Effects of Discrete Headway and Relative Velocity Information on Car-Following Performance

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•ONE WAY to increase the traffic flow on crowded highways is to decrease the time headway between cars. However, as spacing between cars is made smaller, the probability of rear-end collision and resulting chain reactions could increase because the cumulated reaction time of the drivers could induce the so-called shock wave in the flow. The reaction time here consists of the driver making a control movement after he perceives a change in spacing and then making a decision which will correct any deviation from his desired spacing.

It is hypothesized that the time it takes the driver to perceive a change in the car-following environment could be decreased by presenting the driver with information before he visually perceives such a change. Stated differently, our concern is whether or not subthreshold information and/or higher derivative information would be advantageous to the driver in the car-following mode. In recent research at Ohio State University, Rockwell and Snider (4) showed that there are driver thresholds for headway, velocity, and acceleration. The problem of determining the threshold of headway, for example, is complicated by the fact that the threshold is dependent on the initial headway (headway is defined as the separation distance between the rear of the lead car and the front of the following car) and also the acceleration and possibly higher derivatives of lead car performance. If some type of display could present information of a change in the relative spacing of the two cars before the driver could perceive it, perhaps quicker control action could be made by the driver of the following car and thus the spacing of the cars could be maintained more closely to their target level. If this display also gave information as to the required directionality of control motions to be taken, then the driver decision time could be further decreased and the hazards associated with closer spacing reduced.

Relatively few studies have been conducted in this area of driver aids. Bierley (1) conducted a study to establish the effect on spacing control of more information about vehicle headway and relative speed. The effects of two types of information displays were tested. In the first, a meter showed the driver current headway. The driver was asked to maintain a constant headway of 80 feet. It was concluded that the spacing display significantly reduced the average spacing error and reduced even more the error variability over that of the no-display condition. The fact that error variability was decreased suggests that this would help increase traffic flow by maintaining a more stable flow condition. In the second display, the relative velocity between the two cars was algebraically added to the relative spacing signal. With the velocity-aided spacing display, Bierley found that performance was improved over the spacing display. There was a greater reduction in the average spacing error variance, maximum absolute spacing change, and driver reaction or detection time. One interesting result noted in this study is that drivers tended to undercorrect more often during deceleration than during acceleration conditions.

Wright and Sleight (5) conducted car-following experiments with the use of simple judgment aids. One aid was a board in which acuity fusion stimuli were used. At close

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distances the driver could differentiate members of pairs of bars on a board mounted on the rear of the lead car. At farther distances each pair seemed to fuse into a single strip. This aid resulted in significantly lessening the tendency to follow at a greater than requested distance.

Michaels and Solomon (3) conducted a study in which advance warning of acceleration or deceleration maneuvers was given the driver of the following car. The advance speed information was given at one of four time intervals before the onset of speed change. The display consisted of four lights, two for acceleration and two for deceleration, mounted on top of the lead car. It was found that such communications reduced the variation of headway. It was further shown that minimum headway and headway variance were obtained at warning intervals of 1 to 3 seconds depending on the speed at which the test cars were traveling.

EXPERIMENTAL PROCEDURE AND EQUIPMENT

The above studies indicated that a display presenting changing information before the driver can directly sense the change, might improve car-following performance. Accordingly, a research program was established to begin exploratory investigations of an information display for car following. This display would provide information of a discrete nature as to whether the drivers' headway or relative velocity performance were within a bandwidth or error tolerance established by the experimenter or elected by the driver himself. A red light gave the driver information that his performance was outside the lower limit of the bandwidth and required a release of pressure on the gas pedal in order to reestablish the target headway and/or relative velocity. Similarly, a green light indicated an error in the opposite direction. Figure 1 shows the general display information given to the driver for the close target headway condition.

The main task of the driver was to hold the given headway throughout the experimental task, which in terms of the discrete display was a null or keep the lights out during the maneuvers. Primary research interests were whether too small a bandwidth might cause oscillations about the target value and lead to over-response on the part of the driver and conversely, whether too wide a range would not give enough information to improve system performance over a no-display condition. Table 1 shows the various experimental conditions that were employed in the research using both the discrete relative velocity signal information and the discrete headway information.

