DRIVER RISK-TAKING: THE DEVELOPMENT OF A DRIVER SAFETY INDEX

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A methodology to classify automobile drivers according to their risk-acceptance decisions, their visual-perception capabilities, and their driving skills is presented. A drive-through gap situation was used to develop and experimentally investigate the concept of the driver safety index. The concept is based on the assumption that a driver's "safety distance" between the mean of his psychometric risk-acceptance function and the mean of his psychometric visual-perception function for a gap, expressed in multiples of the standard deviation of his driving-skill distribution for centerline path deviations in the gap, is a representative measure of his risk-taking behavior. Four subjects were used in the experimental investigation. A sequential estimation procedure was used to obtain points on the psychometric visual-perception and risk-acceptance functions. The experimentally obtained values indicate that the methodology seems sensitive and successful in detecting differences among the drivers. In addition, the drivers who exhibited either rather large or small values under a given set of experimental conditions exhibited similar large or small values under a different set of experimental conditions. Considerable differences with respect to how the subjects perceived gaps of a given size were found.

•ACCEPTING risks is probably one of the most basic characteristics of mankind. Wherever people engage in some sort of activity, we may expect risk-taking situations. Entering a busy freeway, overtaking a slower moving vehicle, selecting a particular driving speed range, and driving through obstacles are just a few examples of the many risk-taking situations an individual may encounter when driving a car.

Risk acceptance is a basic area of concern in safety. For many years it has been evident to those working in the safety field that individual risk-taking behavior appears to be a major factor in accident causation (23, 25). Studies with respect to risk-taking have been conducted in various fields and disciplines. A series of studies dealing with risk acceptance in man-machine systems and driving (3, 4, 5, 6, 19, 24, 25, 26) represents the background for this research. Much pioneer research has been conducted in related areas such as accident proneness (30), personality correlates (1, 9, 21, 22, 28), decision theory and information-seeking (7, 11, 12, 13, 20, 29), and passing behavior and gap acceptance (2, 8, 9, 14, 16, 17, 18). The research presented here is thought to be one of the first attempts to measure a driver's risk-acceptance behavior in a real driving situation within the framework of his visual perceptual capability and his driving skill.

THE RISK-ACCEPTANCE PROCESS

A drive-through gap situation was used to develop and experimentally investigate the concept of the driver safety index (DSI). Experiments using a similar gap situation

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have been conducted (3, 4, 6, 19). A stationary gap situation is simple when compared with other risk-taking situations such as overtaking or gap-acceptance at intersections. Although little is known about the risk-acceptance process in a gap situation, a risk-acceptance schema can be theorized that incorporates the gap situation, the driver factors, the vehicle factors, the driver decisions, and the outcome. A risk-acceptance schema representing the drive-through gap situation is shown in Figure 1. It is assumed that biographical factors, psychological factors, sociological factors, and previous life experiences, as well as the subjective value of the vehicle, provide the underlying basis for a driver's inherent value judgment. It should be noted that the subjective value of the vehicle is not necessarily limited to a utility value for a dollar and cents amount but may be based on other features of a bio-robot relationship between a driver and his vehicle, as suggested by Cohen and Preston (6). It is assumed that at the time a driver is perceiving a gap, the value judgment with respect to the utility of driving and the utility of not driving is immediately available. It is assumed that a driver has a rather good subjective knowledge about his ability to drive the vehicle as closely as possible through the center of the gap. A driver's driving skill is represented by the standard deviation of vehicle path error from the gap centerline, which includes an element of chance resulting from errors generated by a vehicle's steering mechanism. It should be noted that these random errors beyond a driver's control may represent a considerable proportion of the total standard deviation. It is assumed that the visual perceptual capability of a driver with respect to judging the exact size of a gap, or the task requirements, represents the major uncertainty element in the sensory judgment process of matching personal steering skills with the task requirements. During the approach toward the gap this sensory process of matching personal driving skill ability with the visually perceived task requirements, or gap size, may be repeated for a number of times. It is assumed that this sensory judgment cycle represents the nucleus of the gap risk-taking situation.

