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Driver Preference for Fore-Aft Steering Wheel Location

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ABSTRACT

The fore-aft location of the steering wheel relative to the pedals is a critical determinant of driving posture and comfort. Current SAE practices lack quantitative guidance on steering wheel positioning. This paper presents a model of subjective preference for fore-aft steering wheel position across a range of seat heights. Sixty-eight men and women evaluated the steering wheel positions in a total of 9 package conditions differentiated by seat height and fore-aft steering wheel position. Numerical responses were given on a 7-point scale anchored with the words “Too Close”, “Just Right”, and “Too Far”. A statistical analysis of the results demonstrated that the preferred fore-aft steering wheel position was affected by seat height and driver stature. An ordinal logistic regression model was created that predicts the distribution of subjective responses to steering wheel location. The model can be used to calculate the preferred steering wheel position for individuals or populations. The results were compared to distributions of steering wheel locations in 86 vehicles.

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INTRODUCTION

The comfort and safety of drivers is strongly influenced by the layout of the primary controls in relation to the seat adjustment range and the vehicle structure. The steering wheel location relative to the pedals usually has a much smaller adjustment range than the seat position, and hence the steering wheel position is a major determinant of how the driving “package” feels to the driver.

The standards and recommended practices for vehicle interior packaging developed by the Society of Automotive Engineers (now SAE International) measure driver workstation dimensions from reference points defined near the accelerator pedal. The accelerator heel point (AHP) is a point on the depressed carpet surface near the accelerator pedal that is used as the original for vertical measurements of seat height (SAE H30) and steering wheel height (SAE H17). Many fore-aft dimensions are referenced to the ball-of-foot reference point (BOFRP), which is a point near or on the surface of the accelerator pedal. The procedures for locating and using these points are described in detail in SAE J4002, J4003, and J4004. Prior to the development of these practices, pedal reference points were defined in SAE J1516 (J1516 now applies only to Class-B vehicles, i.e., heavy trucks and buses).

SAE L6 is the fore-aft location of the steering wheel center relative to the BOFRP (see SAE J1100). SAE standards and recommended practices provide quantitative guidance on designing seat track adjustment ranges (SAE J4004), but do not provide information on the steering wheel locations that drivers prefer. To address this issue, subjective ratings of steering wheel fore-aft position were obtained from participants in a laboratory study of driving posture. The results were analyzed to predict the distribution of subjective responses. The resulting model can be used to predict the preferred steering wheel position.

METHODS

As part of a larger laboratory study [1], sixty-eight men and women with a wide range of body size, ranging from less than 5th-percentile female to greater than 95th-percentile male stature relative to the U.S. population, evaluated the fore-aft steering wheel positions in each of 9 packages. Table 1 lists the packages. In each condition, the participant selected his or her preferred seat position on an unrestricted fore-aft track and adjusted the seat back angle (no seat height or seat cushion angle adjustment) prior to providing a numerical rating on the scale shown in Figure 1. The entire sitting period prior to rating was less than five minutes in each condition. Drivers were directed toward a horizontal vision target but no driving simulation was performed. Drivers did not conduct any reach or secondary tasks prior to rating.

Table 1. Package Conditions

Package	H30	L6 (mm)
1	180	650
2	180	550
3	270	650
4	270	600
5	270	550
6	270	500
7	270	450
8	360	550
9	360	450

Too Close			Just Right			Too Far
1	2	3	4	5	6	7

Figure 1. Rating scale for steering wheel position.

A statistical analysis using ordinal logistic regression was conducted to predict the distribution of subjective responses as a function of steering wheel position (L6), other package dimensions, such as seat height (H30), and driver attributes. Due to relatively few responses at the extremes of the scale, responses 1, 2, and 3 were counted as "too close", response 4 as "just right", and responses 5, 6, and 7 as "too far". Using the resulting models, the predicted most-preferred steering wheel position for 86 vehicles was compared to the measured position.

RESULTS

Statistical Analysis of Driver Ratings

Stature, L6, seat height (H30), and seat height squared were significantly related to subjective response. Table 2 shows the ordinal logistic model.

Table 2. Ordinal Logistic Model

Whole Model Test

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	160.42181	4	320.8436	<.0001*
Full	743.40932			
Reduced	903.83114			

RSquare (U)*	0.1775
AICc*	1498.91
BIC*	1527.74
Observations	916

Table 2 (cont). Ordinal Logistic Model

Parameter Estimates

Term	Estimate	Std Error	ChiSquare	Prob>ChiSq
Intercept[-1]	-6.1239	1.8453	11.01	0.0009*
Intercept[0]	-2.7026	1.8279	2.19	0.1393
H30	-0.01854	0.009809	3.57	0.0587
H30^2	0.00004958	1.7962e-5	7.62	0.0058*
Stature	-0.003441	0.0005738	35.96	<.0001*
L6	0.021182	0.001398	229.28	<.0001*

* The RSquare value is a measure of goodness of fit. RSquare values are generally much lower in logistic regression models than in traditional linear models with continuous dependent measures. AIC is the Akake Information Criterion, a measure of goodness of fit. BIC is the Bayesian Information Criterion, which penalizes additional parameters more than the AIC.

