agreement with a minimum of 85% and a kappa over 0.6 is considered a "good" agreement (Altman, 1991). Only questions that met this criteria were used to evaluated belt donning behavior.

The sequence of seat belt donning events followed a grasping, deploying, buckling, and adjusting sequence as shown in Figure 1. During grasping, the participant reached for then grasped the belt with one hand. Thirty-six percent of the participants touched the latch-plate while grasping; 64% grasped the only webbing located either above or below the latch-plate. Eighty-six percent of the participants grasped the belt initially with their left hand, the hand on the same side as the belt. Only 14% reached across their bodies to grasp with the right hand. Seventy-four percent of the participants grasped the belt at the same point at which they first made contact with the belt. Before grasping, the sliding latch-plate was located on the belt below the window level in all of the cars. In the SUVs, the latch-plate was located next to the D-ring 85% of the time. Participants grasped the belt above the shoulder (47%), between the shoulder and window sill (37%) and below the window sill (16%). These percentages did not differ between vehicle types (χ^2=1.77, df=2, p=0.41).

After grasping the belt, the participants pulled the webbing out of the retractor along the left side or in front of their torsos. Then, in all but one observed case, the participants switched the belt to the opposite hand. The change of hands resulted in the right hand being on the latch-plate and the left hand being on the webbing. The hands remained in this configuration as they pulled more belt out of the retractor.

The participants then secured the latch-plate in the buckle. All but one of the observable participants buckled the belt with the right hand while the left hand held the webbing. Most of the belt adjustments were on the shoulder portion of the belt and were made using the left or both hands. Three people tucked the shoulder portion of the belt under the left arm.

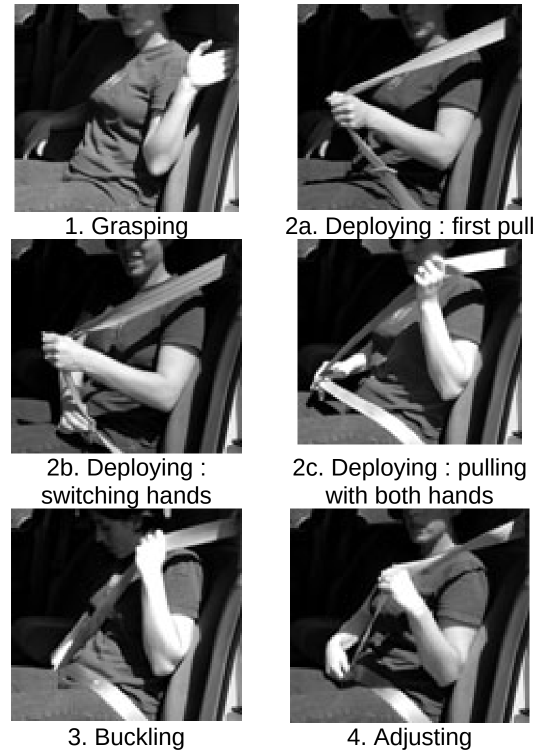

Figure 1. Characterization of the typical seat belt donning sequence.

There were interesting differences in grasp behavior among the 86% who grabbed the belt with the left hand. The orientation of the hand during grasping was described by the direction the plane of the palm was facing and by a line connecting the knuckles and traveling out towards the thumb. Figure 2 illustrates these orientations. The form asked the scorer to describe the orientation of the line of the knuckles and of the plane of the palm as either facing forward, rearward, upward, downward, inboard or outboard.

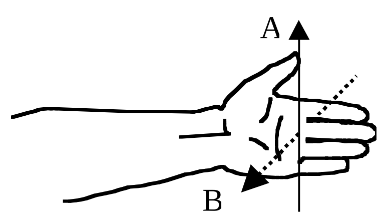

Figure 2. Hand orientation. A = a line connecting the knuckles and traveling out towards the thumb, B = the direction the plane of the palm was facing

The nine distinct hand orientations that were observed are listed in Appendix B. Figure 3 shows the distribution of grasp by hand and primary hand orientation. Photos in Figures 4 and 5 demonstrate the hand orientations. Sixty-one percent of left-hand grasps occurred with the hand in the LEFT-UP orientation, and 39% in the LEFT-DOWN orientation. The most frequently occurring hand grasp posture was with the knuckle line pointing upward and the palm facing outboard.