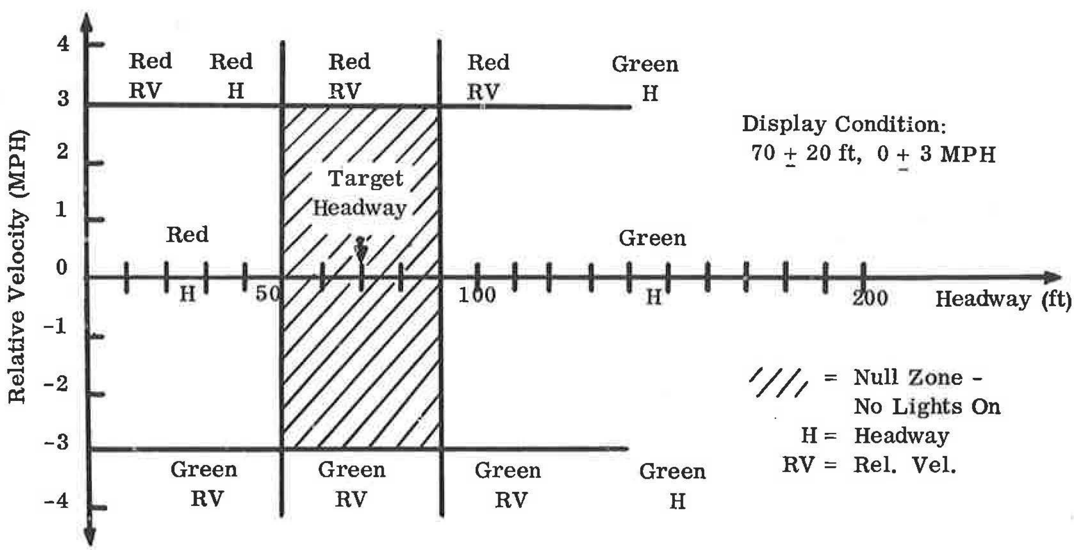

Figure 1. Schematic description of when the display lights come on.

TABLE 1

TREATMENT COMBINATIONS FOR THE EXPERIMENT AND SYMBOL EXPLANATIONS

RV Display	H Display							
	Close				Far			
	SH	MH	LH	NH	SH	MH	LH	NH
SR	x		x		x		x	
MR	x		x		x		x	
LR	x		x		x		x	
NR	x	x	x	x[a]	x	x	x	x[a]

H - Headway
NH - No H Bandwidth
LH - Large H Bandwidth (±27 or 34 ft)
MH - Medium H Bandwidth (±17 or 22 ft)
SH - Small H Bandwidth (±6 or 9 ft)

RV - Relative Velocity
NR - No RV Bandwidth
LR - Large RV Bandwidth (±5 mph)
MR - Medium RV Bandwidth (±3 mph)
SR - Small RV Bandwidth (±1 mph)

[a]The No-display condition was replicated once.

The equipment used in this experiment included a lead car which was equipped with a Stewart Warner Auto Co-Pilot device, mounted near the driver and used to dial in the speed required for the lead car maneuver during each trial run. This device can usually maintain relatively uniform acceleration, deceleration, and constant speed with less variance than a driver can obtain. It is used to keep the lead car maneuvers as fixed as possible from trial to trial and subject to subject. The lead car went through a series of four different random velocity profile maneuvers which were randomly sequenced throughout the experiment so that lead car velocity variance did not affect experimental results. The velocity range was from 35 to 65 mph for the lead car. The following car was a 1963 Chevrolet (Fig. 2) equipped with an automatic transmission. In the back seat of this car were located the recording equipment, control console, and experimenter seat (Fig. 3). Speed, acceleration, gas and brake pedal movements, steering wheel movements, headway and relative velocity were recorded on the 51-channel oscillograph recorder. Figure 4 illustrates the primary recorder data—velocity headway, target bandwidth, and light actuation periods. Experimental difficulties resulted in the loss of gas pedal and steering wheel movement data. The loss of the former was unfortunate as it prohibited any analysis of the frequency and magnitude of driver response to headway change and signal light actuation. Thus, performance is limited to the "driver-vehicle" complex as opposed to the effect of information on specific driver control changes.