The implementation of the model is as follows. The linear portion of the logistic model is given by $\phi = -0.003441$ *Stature* + 0.02118 *L6* − 0.01854 *H30* + 0.00004958 $H30^2$ for driver stature and H30 in mm. The cumulative probability of "too close" is given by

$$P_{-1} = \frac{1}{1 + e^{-(-6.1239) - \phi}}$$

And the probability of "just right" or "too close" is given by:

$$P_0 = \frac{1}{1 + e^{-(-2.7026) - \phi}}$$

Then $P_{too\_close} = P_{-1}$, $P_{just\_right} = P_0 - P_{-1}$, and $P_{too\_far} = 1 - P_0$.

Figure 2 shows the effect of L6 on the rating probabilities for stature of 1750 mm (approximately median U.S. male) and H30 of 270 mm (typical of a midsize sedan). For this seat height, the largest proportion of "just right" evaluations (70%) occurs with an L6 value of 558 mm.

Figure 3 demonstrates that the ratings are somewhat affected by driver stature, but the effect is relatively small. The largest effects are in the "too close" and "too far" categories, with the expected trends. At an H30 value of 270 mm, an L6 value of 550 mm is much more likely to be judged as "too close" by shorter-statured drivers than by taller-stature drivers.

The H30 effect in Figure 4 shows nonlinearity and generally a much weaker effect than expected. The percentage of drivers rating an L6 value as "just right" is predicted to be approximately the same through a large range of H30 values. Only above H30 = 325 mm does the fraction of predicted "just right" responses drop appreciably.

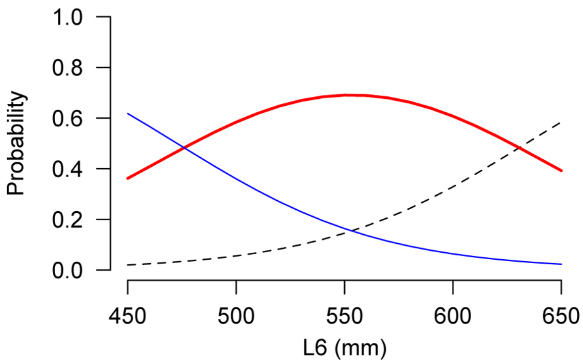

Figure 2. Effects of L6 on driver rating of steering wheel location for drivers 1750 mm tall at an H30 of 270 mm. Thick (red) line is the probability of rating the steering wheel location as "just right", the thin (blue) line is the probability of rating "too far" and the dashed line is the probability of rating "too close".

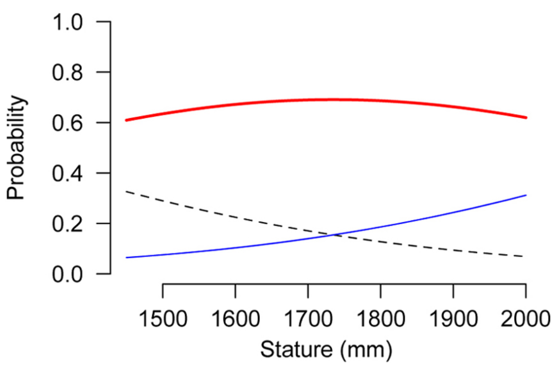

Figure 3. Effects of stature on driver rating of steering wheel location for L6 = 550 mm and H30 = 270 mm. Thick (red) line is the probability of rating the steering wheel location as "just right", the thin (blue) line is the probability of rating "too far" and the dashed line is the probability of rating "too close".

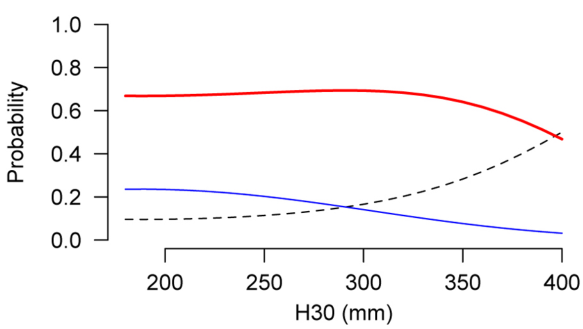

Figure 4. Effects of H30 on driver rating of steering wheel location for L6 = 550 mm and stature = 1750 mm. Thick (red) line is the probability of rating the steering wheel location as "just right", the thin (blue) line is the probability of rating "too far" and the dashed line is the probability of rating "too close".