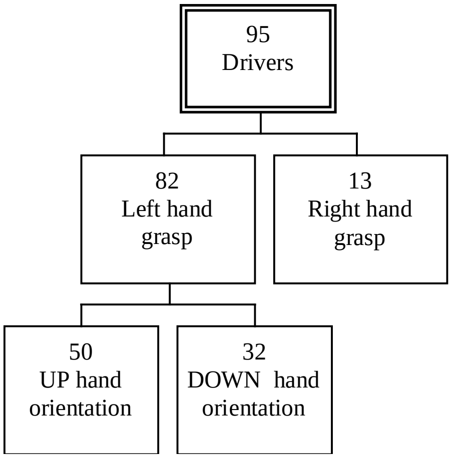

Figure 3. The number of participants who grasped the belt with the right versus left hand, and the number of with LEFT-UP and LEFT-DOWN hand orientations.

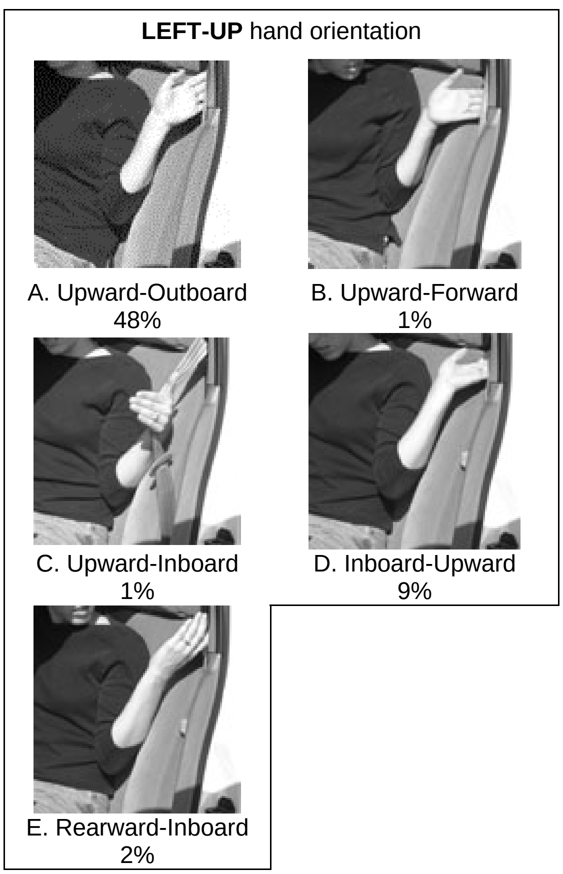

Figure 3a. Illustrations of hand orientations during left hand grasp behavior (knuckle 0rientation – palm orientation) with the arm rotated UP. The percentage of each orientation among people who grasped with the left hand (86 percent of all drivers) is listed.

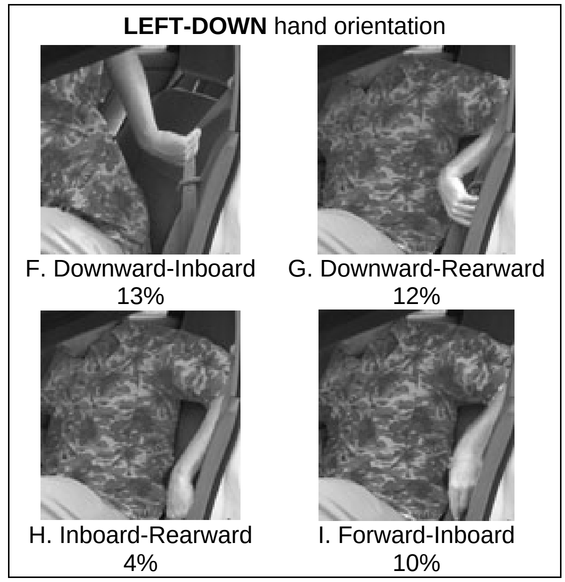

Figure 3b. Illustrations of hand orientations during left hand grasp behavior (knuckle 0rientation – palm orientation) with the arm rotated DOWN. The percentage of each orientation among people who grasped with the left hand (86 percent of all drivers) is listed.