A modified General Motors mechanical take-up reel was used to measure headway and relative velocity. This device, mounted to the front bumper of the following car, used a fine wire about 500 feet in length. The wire was fastened to the rear bumper of the lead car and constant tension was maintained by a slipping friction clutch. The distance between the two cars was measured by a set of potentiometers geared to the reel shaft. In addition, the relative velocity of the two vehicles was measured through a tachometer generator operating off the shaft. The two cars maintained communication by two-way radio; the experimenter wore a headset and throat microphones so that his instructions to the lead car would not be heard by the subject in the following car.

Figure 2. Following car with mechanical take-up reel.

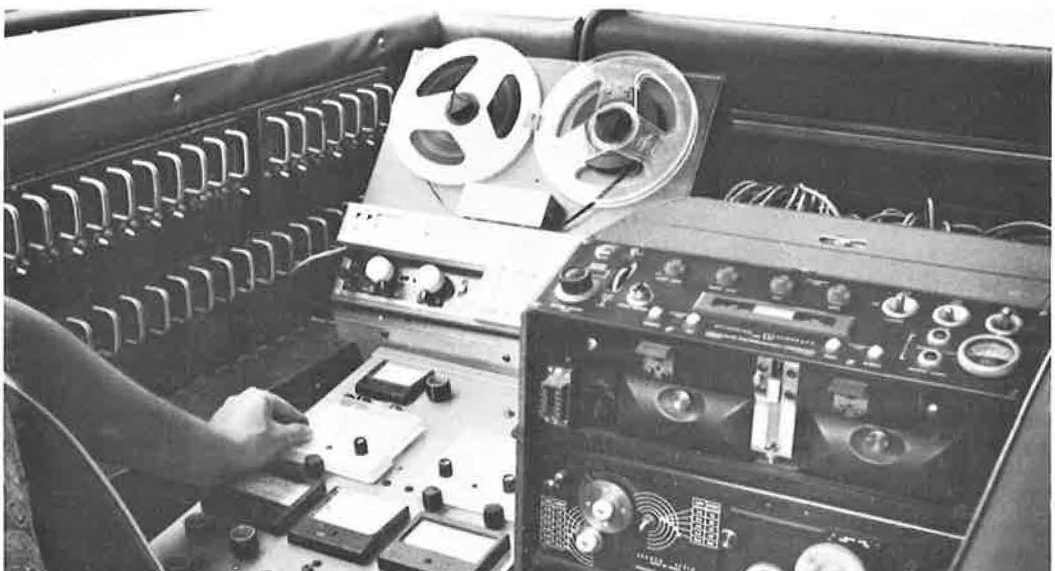

Figure 3. Control console in back seat of following car.