Comparison with Vehicle Data

In a separate study, the dimensions of a large number of vehicles were measured. No driver testing was performed in these vehicles. Figure 5 shows H30 and L6 from 86 passenger cars, light trucks, SUVs, and minivans listed in Appendix A. Pedal reference points and Seating Reference Point (SgRP) were found using J4003-2004 procedures. For the range of seat heights, the optimal L6 was computed using the logistic regression model for a mean population stature of 1692 mm, approximately the mean of the U.S. adult population (see http://www.cdc.gov/nchs/nhanes.htm). Figure 5 shows the resulting curve. In addition, the fraction of the U.S. adult population predicted to rate the fore-aft steering wheel position as "just right" was computed for each vehicle. For 40 vehicles (47%), the fraction predicted as rating the steering wheel position as "just right" was between 068 and 0.7, essentially the maximum possible for this model. Only 6 vehicles had predicted "just right" fractions below 0.6. The lowest predicted "just right" fraction was 0.38 for the outlying vehicle to the right in Figure 5.

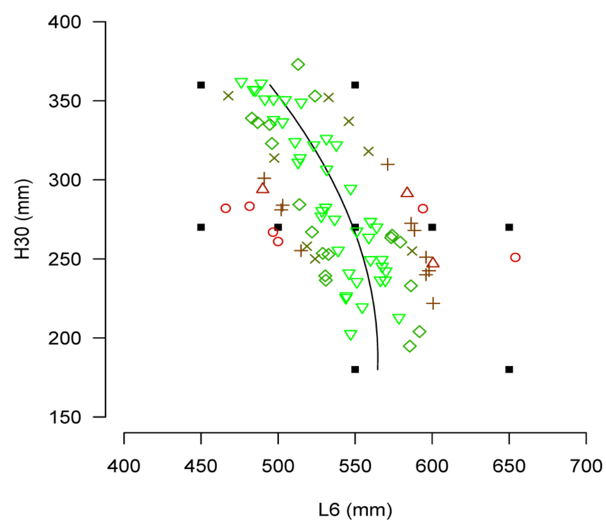

Figure 5. H30 and L6 for 86 vehicles measured at UMTRI. Optimal L6 as a function of H30 based on the current analysis is shown as a curve. Test conditions from the driver response data are shown as filled squares. Vehicle symbols and colors show the predicted fraction of "just right" ratings from 0.68 to 0.7 (inverted triangles), 0.66 to 0.68 (diamonds), 0.64 to 0.66 (x), 0.62 to 0.64 (+), 0.6 to 0.62 (triangles) to less than 0.6 (circles).

DISCUSSION

These results are the first available to quantify drivers' preferred steering wheel positions using subjective responses. The results are broadly consistent with a large sample of current vehicles; in only a few vehicles is the fore-aft steering-wheel position more than 50 mm from the preference line given by the current data.

The stature effect in the model was relatively small, suggesting that postural variables such as elbow angle are probably not strongly related to preference for steering-wheel position. Steering wheel height was not varied independent of H30 in this study, so the independent influence of steering wheel height and fore-aft position could not be explored. Unexpectedly, the subjective responses for the same L6 values differed little for H30 values of 180 and 270 mm.

The study is limited by the laboratory setting, although the posture results from the study have previously been validated against in-vehicle data [2]. Drivers also experienced each condition for less than five minutes, which may not have been sufficient for them to develop a strong subjective evaluation. Most new vehicles sold in the U.S. are equipped with tiltable steering wheels and many have telescoping wheels, but neither feature was investigated in the current study. Nonetheless, these results could be used as a guide for locating the steering wheel adjustment range.

As shown in Figure 5, the test conditions spanned the range of combinations of H30 and L6 for modern vehicles. Exposure to this large range of conditions may have reduced the drivers' sensitivity to small differences. Moreover, the test conditions may have tended to "center" the drivers responses, leading to the "just right" conditions being located near the middle of the matrix. However, the matrix was constructed based on current practice in vehicles, which also can be presumed to have some merit as a measure of what drivers prefer.

In future work, driver's preferences for steering wheel location could also be assessed by magnitude production trials, in which drivers adjust the steering wheel to their preferred position. The disadvantage of that approach is that it does not produce an estimate of the subjective cost of deviating from the preferred position.

REFERENCES

1. Reed, M.P., Manary, M.A., Flannagan, C.A.C., and Schneider, L.W. The effects of vehicle interior geometry and anthropometric variables on automobile driving posture. *Human Factors*, 42 (4): 541-552, 2000.

