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journal or publication title	Tohoku psychologica folia
volume	34
page range	110-123
year	1976-03-30
URL	http://hdl.handle.net/10097/00064960

A DRIVING RECORDER OF EQUIPMENT-FREE TYPE (DREFT) AND ITS APPLICATION TO ANALYSIS OF NATURAL DRIVING BEHAVIOR INCLUDING EYE MOVEMENTS*

By

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A video system for the record of natural driving behavior (DREFT) was described, which was developed to meet the following five requirements. (1) In order to record a driver's natural behavior in driving, no special equipments should be attached to the driver. (2) Gross movements of the eyes should be recordable. (3) The system should be able to record as various kinds of driving behavior as possible. (4) Recorded behavior should be reproduced audio-visually in order that even a layman could plainly point out defects in his driving. (5) The car equipped with the system should be able to run on the public road.

The experimental car was furnished with two video cameras, one of which was used to take the front-view and the manner of steering with the eye-region reflected in a concave mirror. Another camera was used to record the display panel, on which the velocity of the car and various operations by the driver except for steering were represented schematically. The picture taken by this camera was inset with a camera wiper into the lower left part of the scene taken by the first camera.

A pair of polaroid plates were used to wipe out the images reflected on the glasses worn by some of the drivers.

It was considered the five requirements were satisfied from the data of about 200 drivers who attended a retraining course for recovering their suspended licences. From the analysis of the data of 58 drivers out of the 200 odd drivers on the pattern of eye movements, it was ascertained that there are considerable individual differences in the pattern, though they drove the car on an identical model course.

Similar individual differences in driving of which each driver posesses what may be called mirror-vision strategy in each respective way were found among four college students who ran the car on the city streets.

Problem

The main purpose of the present study is to design and develop a system which enables one to record and demonstrate as readily and plainly as possible driving behavior, including the driver's eye movements, with minimal disturbance of their

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* The authors wish to express their grateful thanks to Toyota Motor Sales, Co. Ltd. for the automobile (MS-50D) provided by it, which made an earlier realization of the DREFT possible.

Their sincere gratitude is also due to the staff of Miyagi Safety Driving School, for expert advice and facilities given by them.

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natural performance.

The reasons why it was necessary to develop such a system are as follows:

First, since the study of Ohwaki *et al.* (1957) who launched a project of traffic psychology in Department of Psychology of Tohoku University, our main efforts have been devoted to the development of the psychological tests with which to discriminate between accident-prone drivers and accident-free drivers. Its development, therefore, has necessarily led us to get on with the studies, whose purpose is now to clarify the mental functions and personality traits which are closely relevant to traffic accident proneness. As a direct result of such efforts, we have developed as effective tests two apparatuses for testing mental functions of Speed Anticipation Reaction Test (Maruyama & Kitamura, 1961, 1965) and Discriminative Reaction Test of Multiple Performance Type (Nagatsuka & Kitamura, 1961; Nagatsuka, 1967), and a personality test named TUPI (Kikuchi, 1970, 1974) for measuring personality traits. The functions relevant to accident proneness, for which these two apparatuses are intended, are motor dominance tendency in perceptual-motor integration, which has a close connection with Drake's hypothesis (Drake, 1939–40; Takayama *et al.*, 1972), objectiveness of prospect, and carefulness in a decision making situation, etc. On the other hand, TUPI attempts to pick up such traits as incooperativeness, excitability, psychopathological tendency, and ego-weakness.

At present, these three kinds of tests are not a little used at the training organizations for drivers in Japan. Those trainees who make low marks in the tests are not only told that they are prone to accidents and warned against them, but also pointed to and made aware of the problematic points of which they should be careful in actual driving by explaining to them what kinds of psychological functions and/or traits are reflected in the tests. However, such advice is not framed in such terms that the trainees could act upon it in their daily driving, but expressed in rather abstract and unfamiliar technical terms. Even if it is possible to surmise the problematic points in their actual driving based on the results in the tests, it is a mere inference involving some logical leap. So it is unwarrantable that the low-scored should show such problematic behavior in the actual situations.

It becomes necessary, therefore, to study experimentally the relationship between these abstract functions or traits and the actual driving behavior. Now one realizes the necessity of an apparatus which makes it possible to record an actual driving behavior under natural circumstances.

