Capability of Automobile Drivers To Sense Vehicle Velocity

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This paper presents the results of an investigation into velocity sensing. The psychophysical techniques of magnitude estimation and production were employed. Results are presented in the form of regression lines and confidence intervals.

•ONE IMPORTANT element in the control of a motor vehicle is velocity regulation. The proliferation of speed limits and their attendant radar velocity detectors gives mute testimony to this fact, as does the effect of poor velocity control on traffic flow during periods of high density.

An analysis of the driving task suggests that the driver must employ information other than that from the speedometer in regulating velocity. Also indicative of this is the rather frequent occurrence of people who operate vehicles for extended periods of time without the assistance of a speed display device.

The cues available for judgments about vehicle velocity are indeed many. Various aspects of the information associated with vision, audition, proprioception, and kinesthesis are known to change as a function of velocity or from the behavior of the vehicle due to its velocity.

There are two aspects of velocity sensing which are of concern, velocity estimation and velocity change detection. Basically, velocity estimation may be investigated with the analogous techniques of estimation and production. In velocity estimation, the driver-subject is guided to the desired velocity and asked to estimate it, whereas in velocity production, the subject-driver is given a velocity to produce (in both cases without the aid of a speedometer). In the case of velocity change detection, the vehicle is accelerated or decelerated from a reference velocity at a rate which is less than the subject's acceleration threshold. The subject then responds when he can detect the change in velocity. This paper considers only the velocity estimation and production cases.

With the velocity estimation and production techniques, the scaling factor used by the subjects will be reflected in the regression function as fitted to their data. Variance about this regression function will indicate the consistency with which that response can be made.

Conceptually, there should be no difference between the performance of the subjects in velocity estimation and in velocity production if the subject makes his judgment on the basis of some long-term "memory" pattern. Of course, it is expected that biases will be associated with these two techniques as a result of the techniques themselves.

It should be mentioned that factors such as adaptation, forgetting, etc., may play an important role in velocity control. However, we have chosen to fix the magnitude of most of these variables because of the problems associated with an investigation of their effects without a broad base of information about the basic phenomena.

In an effort to investigate the possible effects of "short-term memory," it was decided to include a series of velocity estimations and productions in which knowledge of results was provided. In this fashion, the role of short-term memory could be investigated and compared with the effects of other factors.

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EXPERIMENTAL PROCEDURE

The general form of this study was established as that of a three-factor, switchback design. Two groups of subjects were involved, one receiving first estimation then production trials without feedback, followed by estimation then production with feedback (EPEP order). The second group received production then estimation trials without feedback followed by production then estimation trials with feedback (PEPE order). The two groups of subjects were used so that the effect of the order or presentation could be analyzed (assuming no differential effects due to subjects). The design is balanced with respect to time and presence or absence of feedback. Each of the two groups consisted of six subjects (male college students), giving a total of twelve subjects for the experiment. Each subject was run through a fixed sequence of 48 velocity treatments in each of the four phases of the experiment. This sequence of velocities consisted of two replications of each of 24 different velocities ranging between 18 and 65 mph. This sequence was randomly selected with the restriction that no two consecutive velocities be less than 5 mph apart.

In conducting the experiment, the subject drove the research vehicle (a 1965 eight-cylinder Plymouth station wagon with automatic transmission) to the test site. During this 25-minute drive, the subject had visual access to a Stewart-Warner police speedometer which replaced the vehicle's standard speedometer. After arriving at the test site, the subject was denied direct access to the speedometer in that it was moved to the back seat where the experimenter sat. All data recording was done by hand with an accuracy to the nearest mph.

The instructions given the subject were as follows: (a) For velocity estimation,

> In this part of the study, you will be estimating different speeds. I will help guide you to the speed I desire by saying faster or slower. When we reach the speed, try to hold the car's speed constant, and I will ask you to estimate the speed to the nearest one mph. We will be using a number of different speeds so we will not be going 10-20-30, for example.

(b) For velocity production,

> In this part of the study, you will be producing various speeds. I will ask you to reach a speed and when you feel that you have reached it, you are to hold your car's speed steady there and repeat that speed to me in order to tell me when you have reached it. When I give you the next speed, you will repeat the procedure.

During phases 3 and 4, the subjects were told their true speed to the nearest mph after completing each judgment.

In operation, the car was stopped before beginning each phase of the research, and the appropriate instructions for that phase were read to the subjects. After repeating the instructions if there were questions, the actual trials were begun.

During the execution of this study, no attempt was made to accurately control the period of time in which the subject was allowed to make his response. Also, no acceleration restrictions were imposed on the subjects when making the velocity changes. At the conclusion of each specific trial, the subject was immediately instructed or guided to the next velocity without stopping the vehicle.

