Influence of Mental Set and Distance Judgment Aids on Following Distance

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Little information is presently available on the relation between various driver characteristics and following distance. Using a photographic technique for measuring distance between vehicles, two experiments were designed to measure (a) the effects on following distance of driver set, or general attitude toward the particular driving situation, and (b) the ability of drivers to maintain specified following distances, both with unaided vision and with two simple judgment aids. When drivers were asked to drive on a newly constructed highway not yet open to traffic under each of three sets—emergency, habitual, and maximum safety—at speeds of both 30 and 50 mph, the results indicated that drivers believed they habitually drove with maximum safety, as far as actual following distances were concerned. The distances obtained under the "habitual" set were found to be somewhat greater than those found in regular traffic on similar highways by previous investigators.

Both aids to distance judgment substantially reduced errors made with the unaided eye, at both 6- and 8-car lengths and a speed of 40 mph.

• FAULTY following distance has been held to be a major, or a contributing, factor in over one-third of American motor vehicle accidents (6). The same poor judgment that in some cases produces collisions may be responsible in other circumstances for disturbances in the even flow of vehicular traffic. Thus, vehicle separation, or the bumper-to-bumper separation of two vehicles traveling in the same lane in the same direction, is a matter of prime interest to those concerned with optimum utilization of highway space.

Freeborn and Orchard (4) conducted a study in which drivers were asked to maintain minimum safe following distances. Forbes et al. (3) used both open highway and tunnel conditions to measure the effects on individual following distance of such factors as acceleration, deceleration, curves, grades, and visibility. Subjects were told to drive "closely but safely as if anxious to get home in heavy traffic" (3, p. 346). Apart from these two studies, following distance behavior on the open highway as an element of individual driver psychology has not previously been studied, in terms either of external factors or of driver characteristics. Mass data are available on environmental factors that affect following distance, such as traffic volume and speed, grades, lateral interferences, curves, and kind of highway, in such source books as "The Highway Capacity Manual" (2). A useful review of other approaches to the study of following distance on the open highway is found in Chandler, Herman, and Montroll (1).

The study reported herein was undertaken to investigate two aspects of following distance vehavior: (a) changes in following distance associated with various mental sets and (b) use of visual aids in maintaining accurate following distances. The mental sets studied were habitual, emergency, and maximum safety driving. These terms are explained more fully later.

The distance judgment aids utilized either timing or the visual fusion phenomenon.

METHOD

To eliminate error resulting from interference by other vehicles the lead car and following cars were the only vehicles present. Speed was controlled by the driver of the lead car, and following distance was controlled by the subject in the following car, according to pretrial instructions.

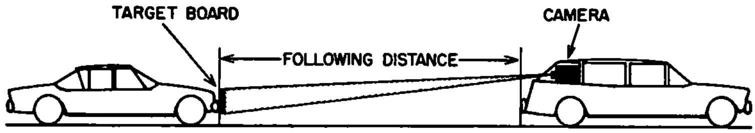

Figure 1. Data collecting situation, illustrating following distance and motion picture camera position.

Distance was measured by an adaptation of the Forbes method (3) using a motion picture camera mounted in the rear window of the lead car and aimed at a target board mounted on the front bumper of the following car, as shown in Figure 1. A frame-by-frame analysis of the following distance was made after the trials; therefore, no feedback information was given the subjects during the data collection.

Previous experimentation had shown that when film projection conditions were standardized, measurements having an average error of less than 2 percent could be obtained for following distances up to 200 ft by using photographs of the target board, then measuring the length of this strip on the projected film image.

The highway used was a 3-mi section of the Baltimore (Maryland) Tunnel Thruway—Northeastern Expressway, which had not been opened to the public. This was a two-lane highway, marked with lane lines. There were no lateral interferences, very little curvature, and adequate sighting distances at all times.

