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27. Some Interactions Among Driver, Vehicle, and Roadway Variables in Normal Driving

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At the Fourth Annual Manual (ref. 1) I reported on a study of driving behavior in which we had related lateral acceleration in curves to the forward velocity. We plotted the data for 50 subjects, each of which drove a course containing 227 identifible curves. The relationship which was obtained was

$$g=P-0.068\left(\frac{v}{20}-1\right) \qquad (1)$$

where g is the lateral acceleration in gravitational units, P is a constant for an individual but variable between individuals (90 percent of the P values were between 0.33 and 0.19 g) and V is the forward velocity in miles per hr between 20 and 60. Since then we have gathered more data, have read some interesting reports by others, and have thought more about the problem. In this report I will discuss all three developments.

In the January 1971 issue of Sports Car Graphic there is an article entitled, "World's Most Advanced Race-Driving School" (ref. 2). At this school aspiring drivers drove an instrumented car which allowed them to study their individual performance. The instrumentation produced a recording of lateral acceleration and forward velocity. The results for the aspiring drivers were compared with those for Mark Donahue in an effort to discover why Donahue could beat them through the course.

The velocity and lateral acceleration data for Mark Donahue were presented in such a way that an equation could be derived to express the relationship between g and V for those curves in which he had a free choice of speed. For Mark Donahue the expression is

$$g=1.25 \qquad (2)$$

No velocity term is in the expression because the lateral acceleration did not vary with velocity. The car would stay on the road at 1.25 g and apparently Donahue's technique for each curve was to achieve and hold that speed which produced 1.25 g.

We may assume that the vehicle used by Mark Donahue would lose adhesion at a g value slightly higher than 1.25. It is estimated that the Buick station wagon which was used in all our experiments will lose adhesion at about 0.67 g. Where Mark Donahue stayed at something like 98 percent of breakaway **g** at all speeds, our ninetieth percentile driver achieved 50 percent of breakaway g at 20 mph, and eased off to about **30** percent at 60 mph.

We have become a little more ambitious and would like to be able to account for vehicle and roadway variables in addition to personal variables. We can expand equation (1) as follows:

$$g=(P_1,P_2\ \ldots\ P_n)(v_1,v_2\ \cdots\ v_n)(R_1,R_2,\ \ldots\ R_n)-0.068\left(\frac{V}{20}-1\right) \qquad (3)$$

where P_1, P_2 etc., are the family of personal variables, v_1, v_2 etc. are the family of vehicle variables, and R_1, R_2, etc. are the family of roadway and environmental variable. We have begun to consider which variables in each family account for most of the variance.

In the first study of this series (ref. **3)** we found that men drove faster and pulled more lateral g's than women. Partially completed analyses suggest that most of this difference may be due to the fact that men drive more miles per year than women. In addition to miles per year we have some data on driver's age, number of years driving, and hand dominance. We have found no significance to age and number of years driving. Our left-handed drivers drove faster than right handed, but the number is too small to be conclusive. In observing our subjects it appeared that there was a relatively large variability due to level of aspiration. Some subjects appeared quite in awe of the experimenter, while others appeared to be making a game of trying to toss the recorder in his lap. We plan an experiment soon in which we hope to measure the influence of the subjects' understanding of what he is trying to do.

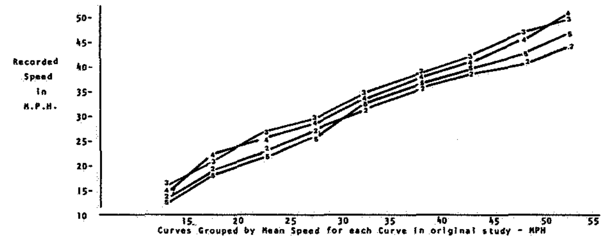
In the original experiment all the subjects were run in the same vehicle, a **1962** Buick Invicta station wagon with power steering and brakes. Experimental controls were applied to insure that no vehicle variables entered into the experiment. Since the original study we have run **60** more subjects (making **110** total) in the same car on the same **110** mile course over Ohio state highways. Fifteen of these were run with the tire pressure lowered to **21** lb cold (from the standard **29).** Another **15** subjects were run with the speedometer covered. The same Buick station wagon was used for these runs also. Low tire pressure was used as a simple way to get a change in the vehicle's dynamic characteristics. The covered speedometer eliminated some of the information which the machine normally provides the driver. Fifteen more subjects were run through the course at night, and a final **15** subjects acted as a control group, repeating the conditions of the first experiment.

The results of these four conditions are shown in figures **1** and **2.** The data points for each curve are grouped by the mean velocity for that curve in the first experiment. Figure **1** shows the recorded speed plotted against the reference speed for each curve. It will be seen that the speeds for the night and the control condition are indistinquishable statistically from each other, but both may be distinquished from the low tires and the no speedometer condition, which are in turn indistinquishable from each other. The general statement is that the group with low tires and the group with no speedometer drove faster than the control group, but the night group did not drive faster than the control.