Two specific types of analysis were performed on this data. These were (a) an analysis of variance of the error data, and (b) a series of regression procedures.

ANALYSIS OF VARIANCE OF ERROR DATA

To conduct an analysis of variance on the data, they were grouped into six velocity ranges. These ranges were:

d_1	d_2	d_3	d_4	d_5	d_6
18 mph	26	35	44	52	60
19	27	37	45	54	61
21	30	39	48	55	63
23	31	40	49	57	65

Each cell entry in this analysis was the algebraic sum of that particular subject's errors in producing or estimating the four velocities in that velocity group.

Velocity was the only factor found significant at the 0.01 level. The order by time interaction and the order-time-feedback interactions were found to be significant at the 0.01 level while the order-velocity, order-time-velocity, and the order-feedback-time-velocity ABCD interactions were significant at the 0.05 level ($F_{0.95}$).

Figure 1 shows graphically the effect of velocity. Each of the six data points shown here is the mean error for that velocity range summed over all other conditions. It is apparent that the subjects tend to overestimate or overproduce in the lower velocity ranges and underestimate or underproduce in the higher velocity ranges. It is also interesting to note that the mean error appears to be zero somewhere in the d_3 (35 to 40 mph) range. A Newman-Keuls Sequential Range Test on the six velocity group means showed the following at the 0.01 level:

$d_1 > d_4$, d_5, and d_6

$d_2 > d_4$, d_5, and d_6

$d_3 > d_5$.

No other differences were found at this or the 0.05 level.

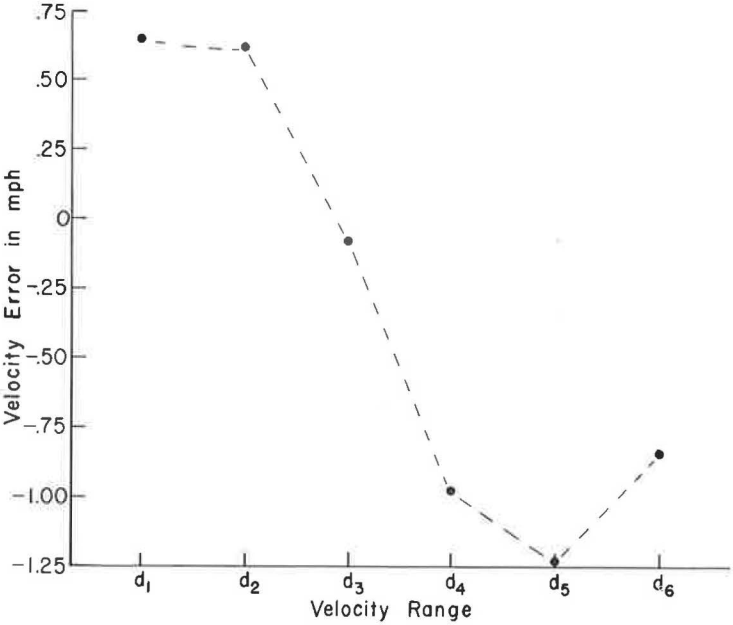

Figure 1. Mean velocity error for each of the six velocity ranges for data summed over all conditions (velocity effect).

The order-time interaction (AC) is quite apparent as shown in Figure 2. Here the positive error for velocity production and the negative error for velocity estimation is obvious as is the relative downward ("more negative") drift of the data in time C_2 with respect to C_1. This interaction is interpreted as being a method of presentation effect. The basis for this interpretation rests primarily on the fact that a differential time effect due only to the two groups of subjects is quite unlikely. Additional evidence for this comes from a Newman-Keuls Sequential Range Test which showed, at the 0.05 level, differences between means from the same group and from the same time but none from the same period. In other words, the Newman-Keuls Sequential Range Test found no difference between group means under the same method.

Figure 3 shows the order-time-feedback (ABC) interaction. Note that these data are identical with those in Figure 2 except that they have been split into two groups on the basis of the presence or absence of feedback information. Because of the interpretation given the order-time interaction, this order-time-feedback (ABC) interaction will be interpreted as that of a method by feedback condition interaction. It is apparent that the feedback conditions exert a powerful influence in that feedback greatly reduces the magnitude of the error but does not change the direction of the method effect or that of the slight time effect. A Newman-Keuls Sequential Range Test on the data showed all means to be greater than the two no feedback-estimate means while no difference could be found between these two no feedback-estimate means. This test also showed that, while the two no feedback-produce means did not differ, the no feedback-produce mean at time C_1 was greater than the two no feedback-estimate means but not greater than the four feedback means (all at the 0.05 level).

