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STRATEGIES OF VISUAL SEARCH
BY NOVICE AND EXPERIENCED DRIVERS

DISSERTATION

Presented in Partial Fulfillment of the Requirements for
the Degree Doctor of Philosophy in the Graduate
School of The Ohio State University

By

Ronald Rodney Mourant, B.A., M.A.

* * * * * *

The Ohio State University

1971

Approved by

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PUBLICATIONS

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"Driver's Eye Movements: An Apparatus and Calibration." Highway Research Record, 1968, No. 247, p. 24-41. (With T. H. Rockwell and C. Overby)

"Mapping Eye-Movement Patterns to the Visual Scene in Driving: An Exploratory Study." Human Factors, 1970, 12, p. 81-87. (With T. H. Rockwell)

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure Page

CHAPTER I

INTRODUCTION

Youthful drivers of automobiles present a paradox. In terms of their psychomotor capabilities they are superior to older adults. Yet, for motorists in the United States under the age of twenty, the death and injury rates are at least twice what they are for forty year olds. There are several possible explanations for this. One is that youthful drivers are truly skillful and their high accident rate is due to high risk taking and poor attitudes. Perhaps as Briggs (1968) has mentioned, they may drive recklessly because of a need to test their limits of skill in vehicle handling. Another possible explanation is that they have not received adequate driver education training, since many driver education programs are poorly funded and conducted by personnel who have had little training. A third possibility and the one investigated in the present research is that youthful drivers do not use their eyes as well as experienced drivers do. This was suggested by the work of Zell (1970), who compared the search and scan patterns of novice and experienced drivers and found the following results.

1. As novice drivers gained experience their fixation locations moved away from the extreme right edge of the highway.
2. Novice drivers used their mirrors less frequently than experienced drivers, and spent a greater proportion of their time fixating straight ahead.
3. Although experienced drivers showed a tendency to seek information about the roadway at a distance proportional to vehicle speed, the novice drivers did not.
4. Novice drivers fixation duration distributions did not change as they gained driving experience.

If the findings of Zell are valid then high risk taking by young drivers may account for only a portion of their higher accident rates. In addition, any knowledge of how drivers visually sample their environment could provide knowledge with which to improve driver education courses.

Another study which provided evidence that novice drivers' search and scan patterns are different from those of experienced drivers was conducted by Mourant and Rockwell (1970). In this study it was found that in freeway driving novice drivers sampled the lane markings quite frequently, while experienced drivers looked far ahead of the vehicle. Thus in freeway driving the experienced drivers apparently used peripheral vision for lane position monitoring while the novice drivers used foveal vision.

In addition to learning how to scan the environment, a novice driver must learn how hard to brake at various velocities, while simultaneously controlling the vehicle's heading by adjustments of the steering wheel. Harootyan (1969) recorded the vehicle's deceleration rate and lateral acceleration for high speed stopping maneuvers and found that after a few hours of experience the novice drivers performed as well as the experienced drivers. This indicates that the learning of driver control responses (brake and steering wheel movements) takes place early in the driver's training. Another study, that of Vojir (1969), found that novice drivers quickly develop the ability to judge distances between vehicles.and to estimate the speed of their own vehicle. Note that Harootyan studied driver control behavior without taking the driver's visual behavior into account, and Vojir studied certain aspects of the visual sensing of drivers without paying attention to driver control movements.

Obviously, the coordinating of visual input with control movements is another element of the driving task that the novice driver must master. Fitts and Posner (1967) have listed three stages in the learning of skilled tasks.

1. Early or Cognitive Phase -- "At this stage behavior is truly a patchwork of old habits ready to be put together into new patterns and supplemented by a few habits."
2. Intermediate or Associative Phase -- During this

phase new patterns of individual units of behavior emerge and errors are gradually eliminated.

3. Final or Autonomous Phase -- During this phase performance is inflexible and automatic. Many visual cues attended to in the early phase now go unnoticed.

With regard to the above three stages of skill learning there are several questions that the present research investigated.

1. At what point in their training do novice drivers begin to make smooth and errorless control movements?
2. What changes occur in the spatial and temporal characteristics of drivers' search and scan patterns as they gain experience?
3. Is the experience of a driver education course sufficient to develop "good" search and scan patterns including those of low probability event detection?
4. Could additional or specific training aid in the development of good visual habits?

A review of the literature concerned with visual perceptual learning is presented in the next chapter. In addition, problems of relating eye movement data to cognitive processes are discussed. A glossary of terms related to vision is included in Appendix A.

CHAPTER II

RELATIONSHIPS BETWEEN EYE MOVEMENTS, ATTENTION, AND PERCEPTUAL LEARNING -- A LITERATURE REVIEW

Eye Movements and Attention

The objects and sections of the visual scene which are imaged on the retina of the eye may be determined from eye movement records. Although this provides information as to what a person is not attending to, perception can not be inferred from retinal images. First, a subject may be "day dreaming" and not paying attention to any visual inputs. This has been investigated by Gaarder (1966) who found that eye movements during inattention are characterized by infrequent saccades and shifting phase relationships between horizontal and vertical movements. In a subsequent study, Gaarder (1967) also has reported that the rate of saccadic movements increased with the absence of the alpha rhythm. Since absence of alpha signifies increased arousal, this suggests a correlation between the amount of attention and the rate of saccadic eye movements.

A second problem is that attention may have moment to moment flucuations in the amount of area covered. Mackworth (1965) found that irrelevant information in a visual field during a recognition task caused tunnel vision. It appears that the useful field of view is a function of the amount of detail being attended to and the total amount of information in the visual field. The useful field of view is also partially determined by the limited ability of the visual system to detect details in the peripheral areas. Recently, however, Kerr (1971) has found visual acuities at 10, 20 and 30 degrees from the fovea to be two to four times higher than those previously reported.

Bhise (1971) has conducted a series of experiments to investigate the relationships between central and peripheral vision in automobile driving. He found that when information was urgently needed, the drivers sampled it foveally. This suggested to him that foveal vision was able to acquire information at higher speeds and rates than peripheral vision.

A third problem is that people may be paying attention to the same area of the visual scene and be seeing different things. A trained photo interpreter, for example, sees many objects in a photographic image which the untrained observer does not recognize. Another example of this phenomenon within subjects is the perceiving of reversing visual illusions. Gregory (1970) discusses how internal perceptual models determine what is perceived, and suggests that reversing illusions represent situations in which there are two equally likely internal models.

Even when information is perceived there is still the question of whether it was useful to subsequent decision making. Senders, et al. (1966) attempted to quantify the spare visual capacity of automobile drivers. They found that drivers voluntarily occluded their vision for an average period of 1.5 seconds (with a fixed .5 second viewing time) while traveling at 60 m.p.h. on a straight road with no traffic. Since such driving situations permit irrelevant information to be sampled, it is difficult to map the relationships between particular visual inputs, short term memory, and subsequent decision making and control responses.

A study of the "spare visual capacity" of automobile drivers is now being conducted by Safford (1971). This study hopes to determine the types and quanity of visual information necessary to safely control an automobile.

Eye Movements and Perceptual Learning

Although there are some valid structural similarities between the eye and a camera, the process of human perception is functionally in no way like the recording of images on film. It is the purpose of this section to elucidate the characteristics of human perception and their relationships to eye movements. Moreover, the learning of perceptual skills by children may be analogous to novice drivers learning where to look.

Recently several studies (Bower, 1967; Salapatek and Kessen, 1966; Fantz, 1967; and Kagan, 1970) have investigated the perceptual world of infants. Only the Bower and Kagan studies will be reviewed here.

Bower studied the visual behavior of eight-week-old infants in relation to the problems of spatial "constancies" and space perception. Spatial constancy is the tendency of an object to be perceived as the same size regardless of its viewing distance (note that its size on the eye's retina decreases with increased viewing distance).

The space perception problem asks how the eye "sees" three dimensions when the retinal image is in two. These problems were investigated by placing different size cubes at different distances from the infants. The infants displayed size constancy in that they responded to the real size of the object and not the retinal size. Bower also found that the infants were capable of depth discrimination, shape constancy, and completion. These results led to the hypothesis that the human perceptual system is tuned to register high-fidelity information in sequences of images rather than the momentary images of single fixations. The differences in perception between adults and children are not due to the type of information that can be registered, but rather reflect the fact that infants have a lower information processing capacity than adults.