In short, the first motive which led us to pursue the present study was the necessity for investigating the concrete problematic behavior that the psychological tests were assumed to reflect.

The second motive was to develop an effective method for the training and education of motor-drivers. The authors are of the opinion that a psychological test for drivers, that is, so-called driver's aptitude test should not be used with the sole object of selecting or discriminating drivers, but utilized in the course of training and schooling. For the very purpose the development of efficient teaching technique is an absolute necessity. If we could utilize a technique which enables us to record and reproduce such a driving behavior as it actually occurs on the street, then it would be a most suitable corrective retraining method, as it would induce self-reflections in the trainees on their driving. Specific, concrete advice derived from this method, based on general comments on psychological characteristics measured by the tests, would increase persuasive power considerably. And it will be a training method closely connected to testing.

Thus, as can be seen from these considerations, the following five conditions were regarded as necessary requirements to be met in an actual contrivance of a versatile apparatus.

(1) The *S* should be able to drive the car equipped with the apparatus on the public road.

(2) No instruments should be attached to the *S*. Our aim is to record unaffected behavior of the driver.

(3) The system should record as diversified kinds of behavior as possible.

(4) The driver's eye-movements should be recordable. However, for the purpose of the present study gross movements of the eyes are sufficient if it is possible to have a general idea of the scene he is looking at. In this respect, a commercially available eye-mark-recorder may be taken into account, but as it cannot satisfy the above mentioned conditions of (1) and (2), we must give up its employment.

(5) Display of the recorded performance should be made audio-visually, in order that even a layman can get suggestions readily.

Technical Design of DREFT

Principles of the method

A special video recording system which will satisfy the five requirements, was contrived. It can record front-scene, eye-region of the driver's face, and their performance all at once. To be precise, it is noticed that a TV camera placed just behind the driver's left shoulder can record both front-scene and driver's behavior at the same time. Eye-region of the driver reflected by a room mirror with little vibration is also photographed. This is the basic principle of the method which is simple enough in that it records a driver's performance from behind. Driver's operations such as gear-shift and applications of the brake and so on reflect themselves separately. The picture is taken by another camera and inserted in a corner of the scene taken by the first camera. Thus, the whole system consists of two channels: one records the front-scene in which is involved the eye-region of the driver and his general performance, while specific manipulations of the car are recorded through the other channel.

The automobile used in the study was Toyota Crown (MS–50D) which was of the same type as those used in the driver's school or driving-licence examination organizations.

Recording of front-view and eye movements

The camera for front-view and eye movements was attached to a bracket on a specially designed beam which was fixed close to the ceiling, near the upper ends of the center pillers, the beam being parallel to the front-glass. At the center of the beam hanging perpendicular to it was there a J-shaped arm (SONY, SL–5), at the end of which attached upward a bracket for a video camera (SONY, AVC–3500). Fig. 1 shows the side view of the setting. By turning the bracket the camera angle was freely adjustable to obtain the best angle. A wide-angle lense (TAMURON, 0620–3; focal length of 6.0 mm; viewing angle of 84°58′) is used for this camera. Since the part of the face reflected in the room mirror is in fact too small to be taken by a camera, and the wide-angle lense attached to the camera further reduces an image in the mirror,

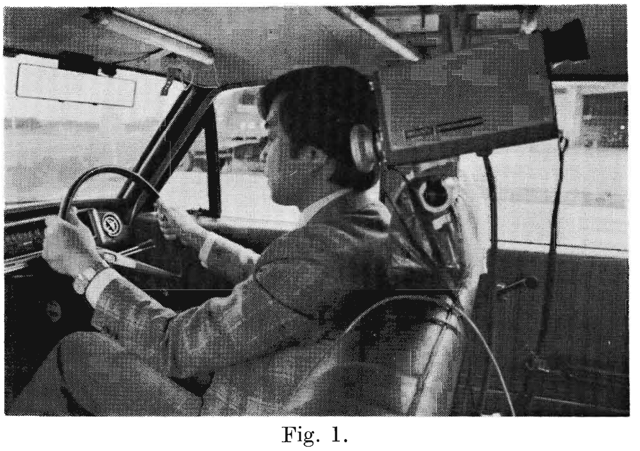

Fig. 1.