The order-velocity (AD) interaction is shown in Figure 4. This interaction was found significant at the 0.05 level. A Newman-Keuls Sequential Range Test showed the group A_2 means at both the d_1 and d_2 velocity range levels to be greater than the A_2 means at the d_4, d_5, and d_6 velocity ranges and greater than the group A_1 mean at the d_5 velocity range. No other differences were found significant. This interaction is quite interesting in that it appears that most of the velocity effect is associated with group A_2. This group received the PEPE treatment order while group A_1 received the EPEP treatment order. Apparently, some sort of transfer effect produced this result—it is unlikely that this effect is due to innate differences in the subjects.

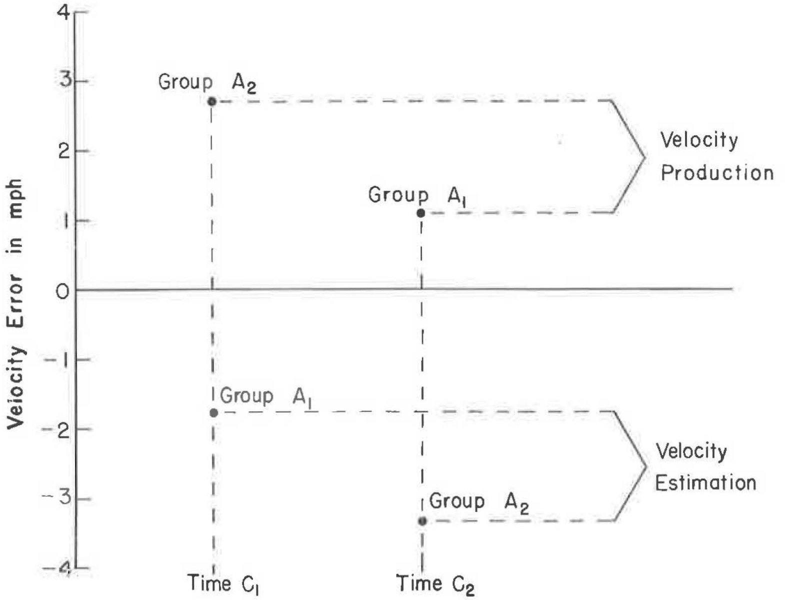

Figure 2. Mean velocity error for data grouped to show order of presentation and time interaction.

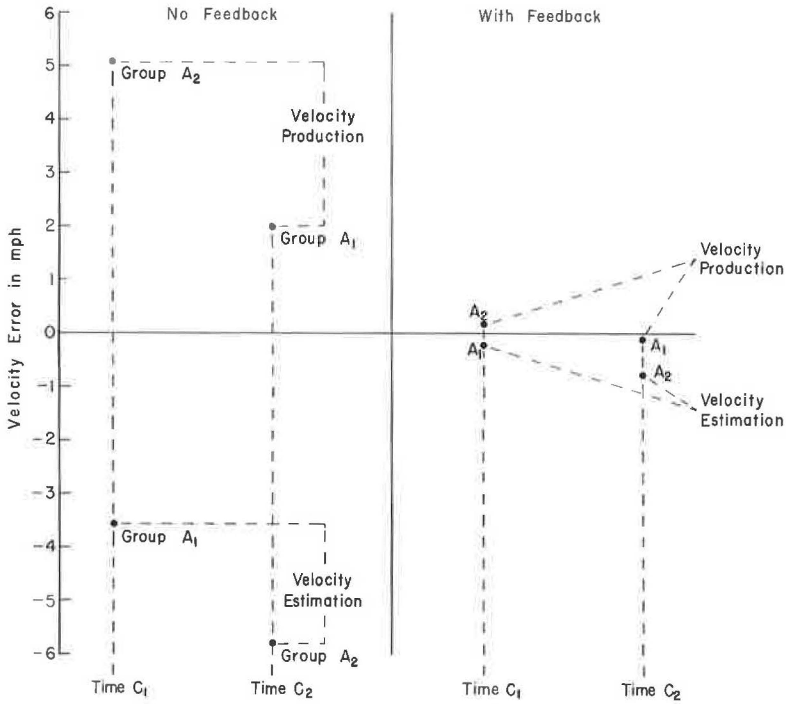

Figure 3. Mean velocity error for data grouped to show order of presentation, feedback, and time interaction effects.