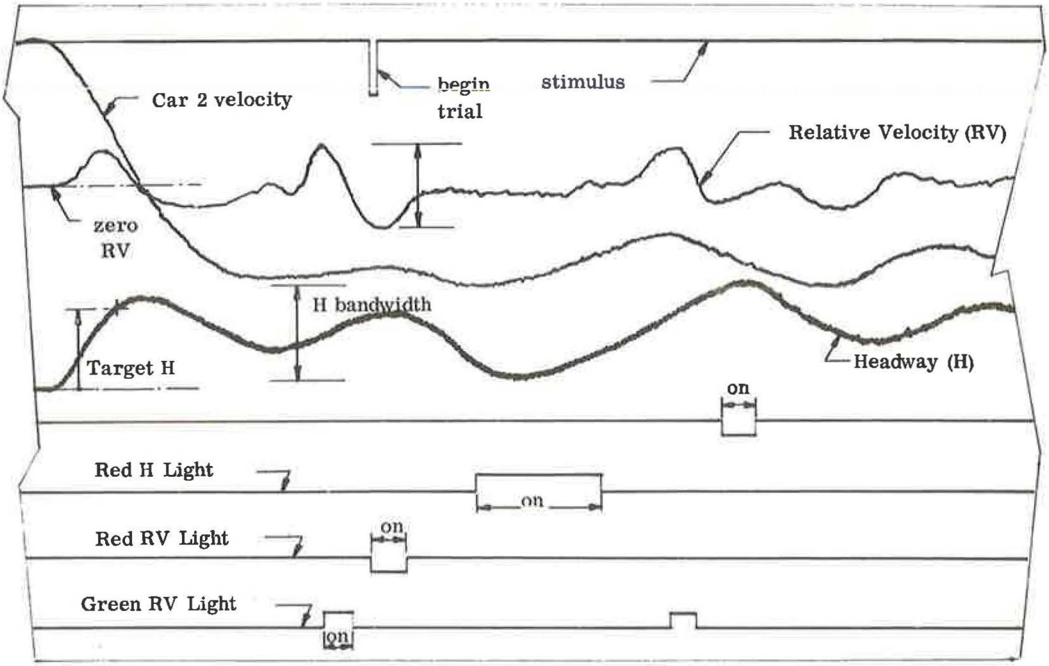

Figure 4. Example of chart paper output (not to scale).

Figure 5. Display lights on dashboard of following car.

With his control console the experimenter had relative velocity and headway information and could set the bandwidth selection for any given trial. Tests were conducted in light traffic on a limited-access highway.

The display (Fig. 5) consisted of four lights located in front of the subject on the dash board in the following car. The research was conducted at two target headways, a close headway which was approximately 70 ft and a far headway which was approximately 170 ft. The bandwidth for the headway display was approximately ±6 ft, ±17 ft, and ±27 ft for the small, medium, and large headway bandwidth at the close target headway and ±9 ft, ±22 ft, and ±34 ft for the far target headway. The relative velocity bandwidths, for both close and far target headways, were established around 0 miles per hour at ±1 mph, ±3 mph, and ±5 mph. It should also be noted that for a control condition, the drivers drove without the benefit of the displays.

The experiment was not a complete orthogonal design because all combinations of variables of interest were not included; specifically, the relative velocity display was not used by itself, as the main task for the driver was to maintain a constant headway. The no-display condition for both the close and far target headway conditions were the first two trials for each subject. The next 18 trials were in random order of the treatment combinations of target headway, headway display bandwidth, and relative velocity display trials. In the last two trials, runs 23 and 24, the subject was asked to select the headway bandwidth that he preferred for both the close and far conditions (Table 2). Each trial lasted approximately 9 minutes while the lead car went through the velocity change maneuvers. Data were sampled every 2 seconds during this period. Four college-age male drivers were used as subjects in this research. The intent of the research was to explore the effects of these display aids in some depth rather than to try to establish the effect of displays across a more representative sample of the population.

The subject driver was given approximately a half hour to get the feel of the car, driving from the laboratory to the test site. The speedometer was covered throughout the experiment. The subject for each trial was homed in, at either the close or the far target headways, and when he replied that he felt he could establish this distance visually, the experimental trial would begin. Five-minute rest periods were introduced approximately each half hour of driving. Although the subject was given information as to which display he would receive, he was not given information on the bandwidth of the headway and relative velocity aids, except for the last two trials in which the subject would establish by trial and error basis the bandwidth most comfortable to him. The accuracy in the headway bandwidth was less than ±2 feet. The percent of time the lights were on during the various trials for subject 2 is shown in Table 3.

TABLE 2

H BANDWIDTH SELECTED BY SUBJECTS

Subject	Target Headway	
	Close	Far
1	17 (MH) feet	16 (SH/MH) feet
2	6 (SH)	16 (SH/MH)
3	6 (SH)	22 (MH)
4	6 (SH)	16 (SH/MH)

Note: ( ) indicates approximate experimental H bandwidth condition.