THE DRIVER SAFETY INDEX CONCEPT

Based on the risk-acceptance schema in Figure 1, it seems almost mandatory that a driver's risk-acceptance decisions should be viewed within the framework of his visual perceptual capability and his driving skill ability. The DSI concept is based on the assumption that a driver's "safety distance" between the mean of his psychometric risk-acceptance function and the mean of his psychometric visual-perception function for a gap, expressed in multiples of the standard deviation of his driving skill distribution for centerline path deviations in the gap, is a representative measure of his risk-taking behavior.

The DSI for a given set of experimental conditions is defined as follows:

$$DSI = \frac{\mu_{RA} - \mu_P}{\sigma'_S}$$

where

μ_{RA} is the mean of the psychometric risk-acceptance function for a given set of experimental viewing conditions;

μ_P is the mean of the psychometric visual-perception function for the same set of experimental viewing conditions as were used in the risk-acceptance experiment; and

σ'_S is the adjusted standard deviation of the driving-skill distribution for a given set of experimental driving skill conditions.

The following steps outline how a driver's DSI is obtained from experimentally collected data:

1. The mean μ_P and the standard deviation σ_P with respect to judged gaps of equal car width are obtained from the experimental data. These two parameters are used to represent the driver's visual perceptual capability. The standard deviation is not directly used in the DSI. However, σ_P is used by the experimenter to obtain some idea about the consistency of a driver's perceptual judgments. Both estimates are expressed in inches.

2. The mean μ_{RA} and the standard deviation σ_{RA} with respect to the risk-acceptance decisions are obtained from the experimental data. These 2 parameters are used to represent the driver's risk-acceptance behavior. Again, the standard deviation is not directly used in the DSI but is used to give the experimenter some idea about the consistency of a driver's risk-acceptance decisions. Both estimates are expressed in inches.

3. The mean μ_s and the standard deviation σ_s with respect to vehicle deviations from the gap center are obtained from the experimental data. If it is assumed that the vehicle deviations from the gap center are normally distributed (experimentally confirmed) with a mean μ_s, any absolute deviation of the mean μ_s from the gap centerline will result in some increase with respect to the probability of failure, or making contact with the obstacles, for a given positive gap clearance. The skill measure used in the DSI concept should therefore be based on an adjusted standard deviation σ'_s, which will account properly for the increase in the probability of contact due to a given absolute deviation of the mean μ_s from the gap centerline. The adjusted standard deviation σ'_s is defined as the standard deviation of a normal distribution with a mean of zero that yields the same probability of contact for a given positive gap clearance as the normal distribution with mean μ_s and standard deviation σ_s. Thus, to determine σ'_s for a given positive gap clearance, the probabilities of contact have to be determined for the left-hand tail and the right-hand tail of the normal distribution with mean μ_s and standard deviation σ_s. The sum of these 2 obtained tail probabilities is then divided by 2 and the appropriate Z-value from a standard normal table is assigned to this tail probability. This Z-value represents the number of adjusted standard deviations that make up half of the positive gap clearance. Dividing half of the positive gap clearance by the Z-value will provide the adjusted standard deviation σ'_s in inches. (Note that $\sigma'_s \geq \sigma_s$.)

4. The mean gap estimate of judged equal car width is subtracted from the mean gap estimate of the risk-acceptance decisions. This difference represents a driver's appreciation for safety. A large positive difference would generally suggest a rather high appreciation for safety, whereas a small positive difference would generally suggest a rather low appreciation for safety. A negative difference would suggest that a driver is making irrational decisions most of the time.

5. The obtained difference between the gap mean of the risk-acceptance decisions and the gap mean of the visual perceptual judgments will be divided by the adjusted standard deviation σ'_s. The DSI is thus a dimensionless number that represents the positive difference attributed to a driver's appreciation for safety in multiples of his actual driving skill.