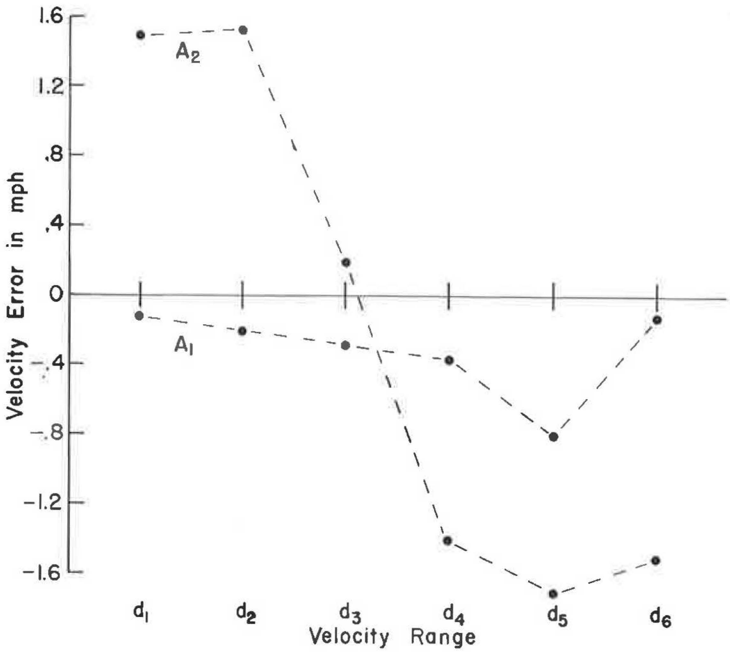

Figure 4. Mean velocity error for the order-velocity range interaction.

Figure 5 shows the order-time-velocity interaction (ACD). Here, both groups (A_1 and A_2) approach zero error in the higher velocity ranges for time C_1 while only group A_1 does so in time C_2. (Again, we are probably seeing the effects of order of presentation.)

The order-time-feedback-velocity interaction (ABCD) is shown in Figure 6. This is a method-feedback-velocity interaction, but it is presented without summing over the two groups (A_1 and A_2). The performance of group A_2 under the no feedback conditions is in sharp contrast with the mirror-image performance of group A_1 under the same conditions.

Figure 7 shows the order-feedback-velocity interaction. Here again, note the relation of group A_1 and group A_2 under the no feedback condition.

REGRESSION ANALYSIS

A standard linear regression was applied to the data from each of the 12 subject's four runs and to the data when pooled across subjects but arranged by experimental condition. Standard error scores were also calculated for these regression lines. These regression lines were fitted with a linear regression procedure which simultaneously evaluated the fit of higher order polynomials through a piecewise linear approach. This analysis indicated that the linear regression provided a satisfactory fit.

Figure 8 shows the regression lines and their corresponding 95 percent intervals for the E and P trials without feedback for group A_1 (EPEP). Note that the approximate slope of the E line is > 1 while that for P is < 1. Also, note that the two regression lines cross at approximately 40 mph.

Figure 9 shows the regression function for the group A_1 trials with feedback. It is apparent that the feedback reduced the variability about the regression line and shifted the slopes of the regression line toward a value of one.

Figure 10 shows the regression functions for the no feedback cases for group A_2 (PEPE group). Note the wider deviation of the slopes of these regression lines than for the corresponding data for group A_1. Figure 11 shows the group A_2 data for the feedback conditions. Again, note how the slope has returned to approximately one,

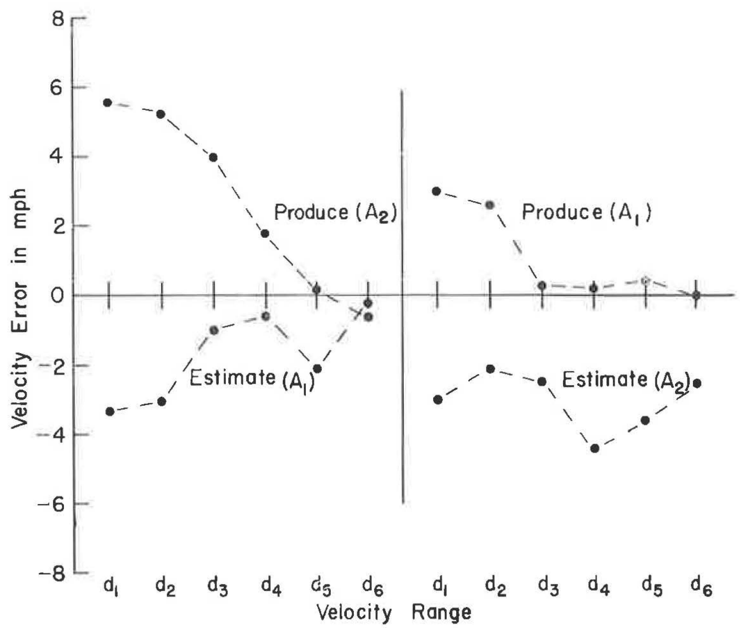

Figure 5. Mean velocity error for the order-time-velocity range interaction.