Subjects

The subjects were 20 male and 6 female adults, representing approximately the proportions of each sex in the three age groups (21-26, 35-40, 50-55) of the driving population.

All subjects were screened in terms of age, education, driving experience, occupation, and experience with the type of car and transmission to be used in the experiment. Those selected were tested for 12 visual abilities, for brake-response time, and for attitudes toward driving (5).

No subject admitted having had an accident in which there was loss of life, or damage exceeding $500. Mean driving experience was 14.3 years, and the average of total miles driven was 165,000. These data are given in Table 1.

Socioeconomically, the subjects were quite diversified. Among the occupations represented were housewife, policeman, college student, taxi-driver and accountant. Mean number of years of education was 12.3, with a spread from 8 to 18 years, the majority did not go to college.

Apparatus

The measurement apparatus consisted of a 16-mm motion picture camera mounted over the back seat of the lead car and focused on a 5-ft target board fastened to the front bumper of the following car. The camera was run at a constant rate of 8 frames per sec.

The automobiles were late-model automatic transmission sedans of American manufacture.

TABLE 1

SUBJECT CHARACTERISTICS

Characteristic	Mean	S.D.
Age (yr)	34.62	10.29
Education (yr)	12.27	2.85
Driving experience (10,000 mi)	16.51	19.74
Vision:		
Acuity:[1]		
Both	18.83	5.65
Right	23.04	9.51
Left	23.87	12.36
Phoria:[2]		
Vertical	-0.06	1.60
Lateral	0.97	2.23
Stereopsis[3]	6.87	2.46
Brake response time (sec)	0.425	0.036

[1] Snellen equivalents may be obtained by writing 20 above score.
[2] Zero indicates complete muscular balance.
[3] High scores indicate good stereoscopic ability (range 0 to 9).

Figure 2. Visual aid stimulus board for distance judgments.

Two special pieces of equipment were developed for this study, both mounted by brackets to the bumper of a car. The first, used in the photographic measurements, was a 5-ft white rectangle mounted on a matte black finish board.

The second, a special stimulus board used in estimating following distance, consisted of two sets of stimuli utilizing the visual fusion phenomenon, as shown in Figure 2. One set was comprised of four pairs of reflectorized yellow bars, 1 by 5 in., mounted in vertical parallel pairs. The spaces between the bars were $\frac{1}{32}$ in., $\frac{2}{32}$ in., $\frac{3}{32}$ in., and $\frac{4}{32}$ in.

The other set of stimuli consisted of four Landolt "C" rings having gaps equal to the separations of the parallel bars. The gaps were oriented randomly.

Both sets of stimuli were mounted on the same matte black finish board, which in turn was mounted on the rear bumper of the lead automobile.

Procedure

Phase I. Mental Set.—An attempt was made to influence the subjects' mental set through verbal instructions. Three sets of instructions (habitual, emergency, and maximum safety) were given at various stages of the experiment. The following standardized wording of the instructions were used:

Habitual: In your first test run, you will simply be asked to follow this lead car at whatever speed he sets. Just travel along behind him as you would ordinarily do if you wanted to drive at about the same speed. This is all there is to it. This run will be made four times in succession, at two different speeds.

Maximum Safety: We are now going to make a run just as we have already done, with one exception. You are to suppose that you wish to drive as safely as possible while at the same speed as your friends in the lead car. You have your family in the car and you are going to a picnic. One older person is very nervous about riding in traffic, and there are a couple of very active and noisy children. You are in no hurry whatever, and wish to be entirely sure of your safety. Do not pass the lead car, and be sure to travel at about the same speed.

Emergency: You will now make a run just as you have already been doing, with one exception. Imagine this time that you are in a situation where you must get where you are going just as fast as you possibly can, but you are prohibited from passing the car in front of you. For instance, suppose that you are in an evacuation from the city, and you are in a mass of traffic. The main idea is to get as many cars past the city line as possible, in as short a time as possible. You have been requested to drive as close to the car in front of you as you possibly can, without endangering your car or yourself, and without causing a traffic tie-up by a collision.