The following example will illustrate how a single DSI is determined from a given set of experimental data. In this example the visual perception mean μ_P has been assumed to be 73 in. and the standard deviation σ_P 3 in. The risk acceptance mean μ_{RA} has been assumed to be 91 in. and the standard deviation σ_{RA} 3.8 in. These values are rather typical for a 46-ft static viewing distance and an 80-in. wide car at the gap. The two psychometric functions are plotted as a function of the gap size in the top half of Figure 2. Based on a 90-in. wide gap, a 79-in. wide car and a 20-mph driving speed, the mean μ_s of the driving skill distribution has been assumed to be located 1.2 in. to the left of the theoretical gap center. The standard deviation of the driving skill distribution σ_s has been assumed to be 2.75 in. Using the previously outlined steps, the adjusted standard deviation σ'_s was determined as 3.0 in. The driving skill distribution is shown in the lower half of Figure 2.

Based on the foregoing data, a DSI of $(91.0 - 73.0)/3.0 = 6.0$ is obtained. A DSI of 6.0 would suggest that this particular driver would probably be classified as neither a "truly" high risker (DSI range 0-3) nor a highly cautious individual (DSI range > 15) but would straddle these 2 extremes.

According to the DSI concept the "truly" high risker (low DSI, range 0-3) would be an individual who seems to have assigned rather low utilities to the range of possible bad outcomes. His risk-acceptance decisions appear to be based on a set of value judgments that seem rather conducive to engaging in risk-taking situations characterized by high subjective probabilities of failure. It should be noted that if a "truly" high risker

Figure 1. Risk-acceptance schema for the drive-through gap situation.

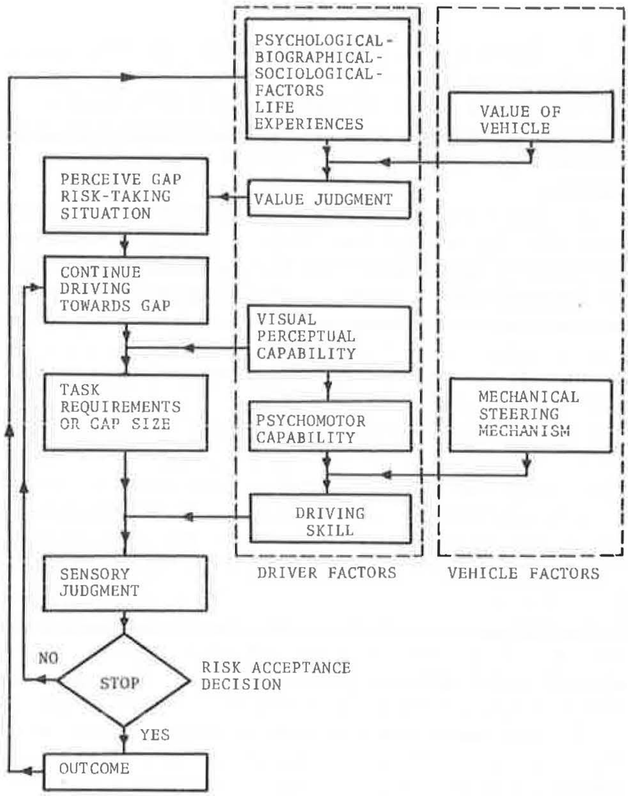
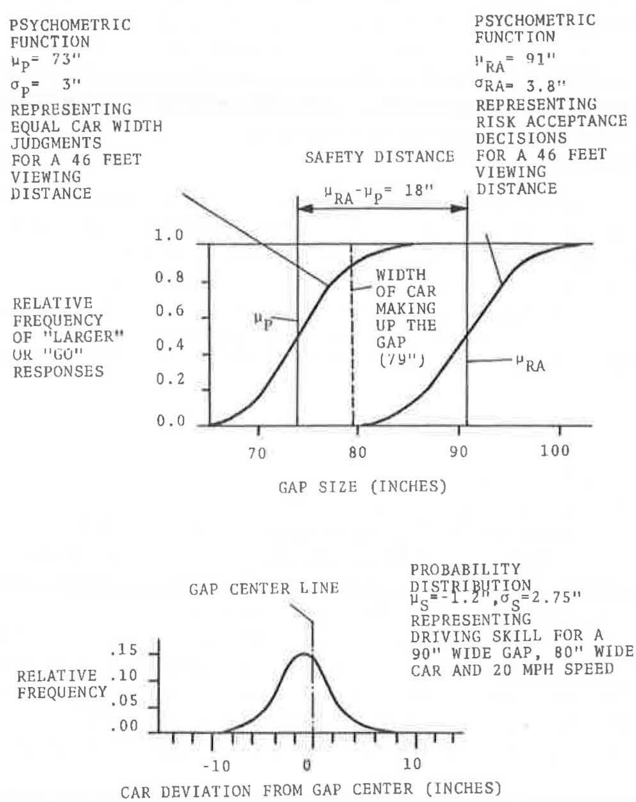