TABLE 3

PERCENT OF TIME DISPLAY LIGHTS WERE ON DURING TRIALS—SUBJECT 2

Bandwidth Combinations	Close		Far	
	H	RV	H	RV
SH-SR	24%	16%	65%	61%
SH-MR	27	2	42	16
SH-LR	8	0	55	2
SH-NR	38	—	54	—
MH-NR	2	—	39	—
LH-SR	3	24	9	42
LH-MR	2	5	19	12
LH-LR	3	0	22	4
LH-NR	3	—	27	—

Note: Each trial is approximately a 9-minute run.

RESULTS

Before interpreting the results of this experiment, analysis was made to determine whether or not the lead car programs were effectively the same for each driver on each trial. These statistical tests indicated that effectively there was no significant difference among the lead car velocity programs from subject to subject. Statistical tests were also conducted to determine whether or not there were any significant learning effects during the research testing period. Tests were made to compare the first two no-display runs at close and far distance target headway with the replication later near the end of the experiment. There were no statistically significant differences in headway variances. With subject 4 the second 100 sample points of each of the 18 display combination trials were used to calculate the headway variance. These were then compared with the headway variance of the same trials calculated from all sample points available (samples were taken at 2-second intervals). There was no significant difference between the headway variances computed by these two techniques. Again, while we cannot be absolutely sure that there was no learning effect, it appeared to be minimal, particularly when viewed against the main effects of the experiment.

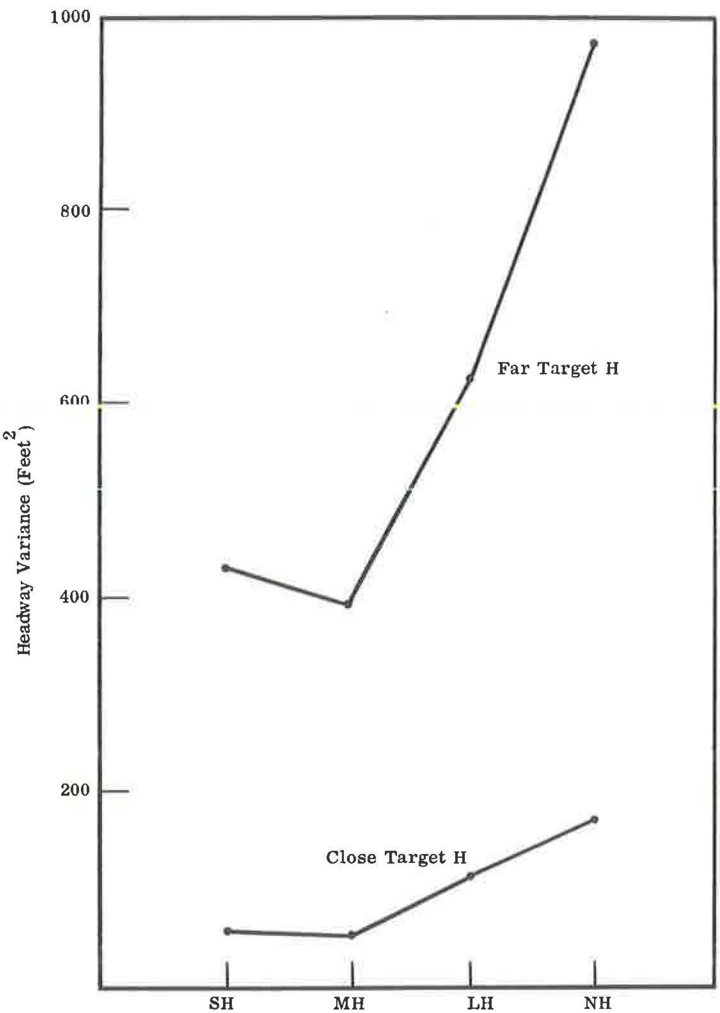

Figure 6. Headway variance for H bandwidth and target H over all subjects.