Figure **2** shows lateral acceleration plotted against the reference speed for each curve. It will be seen that the night group produced lower accelerations than the low tires, no speedometer, and the control groups; these latter three being statistically indistinquishable.

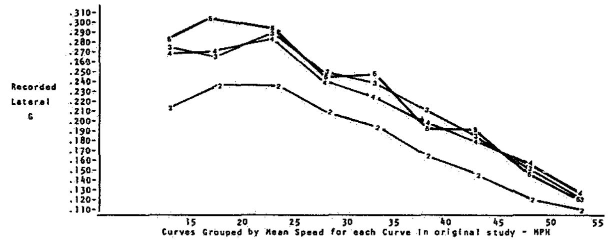
How is it possible that the control group drove no faster than the night group but still produced higher lateral accelerations? When the data from the two-channel Brush recorder were read, the acceleration value read was the peak acceleration produced in a given curve. The velocity was then read at that point. If the control group drivers systematically jerked the wheel to a greater degree than the night group, thus producing greater spikes on the lateral acceleration trace, the result would be as observed in the two figures.

In the report we gave at the 4th Annual Manual (ref. **1)** we showed figure **3,** which is a plot of the recorded speed as a function of the speed values of advisory signs. Our subjects drove faster than



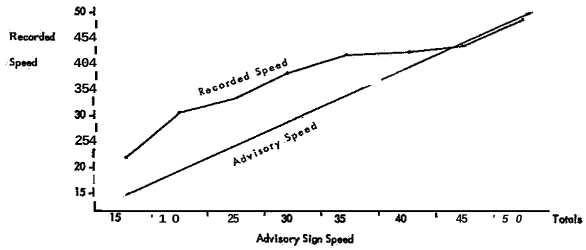
2 Night	Mean	13.106	18.856	22.806	27.131	31.369	36.031	39.056	41.756	14.331
	S.D.	2.344	3.027	2.667	3.612	3.662	4.198	4.461	4.200	4.343
3 Speedometer	Mean	15.753	20.053	26.187	30.060	35.500	39.353	43.407	46.780	49.293
	S.D.	2.488	5.948	5.023	1.170	4.252	3.936	4.269	5.169	5.417
4 Low Tires	Mean	14.360	22.107	24.607	28.240	33.313	37.993	41.600	45.767	49.367
	S.D.	2.883	5.187	3.437	3.859	4.504	4.973	5.142	5.281	5.966
5 Control	Mean	12.629	18.821	22.421	26.864	32.036	36.307	40.171	43.450	46.714
	S.D.	2.632	3.352	3.122	4.043	3.949	1.876	4.422	4.125	1.607

FIGURE 1.—Comparative speed in turns for night (2), no speedometer (3), and low tires (4).



2 Night	Mean	.216	.239	.238	.211	.198	.169	.150	.123	.112
	S.D.	.065	.064	.050	.064	.038	.038	.026	.024	.029
3 No Speedometer	Mean	.275	.264	.288	.250	.241	.213	.184	.150	.127
	S.D.	.056	.092	.065	.056	.055	.048	.041	.035	.037
4 Low Tires	Mean	.270	.273	.284	.240	.228	.199	.183	.152	.129
	S.D.	.035	.037	.057	.048	.040	.051	.034	.028	.042
5 Control	Mean	.282	.306	.291	.241	.249	.194	.191	.149	.127
	S.D.	.024	.064	.067	.054	.050	.063	.037	.022	.023

FIGURE 2.—Comparative lateral acceleration for night (2), no speedometer (3), and low tires (4).



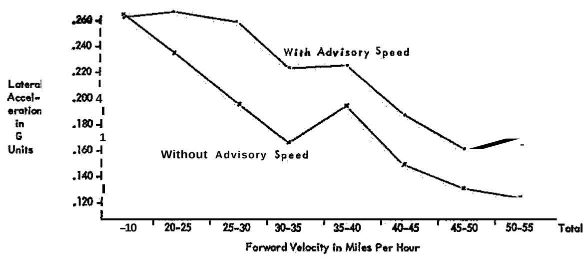
		15	10	25	30	35	40	45	50	Totals
Recorded Speed	Man	21.950	30.460	32.383	37.900	42.177	42.109	44.425	49.633	39.006
	SD	1.900	5.001	2.060	2.036	2.996	3.361	4.187	3.984	7.919
	N	4	10	6	6	13	11	12	6	68

F = 38.1515 DF = 7/60

		15	10	25	30	35	40	45	50	Totals
Lateral Acceleration	Mean	0.253	0.251	0.228	0.226	0.210	0.197	0.162	0.138	0.205
	SD	0.072	0.057	0.061	0.015	0.039	0.053	0.049	0.041	0.059

F = 5.1144 DF = 7/64

FIGURE 3.—Actual speed in curves in relation to advisory sign speed.