Figure 2. Examples of a visual-perception and a risk-acceptance psychometric function and a driving-skill distribution.



perceives gaps consistently much smaller than they actually are, then he might not incur any hazard, hazard being defined as the actual or objective probability of failure. However, such a driver would still be classified as a "truly" high risker according to the DSI concept. A "perceptual" high risker would be an individual who could have a rather high DSI (6-10). However, considerable hazard is incurred because he perceives gaps consistently as much larger than they actually are (dangerous perceiver). The driver in the foregoing example could be considered as a slightly dangerous perceiver since he indicated a too-small gap (approximately 9 percent) as being equal in width to the car.

It should be noted that the measurements of human characteristics such as risk-acceptance behavior, visual-perception capability, and driving skill are not as accurate as the measurements of height and weight, for example. Thus, the DSI, which is based on all three characteristics, will itself be a measure of limited accuracy. There are not enough experimental data available at the present time to make any reliable statements about the degree of accuracy of a single DSI measurement. Further, traumatic experiences might alter temporarily or permanently a driver's previously obtained DSI. If other psychological or physiological human characteristics and their changes over time are considered, it seems very likely that shifts in a driver's DSI will occur over his lifetime.

THE DRIVER SAFETY INDEX EXPERIMENTS

Subjects

Four subjects were used in the DSI experiments. Three of the subjects (E.T., B.B., M.P.) were 16-year-old female high school students. All of the 3 subjects were enrolled in a school driver education program and had very little driving experience at the beginning of these experiments. The other subject (R.F.) was a 25-year-old experienced male driver. All subjects drove without glasses and had a visual acuity equal to or better than 20/20. Peripheral vision as well as other aspects of vision were all within normal ranges. None of the subjects had any physical handicaps. The subjects were paid and participated in these and other experiments over a period of 3 months.

Test Site

The test site is shown in Figures 3 and 4. A straight, dead-end service road approximately 1,000 ft long and 15 ft wide was used to conduct all of the DSI experiments. The road was paved and had no lane markings. A wire fence with wooden posts, 10 ft away from the pavement edge, extended along both sides of the road. The road traversed an open field and no buildings were located along the road. All experiments were conducted during daylight and with no other traffic on the road.

Arrangement for Visual-Perception and Risk-Acceptance Experiments

The experimental arrangement for the perception and risk-acceptance experiments was the same. The selected experimental arrangement consisted of a gap placed approximately at the midway point of the road as shown in Figure 3. The gap was made up by a dark blue 1970 Buick Electra (79 in. wide) parked on the left side of the road with the front toward the front of the experimental car and a 4-ft high, 4-in. square black and white wooden post placed on the road perpendicular to the B-pillar position of the Buick. A 1-in. wide strip of beige adhesive masking tape was placed across the road surface perpendicular to the B-pillar position of the Buick. The tape was marked in 2-in. intervals, and different gap sizes were obtained by positioning the post closer or further away from the Buick along the tape. These marks were such that they could not be seen by the subjects. The experimental car (1969 Chrysler Newport) was parked in front of the gap so that there was either a viewing distance of approximately 46 ft or 300 ft from the subject's eyes to the perpendicular B-pillar gap line. The 46-ft viewing distance was considered as the minimum safe stopping distance when approaching the gap with a speed of 20 mph. The 300-ft viewing distance was selected as an upper limit since pilot eye movement experiments indicated that gaps located further away had little or no influence on the driver's information-seeking activities when approaching the gap at 20 mph.