Analysis of variance was used to test the data. Subjects, bandwidth, and type of display were considered as major independent variables in the experiment as well as the initial target headway. The dependent variables were the headway variance and relative velocity variance over the trial. Figure 6 shows the general results of headway display bandwidth selection on headway variance for the two target conditions over all subjects. It had previously been established through statistical tests that subjects were not a significant effect in the analysis using headway variance and, thus, subject data were pooled in the case of headway bandwidth. It was interesting to note that there is a significant reduction in headway variance with the use of the headway display alone (over 60 percent for both target headways). Figure 7 shows the effects of the various headway bandwidths on relative velocity variance. Since in this case the individual subjects were slightly statistically significant, their data are shown individually. A general trend exists in which the relative velocity variance is actually larger with decreasing error bandwidth. This is probably explained by the frequent corrections made by the driver in maintaining his primary task, that of target headway, with subsequent resultant changes in relative velocity. Figure 8 shows the effects of relative velocity bandwidth displays on headway variance for all subjects. The variance is the average for the two headway bandwidths used with each RV display. Again it is noted that the headway variance decreases with smaller bandwidth for the far-target condition. At the close-target condition, there appears to be little advantage to the use of the RV display system.

Figure 9 depicts the general trends of results of the entire experiment showing the two criteria, the two target headways, and the display conditions involved. For this figure, the data are pooled for all subjects even though subjects were found to be statistically significant for a few of the cells. Results are described in comparison with performance under the no-display condition. As can be noted in a few instances, particularly at close headways with relative velocity variances as the criterion, the displays reduced performance (i. e., increased the variance). However, for the large

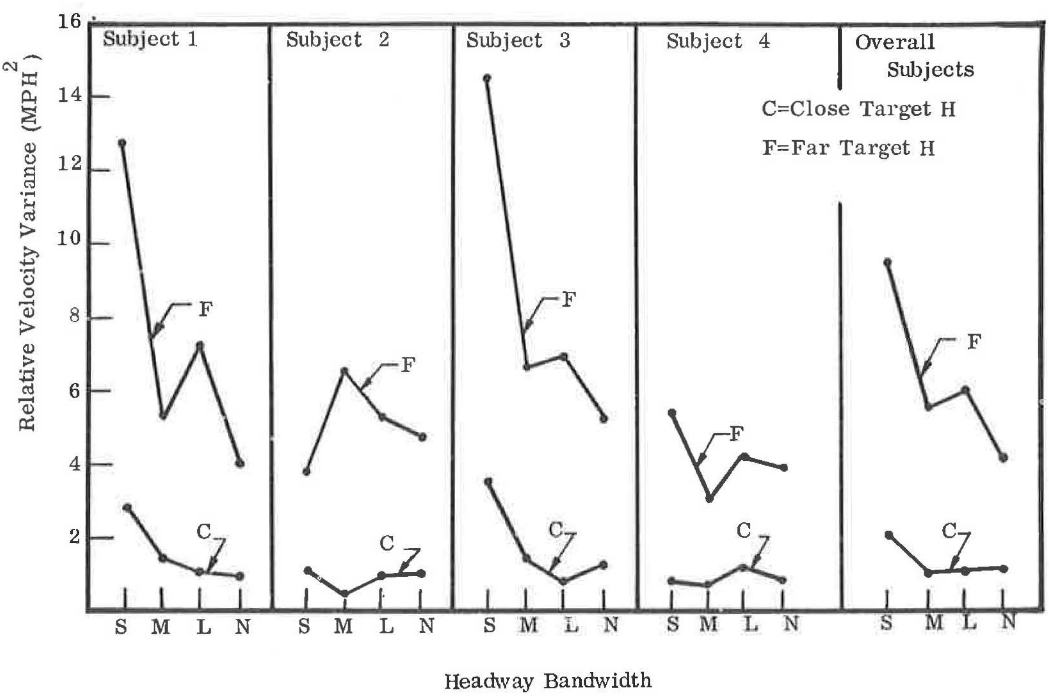

Figure 7. Relative velocity variance for H bandwidth and target H for each.