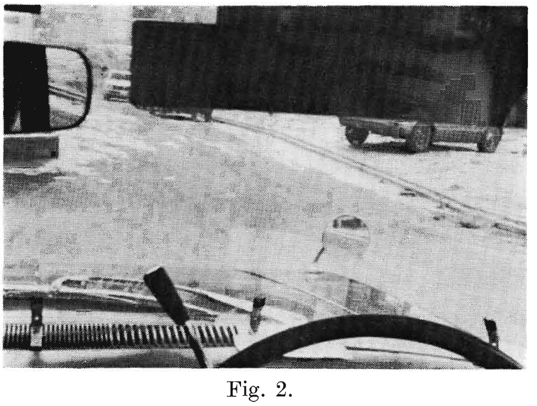

Fig. 2.

it is necessary to magnify the image. Consequently, a concave mirror (40 cm × 8 cm) with focal length of one meter which magnified the eye-region is needed, to facilitate recording of eye movements. It is set to the right of the front glass as is shown in Fig. 2. An angle to elevation of the mirror could be adjusted with a remote-controlled-micro-adjuster (driven by a micro motor) to obtain the best angle relative to the posture of each driver. Its adjustment was made, if necessary, during driving by an attendant experimenter who was watching a monitor TV (Sony, AVF–3300, remodeled in order to work by DC 12V car-battery) set in front of the assistant driver's seat.

One of the most difficult obstacle for recording in the development of the apparatus was to eliminate the images reflected in the glasses worn by some of the drivers. The images in the glasses hid the eyes behind the glasses. As not a few Japanese wore glasses these reflected images had to be wiped out. Fortunately, one of the associates, Matsumura, incidentally found a solution. It was to use a pair of polaroid plates. With their appropriate combination the reflected images disappeared. To be precise, a sheet of thin polaroid plate (A product of Polaroid Corporation of Japan, HN38; 0.762 mm in width) was fastened at the corners to the inside of the front glass with four clasps and made detachable. Another piece of polaroid plate was cut out to the size of the camera lense and attached to it, at appropriate angles of polarization between the two plates.

With respect to recording eye movements it soon occurred to the authors to use an eye-mark-recorder, which is commercially available also in Japan. There are such studies as those of Michon & Koutstaal (1969) or Mourant & Rockwell (1972), using this type of eye-cameras. These apparatuses have an advantage in that they could minutely record the movements of the eyes, but necessarily require some attachments to the driver. Such installations would increase driver's awareness of the experimental situation and disturb his natural behavior. However, it was one of the most important points in the present study to establish a unaffected conditions under which to observe a driver's behavior. Besides, it was thought to be sufficient if we could read gross movements of the eyes, and displays to the trainees seemed to become more effective if it actually showed to them their own face. Thus the employment of the eye-mark-recorder was given up.

A fluorescent lamp set on the ceiling just over the concave mirror (as is shown in Fig. 1) cast illumination on the driver's face.

Actual reproduction of the front view and eye-region is illustrated in Fig. 3.

Recording of Car Operations

A lower left quarter of the TV scene was, as can be seen from Fig. 3, redundant, so car operations and velocity were indicated at this part.

The driver's operations of brake, accelerator, crutch, gear, and turn signals were introduced into a display apparatus of special make and schematically reproduced on the display panel (28.5cm × 23.5cm) with car velocity. These representations

Fig. 3.

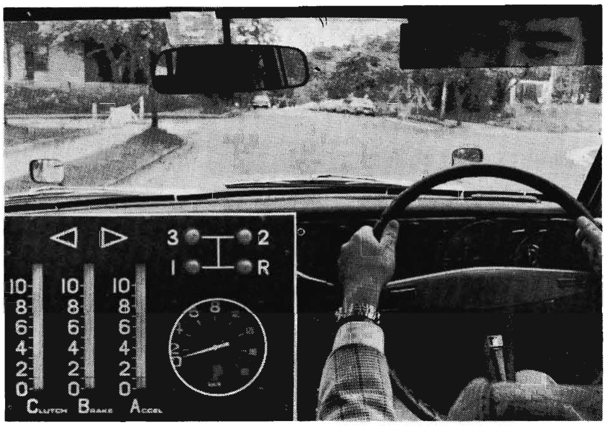

Fig. 4.