Arrangement for Driving-Skill Experiments

The experimental arrangement for the driving-skill experiments is shown in Figure 4. Frequent grazing of the obstacles was expected when gaps with rather small clearances were presented. Thus, for safety reasons, as well as for economic reasons, the car and the wooden post making up the gap in the perception and risk-acceptance experiments had to be simulated in the driving-skill experiments. The Buick at the gap was simulated by 2 white 4-ft high, 2-ft wide, 1-in. thick Styrofoam plates placed 10 ft apart from each other, and the wooden post was replaced by an identical Styrofoam post. The softness and the light weight of the Styrofoam obstacles prevented any damage to the experimental car and the car occupants when contact with the obstacles was made.

A heavy steel plate was used to hold the Styrofoam post in place on the road. Two U-shaped steel posts were driven into the ground at the pavement edge to hold the Styrofoam plates. Three black rubber mats, approximately 7 in. wide and 24 in. long, were placed inside the gap in front of the 2 plates and the post. The mats were kept slightly wet so that the tire tracks of the experimental car could be seen. The 3 tire-track measurements were used subsequently to determine the relative gap position of the experimental car for each gap run. Gaps of different sizes were obtained by positioning the steel plate holding the post closer or further away from the 2 Styrofoam plates. To facilitate the accurate positioning of the steel plate holding the post, the same masking tape arrangement used in the perception and risk-acceptance experiments was used. The position of the gap along the road was again approximately at the midway point.

Procedure for Perception and Risk-Acceptance Experiments

Each subject was given a 2-hour introductory field session in which the subject was introduced to the perception and risk-acceptance aspects of the gap situation and to the driving skill requirements of the simulated gap situation. It was expected that this introductory session would provide a framework where initial learning with respect to the risk-taking task could take place and thus provide a more homogenized group for the subsequent DSI experiments. The order of the DSI experiments was not systematically determined and was of a somewhat random nature due to the availability of the subjects and the experimental equipment. Some of the subjects had their skill experiments between the perception and risk-acceptance experiments, whereas others had their skill experiments after the perception and risk-acceptance experiments were completed.

The experimental procedure used for the perception and risk-acceptance experiments required 2 experimenters. One experimenter was stationed at the gap while the other experimenter was sitting beside the subject in the experimental car. The 2 experimenters were able to communicate with each other using radios. At the beginning of the experiment the subject was given the appropriate set of instructions. The subject's gap judgments or the risk-acceptance decisions were recorded by the experimenter sitting beside the subject and then communicated via radio to the experimenter at the gap. The experimenter at the gap recorded the judgments too and determined the next gap size based on the previous judgments or decisions made by the subject. A new gap was subsequently set up by the gap experimenter by moving the post into a new position. The experimenter sitting in the subject's car then told the subject to look at the new gap after the gap experimenter disappeared behind the Buick. A series of 60 to 100 gap presentations took approximately 1 hour.

The Up-and-Down Transformed Response (UDTR) rule (31) was used to estimate the mean and the standard deviation of the psychometric functions. This rule is a generalization of the Up-and-Down (UD) rule (10). The 2 selected UDTR rule patterns provided estimates for the 70.71 and 29.29 percentage points of the psychometric functions. Both rules were presented alternately. Under the first pattern, 2 positive or "L" responses at a given stimulus level, or gap size, move the gap size 1 step down (smaller) for the next presentation, whereas a negative response always moves the gap size 1 step up (larger) for the next presentation. Under the second pattern 2 negative or "S" responses at the same level move the gap size 1 step upward (larger) for the next presentation, whereas a positive response "L" always moves the gap size 1 step down (smaller). During the course of experimentation the subjects were usually complimented with respect to their performance but were never told specifically how accurately they perceived or what type of risk-acceptance decisions they made. It was found that the thresholds of some of the subjects shifted considerably during a given experiment.