(After the second run, further instruction was given:) You will be repeating these runs, and others, several times. Vary your driving in any way you wish from time to time. You do not have to drive the same way each time, as long as you travel at about the same speed as the lead car.

Each subject drove the experimental route twice to familiarize himself with the road and the test car.

All subjects were given the habitual driving instruction first. The order of the maximum safety and emergency instructions was varied randomly from subject to subject.

Each subject drove twice under each instruction, at each of two speeds, making a total of 12 runs per subject, or four runs per instruction.

The subject drove alone in his car. The lead car driver was accompanied by an experimenter until he had been thoroughly trained. He then drove alone, operating the camera by a remote control cable.

Phase II. Estimation of Following Distance.—Various techniques of estimating distance were evaluated for their utility in aiding the subject to maintain a pre-set following distance.

TABLE 2

FOLLOWING DISTANCE IN RELATION TO SPEED AND MENTAL SET (INSTRUCTIONS)

Speed (mph)	Following Distance (car lengths)					
	Emergency Set		Habitual Set		Safety Set	
	Mean	S D.	Mean	S.D.	Mean	S D.
30	3.0	1.9	5.8	4.2	6.1	4.7
50	5.6	3.7	11.5	8 7	13.6	10.9

The subject was introduced to the concept of car length as an interval of 16 ft. He was then positioned in the test car at distances from 1- to 10-car lengths behind another car. Positionings were in whole car lengths and were made both while approching and while withdrawing (backing away) from the lead car. The subject was told the number of car lengths at each position.

He was next asked to approach the stationary lead car and stop at a distance of 6-car lengths. He was told his actual distance. This procedure was repeated, stopping at 8-car lengths. Training was continued until the subject was able to estimate both distances, twice in succession, with an error of less than ½-car length. He then drove two runs maintaining each of the two following distances, making a total of four runs. No special visual or other experimental cues were used during this part of Phase II.

The subject was then trained in the use of fusion stimuli as an aid to distance judgment. The special stimulus board (described earlier) was attached to the rear bumper of the lead car. From the driver's seat in his car, the subject was shown that each member of the pairs of bars could be differentiated at close range, but as the distance increased, the pairs tended to fuse into a single stripe, in inverse proportion to the width of the space separating the pair. The same phenomenon was demonstrated with the open "C" or Landolt rings.

The subject familiarized himself with both the bars and rings at a distance of 6- and 8-car lengths. He was trained in approaching and stopping at a specified distance behind a stationary lead car until he could fulfill the accuracy requirements previously specified.

The subject was then taught the use of a time judgment method of distance estimation. He was trained to count 10 sec, by saying aloud "one thousand one, two thousand two, three thousand three..." until he achieved an error of less than 1 sec. The subject then made two training runs, accompanied by an experimenter. During these runs the subject attempted to maintain specified separations of 1½ and 2 sec between his and the lead car. These were the time equivalents of 6- and 8-car lengths. Fixed objects, such as expansion joints in the pavement, road signs, or guardrail posts, were used as reference points.

When training in the use of fusion and time judgment techniques was completed, the subject made eight runs, two for each combination of technique and following distance. Instructions for the judgment aid and following distance were given at the beginning of each run. A speed of 40 mph was used throughout Phase II.

Method of Measurement

Frame-by-frame analysis of the films was used to measure the following distances. Thus, the exact separation of the vehicles was measured at intervals of ⅛ sec.

Technical difficulties prevented the use of the target board as a reference in some of the films. However, other fixed reference points on the vehicle proved to be equally useful and the over-all maximum error of measurement was less than 3 percent.

Unfortunately, a certain number of run films were unusable, for a number of technical and operator error reasons. Thus, 25 of 26 subjects produced usable data for Phase I and 18 of 26 subjects for Phase II.