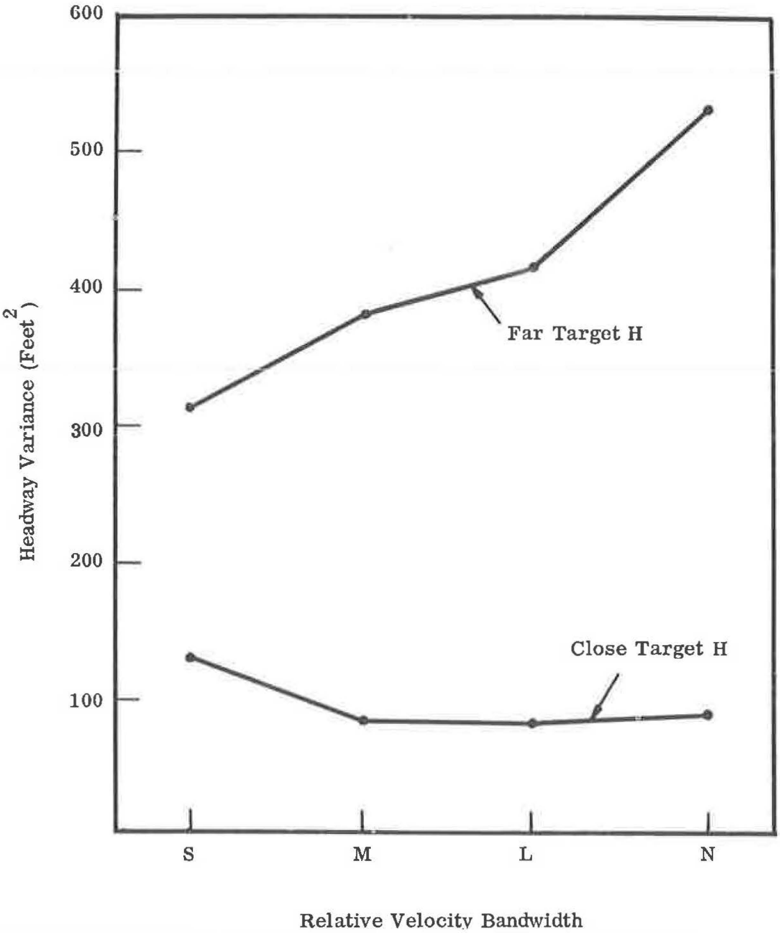

Figure 8. Headway variances for target H and RV display interaction (variances averaged for the 2 headway bandwidths used).

majority of conditions, the use of displays led to improved car-following performance. It is also evident that average car-following performance is much better at close target headways than at far headways and that display improvement appears to be less evident here. This may come from the fact that at close headways the driver's sensory capability for headway and relative velocity detection is better and that he tends to rely more on his perceptual processes and less on the display at these more risky car-following conditions. In general, for the entire experiment target headway was highly significant, bandwidth was usually significant, and subjects were slightly significant as found in the analysis of variance.

Finally, in regard to the elected bandwidth that the subjects would select voluntarily (Table 2), it is interesting to note that although the subjects need more headway information at the far distance, they are apparently willing to sacrifice sensing information for comfort. That is, they will accept less headway error information so that they will not have to make so many control corrections.