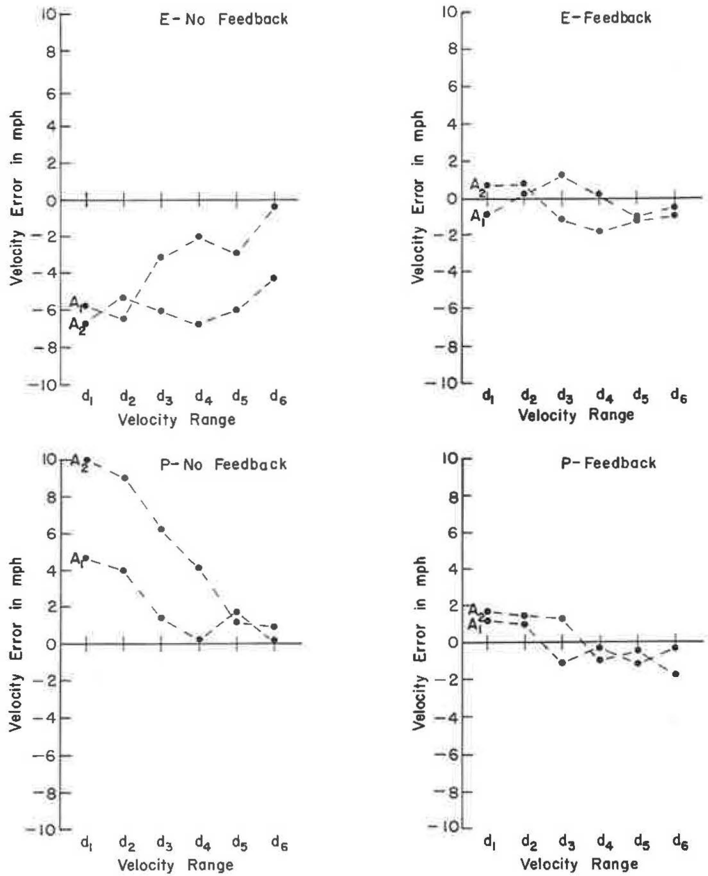

Figure 6. Mean velocity error for order-feedback-time-velocity range interaction.

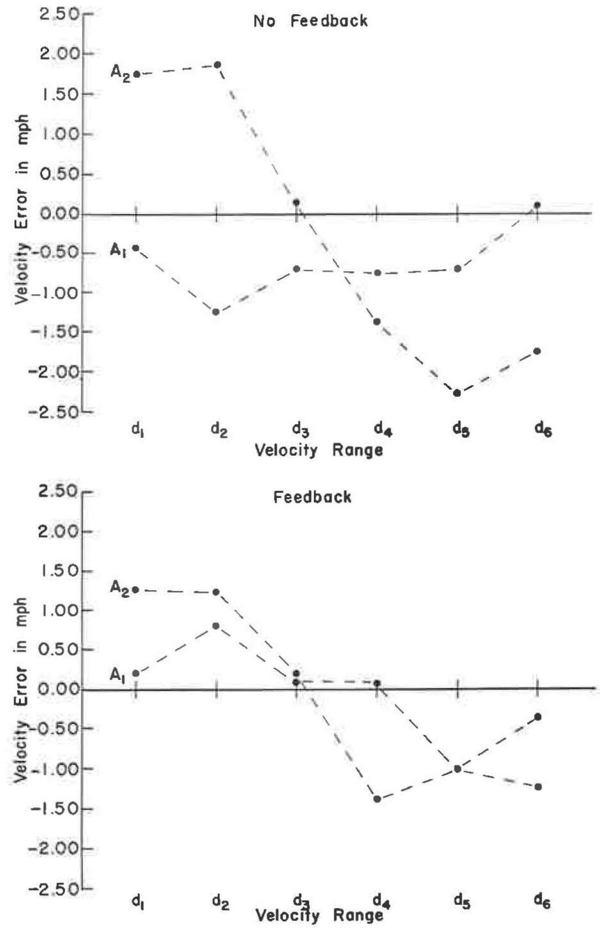

Figure 7. Mean velocity error for data grouped to indicate order-feedback-velocity range interaction.