Procedure for Driving-Skill Experiments

The driving-skill experiments were conducted using the simulated gap situation consisting of 2 Styrofoam plates and a Styrofoam post. The gap was always set at 90 in. and the vehicle speed was instructed to be 20 mph. The overall width of the experimental car (Chrysler) was approximately 80 in., which left a total gap clearance of about 10 in. Previous pilot driving-skill experiments had indicated that a gap size of 90 in. represents a rather challenging gap situation for most drivers. Thus, contact with the obstacles could be expected in approximately 5 to 25 percent of all gap runs. In order to obtain some base data with respect to temporal information-seeking behavior, most of the driving-skill experiments were also used to collect TV data about a driver's temporal information-seeking activities. The experimental car was equipped with a TV eye-movement recording system and other electronic recording equipment. A detailed description of this TV eye-movement recording system (3 TV cameras, monitor, video recorder) is given elsewhere (27).

The gap was approached from both sides, which increased the efficiency of the data-collection process. Three experimenters were used to conduct the driving-skill experiments and to collect the TV data about the temporal information-seeking activities. One experimenter was at the gap, measuring and recording the tire tracks on the 3 rubber mats after each gap run. Further, in the case where the experimental car made contact with the obstacles, the damages were recorded and the damaged obstacles had to be replaced. The tire tracks were recorded to the nearest $^{1}/_{10}$ in., measured from the end of the obstacle toward the center of the gap. The other 2 experimenters were in the experimental car. The experimenter sitting beside the subject had to be prepared to use the dual braking system in case of an emergency. The other experimenter operated the TV equipment and the Honeywell recorder used to record the vehicle speed. At the beginning of each experiment the subject was again given a set of appropriate instructions. The subjects were instructed to read out loud as many speed values from the speedometer as they could while approaching the gap. A driving-skill experiment consisting of approximately 40 to 50 trials required usually about 2 hours.

Results of DSI Experiments

The estimates of the means and standard deviations for the 3 DSI components are given in Table 1. The comparison of gap means and standard deviations obtained from the perception and risk-acceptance experiments are shown in Figure 5.

The DSI sample values obtained under the stationary viewing distance of 46 ft and the DSI sample values obtained under the stationary viewing distance of 300 ft are shown for each subject in Figure 6. In Figure 6 we see that subjects E.T. and R.F. exhibited under both viewing distance conditions rather low DSI sample values. Subject M.P. exhibited ultra-conservative risk-taking behavior under the 300-ft viewing distance condition. The perception means in Table 1 indicate that all 4 subjects decreased their mean estimates under the 300-ft perception distance condition (E.T., 6.3 in.; M.P., 2.4 in.; B.B., 4.1 in., and R.F., 8.1 in.). The same holds true for the risk-acceptance means with the exception of subject M.P., who exhibited ultra-conservative risk-taking behavior (E.T., 13.1 in.; M.P., -34.9 in.; B.B., 12.0 in.; and R.F., 4.6 in.).

Other effects, such as driving speed, a different gap setup and environment, and a 2-dimensional reduced-scale ($^{1}/_{12}$ and $^{1}/_{24}$ scale) laboratory gap display, on the DSI components were experimentally investigated in an exploratory manner. The results of these experiments and other driving-skill and information-seeking experiments are discussed elsewhere (32).

Figure 3. The gap situation for the visual-perception and risk-acceptance decision experiments.

Figure 4. The simulated gap situation for the driving-skill experiments.

Table 1. Estimates of means and standard deviations for 3 DSI components.