2. Reed, M.P., Manary, M.A., Flannagan, C.A.C., and Schneider, L.W. A statistical method for predicting automobile driving posture. *Human Factors*, 44 (4): 557-568, 2002.

APPENDIX

APPENDIX A: VEHICLE DIMENSION DATA

Make	Model	Year	H30 (mm)	L6 (mm)	H17 (mm)
Ford	Taurus LX	2001	264	559	626
Chevy	Silverado LS	2000	307	532	734
Dodge	Caravan	2005	336	487	692
Honda	Civic EX	2004	225	544	617
Honda	CRV	2003	314	514	662
Buick	Regal	2003	268	589	656
Ford	Ranger	2000	261	579	641
Chevy	Impala	2004	236	570	637
Ford	Focus	2001	267	497	691
VW	Passat	2002	237	531	633
Mercury	Mountaineer	2002	291	584	637
Toyota	Corolla	2003	283	482	647
Oldsmobile	Intrigue	2002	282	594	643
Mazda	6	2004	249	560	647
Saturn	S-Series	2002	204	592	598
Cadillac	Deville	2004	233	586	627
Toyota	Sienna LE	2004	362	476	707
Mazda	Protégé	2003	280	529	658
Toyota	Tacoma	2002	239	531	637
Nissan	Altima 3.5 SE	2003	275	537	647
Ford	Freestyle	2005	337	503	713
Jeep	Liberty	2002	352	533	695
Toyota	Camry	2002	255	539	627
Chevy	Malibu	2003	250	567	630
Infinity	FX45	2004	295	547	672
Chrysler	Pacifica	2005	326	531	688

Honda	Accord EX	2004	254	529	640
Jeep	Gd. Cherokee	2004	318	559	667
GMC	Envoy	2004	337	546	693
Dodge	Ram	2005	351	505	719
Toyota	Solara	2006	258	519	626
GMC	Yukon	2005	322	538	712
Ford	Expedition	2006	351	491	706
Ford	Freestar	2005	335	495	694
Ford	Taurus SE	2002	268	551	649
Pontiac	Grand Prix SE	2001	273	586	657
Honda	Civic	2000	220	555	613
Oldsmobile	Ciera S	1990	243	598	636
Cadillac	DeVille	1997	247	601	626
Ford	Windstar GL	1997	353	468	731
Mazda	626 LX	1998	245	568	621
Saturn	Vue V6	2007	322	523	675
Pontiac	Bonneville SLE	2000	242	570	631
Toyota	Prius hybrid	2006	283	531	621
Ford	Explorer Sport	1996	251	596	633
Ford	Mustang SVT	1999	251	654	586
Chevrolet	C2500	1991	310	571	689
Chevrolet	S10 LS	1996	222	601	654
Ford	Contour SVT	1998	274	560	633
Chevrolet	Tracker	2000	314	498	671
Toyota	Corolla DX	1996	227	544	632
Acura	Integra GS	1992	203	547	584
Toyota	Camry DX	1991	253	533	640
Subaru	Legacy Outback	1999	195	585	574
Subaru	Forester L	1998	237	566	603
Ford	Probe GT	1994	213	578	576

Chevrolet	Nova	1988	284	514	638
Honda	Accord LX	1992	236	551	589
Toyota	Tercel STD	1992	255	515	631
Ford	Taurus GL	1991	263	573	661
Toyota	Sienna LE	1999	357	485	696
Chevrolet	Traverse	2011	323	496	692
Volvo	XC60	2010	339	483	693
Ford	Taurus	2006	265	574	647
Honda	Civic	2010	267	522	654
Dodge	Caravan	2010	373	513	734
Ford	Taurus	2011	311	513	673
Hyundai	Sonata	2011	270	564	638
Toyota	Sienna	2011	351	497	693
Chrysler	Grand Caravan	2011	349	515	719
Kia	Soul	2011	338	497	694
Nissan	Versa	2011	284	503	654
Chevrolet	Impala	2011	240	596	655
Ford	Explorer	2011	357	484	719
Mitsubishi	Lancer	2011	281	502	651
Mazda	3	2011	261	500	631
Ford	F150	2011	324	511	707
Chevrolet	Tahoe	2011	353	524	705
Volkswagen	Eos	2012	250	524	619
Audi	A4	2004	241	546	607
Ford	Focus	2004	282	466	664
Hyundai	Accent	2010	277	528	649
Honda	Fit	2009	294	490	667
Nissan	Cube	2011	361	489	695
Ford	Fiesta	2011	255	587	674
Chevrolet	Aveo	2011	301	491	697