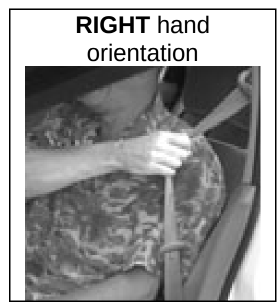

Figure 4. Illustration of grasping the belt with the right hand.

Grasp behavior was influenced by occupant characteristics, but did not differ between vehicle categories. There were significant differences related to gender and body dimensions.

Gender Twenty-six percent of male drivers and five percent of female drivers initially grasped the belt with their right hand (χ^2=6.866, df=1, $p<0.05$)[1]. The frequencies of the three hand orientations were different for females and males (χ^2=34.74, df=2, $p<0.05$) as shown in Figure 3. (Cell totals were not large enough to analyze car and SUV drivers separately.)

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[1] In 2 x 2 chi-square tests in which one of the cell counts was less than 5, Yate's correction was employed.

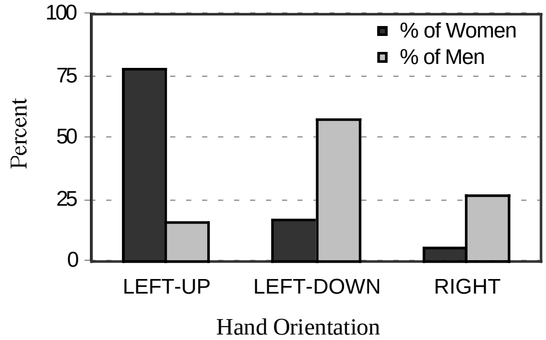

Figure 3. Percentage of men and women in all vehicles with LEFT-UP, LEFT-DOWN, and RIGHT hand orientations.

Vehicle Type The same proportion of car drivers than SUV drivers initially grasped the belt with their left hands (χ^2 =2.787, df=1, p=0.10) as shown in Figure 4. Also the proportion of people who had LEFT-UP, LEFT-DOWN and RIGHT hand orientations was the same (χ^2 =4.00, df=2, p=0.14) for both vehicle types.

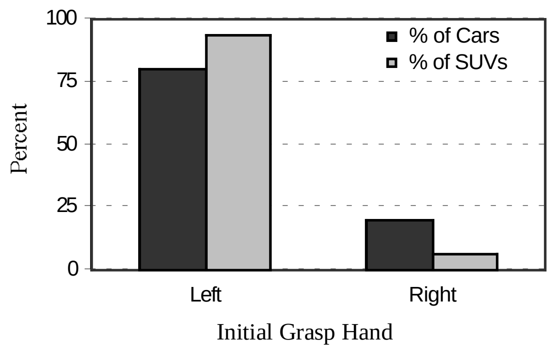

Figure 4. Percentage of car and SUV drivers who initially grasped the belt with the left and right hand.

Body Dimensions. The car and SUV groups did not differ significantly in stature, erect sitting height or body mass index (BMI= kilograms mass / millimeters stature squared). A greater proportion of smaller people than larger people grasped the belt with the LEFT-UP orientation as shown in Figure 5.