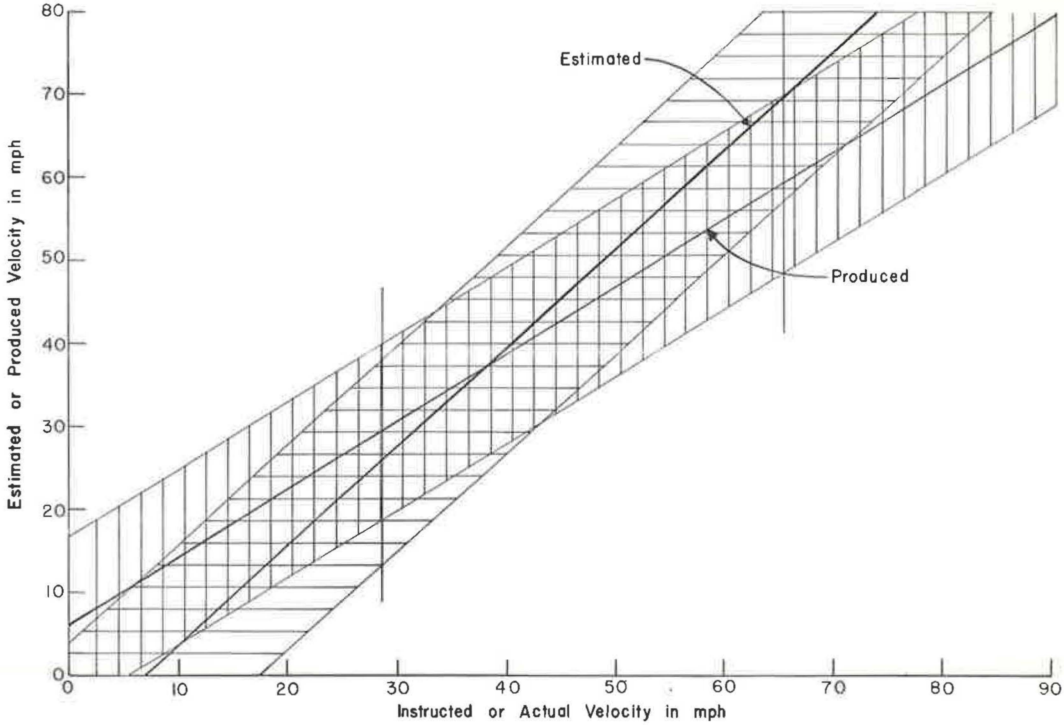

Figure 8. Regression lines and 95 percent confidence intervals for data for estimated and produced velocities, no feedback conditions for subjects 1 through 6 pooled.

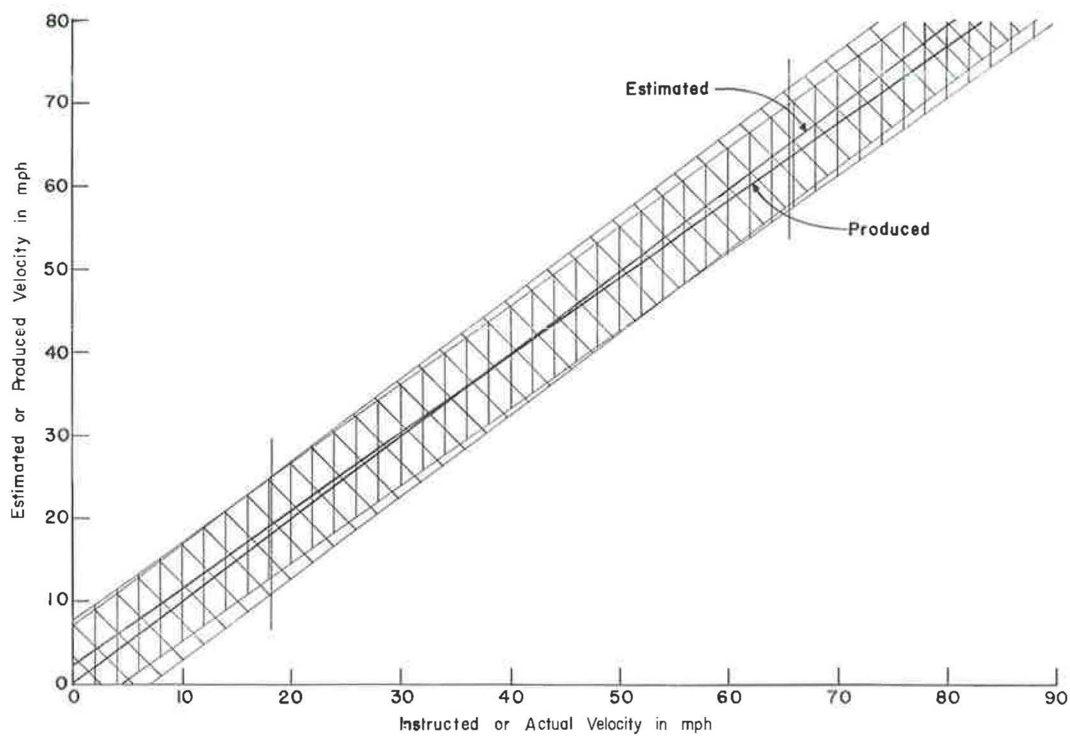

Figure 9. Regression lines and 95 percent confidence intervals for estimated and produced velocities, feedback conditions for subjects 1 through 6 pooled.