were taken by the other camera (Sony, AVC–3500) and combined with the scene taken by the first camera using a video camera wiper (Sony, CMW–100A remodeled in order to work by DC 12V car-battery), as is shown in Fig. 4. This was the final picture recorded actually. The display apparatus and the second camera were arranged through a pair of mirrors in such a way that they could be contained in a box, 69 cm × 36 cm × 43 cm in size, which was placed on the backseat. A wide angle lense was attached to the camera, which had a focal length of 8.5 mm. The panel was illuminated by two lamps. Applications of the footpedals were mechanically picked up and transmitted to the display, thus being represented in analogue. The position of the gear and turn signals were electrically picked up and shown with lamps, while the speed meter was branched from that of the car and shown in like manner on the panel. The videocorder used in the study was Sony AV–3500. The whole system with two cameras were driven by DC 12V car-battery.

List of Component Parts

The component parts which constituted the DREFT are summarized below.

A) A videocorder.

B) A video camera (1): for recording front-view and eye-region.

C) A video camera (2): for recording driver's operations and car velocity which were reproduced on a display panel.

D) A wide-angle lense (1) which was attached to the camera (1) with a focal length of 6 mm.

E) A wide-angle lense (2) which was attached to the camera (2) with a focal length of 8.5 mm

F) A beam to which the camera (1) was fastened with a bracket.

G) A concave mirror with a remote-controlled-angle-adjuster (focal length of 1m; 40cm×8cm in size).

H) A fluorescent lamp (10 wat) to cast illumination on driver's face.

I) A pair of polaroid plates to eliminate the reflected images on the glasses. One of them was attached to the inside of the front glass and the other was to the video camera (1) at appropriate angle relative to the former plate.

J) Pickups of driving operations and their display panel. The panel represented operations of accelerator, brake-pedal, crutch-pedal, gear, turn signals, and speed meter.

K) A video camera wiper which was used to insert the scene taken by camera (2) into the one taken by camera (1).

L) A monitor TV.

PILOT RESULTS

Since 1973, we have had occasion to utilize the DREFT for reeducation of those who have got some administrative measure at Miyagi Safety Driving School. Those who got licence suspensions for 90 days or more must receive a retraining, in which they drive a car with an instructor beside them on a model course. It was on these occasions that we could apply the DREFT to recording their driving, which was followed by examination of the driving behavior and by displaying the recorded picture to them with appropriate detailed advice. Comparison was made between the effects of this training and those of the traditional method in which no recording was presented to the trainee. At the same time, correlations between this test and the psychological (aptitude) tests, and between the former and the check list filled by an instructor were obtained. These results will be published in the following paper.

Below, we shall draw a conclusion on the characteristics of the system assessed on the basis of the data obtained from about 200 trainees. In short, we reached a conclusion that five requirements mentioned in the purpose were practically satisfied, as the following summary shows.

(1) The instruments mounted on the car interfered little with driving on the streets except towards evening when the front view became too dark owing to the polaroid plate on the front glass. Driving in the daytime, however, was equivalent approximately in brightness to wearing sunglasses with just appropriate brightness for driving. This darkening happened to give an advantage of weakened contrast to the recorded picture.

An informal advice from one of the staff of Sendai Traffic Bureau was that the concave mirror should be so placed that a driver would not hit his head against it when he should fall forward with the emergency brake on. Otherwise, he should wear a helmet. With such protective measures it would be quite safe to drive the car on the public road from administrative point of view.

(2) In this system, recording was realized with only minimal attachments such as a helmet to the driver, as was initially desired. Therefore it was unnecessary to pre-adapt the drivers to the apparatus. They could begin driving as usual, sitting behind the wheel, while an experimenter started the videocorder.

By means of the remote-controlled-micro-adjuster an optimal angle of the concave mirror was readily obtained by an experimenter who was watching the monitor TV.

No drivers complained that the apparatus mounted on the car interfered with their driving. Few reported that they were anxious about the mirror or the TV camera behind them. Thus we succeeded in minimizing disturbance in the usual driving behavior.

(3) Most of the operations necessary for driving were recorded. Rough manners of steering of the wheel could be seen from the reproduced scene, since it contained driver's hands on the wheel. In addition, concomitant sounds such as conversation with an attendant experimenter were recorded at the same time.

(4) We could record the movements of head and eyes with the adjustable mirror.