Kagan (1970) investigated the eye fixation time of infants in accordance with the establishment of visual schemata. He defined a schema as, "a representation of experience that preserves the temporal and spatial relations of the original event, without being necessarily isomorphic with that event." The schema Kagan worked with was the human face which has the invariant features of number and location of eyes, ears, nose and mouth. When one-week-old infants were shown a photograph of a human face and a simple line drawing they spent equal time fixating both. This was due to their visual attention being directed at contours, and their not having any well developed schema for the human face. A four month old, however showed a greater amount of fixation time on the photographic representation indicating that he had acquired a schema for a human face.

Six months to one year-old infants again displayed equivalent fixation times for the photograph and line drawing, but the amount of fixation time was reduced 50 percent. This indicated to Kagan that the schema for the human face had become so well established that both the line drawing and photograph were easily assimilated. He then postulated a curvilinear relationship (an inverted U) between attention (as shown by amount of fixation time) and the degree of discrepancy between the internal schema and displayed object. When there is no schema, discrepancy is large and fixation time small, when discrepancy is moderate fixation time is great, and when the schema is well developed discrepancy is small and fixation time is again small.

Kagan then reported that fixation time of infants increased as they matured from 12 to 36 months. In addition the education level of the infant's family was positively correlated with fixation time after 1 year but not prior to 1 year. Kagan suggests that at the end of one year a new cognitive structure emerges. This structure consists of children having hypotheses pertaining to the recognition of objects. The testing of these hypotheses resulted in longer fixation times. In summary Kagan found that fixation time of infants was controlled by the amount of contour, discrepancy, and the activation of hypotheses.

The scanning strategies of children between the ages of 3 and 10 has been investigated by Vurpillot (1968). Using drawings of pairs of houses, the children were asked to say "same" or "different". Each house had three rows of two windows with objects displayed in them. If all six windows in both houses in the pair had the same objects, the houses were identical. For the houses that were different the number of correct responses increased with age until at age nine children made no mistakes. For the identical pairs of houses, more than 90% of the responses revealed that children 6 years and older fixated more windows and made more paired comparisons on identical pairs of houses than different pairs of houses. Thus, they responded like adults. Children under six, however, seldom scanned between all six windows, and thus based their decisions on insufficient information. Nevertheless, when finding that corresponding windows contained different objects, they always made the correct response. These results were viewed as in agreement with Piaget's theory that with increasing age children extend in time and space their perceptual activity.

Mackworth and Bruner (1970) compared the scanning behavior of six year old children and adults on sharp and blurred photographs. They found the following results:

1. When viewing the sharp pictures the total eye travel distance of the children averaged only two-thirds that of adults.
2. In viewing the sharp pictures the eye fixations of children occasionally followed definite contours. This was never found in the records of adults.
3. When adults viewed the blurred pictures their sampling time on areas that contained the most information was double that of children.
4. For both groups of subjects eye fixation durations were greater when viewing the blurred than the sharp photographs.

It appeared as if the children could not examine details with central vision and at the same time simultaneously monitor their peripheral field for future objects to inspect. Thus adults made long leaps to connect related objects in the blurred photographs while children did not.

In the Mackworth and Bruner article a general discussion of the above results in relation to perceptual strategies was also provided. They state that the function of eye movements is to centralize significant features of the visual scene on the fovea. While the fovea is identifying the fine details of the object, a more diffuse system, the peripheral monitoring process, is involved in generally monitoring the whole field. As Neisser (1968), and Welford (1970) have pointed out, the conscious visual world is derived from the information taken in during many different fixations. Yarbus (1967) has noted that visual search strategies change from being initially controlled by the nature of the stimulus and its intrinsic features to one which appears to be controlled by the thoughts of the observer. This suggests that young children construct their visual world from a series of fixations whose locations are dictated by similar features. As Mackworth and Bruner found, they have difficulty in synthesizing various parts of the picture into a conceptual whole. Whether this is due to a lack of ability to coordinate peripheral and fovea inspection processes and/or inadequate search strategies needs further investigation.

When adults were presented pictures to scan, their initial familiarization stage was isolation of the informative areas (Mackworth and Morandi, 1967; Zinchenko Chzhi-Tsin and Tarakanov, 1963). This was followed by a recognition stage in which Zinchenko et.al. believe that many features of the stimulus pattern become redundant. Gould (1967) found support for this in that the mean fixation durations of subjects while viewing dot patterns decreased from 480 msec. during the familiarization stage to 360 msec. during the recognition stage. Thus, as more processing time was needed fixation duration increased.

Mackworth and Bruner (1970) reported that subjects' programmatic search patterns are based on internal models, or schema which have committed redundant features of stimuli to memory. It is interesting to note that Garner (1969) has equated "good" patterns with increasing redundancy. Poor patterns are those which are not redundant and thus have many alternatives. This leads to the prediction that initial recognition time of patterns is a function of their redundancy.

An in-depth account of the development and functioning of internal perceptual models has been given by Gregory (1970). Gregory states that,

> "perceptual models are aggregates of data about objects, and about how objects behave and act in various circumstances. We may think of sensory data suggesting, testing and sometimes modifying perceptual models in much the same way that scientific data suggest, test and modify theory and hypotheses in science.
>
> When we look at a picture we can read all kinds of significance beyond mere shape and colour. The picture serves to evoke our internal models, which have been developed by handling objects, so that non-optical features have become associated." (page 32)

An example of reading non-optical properties is that many older adults perceive all long-haired young people as irresponsible and lazy. Another example, relevant to driving, was given by Gregory (1970). Consider the image of a wet road on the retina. Although the image is simply an arrangement of patches of light, the amount of slipperiness of the road surface is perceived because of matching with a previously learned perceptual model.

In Figure 1 are some possible relationships between search and scan patterns and the perceptual processes discussed above.

With the above literature review in mind, consider again the problem of determining how novice drivers search and scan patterns change with training. It appears that a likely solution would be to conduct an experiment, and test a group of experienced drivers as a control. The design of such an experiment is given in the next chapter.

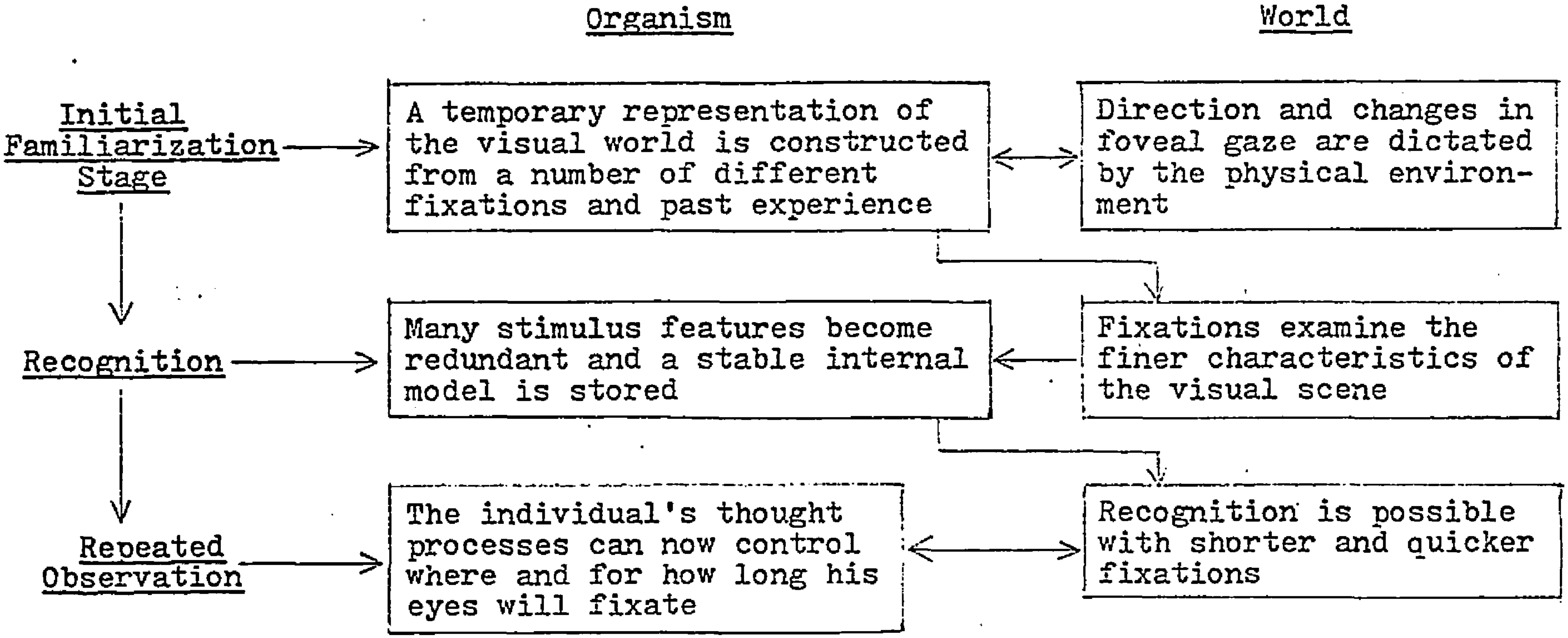

Figure 1. Hypothetical Relations Between Perceptual Processes and Search and Scan Patterns.