RESULTS

Phase I. Mental Set

Mean following distances and times for all subjects under each instruction and speed are given in Table 2, and the analysis of variance results in Table 3.

The analysis showed that the effects of both instructions and speeds on following distance were significantly greater than the differences between subjects and between measurements. This was true because the error term used for making the F-test contained both subject and measurement effects. The interaction between speed and instruction was also significant. No term involving trials was significant.

When the means of Table 2 were examined for the explanation of these findings, the Duncan range test showed that significant differences occurred between the means for emergency instructions and those for either habitual or safety. There was no significant difference between habitual and safety instructions at 30 mph.

Inasmuch as neither trials nor subjects nor individual measurements significantly affected the results, it is believed that all problems of measurement and procedure were satisfactorily solved.

Phase II. Estimation of Following Distance

Errors of estimation may be positive (underestimation, that is, greater than requested following distance) or negative (overestimation). In a continuous pursuit task such as following, both types of error may occur during the same trial period. In fact, errors in one direction may be the result of overcompensation for errors in the other. Analysis of these errors may be in terms of the direction of error or the absolute amount of error.

Analysis of the direction of error is called vector error and is obtained by algebraically summing all individual errors. Thus, the negative errors compensate for, or cancel out, positive errors, and vice versa. The absolute error, called scalar error, is obtained by adding the absolute values of all the individual errors. The direction, or vector, score gives the direction and magnitude of the subject's average error; the absolute or scalar score gives the over-all magnitude of the error.

Hence, a subject who underestimates by 1-car length 50 percent of the time, and overestimates 1-car length the other 50 percent, would have a direction (vector) error score of 0 and an absolute (scalar) error score of 2.

TABLE 3

LENGTH OF FOLLOWING DISTANCE IN RELATION TO MENTAL SET, SPEED, AND TRIALS—ANALYSIS OF VARIANCE
(N = 25)

Source	df	MS	F
Mental set	2	860.66	20.13[a]
Speed	1	2,089.61	48.87[a]
Trials	1	11.64	0.27
Mental set × speed	2	154.42	3.61[b]
Mental set × trials	2	21.48	0.50
Speed × trials	1	2.25	0.05
Mental set × speed × trials	2	6.11	0.14
Within cells (error)	288	42.76	
Total	299		

[a] Significant beyond the 0.01 level.
[b] Significant at the 0.05 level.

TABLE 4

MEAN VECTOR ERRORS OF ESTIMATION OF FOLLOWING DISTANCE BY JUDGMENT AID AND DISTANCE[1]

Distance (car lengths)	Judgment Aid (car lengths)					
	Habitual		Fusion		Timing	
	Mean	S. D.	Mean	S. D.	Mean	S. D.
6	1.7	2.6	0.3	1.5	-0.2	1.7
8	1.5	2.9	-0.2	3.3	0.2	1.9

[1] Positive means indicate errors of underestimation (distance greater than required); negative means indicate errors of overestimation (distance less than required).

TABLE 5

VECTOR ERRORS OF ESTIMATION OF FOLLOWING DISTANCE IN RELATION TO ESTIMATION AIDS, SPECIFIED DISTANCES, AND TRIALS— ANALYSIS OF VARIANCE
(N = 18)

Source	df	MS	F
Aids	2	55.95	12.16[a]
Distances	1	0.46	0.10
Trials	1	0.70	0.15
Aids × distances	2	2.50	0.54
Aids × trials	2	0.00	0.00
Distances × trials	1	2.83	0.62
Aids × distances × trials	2	1.07	0.23
Within cells (error)	204	4.60	
Total	215		

[a] Significant beyond the 0.001 level.

The mean vector scores for all subjects under each condition of distance and judgment aid are given in Table 4, and the analysis of variance in Table 5. Table 6 gives the scalar scores, with the analysis of variance in Table 7.