The polaroid method was reliable enough to expose the eyes by eliminating the image reflected on the glasses, although this method could not applicable to those who wear sunglasses.

Not much experience was required to judge to which direction the line of vision was from the reproduced records, though fine discrimination of the line of vision that would be obtained with an eye-mark-recorder was actually impossible. Thus we could score the line of vision in such a way as "he looked to the right", "he looked at the room mirror", "he looked at a side mirror", and "he paid attention to the dashboard", etc.

5) The reproduced scene was finer than we had expected, with little blur due to vibration from a running car.

All the informations relevant to driving were reproduced audio-visually in a plain form, so that a naive trainee can easily see the defects of his driving. In addition, an instructor could give his useful advice according to the actualities of the case, utilizing stop motions and slow-video as well as the normal manner of presentation. Incidentally, it may be noted that some reported an increase in interest in the training process by watching their own performance with their own eyes.

Individual Differences in Eye Movements during Driving (1)

One of the associates, Kato, mainly analyzed a portion of data collected up to now and obtained the following results:

Subjects: 58 drivers who got suspension of more than 90 days as an administrative penalty owing to some accidents or violations of the traffic regulations. They had to attend a retraining course at Miyagi Safety Driving School.

Procedure: The trainees were required to drive the experimental car over the course for licence examination in the school, an aerial view of the course being shown in Fig. 5.

Several checkpoints including straight ways and intersections were chosen over the course, at which *S*s' driving and their eye movements were selectively analyzed. Eye movements were scored according to (1) the types, (2) the directions, and (3) the number of movements. The classification of movement types of the eyes was the following. A-type: sheer movements of the eyes without turning his head. B_1-type: eye movements with head turning but without fixed gaze, the head coming back to the original position quickly. B_2-type: eye movements with head turning and momentary fixation toward head-turning direction. Directions of the line of vision were classified: to the right, to the left, backward, and downward (at the dashboard). As for the over-all performance, it was noted whether or not there was any problematic behavior, whether they manipulated the car smoothly, and whether they observed the traffic rules.

58 *S*s were divided into two groups of good drivers (who obtained a mark of

Fig. 5.

three points or above, 41 *S*s) and of problematic drivers (who obtained a mark of 2 points or below, 17 *S*s), according to the level of performance in a battery of sensory-motor tests (speed anticipation test, discriminative reaction test, and rotating table test). Their actual drivings recorded with the DREFT were compared between these two groups.