CHAPTER III

METHODOLOGY

This chapter describes the details of the experimental design, subject characteristics, experimental procedures, subject instructions, apparatus, data reduction, and measures of driving performance.

Experimental Design

In Figure 2 is an outline of the experimental plan. The visual and control performance of a group of six novice drivers was recorded before they had any driving experience (training level 1), when they were half way through a driver education course (training level 2) and just after they completed the driver education course (training level 3). At each training level they drove on a neighborhood route which contained nine subtasks and on a freeway route which contained six subtasks. The control group, consisting of four experienced drivers, was tested twice (run 1 and run 2) on the same routes. Test sessions for all drivers were separated about two weeks apart.

The neighborhood route was 2.1 miles long and contained the following driving subtasks which are diagramed in Figure 3:

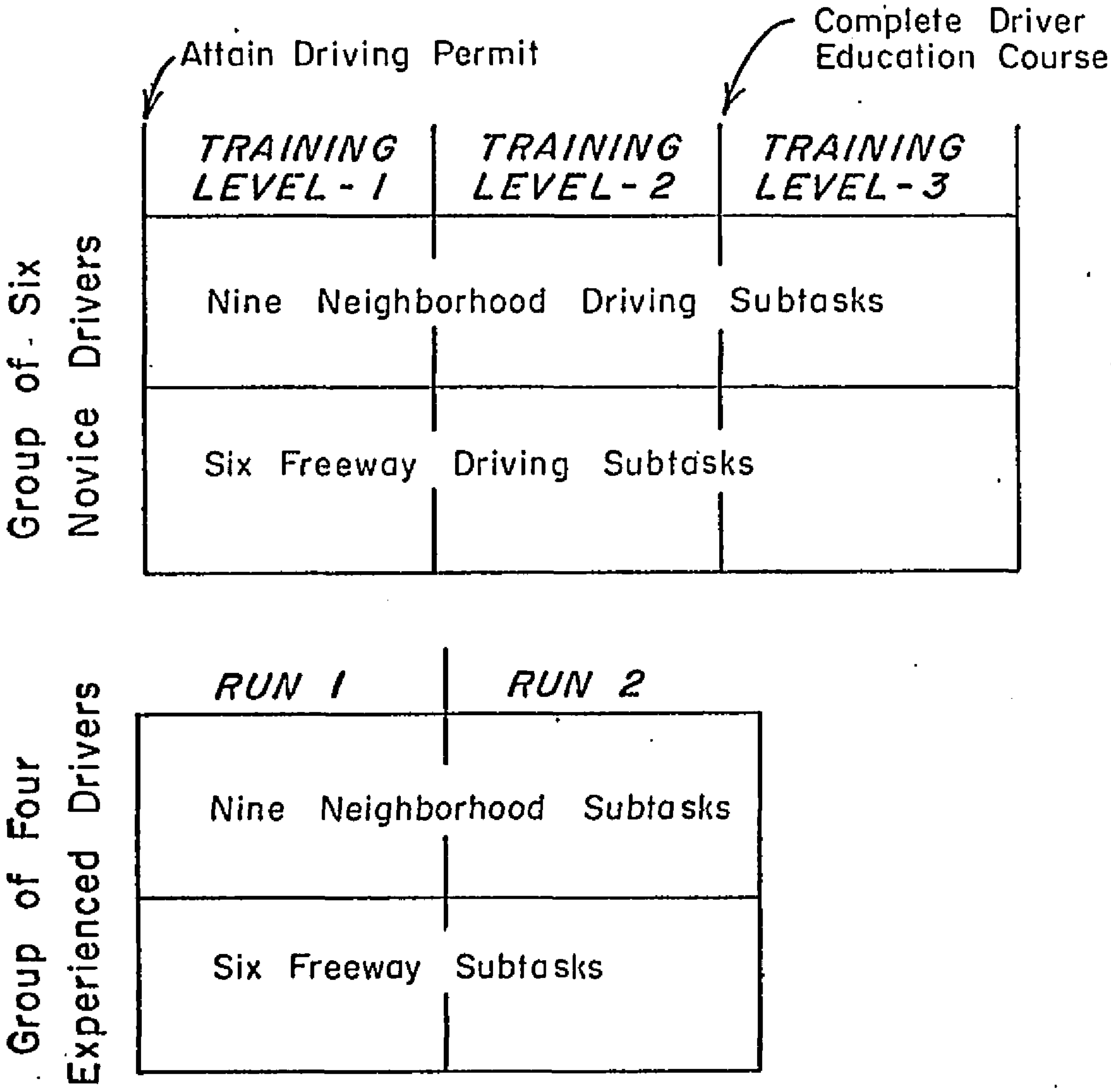

Figure 2. Experimental Design.

1) Approach-to-Stop-Sign-1
2) Approach-to-Stop-Sign-2
3) Approach-to-Traffic Signal
4) Approach-to-Left-Turn (continuous)
5) Approach-to-Right-Turn (continuous)
6) Right-Turn-After-Stop
7) Continuous-Right-Turn
8) Continuous-Left-Turn, and
9) Left-Turn-After-Stop.

For data reduction purposes Tasks 1 through 5 were defined as beginning when the driver applied the brake pedal and ending when the vehicle stopped. Included in Tasks 6 through 9 was only the time when the vehicle was actually turning as determined by a record of lateral acceleration.

Several of the physical areas of the driving subtasks had unique characteristics. For Tasks 1 and 6 the intersection was a T, with a house directly in front of the vehicle as it approached the stop sign. The cross-street at Stop Sign 2 was about ten feet wider than normal and moderately traveled. For Task 5, the road began to curve to the right just prior to where the driver was instructed to turn left. Some of the above environmental factors appeared to have some effect on the drivers search and scan patterns, although they were not the subject of this study.