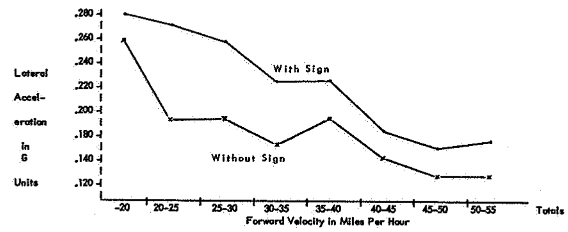


		–10	20–25	25–30	30–35	35–40	40–45	45–50	50–55	Total
With Advisory Speed	Man	0.263	0.268	0.257	0.222	0.224	0.185	0.161	0.169	0.205
	SD	0.	0.081	0.061	0.053	0.037	0.053	0.043	0.032	0.059
	N	1	4	6	10	12	19	13	3	68
Without Advisory Speed	Mean	0.264	0.234	0.193	0.165	0.195	0.146	0.130	1.126	0.155
	SD	0.059	0.059	0.043	0.021	0.045	0.035	0.039	0.041	0.059
	N	8	2	5	6	8	9	22	34	94
Between Groups	F	0.0003	0.265	3.989	6.319	2.445	4.064	4.726	3.156	28.305
	DF	1/7	1/4	1/9	1/14	1/18	1/26	1/33	1/35	1/160

FIGURE 4.—Effect of **the presence** of **advisory speed sign upon choice** of **speed in curves.**

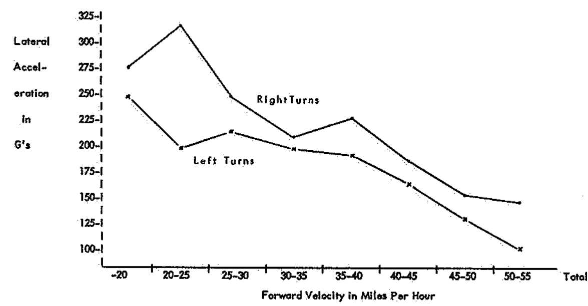
the signs reading below 40, but did not drive faster than advisories of **45** and **50.** Figure **4** shows the lateral acceleration for those curves with advisories and for the curves without advisories. We have looked at the individual curves with advisories in relation to their advisory speeds. Mean values for our **110** subjects show considerable variability in speed and acceleration with a given advisory speed. Using these data we are negotiating with the Ohio Department of Highways a contract to revise considerably the methods by which advisories are assigned.

Selecting **162** curves which gave the drivers a free choice of speeds, we had **79** with a curve sign and **83** without. Figure **5** shows the plot of lateral acceleration for these two conditions. (Note that all **68** curves with advisory signs in figure **4** are among the **79** curves in figure **5**



		–20	20–25	25–30	30–35	35–40	40–45	45–50	50–55	Totals
With Sign	Mean	0.280	0.270	0.257	0.222	0.223	0.183	0.159	0.174	0.2024
	SD	0.024	0.071	0.061	0.053	0.035	0.051	0.037	0.028	0.0582
	N	2	5	6	10	13	21	18	4	79
Without Sign	Mean	0.259	0.193	0.193	0.165	0.192	0.140	0.124	0.124	0.1503
	SD	0.062	0.	0.043	0.021	0.048	0.139	0.042	0.040	0.0582
	N	7	1	5	6	7	7	17	33	83
Between Groups	F	0.193	0.993	3.989	6.319	2.753	4.180	7.109	6.002	32.492
	DF	1/7	1/4	1/9	1/14	1/18	1/26	1/33	1/35	1/160

FIGURE 5.—Effect of the presence of a curve sign on **the choice** of **speed in curves.**



		–20	20–25	25–30	30–35	35–40	40–45	45–50	50–55	Total
Right Turns	Mean	0.276	0.317	0.247	0.109	0.226	0.188	0.151	0.145	0.188
	SD	0.054	0.037	0.070	0.070	0.038	0.062	0.048	0.038	0.068
	N	5	3	5	5	12	13	19	23	85
Left Turns	Mean	0.249	0.198	0.212	0.197	0.191	0.159	0.131	0.102	0.162
	SD	0.061	0.020	0.054	0.033	0.040	0.037	0.034	0.033	0.056
	N	4	3	6	11	8	15	16	14	77
Between Groups	F	0.477	23.593	0.850	0.192	3.878	2.405	2.020	12.381	7.086
	DF	1/77	1/4	1/9	1/14	1/18	1/26	1/33	1/35	1/160

FIGURE 6.—Effect of the direction of **turn** on **the choice** of **speed in curves.**

which had curve signs. No curve had an advisory without a curve sign, but **11** had curve signs and no advisory.)

These **162** curves consisted of **85** right turns and **77** left turns. The speed versus lateral acceleration data for right versus left are shown in figure **6.** The difference is reliable because the two curves do not overlap. It is a small difference, however, and is about the same order as the limits of the relatively simple instrumentation system. Therefore, these data must be considered as being subject to revision.

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