	Driving Skill[a]			Perception[b]				Risk Acceptance[c]				DSI	
				46 Ft		300 Ft		46 Ft		300 Ft			
Subject	μ_S (in.)	σ_S (in.)	σ_S' (in.)	μ_P (in.)	σ_P (in.)	μ_P (in.)	σ_P (in.)	μ_{RA} (in.)	σ_{RA} (in.)	μ_{RA} (in.)	σ_{RA} (in.)	46 Ft	300 Ft
E. T.	0.06	4.05	4.05	73.34	3.13	67.03	2.78	82.95	1.19	69.84	3.73	2.4	0.7
M. P.	0.00	2.81	2.81	78.23	1.21	75.80	2.36	95.44	2.35	130.32	3.86	6.1	19.4
B. B.	-0.98	2.99	3.14	62.96	1.71	58.90	2.08	93.56	2.96	81.58	4.12	9.8	7.2
R. F.	-1.55	1.98	2.45	70.71	1.26	62.60	1.97	74.19	1.31	69.58	2.75	1.4	2.9

[a]Gap size 90 in., speed 20 mph, 80-in. wide car.
[b]Gap size perceived as equal to 79-in. wide car at 0 mph.
[c]Gap size accepted for 79-in. wide car at 0 mph.

Figure 5. Comparison between the means and standard deviations of the visual-perception and risk-acceptance psychometric functions obtained under the 46-ft and 300-ft viewing distances for all subjects.

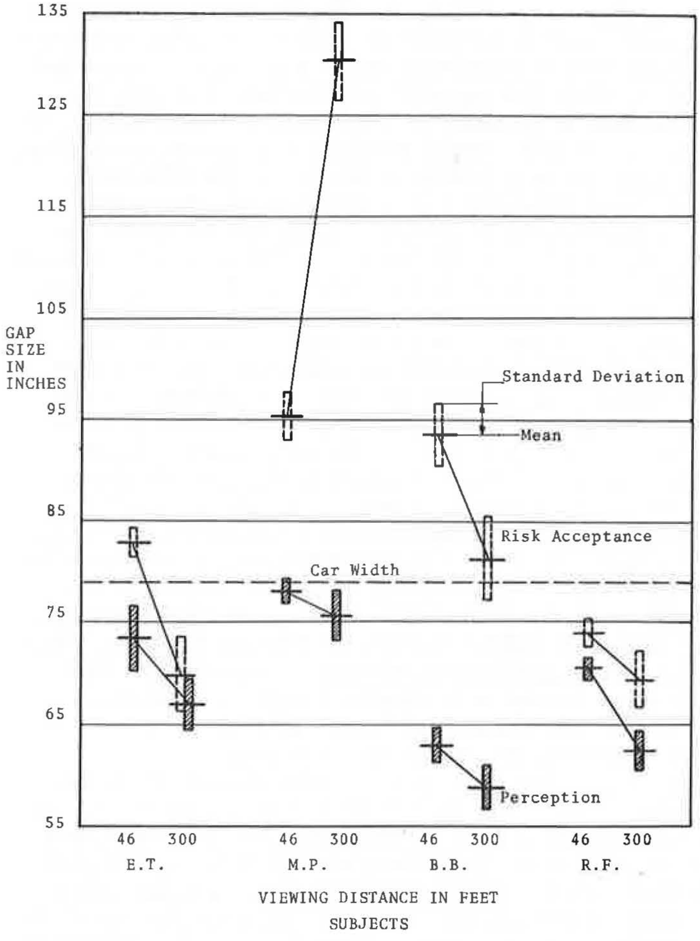
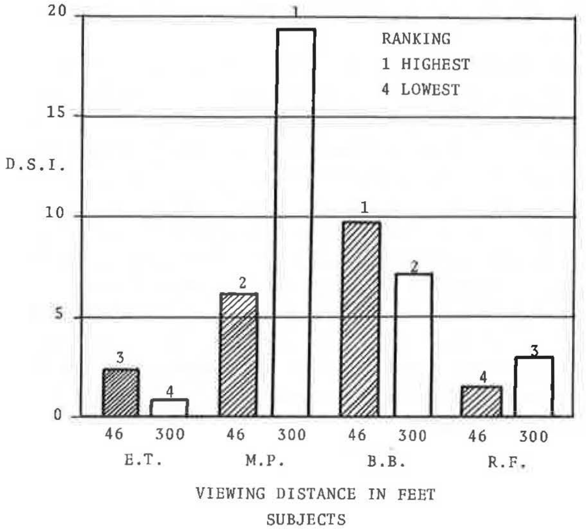


Figure 6. Comparison of DSIs obtained under the 46-ft and 300-ft viewing distances for all subjects.