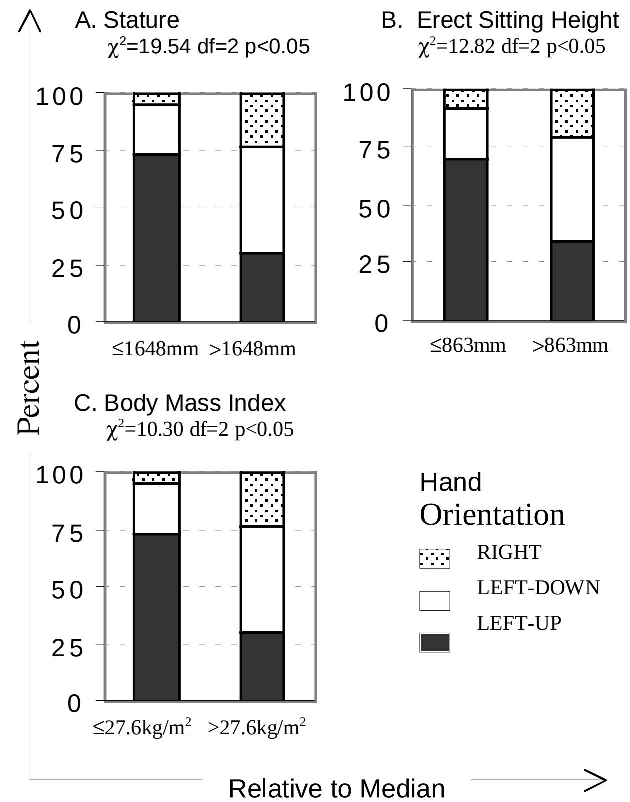

Figure 5. Percentage of participants below and above the median stature, erect sitting height, and BMI who grasped the belt with UP, DOWN, and RIGHT hand orientations. Left and right columns summarize results from 48 and 49 people, respectively.

Vehicle Geometry The shoulders of the participants were closer to the D-ring in the cars than in the SUVs as listed in Table 2. Figure 6 shows that people whose left shoulder was closer to the D-ring were more likely to grasp the belt with the LEFT-DOWN hand orientation. The sample size was not large enough assess D-ring position effects within vehicle category.

Table 2
Comparison of D-ring Proximity to Shoulders of Participants in Cars and SUVs

	Cars	SUVs	Cars Versus SUVs
Measures	Mean ± S.D.	Mean ± S.D.	t-test (df=93)
Shoulder to D-ring (mm)	236 ± 41	277 ± 65	t = -3.684 p < 0.05
Horizontal distance between D-ring and shoulder (mm)	170 ± 46	195 ± 57	t =-2.323 p < 0.05
Vertical distance between D-ring and shoulder (mm)	132 ± 41	161 ± 50	t = -3.084 p < 0.05

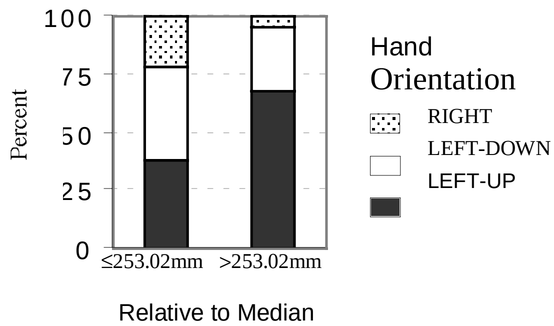

Figure 6. Percentage of participants below and above the median 3 dimensional shoulder to D-ring distance who grasped the belt with UP, DOWN, and RIGHT hand orientations (χ^2=10.38, df=2, $p<0.05$).

SUMMARY AND DISCUSSION

Prior to conducting this study, an informal survey of people suggested that most people believe that they, and most other people, grasp the belt with their right hand by reaching ove r their left shoulder. The most surprising observation of this study was that the right-hand graspers were a clear minority, and that the belt donning behavior is a complicated, two-handed process for most people.

The sequence of belt donning was the same for most drivers. Following the grasp (usually with the left hand), there was a deployment stage during which the belt was pulled from the retractor and while the right hand grasped the latch plate. There was considerable variability and idiosyncrasy in the deployment stage, with drivers using a combination of visual and tactile search to locate the latchplate. Once the latch plate was grasped by the right hand, the buckling and adjustment sequence proceeded similarly for all drivers.

Smaller people, mainly women, were more likely to use a LEFT-UP hand orientation to grasp the belt, while larger people, mainly men, were more likely to use a LEFT-DOWN hand orientation. A shorter distance between participants' shoulders and the D-ring (more rearward and higher shoulder locations) corresponded to more LEFT-UP hand orientations.

This study is limited primarily by the restriction of vehicle geometry. In particular, the starting location of the belt relative to the driver's sitting position can be expected to affect the donning tactics. The observation that more men than women used a right-hand grasp may be due more to the more rearward seat positions of the men than to arm-length differences. A more systematic study of belt location effects will be needed to clarify these effects.

Assessments of belt accessibility and donning difficulty should take into account the range of belt donning behavior. For the majority of drivers who grasp the belt with the left hand, the clearance between the seat and B-pillar and the interference posed by the seat are important. The hanging position of the latchplate may be less important, since a hand-switch phase is required, during which the latchplate can be located with the right hand.