From Table 4 it is apparent that without judgment aids subjects tended to underestimate following distance. That is, they thought the distance was shorter than it actually was, and therefore used a longer distance than was required.

Analysis of variance confirmed the significance of the effects of both types of judgment aid: the level was better than 0.001. Examination of the mean differences by t-ratios indicated that there was no significant difference between the effects of visual fusion and timing judgment aids.

Actual car lengths of error were about the same at one distance as at the other, but percent of error (length of error divided by length of required distance) showed a consistent decline for the longer distance, under all three judgment conditions.

The absence of significant effects by trials, or by any of the interactions, when compared to subjects and measurements, indicates that reliability has been achieved in spite of difficulties of measurement, design, and subject selection.

TABLE 6

MEAN SCALAR ERRORS OF ESTIMATION OF FOLLOWING DISTANCE BY JUDGMENT AID AND DISTANCE

Distance (car lengths)	Judgment Aid (car lengths)					
	Habitual		Fusion		Timing	
	Mean	S. D.	Mean	S. D.	Mean	S. D.
6	2.1	13.0	1.2	4.6	1.4	5.3
8	2.2	14.3	1.5	6.8	1.5	6.6

TABLE 7

SCALAR ERRORS OF ESTIMATION OF FOLLOWING DISTANCE IN RELATION TO ESTIMATION AIDS, SPECIFIED DISTANCES, AND TRIALS—ANALYSIS OF VARIANCE
(N = 18)

Source	df	MS	F
Aids	2	13.75	5.75[a]
Distances	1	1.34	0.56
Trials	1	5.80	2.43
Aids × distances	2	0.12	0.05
Aids × trials	2	0.74	0.30
Distances × trials	1	2.11	0.88
Aids × distances × trials	2	0.07	0.03
Within cells (error)	204	2.39	
Total	215		

[a]Significant beyond the 0.05 level.

The virtual elimination of vector errors when aids are used indicates that the habitual tendency to follow at a distance greater than requested can be overcome by using such aids. Reduction in the scalar errors indicates that judgment aids also assist the subject in reducing the total amount of error.

ANALYSIS

The absence of significant differences between habitual and safety sets suggests that either these drivers did not interpret the instructions correctly or they believed that they habitually drove as safely as possible. This was checked at the end of testing, by asking the subject whether he felt the distances he maintained under safety instructions were sufficient to preclude collision. Answers were always affirmative. When asked whether he could have driven closer under emergency instruction, the subject often indicated that he could have used a shorter distance but thought his instructions required at least some margin for safety.

These responses seem to indicate the subjects really did not perceive significant differences at 30 mph between the distances they ordinarily preferred and those affording maximum safety. This perception is even more striking when one realizes that some subjects drove at distances less than 3-car lengths at 30 mph, yet insisted that these distances were completely safe. Other subjects dropped back as far as 50- or 60-car lengths, and one drove over 100-car lengths behind, under "safety" instructions.

The data on estimating following distance indicate that it is possible to reduce error substantially by providing simple judgment aids. Even greater improvement may be possible with more refined aids.

Actual amount of error remained approximately the same at 6- and 8-car lengths; that is, percent of error was less at 8-car lengths for each aid used than it was at 6.

The general tendency to underestimate, or err in the direction of greater separation, implies a general resistance to driving at distances as short as 6- or 8-car lengths when speed is 40 mph. Available data on length of following distance support this conclusion.

CONCLUSIONS

Analysis of the data resulted in these conclusions for the subjects used:

1. Following distance is a stable measure of driving performance.
2. Both speed and emergency instructions affected following distance, with the higher speed resulting in longer distances and the emergency mental set resulting in shorter distances.
3. Percent of error was significantly less at the longer of the two requested following distances.
4. Use of the visual and timing aids resulted in significantly lessening the tendency to follow at a greater than requested distance.
5. On the average, drivers drove at about the same following distance under both habitual and maximum safety instructions, at 30 mph.

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