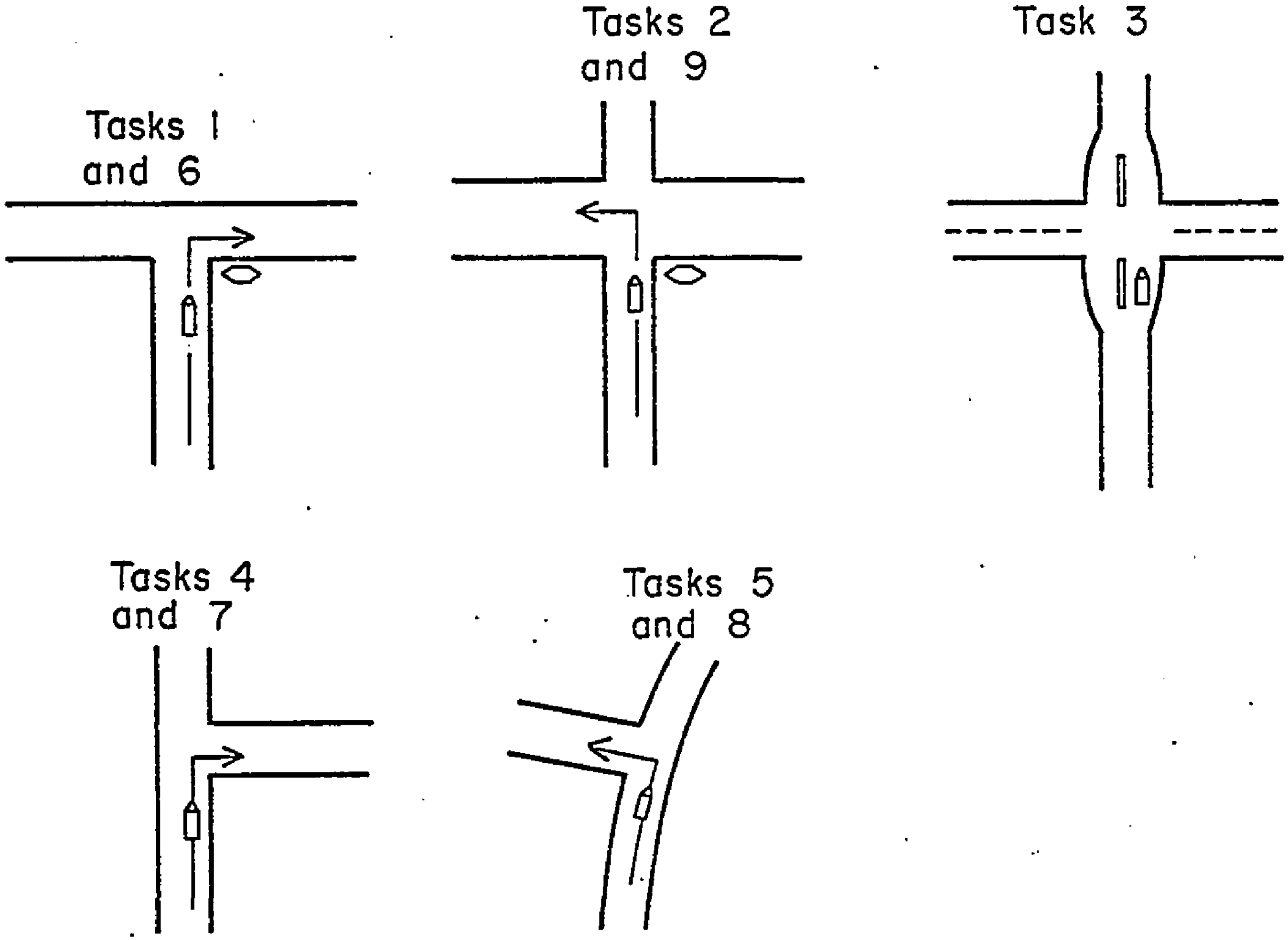

Figure 3. Task Diagram.

The freeway route was 4.3 miles long and contained the following driving subtasks:

10) Changing from right to left lane
11) Traveling in left lane (next to center median)
12) Changing from left to right lane
13) Traveling in right lane (next to shoulder)
14) Monitoring traffic ahead
15) Deceleration prior to exiting ramp.

Tasks 10, 11, 12 and 13 were sequential. Task 14 occurred at some randomly selected period, after Task 13 and before 15, in which the subject monitored traffic that was 400 feet or less in front of his vehicle. Task 15 was defined as beginning when vehicle velocity started to decrease from 70 m.p.h. and ending when the ramp began to curve.

The dependent variables recorded for these taks were:

1) vehicle velocity,
2) vehicle lateral acceleration,
3) driver gas pedal movements (continuous),
4) driver brake pedal applications (on or off),
5) driver eye movements (including fixations to the vehicles's mirrors and speedometer),
6) driver eye blinks, and
7) driver head movements.

Subjects

All the novice drivers were male and either 16 or 17 years old. They were selected because of their almost complete lack of driving experience. In addition, none had any driver education instruction prior to being tested at training level 1 , although novice drivers A, C and F reported that they had driven a friend's car for less than 15 minutes. Novice drivers C and B did a moderate amount of bicycle riding. Novice driver E had driven a tractor for about eight hours, and listed automotives as one of his hobbies. Novice drivers B, D, E and the special novice driver had never operated an automobile prior to being tested at training level 1.

Two of the experienced drivers, W and X were employees of a firm which sells automobile insurance, and had taken a course in defensive driving. Their ages were 31 and 43, respectively. The other two experienced drivers were students at The Ohio State University. They were both 21 years old. All the experienced drivers had driven at least 8,000 miles a year for the last five years. None had received any traffic tickets, or been the cause of any accidents. One driver, W, had been hit from behind while stopped for a traffic light.

All subjects were given visual examinations and had 20/20 unaided visual acuity. (Reported in detail in Appendix B). The experienced drivers were paid $3 per hour for being in the experiment, while all novice drivers received a free commercial driver education course (valued at $79.50) for their participation. The commercial driver education course helped assure that all the novice drivers received the desired amount of on-the-road driving experience between the testing periods.

Procedure

At training level 1 for the novice drivers and run 1 for the experienced drivers, each subject rode as a passenger on the neighborhood and freeway runs prior to any data collection. This was done to try to eliminate the possible confounding of any amount of driving experience with the effect of route familiarity.

On each run neighborhood data was collected prior to freeway data. Before neighborhood data collection all drivers were given instruction as to the location of vehicle controls and displays. Then they moved the three-way power seat so that their eye-height was 44 inches above the ground, and adjusted their rear and side view mirrors. Prior to every data collection run, the novice drivers made several stops and turns in a parking lot in order to familiarize themselves with the vehicle's handling characteristics.

Calibration checks of the eye-movement system were made before the start of data collection, after the stop at Stop-Sign -1, after the stop at Stop-Sign-2, and at the end of the neighborhood route. For the freeway run formal calibration checks were recorded only at the beginning and ending points, but the television monitor provided a means for continuously checking calibration.

At the beginning of the neighborhood route, the subjects were read the following instructions:

> "On this test run your visual behavior will be recorded by our television cameras. Please follow the route that you just rode as a passenger. Obey all traffic signs and signals, and the speed limit of 25 m.p.h. At your right is a safety experimenter, who has the option of applying the dual brake should the need arise. When we reach the end of the route, rmember to put the vehicle in park gear prior to the ending calibration check. Do you have any questions?"

At the beginning of the freeway route, the subjects were read the following instructions:

> "On the freeway travel about 70 m.p.h. but do not monitor your speed any more than you normally do. The safety man will assist you in watching for other traffic during merging, lane changing, and exiting maneuvers. At some point during the route, I will direct you to change lanes, and then return to the right-hand lane. Please stay in the right-hand lane except when traffic ahead forces you to go slower than 70 p.m.h. Do you have any questions?"

Data collection sessions for all drivers averaged about two weeks apart, with rain and snow causing cancellation of some scheduled sessions.

The novice drivers were instructed not to do any driving between driver education training sessions in order to insure that all drivers had the same amount of experience at each testing period.

Apparatus

A new television eye movement recording system (Figure 4) was developed for this experiment. In the figure a sketch of the on-line TV monitor illustrates the system's output. The eyespot (representing the driver's direction of gaze) could