CONCLUSIONS

As pointed out previously, the concept of the DSI is based on the assumption that a driver's "safety distance" between the mean of his psychometric risk-acceptance function and the mean of his psychometric visual-perception function for a gap, expressed in multiples of the standard deviation of his driving-skill distribution for centerline-path deviations in the gap, is a representative measure of his risk-taking behavior. The experiments conducted with respect to the DSI concept provided several major findings. First, the DSI methodology was successful in detecting rather large DSI differences among the individual drivers when tested under the same experimental conditions. In addition, Figure 6 shows that the 2 drivers who exhibited a rather low DSI under the 46-ft viewing distance exhibited again a rather low DSI under the 300-ft viewing distance, whereas the 2 drivers who exhibited a considerably higher DSI under the 46-ft viewing distance exhibited again a considerably higher DSI under the 300-ft viewing distance. Due to the small number of subjects tested and the observed magnitudes of the intrasubject variability, no really significant association between the 46-ft and the 300-ft viewing distances can be demonstrated (Kendall rank correlation coefficient: +0.333, significant only at the 0.375 level). Another interesting finding is the fact that the obtained standard deviation estimates for the psychometric risk-acceptance functions were generally only slightly larger than the obtained standard deviation estimates for the corresponding psychometric visual perception functions. The rather modest observed increases in risk-acceptance judgment variability seem to suggest that the gap clearance that drivers consider as "safe" to drive through seems to be a rather stable and distinct quantity in their minds. Thus, based on these rather exploratory experimental findings, we may tentatively conclude that the DSI methodology appears to be a promising tool for classifying drivers with respect to their risk-taking behavior. Further, the values of the 3 individual DSI components could make it possible to predict whether a particular driver would incur hazard in a gap risk-taking situation more likely due to his perceptual limitations, due to his limited skill ability, or due to a rather biased value judgment with respect to the consequences of failure.

If a satisfactory predictive accuracy and generality of the DSI, as well as an economically feasible testing procedure is assumed, the DSI methodology could be applied to all segments of the driving public and serve as a screening and/or diagnostic device. The DSI methodology could make it possible to direct the educational or improvement efforts to the specific area (risk acceptance, visual perception, driving skill) where modification seems most needed and of most benefit. Should a broad application of the DSI methodology prove to be politically or economically infeasible, it might be applied on a limited basis for the selection of bus drivers or other special-vehicle drivers where somewhat higher safety considerations would offset the rather high cost of testing. The basic concept of this methodology is by no means limited to the particular driving situation investigated. The methodology could easily be adapted and used in any other risk-taking situation where some visual perceptual capability and some degree of skill are required to engage in a particular activity.

In all the DSI perception experiments, a considerable variability among the drivers with respect to how they perceived the width of a given gap was found. This rather unexpected result [contrary to the findings of Gilinsky (15) for similar perception experiments] is considered to be of major importance. If it is assumed that future research would confirm the observed large perceptual judgment variability among drivers, the relationship between accidents and perceptual judgment capabilities should be investigated next. Should a significant relationship exist, driver education and improvement could be changed to include and provide adequate perceptual judgment training, and the driver licensing procedures could be changed to include perceptual judgment tests.

Before we conclude this discussion with respect to the DSI concept, we should point out once more the limitations and the exploratory nature of this investigation. Before the DSI concept can be applied successfully as a screening and/or diagnostic device in such areas as driver licensing, much more research will be needed to validate its generality as well as its satisfactory predictive accuracy.

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