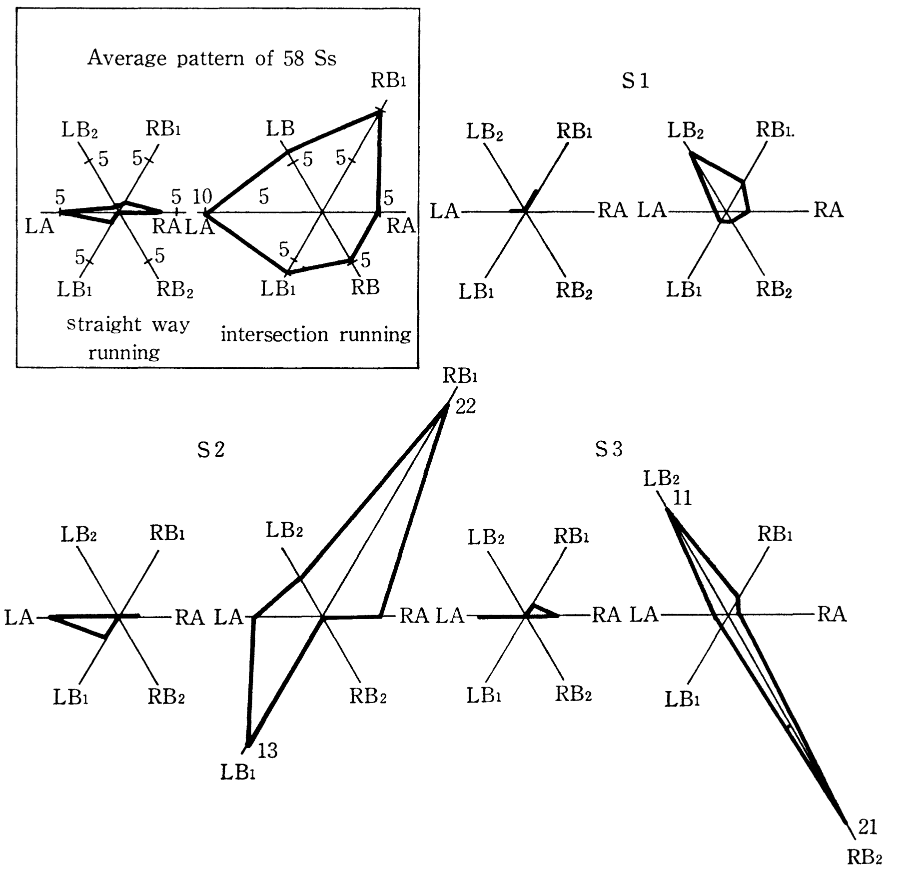

Fig. 6. Patterns of eye movements, including the types, the directions and the number of movements, for the average of 58 *S*s (upper-left graph), and for the three individual *S*s. Subject number 1 (S1) is a case who had fewer eye movements compared with the average pattern. S2 is a case who had many eye movements of B_1-type, while S3 had many eye movements of B_2-type in running the intersection.

RA : eye movement of A-type to the right direction.
LA : eye movement of A-type to the left direction.
RB_1: eye movement of B_1-type to the right direction.
LB_1: eye movement of B_1-type to the left direction.
RB_2: eye movement of B_2-type to the right direction.
LB_2: eye movement of B_2-type to the left direction.

Results: The results concerning eye movements are summarized here.

On the straight runway, there were no differences between the two groups. At the intersection, both groups did not differ from each other in direction and frequency of eye movement of A-type, whereas the problematic group tended to use B_2-type more often than B_1-type when they look to the right or left. However, this difference was not significant. Thus there was little difference found in the manner of eye movements between the two groups.

Next, considerable individual differences in the type of eye movements were found in spite of the fact that the test situation was almost identical for each *S*. For example, Fig. 6 shows typical patterns of eye movements observed in three *S*s in comparison with mean data of 58 *S*s.

These results should be interpreted with respect to a normative data of good search and scan patterns, as was suggested by Rockwell (1972).

Individual Diferences in Eye Movements during Driving (2): Mirror-Vision Strategy

The above mentioned results were not only based on a special sample of drivers, that is, those who got suspension for 90 days or more but also obtained from observations on a model road in the Safety Driving School, where the test lasted only 6 to 7 minutes. Therefore it does not provide normative data in terms of *S*s' sampled and experimental situation. In order to obtain a generalizable conclusion, data collected from various *S*s under varied situations are indispensable. As a first step toward that goal we obtained data from college students who ran the car on the city streets for a time considerable longer than that in the above mentioned experiment. The study which was performed mainly by Yoshida, Kato, and Matsumura is as follows:

Subjects: Three male and one female college students who have been at the wheel for more than three years and got no accident records, served as *S*s.

Procedure: Each *S* was asked to drive the experimental car on the pre-determined course in the town which it took about 30 min. to run through.

Several sections and points were selected in advance on this course, at which their eye movements were checked to determine their visual-strategy, especially with regard to how they looked at mirrors while changing lanes, running straight, turning right or left, and stopping the car.

Results: Table 1 summarizes the data concerning all the way or mode of eye movements with which the *S*s paid attention to other cars through mirrors when they changed lanes. As can be seen from it each *S* seems to have adopted specific mirror-vision strategy. Thus, F.C. tended to rely on the inside-mirror or on direct looking-back when she wanted to make sure that it was safe to change lanes, whereas T.Y. and Y.Y. looked at both the inside mirror and outside mirrors equally often. Still another strategy is found in H.H. who mainly paid attention to the outside mirrors in this situation. On the straight road, Table 2 shows frequencies of mirror-usage for each *S*.

Table 1. Temporal sequence and type of mirror vision in changing lanes.