TELEVISION EYE-MOVEMENT SYSTEM FOR AUTOMOBILE DRIVING

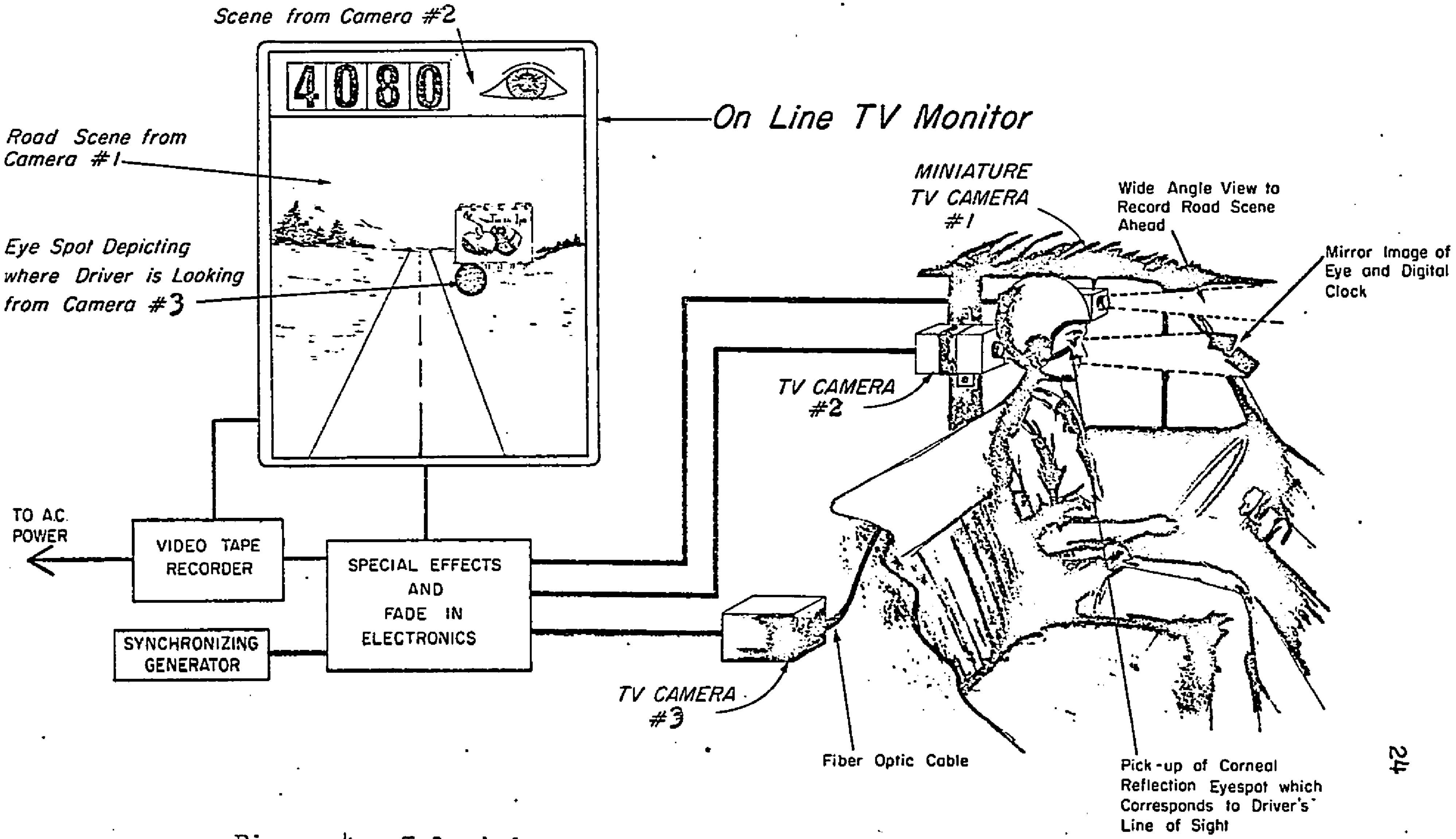

Figure 4. Television eye movement recording system.

range over 40 degrees in the horizontal direction and over 35 degrees in the vertical direction. If larger eye movements were made (such as fixations to the vehicle's mirrors and speedometer) their location could be determined from the picture of the driver's eye.

Correspondence between the eyespot and the visual scene was 1/2 degree in the horizontal direction and 1 degree in the vertical direction. The electronic digital clock, which was updated 20 times every second, provided an accurate method for calculating the duration of eye fixations. The on-line monitor permitted monitoring and calibration checks of the data while it was being collected. Once the data was collected, (as in the case of the special driver study) it could be instantly reviewed by the experimenter and/or shown to the subject-driver to provide him with feedback of his visual performance.

The driver wore a special stabilization unit when data was being collected. This was necessary because of the requirement of the pick-up apparatus for the driver's corneal reflection to remain in the same position with respect to the driver's head regardless of roadway bumps and driver originated head movements. As pointed out by Young (1963) a lateral displacement of 0.1 mm in the pick-up apparatus induces an error of about 1 degree in the measured eye position. The stabilization unit consisted of an inner liner under the helmet, a bite bar for the upper teeth, and a mechanism to tighten the pressure between the driver's upper teeth and head.

A small incandescent light source (6 volts, 0.2 amps) was mounted on the unit and positioned to shine into the drivers right eye. This created the corneal reflected eyespot which was then picked up by a lens and focused on to a fiber optic cable. Under daytime levels of illumination the light created by the source was not noticeable to the driver.

A miniature television camera (#1) was also mounted on the stabilization unit and took a 54° x 41° view of the road scene ahead of the vehicle. This camera weighed 2.5 pounds and was counter-balanced by a pulley and weight placed in back of the driver. The pulley system permitted considerable freedom of lateral head movement and head rotation.

A second TV camera (#2) was mounted on the door post between the front and rear doors and to the left of the driver. This camera took a telephoto view (14° x 11°) of two front surface mirrors which were mounted on the left-A post. One mirror was adjusted to contain an image of the driver's left eye in order to record instrument panel fixations, mirror usage, and eye blinks. The other mirror imaged a four-digit, seven-segmental electronic clock which was updated one unit every fifty milliseconds to provide fixation duration information. A third TV camera (#3) was mounted behind the front seat and received the corneal reflected eyespot which was transmitted by means of a three-foot fiber optic cable. A double convex achromatic lens (25 mm. FL., 15 mm. diameter) was used to focus the eyespot directly on the vidicon of the TV camera. This technique in combination with the eyespot pick-up method permitted tailoring of the eyespot travel length to correspond to the visual scene for each subject. Thus, variations between cornea shapes of the drivers had little effect on system accuracy.

The video signals from all three television cameras went into a sync-generator and then into special effects electronics. The special effects electronics permitted the eyespot to be superimposed on the picture of the visual scene taken by the head mounted camera. It also allowed the scene containing the digital clock and driver's right eye to be cut-in to the upper one-fifth of the picture on the television monitor. During data collection periods, the experimentor could view the system's performance on an eleven inch television monitor. A one-half inch video tape recorder with stop action capability made a permanent record of the data. The television equipment was powered in the vehicle by a 24 volt, 100 amp alternator which was connected to a 750 watt inverter to provide 110 volt alternating current.

Also mounted in the vehicle was a direct-print oscillograph recorder. This made a record of the vehicle's velocity from a tachometer, and the vehicle's lateral motion from an accelerometer. By means of a transducer on the carborator-input-control, a record of driver gas pedal movements was recorded. Driver brake pedal applications were recorded by an on-off switch connected to the brake lights since the vehicle was equipped with power brakes. The oscillograph was powered by a 12 volt, 100 amp alternator. Synchronization between the oscillograph and television recordings was achieved by pressing two stimulus buttons simultaneously.

The instrumented vehicle which contained the above equipment was a 1970 Chrysler Newport with power steering, power brakes, and a three-way adjustable power front seat.

Data Reduction

An 18 inch television monitor and a video tape recorder with stop action capability was used for examination of eye-movement TV tapes. Superimposed on the monitor was a grid with one-degree squares which ranged 54 degrees in the horizontal direction, and 41 degrees in the vertical direction. This corresponded to the size of the scene recorded by the miniature head-mounted TV camera.

Eye fixations were mapped to the visual scene by the following procedure. At the beginning of the reduction of each task, the starting driver's head position was taken to be the point imagined to be located at the focus of expansion. The horizontal and vertical distances to this position with respect to a fixed point on the vehicle's hood were then noted.

If the driver moved his head, then the movement of the head-mounted camera resulted in different grid coordinates corresponding to the fixed position on the vehicle. In this manner driver head movements were recorded. The coordinates of eye fixations were simply the grid location in which they appeared. A computer program subtracted the head location from the eye location at each fixation point to establish the location of the eye fixation with respect to the focus of expansion.

The following types of visual events were included in the data:

1) eye blinks shown by the insert of the driver's right eye
2) eye fixations shown by the eyespot remaining relatively stable
3) eye-travels shown by the viewing of a blurred eyespot that is obviously in motion
4) pursuit movements shown by the eye smoothly following a moving object
5) speedometer fixations detected by the eyespot disappearing and the eye in the insert moving down
6) mirror fixations detected by eyespot disappearance and eye moving slightly up and over for the rear mirror, and down and in the opposite direction for side-mounted mirror.

For all the above events the beginning and ending times were noted from the four digit electronic clock.

The eye fixations were also classified as to whether they appeared to be on traffic, on road signs, on miscellaneous objects directly straight ahead (at least 300 feet ahead of the vehicle), or having to do with vehicle lane position (scanning the curb, lane markings, or road close in front of the vehicle).

The vehicle data, velocity and lateral acceleration was sampled every quarter of a second, by noting the position of the analog trace with respect to the paper grid coordinates. A computer program subtracted the zero point and multiplied the data by a scale factor.

Measures of Performance

Below is a list of the statistics calculated from the dependent variables listed in the section on experimental design. The statistics are listed in the order in which they are presented in Chapters IV through VII.

A. Visual Activity Measures
    1) Travel Distance per Second
    2) Range of Horizontal Fixation Locations
    3) Range of Vertical Fixation Locations
    4) Mean Fixation Duration
    5) Correlations between the first four measures

B. Visual Location Measures
    1) Median of Horizontal Fixation Locations
    2) Median of Vertical Fixation Locations

C. Mirror and Speedometer Measures
    1) Number of Rear View Mirror Glances
    2) Number of Side Mirror Glances
    3) Number of Speedometer Glances
    4) Mean Duration of Rear View Mirror Glances

    5) Mean Duration of Side Mirror Glances
    6) Mean Duration of Speedometer Glances

D. Pursuit Eye Movements
    1) Number of Pursuit Eye Movements
    2) Median of Pursuit Duration
    3) Range of Pursuit Duration
    4) Percent of Total Visual Fixation Time

E. Eye Blinks
    1) Number of Blinks per Minute

F. Head Movements
    1) Range of Head Movements

G. Control Measures
    1) Mean Deceleration Rate (Tasks 1 through 5)
    2) Maximum Lateral Acceleration (Tasks 1 through 5)
    3) Effective Curvature (Tasks 6 through 9)
    4) Average Vehicle Velocity (Tasks 10 through 15)
    5) Standard Deviation of Lateral Acceleration (Tasks 10 through 15)

Reasons for the selection of these measures are given in Chapters IV through VII.