Simulations of belt donning behavior using digial human figure models should include all of the major donning behaviors. Spatial interference with the seat and B-pillar clearly affected drivers movements, as did the visual search for the belt, latchplate, and buckle. Simulations must address these issues to provide realistic assessments of the likely effects of design changes on belt accessibility and donning difficulty.

ACKNOWLEDGEMENTS

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APPENDIX A

Answers to Scoring Form Questions and the Percentage and Observer (N=2) Reliability

Question	Possible answers	Answer count			Scoring agreement			
					Inter-observer		Intra-observer	
		Car	SUV	Total	%	k	%	k
Before belt donning, the latch-plate was located	1. Next to Dring	0	39	**39**	100	1.00	100	1.00
	2. Above the top of shoulder but not next to Dring	0	1	**1**				
	3. Below shoulder but above window level	0	4	**4**				
	4. Below window level	49	2	**51**				
The hand that initially grasped the belt	1. Right hand	10	3	**13**	100	1.00	100	1.00
	2. Left hand	39	43	**82**				
Initial hand contact with the belt before grasping the belt was	1. At the same point as where the belt is grabbed	35	32	**67**	90	0.77	100	1.00
	2. Above the point where the belt is grabbed	10	3	**13**				
	3. Below the point where the belt is grabbed	2	8	**10**				
During the grasp the hand was	1. Touching the latch plate	9	25	**34**	95	0.91	100	1.00
	2. Above the latch plate on the belt	40	5	**45**				
	3. Below the latch plate on the belt	0	16	**16**				
The initial grab (relative to normal sitting) position was made…	1. Above the top of the shoulder	20	25	**45**	85	0.72	85	0.75
	2. Below the shoulder but above window level	20	15	**35**				
	3. Partially or completely below window level	9	6	**15**				
The information concerning the orientation of the hand grasping the belt is addressed in Appendix B.								
After the first pull on the belt, the pulling hand was located..	1. To the left of the subject's torso	38	17	**55**	85	0.67	85	0.68
	2. To the right of the subject's torso	0	1	**1**				
	3. In front of the subject's torso	11	28	**39**				
Switched belt to non-grasping hand	1. Yes	44	42	**86**	100	1.00	85	0.68
	2. No	5	3	**8**				
The 1st time the belt changes hands, the opposite hand grasped	1. Latch-plate	33	31	**64**	95	0.86	100	1.00
	2. Belt and feels for the latch-plate	9	11	**21**				
Left hand pulled from retractor while right was on latch-plate	1. Yes	47	45	**92**	95	0.64	89	0.79
	2. No	2	0	**2**				
Hand on Latch-plate while buckling	1. Right	48	45	**93**	100	1.00	94	0.63
	2. Left	0	1	**1**				
Other hand on belt while buckling?	1. Yes	48	44	**92**	90	0.90	100	1.00
	2. No	0	0	**0**				
Adjustment of belts	1. Adjustment of shoulder portion only	31	36	**67**	100	1.00	90	0.90
	2. Adjustment of lap portion only	1	0	**1**				
	3. Adjustment of both lap and shoulder segments	4	0	**4**				
Adjustment hand	1. Adjustment with right hand only	3	1	**4**	90	0.84	95	0.92
	2. Adjustment with left hand only	19	17	**36**				
	3. Adjustment with both hands	15	18	**33**				

APPENDIX B

Orientation of the Line of the Knuckles and the Plane of the Palm at Belt Grasp

Donning Hand	Photo Letter	Knuckle Orientation Inter=95%, k=0.95 Intra=100%, k=1.00	Palm Orientation Inter=85%, k=0.78 Intra=95%, k=0.92	Car	SUV	Total	Hand Orientation
LEFT	A	Upward	Outboard	20	19	39	UP
	B	Upward	Forward	1	0	1	
	C	Upward	Inboard	0	1	1	
	D	Inboard	Upward	2	5	7	
	E	Rearward	Inboard	0	2	2	
			Total	**23**	**27**	**50**	
	F	Downward	Inboard	6	5	11	DOWN
	G	Downward	Rearward	4	6	10	
	H	Inboard	Rearward	0	3	3	
	I	Forward	Inboard	6	2	8	
			Total	**16**	**16**	**32**	
	Left Hand Total			**39**	**43**	**82**	UP and DOWN
RIGHT	**Right Hand Total**			**10**	**3**	**13**	RIGHT