Point*2	Driving*1	Driver: F.C.	Driver: T.Y.	Driver: Y.Y.	Driver: H.H.
Lane change from left to right					
	1st	I I s I c	I R R s R c	R I s R c	R s R R c
1	2nd	I I I s B I I c	I s R c	R R R s R I R c	R s R R R c
	3rd	I I I I s I I c	I R s R c	R R R s I c	R R s R c
	1st	—	—	—	—
2	2nd	—	I B R R s I c	—	—
	3rd	—	—	—	—
	1st	I B I c	R I R c	—	—
3	2nd	B I I c	R R I R c	I R R s R A R R c	R R R s R c
	3rd	—	R R R I R c	R s R I R c	—
	1st	I I I I I c I	I R R c	R R R I c	R R R s R c
4	2nd	I I I I c	s R I R c	R R R I c	R R R R s R R I c
	3rd	I c	R I c	R R R c	R s R c
	1st	—	—	—	—
5	2nd	—	A R c	—	—
	3rd	—	—	—	—
	1st	—	R I R c	—	—
6	2nd	—	I s R R c	—	R c
	3rd	—	—	—	—
	1st	I I B I B I B c I	R I R R R R c	R R I R c R	I R R R c
7	2nd	I I A I c	R R R R c	R I R c R	R R R s R c
	3rd	I B s c I	s I c	R R c	R I R I R s R R c
Type		I(B) type	R-I / I-R mixed type	R-I type	R type
Lane change from right to left					
	1st	c	I c	I L s L L c	I L L c
1	2nd	I I B I I c	I s c	s I L c	I I I I s c
	3rd	I I I I c I	I I I L I s c	I L s L c	I I L s c
	1st	I c	I c	s I L c	L s L L L c
2	2nd	I I I c	I I I c	I s I L c	I I s L L L I L c
	3rd	I I I c	I I I c	I s L L c	s I c
	1st	I I I c	—	—	s I c
3	2nd	—	—	—	—
	3rd	—	—	I s L L c	—
Type		I(B) type	I(L) type	I-L type	I / L / I-L mixed type

† Signs used in the temporal sequence were as follows: I; inside room-mirror, R; right side-mirror, L; left side-mirror, B; looking back directly, A; looking aside directly, s; turn signal, c; termination of lane change, —; no lane change observed.

*1 Total of 4 drivers run three times on the same course.

*2 7 points in lane change from left to right were as follows. Point 1 was set on the three-lane road and lane change from second to third lane was examined. Point 2–4 and 5–7 were set on the four-lane road, respectively, and lane changes from first to second lane (Point 2 and 5), from second to third lane (Point 3 and 6) and from third to fourth lane (Point 4 and 7) were examined. 3 points in lane changes from right to left were all set on the three-lane road and lane changes from second to first lane were examined in each point.

Table 2. Frequencies of mirror vision in straight way running.

Driver	Point* / Driving	1	2	3	4	5	Total	Frequency ratio of I:L:R
F.C.	1st	2	0	0	3	2	7	29:0:0
	2nd	3	2	2	0	0	7	
	3rd	2	5	4	3	1	15	
	Total	7	7	6	6	3	29	
T.Y.	1st	2	2	0	0	2	6	10:6:1
	2nd	2	3	0	1	2	8	
	3rd	0	1	0	1	1	3	
	Total	4	6	0	2	5	17	
Y.Y.	1st	1	0	0	8	0	9	7:6:6
	2nd	3	0	0	3	2	8	
	3rd	2	0	0	0	0	2	
	Total	6	0	0	11	2	19	
H.H.	1st	4	0	3	0	6	13	35:7:0
	2nd	5	5	0	2	1	13	
	3rd	2	2	3	5	4	16	
	Total	11	7	6	7	11	42	

* 5 points were all set on the straight road in the driving course and frequencies of mirror vision were counted in each point.

Table 3. Frequencies of mirror vision observed when the car stops and starts.

Situation / Driver	During stopping	Just before stopping and just after starting	Total frequency	Frequency of car stopping
F.C.	58	11	69	32
T.Y.	15	6	21	28
Y.Y.	5	5	10	23
H.H.	19	10	29	26

It shows that F.C. and H.H. generally looked at mirrors more often than the other two and they relied on the inside mirror most often.

On stopping car, F.C. and H.H. were found to look at mirrors more often than T.Y. and Y.Y. who, nevertheless, did sometimes look at the mirrors (see Table 3).

On turning right or left, no consistent individual differences were found among the four *S*s in this behavior.

Generally, it may be concluded that each driver possesses what may be called mirror-vision strategy in each respective way.

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(Received August 25, 1975)