CHAPTER IV

RESULTS--MEASURES OF VISUAL ACTIVITY AND LOCATION

For all measures in Chapters IV through VII, tests of significance over training levels for the novice drivers were conducted using a linear model which considered subjects to be a random effect. The model and assumptions of the tests are presented in Appendix C. In Appendix D are all the analyses of variance summary tables. This model was also used to test for significant differences between Run 1 and Run 2 for the experienced drivers. No differences between runs for the experienced drivers were found to be significant for any of the measures reported.

Possible significant differences between the novice and experienced groups were investigated using the Mann-Whitney U Test. The assumptions of this test were met in all cases and are given in Appendix B. For all statistical tests the probability of rejecting a true null hypothesis had to be .10 or less for the result to be called significant. The actual alpha level (probability of rejecting a true null hypothesis) is reported with each result.

Eye Travel Distance Per Second

For any sequence of eye movements over time the sum of the travel distances between fixations divided by the total time gives the statistic, eye travel distance per second. Large values of this measure indicate that the driver is scanning a large area and/or that he is making small jumps and quick fixations in a small area. For either case, a large travel distance per second value means that the driver's visual system is actively obtaining information from the environment. Hence, this measure is positively correlated with the amount of visual attention which drivers direct towards the control of their vehicles.

In Figure 5 average travel distance per second is graphed by training levels and driving tasks. One obvious effect is that the novice drivers decreased their scan activity rate as they acquired driving experience. Analyses of variance indicated that search activity at the training levels were statistically significant on the following tasks:

1. approach to Stop Sign 1 ($p <.10$)
2. approach to Stop Sign 2 ($p <.10$)
5. approach to Right Turn ($p <.05$)
12. change to Right Lane ($p <.05$)

Thus, as shown in Figure 5, the average for the novice group moved away from that of the experienced group when going from training level 1 to training level 3. Therefore, a conservative test of the differences between the novice and

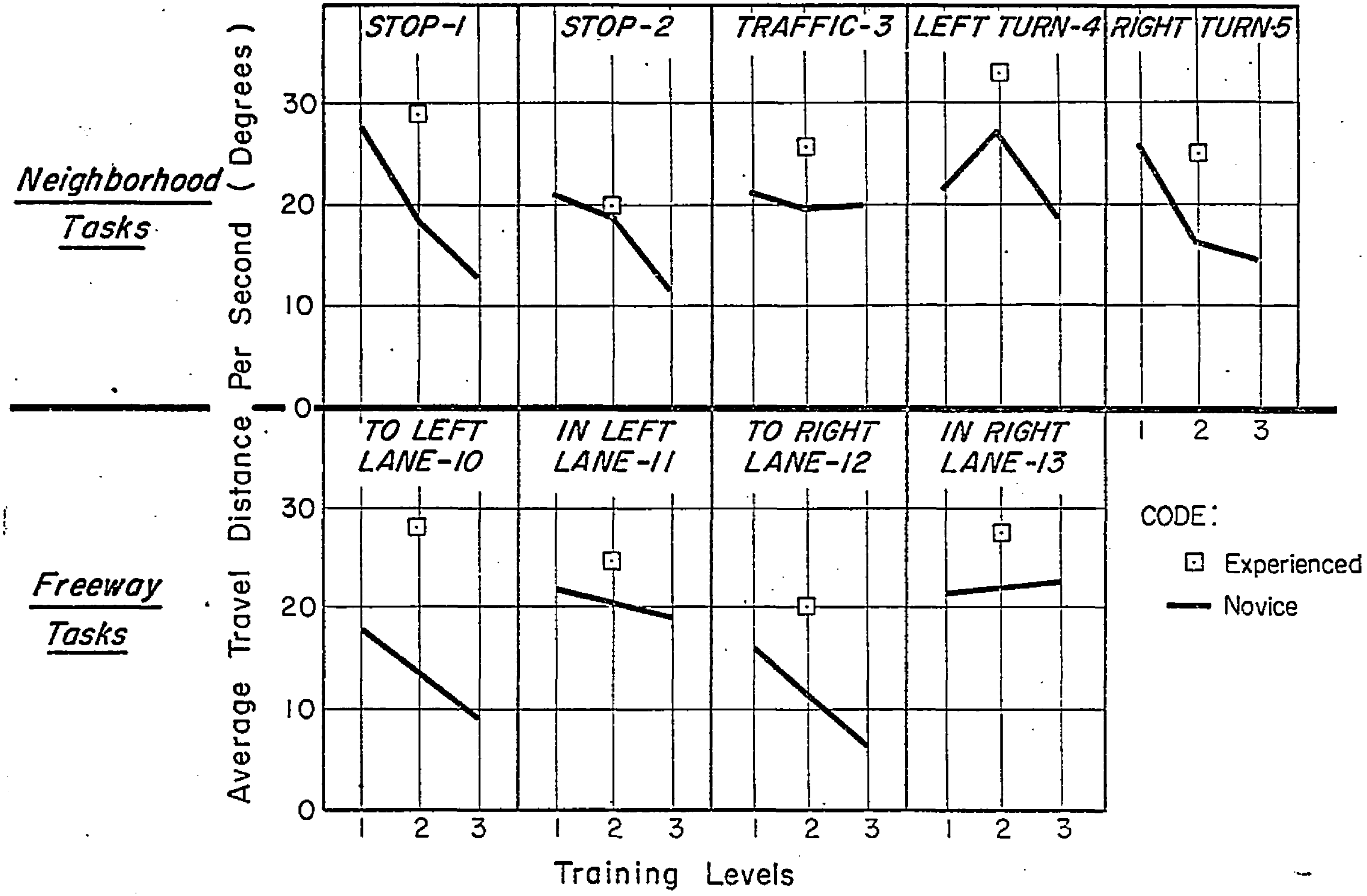

Figure 5. Average travel distance per second by driving tasks and training levels for the novice group and by driving tasks for the experienced group.

experienced groups would entail using the novice drivers' average over training levels. Mann-Whitney U Tests indicated that the activity level of the novice group was below that of the experienced group on the tasks listed below:

1. approach to Stop Sign 1 ($p < .033$)
3. approach to Traffic Light ($p < .007$)
4. approach to Left Turn ($p < .003$)
10. change to Left Lane ($p < .01$)
11. driving in Left Lane ($p < .086$)
12. change to Right Lane ($p < .019$)

Clearly, the activity levels of the novice drivers were less than those of the experienced group. This may indicate that the experienced drivers scanned wider in the horizontal direction, vertical direction, and/or that they had shorter fixation durations. The next three dependent variables to be considered, range of horizontal fixations, range of vertical fixations, and duration, all partially relate to changes in the visual activity measure. Correlations among these measures are presented in a later section.

Range of Horizontal Fixation Locations

The range of a collection of values is simply the absolute value of the smallest value subtracted from the largest value. The locations of mirror and speedometer fixations were always excluded when calculating the ranges since they were so extreme and occurred infrequently. Note that when the direction of foveal vision is shifted through a wide range and a fixation occurs, then during the fixation period the surrounding area may be monitored with peripheral vision. Thus fixation ranges are sensitive to the amount of area that was searched.

The average ranges of horizontal fixation locations are plotted in Figure 6. A major trend was for the novice drivers to decrease their horizontal sampling range as they progressed through driver education training. The following tasks had significant training level effects:

1. approach to Stop Sign 1 ($p < .01$)
2. approach to Stop Sign 2 ($p < .05$)
3. approach to Traffic Signal ($p < .10$)
4. approach to Left Turn ($p < .05$)

However, on Task 4 the difference in horizontal range between training levels 1 and 3 was not significant.