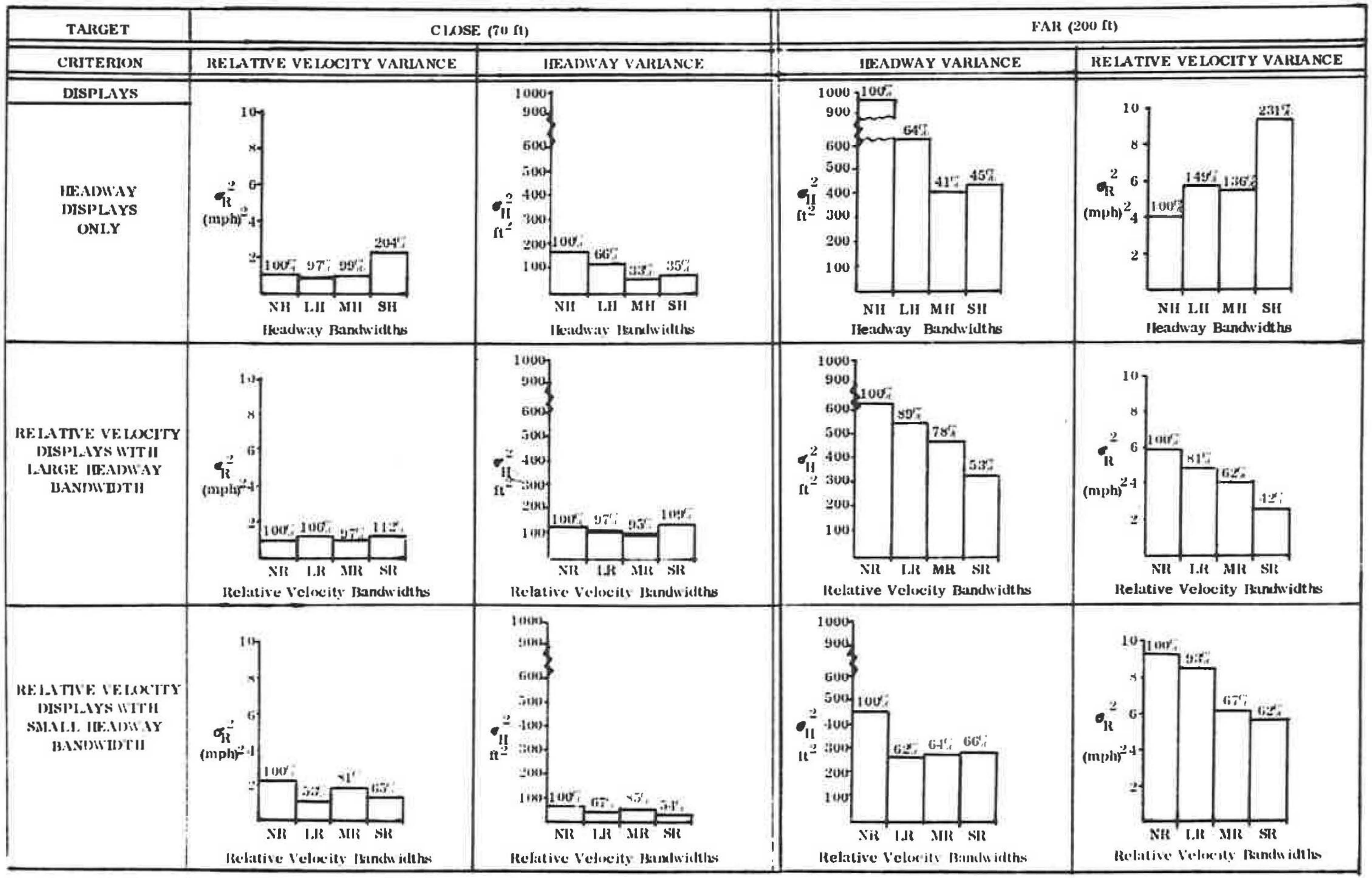

Figure 9. General trends of experimental results (data pooled for all subjects; all percentages in terms of the no-display condition).

CONCLUSION

On the basis of this exploratory work any generalizations are tenuous. The research does indicate that a discrete light display presenting headway and relative velocity information can improve car-following system performance. Over 60 percent reduction of headway variance can be obtained by using a headway bandwidth display alone at both target headways. Overall, the medium headway bandwidth display produced the best reduction in headway variance. The addition of the relative velocity bandwidth display reduced headway and relative velocity variances up to 47 percent and 58 percent, respectively, at the far distance. The relative velocity display in combination with large headway bandwidth appeared to have little effect at the close target distance. However, with small headway bandwidth the same general improvement as found earlier is seen. There appears to be no single display combination which is clearly optimal for the experimental conditions, although the SH-SR combination would be a leading candidate.

If it is assumed that headway variance is an important performance criterion and that close target distance is more realistic for increased traffic flow, then the best display combination would appear to be the small bandwidth for both displays. However, the absolute performance improvement at the close target headways seems rather small. It appears that at the close target headway conditions, the driver may prefer to use other cues than those provided by the display.

Future research suggests a larger treatment of this experiment and, perhaps, the use of time-delayed information to prohibit oscillations in control whereby the driver would be out of phase with the actual conditions between the two vehicles. It might also be fruitful to provide higher order derivative information on preview-type displays which measure traffic dynamics upstream.

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