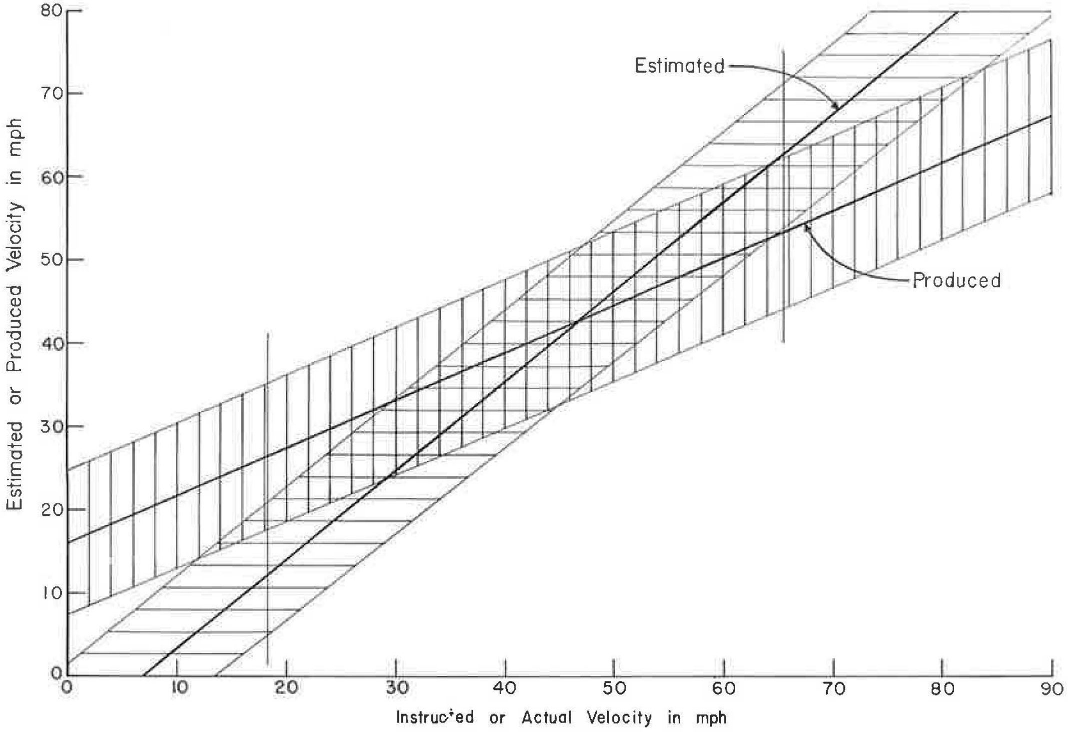

Figure 10. Regression lines and 95 percent confidence intervals for estimated and produced velocities, no feedback conditions for subjects 7 through 12 pooled.