That there is not a perfect correlation between horizontal range and travel distance per second can be seen most readily by examining the points for the experienced group on Tasks 10 and 11. Again, the experienced group had larger values than the novice group. Mann-Whitney U Tests on the data gave the following significant differences between the groups:

1. approach to Stop Sign 1 ($p < .019$)
4. approach to Left Turn ($p < .056$)
5. approach to Right Turn ($p < .086$)
10. change to Left Lane ($p < .017$)

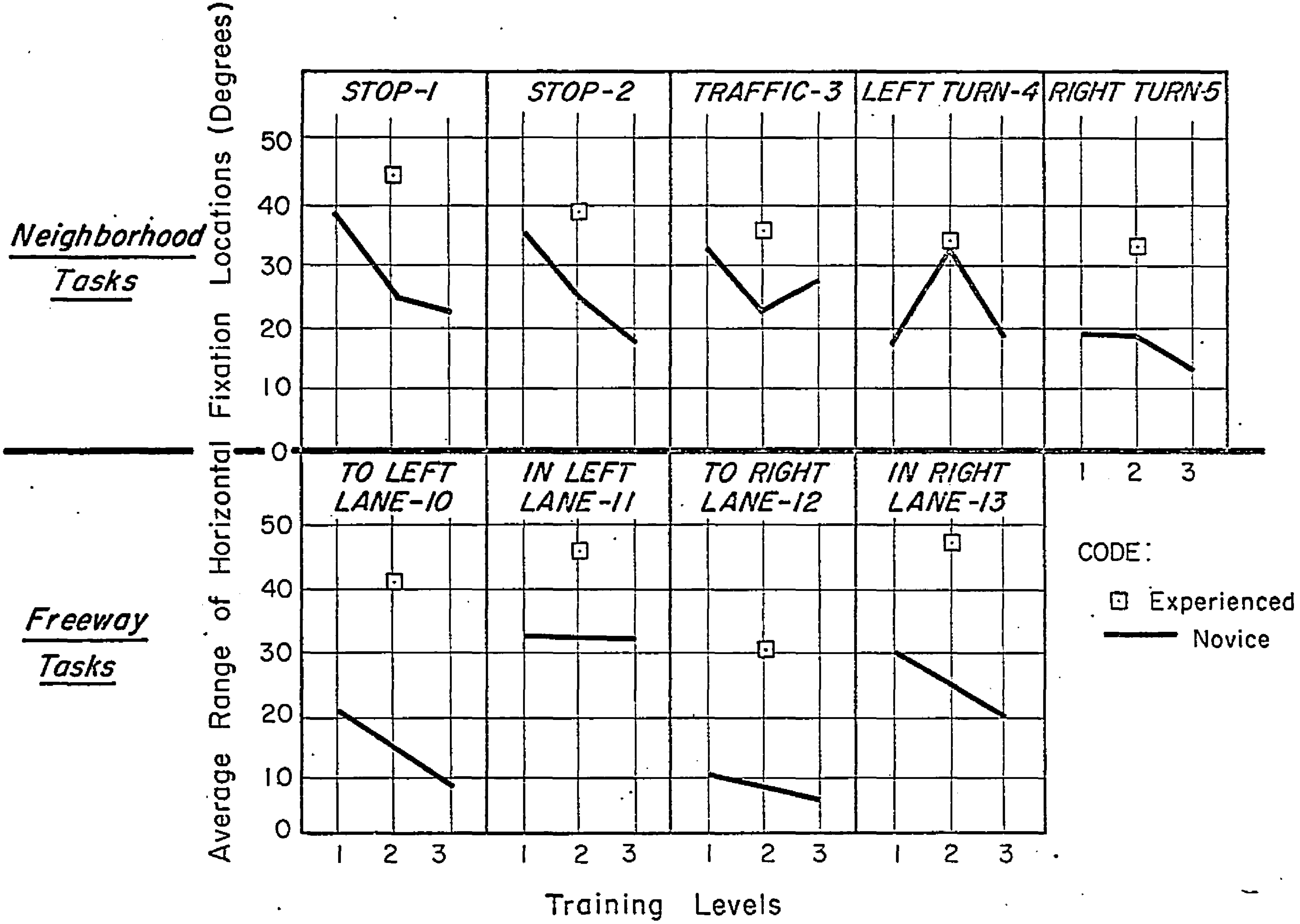

Figure 6. Average range of horizontal fixation locations by driving tasks and training levels for the novice group and by driving tasks for the experienced group.

11. driving in Left Lane ($p < .086$)
12. change to Right Lane ($p < .019$)

Range of Vertical Fixation Locations

The average ranges of the vertical fixation locations are plotted in Figure 7 as a function of novice driver training levels. There does not appear to be any trend toward decreases in vertical ranges with amount of driver training. However, for the tasks listed below the differences between training levels was significant.

2. approach to Stop Sign 2 ($p < .10$)
4. approach to Left Turn ($p < .10$)
5. approach to Right Turn ($p < .05$)

There were no significant differences for any of the freeway tasks. The largest significant change in vertical range occurred for the approach to Right Turn Task, and appears to account for some of the decreased activity for this task shown in Figure 5.

On only one driving task, the change to Left Lane (#10), was the value for the experienced group significantly higher than that of the novice group ($p < .086$).

Fixation Duration

The mean fixation durations for the neighborhood and freeway driving tasks are graphed in Figure 8. Consider first the changes with training levels for the novice group. For the neighborhood tasks there were no significant

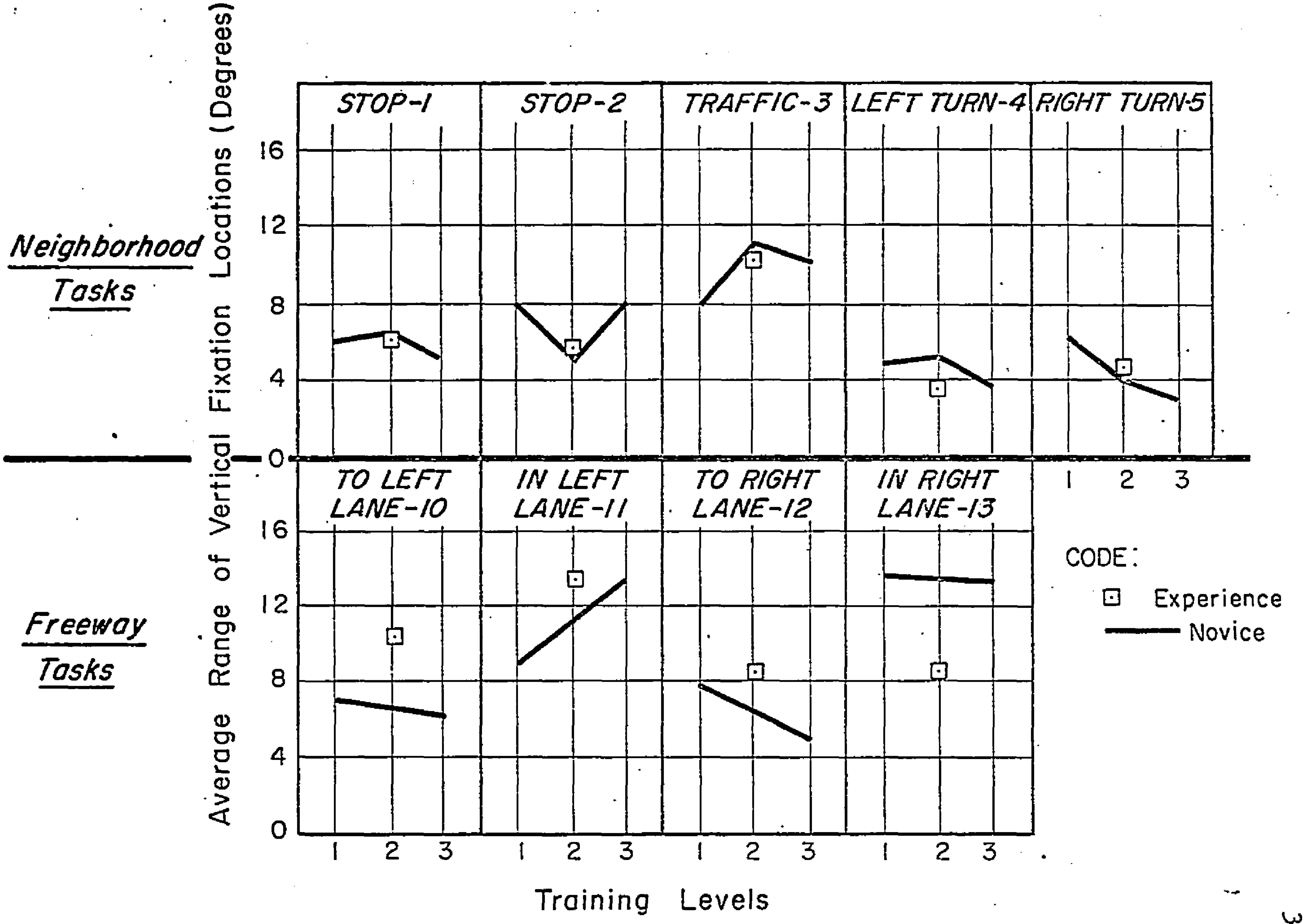

Figure 7. Average range of vertical fixation locations by driving tasks and training levels for the novice group and by driving tasks for the experienced group.