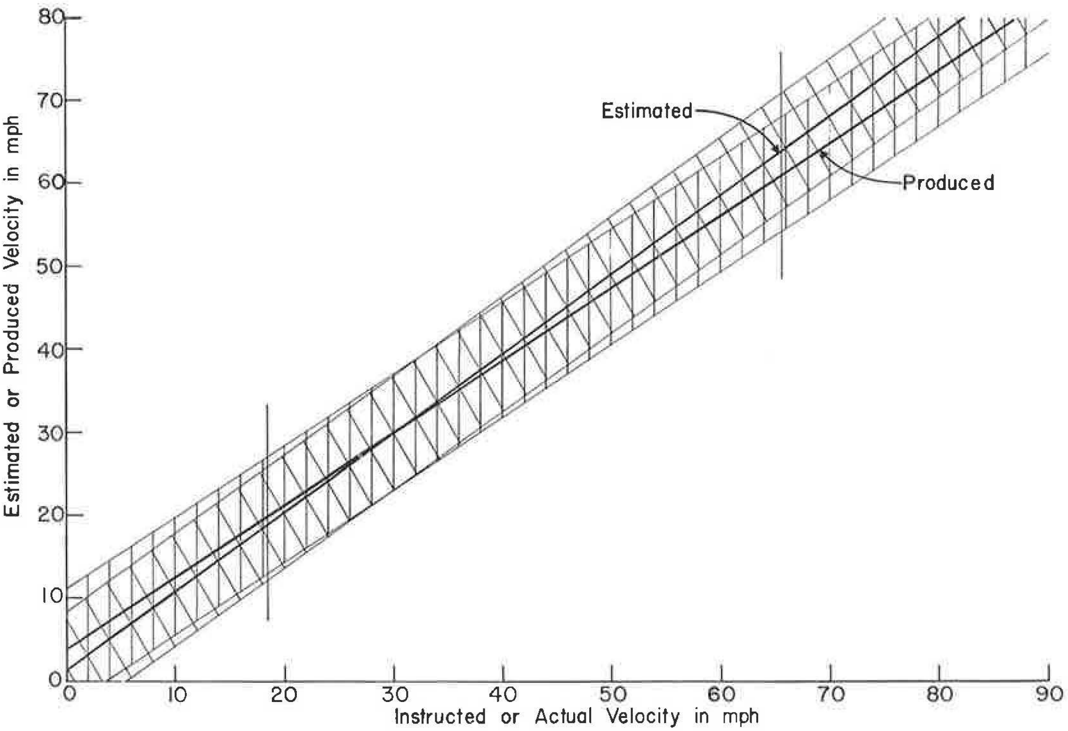

Figure 11. Regression lines and 95 percent confidence intervals for estimated and produced velocities, feedback conditions for subjects 7 through 12 pooled.

and the variance is reduced. It is interesting that in all cases the estimated values are greater than the produced values in the high velocity range (the opposite being the case in the lower velocity ranges) and that the two regression lines intersect somewhere in the 40-mph range.

The range of the standard error scores for all of the individual subject's treatment regression lines were from 1.92 to 5.38 mph with a mean score of 3.09 mph. This compares with a range of from 3.28 mph to 6.25 mph with a mean of 4.27 for all data when pooled. In addition to these analyses, a number preference analysis and a transition analysis were performed. The number preference analysis failed to find a significant bias on the part of the subjects for particular numbers. The transition analysis also failed to find a significant effect due to the magnitude of the various velocity changes which were required from trial to trial.

In general, this study has involved the construction of scales for man's sensing of velocity. Two psychophysical methods have been employed which are roughly the antithesis of each other. These are the method of magnitude estimation and the method of magnitude production. Stevens (1) reports that these two techniques may well be used together in such a way that the biases innate to each are offset by the other. It would appear that this is the case.

For those subjects who received the EPEP treatment order, the two no feedback regression lines (Figs. 8 and 9) do, in fact, intersect the "correct response" line at approximately equal angles (i.e., have the same error magnitude for a given instructed or actual velocity). For the two cases with feedback, little error exists between the two regression lines and the slope 1,0 intercept line. These observations do not appear to hold for those subjects who received the PEPE treatment order. With this order, under the no feedback condition, the slope of the regression line for the P instruction is very small, reflecting an extreme tendency to underproduce in the high velocity range, whereas the regression line for the E instruction is approximately where it fell in the EPEP order. There is little difference between the performance of those two groups under the feedback condition. Also, little difference is observed in the S.D. error of the data about these regression lines, other than for the large reduction associated with feedback.

The small slope of the P no feedback regression line for group A_2 may well be due to a mistaken use of the cues available to the subject. The subjects may rely only on cues that are associated with the vehicle until they are required to estimate the vehicle speed. When the subject estimates rather than produces, he apparently makes better use of the information which he has available to him. By so doing, he "learns" to better perform the task and continues to do so. Thus, this effect would not be apparent for those who received the EPEP combination because they estimated the vehicle velocity before producing it. This explanation would also account for other effects because under the feedback trials, both the group A_1 and group A_2 subjects would have previously experienced an E trial.

A characteristic illustrated in Figures 8 through 11 is that the regression lines all cross in the mid-velocity range (40 mph). This may be accounted for by the fact that the vast majority of driving is at speeds in this range. Thus, experience may well have produced "anchor points" in this speed range.

CONCLUSION

This paper has presented a study of the ability of automobile drivers to sense one of the many types of information which is available to them. The use of other techniques, such as stimulus change detection, is necessary to fully define this sensory capability. This study is one of a series of investigations aimed at defining the capability of drivers to sense that information which is necessary for longitudinal vehicle control. Investigations are currently being conducted on the ability of drivers to sense velocity (as reported here), acceleration, jerk, headway, and relative velocity. It is felt that by knowing the sensory capability of drivers, it will be possible to better predict the

performance of drivers under such conditions as the high density freeway and that it will be possible to evaluate the possible benefits of augmenting the driver's sensory capability.

REFERENCE

1. Stevens. Problems and Methods of Psychophysics. Psychological Bull., Vol. 55, No. 4, July 1958.