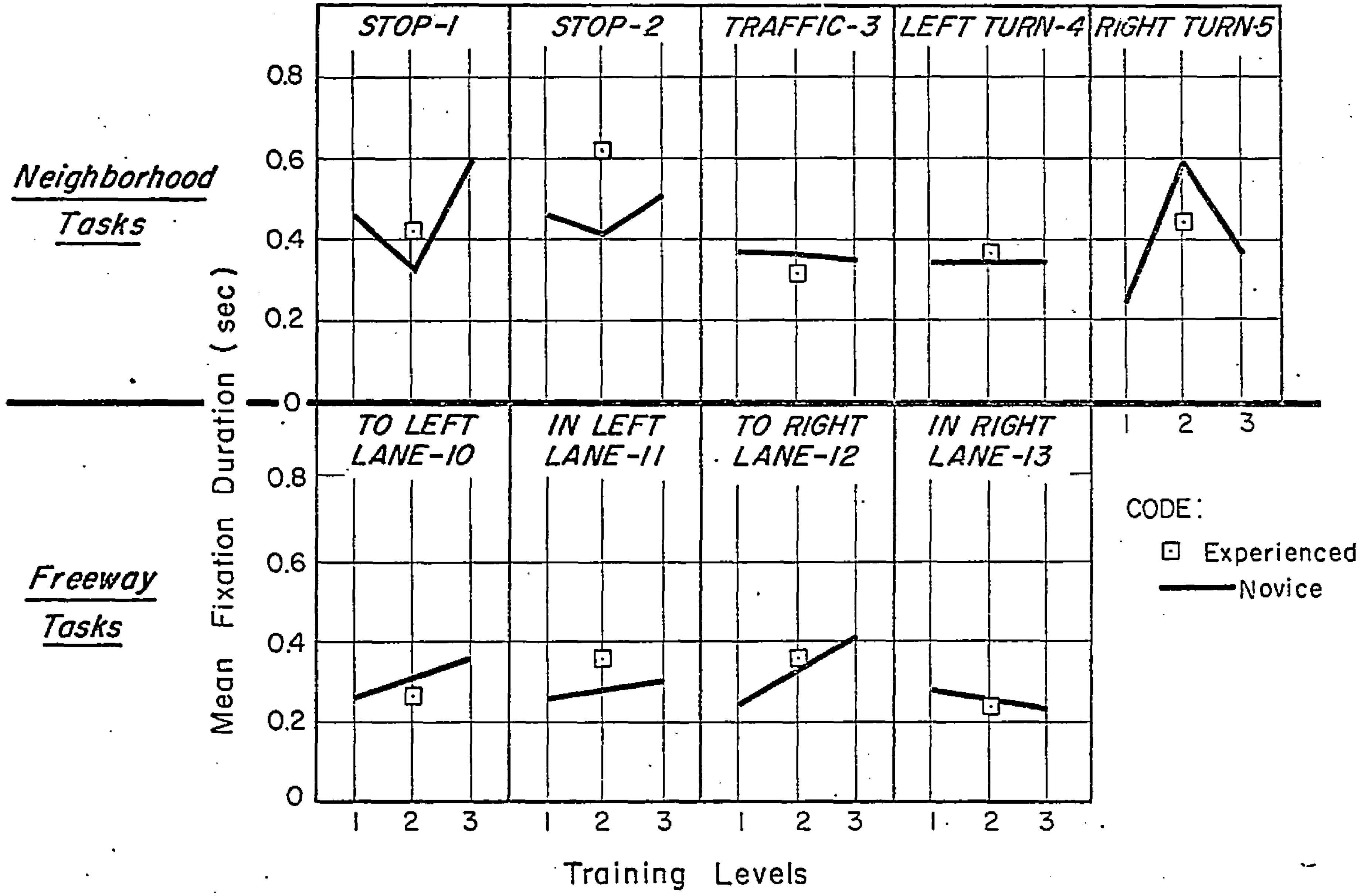

Figure 8. Mean fixation duration by driving tasks and training levels for the novice group and by driving tasks for the experienced group.

differences. The unusually large values for level 3 of Task 1 and level 2 of Task 5 were caused by one of the drivers staring for a long period. Below are the freeway tasks that had a significant training levels effect:

10. change to Left Lane ($p < .05$)
12. change to Right Lane ($p < .10$)

This increase in fixation durations may account for part of the decreases in activity shown for Tasks 10 and 12 in Figure 5.

Although there were no significant differences between the novice and experienced groups on the neighborhood tasks, there were for the Freeway tasks listed below.

10. change to Left Lane ($p < .019$)
11. driving in Left Lane ($p < .01$)

The longer fixation time by the novice drivers on Task 10 may be due to difficulty in abstracting lane position information when changing lanes. This hypothesis is supported by the large number of tracking eye movements made by the novice group and reported in Chapter V.

Activity Measures--Correlations and Individual Differences

Correlations were computed between the following dependent variables by driving task and subject group:

1) Eye Travel Distance Per Second and Horizontal Range
2) Eye Travel Distance Per Second and Vertical Range

3) Eye Travel Distance Per Second and Mean Fixation Duration

These are shown in Table 1 with a •(dot) indicating the correlations found to be significantly different from zero ($t < .05$).

Considering Distance Per Second and Horizontal Range, the most striking result is that the only non-significant correlations were for the experienced group on the two freeway lane change tasks. This suggests that freeway lane changing requires a different sampling strategy than the other tasks. The novice group, except for the approach to the Traffic Light and traveling in right lane Tasks always had about 50% of the variance in the Distance Per Second scores accounted for by the Horizontal Range scores.

In terms of Distance Per Second and Vertical Range significant correlations were found for the novice group in the neighborhood tasks, but only one (Task 1) was significant for the experienced group. Thus for an experienced driver greater scan activity does not mean sampling a larger vertical area.

For all the experienced drivers' freeway tasks the correlations between Distance Per Second and Fixation Duration were significant while for the novice drivers only Tasks 11 and 12 had significant correlations. Thus the experienced drivers relied on increases in frequency of sampling to abstract information while driving on the freeway.

Table 1

Correlations Between Activity Measures

N = 36 Novice Drivers

N = 16 Experienced Drivers

		Tasks								
		1	2	3	4	5	10	11	12	13
Distance/Sec x Range	Novice	.75	.77	.51	.72	.75	.79	.70	.84	.56
	Experienced	.77	.84	.74	.85	.78	.96	-.04	.60	.12
Distance/Sec y Range	Novice	.48	.54	.48	.50	.40	.55	-.20	.56	-.34
	Experienced	.50	.30	.43	.29	-.06	.19	-.32	.56	-.04
Distance/Sec and Duration	Novice	-.44	-.66	-.48	-.32	-.43	-.06	-.51	-.60	-.32
	Experienced	-.38	-.52	-.41	-.64	-.58	-.79	-.66	-.50	-.49

In correspondence with Table 1 is Figure 9, which is a summary of the relationships between the activity measures for the novice and experienced groups. Significant differences between the novice and experienced groups are shown by the symbol Ⓣ. Note also that fixation rate (fixations/sec) is shown in place of fixation duration.

The largest differences are for the horizontal range measure of the freeway tasks. Note that for the tasks that appear to be somewhat difficult, changing to the left lane and changing to the right lane, the differences were larger than for the easier tasks.

It should be evident from Figure 9 that there are various relationships between tasks and driving groups for the activity measures. Each task appeared to demand from the drivers a special strategy in terms of the types and amount of visual activity. For example compare the strategies of the experienced group when approaching Stop Sign 1 and when approaching the traffic light. Although the activity levels are about equal, for the traffic light task the experienced drivers decreased their horizontal range of sampling, increased their vertical range of sampling and increased their number of fixations per second.

No study of learning would be complete without some attention being given to individual subject tasks. Because space prohibits displaying the performance of every driver, the results of two novice drivers whose performance appeared

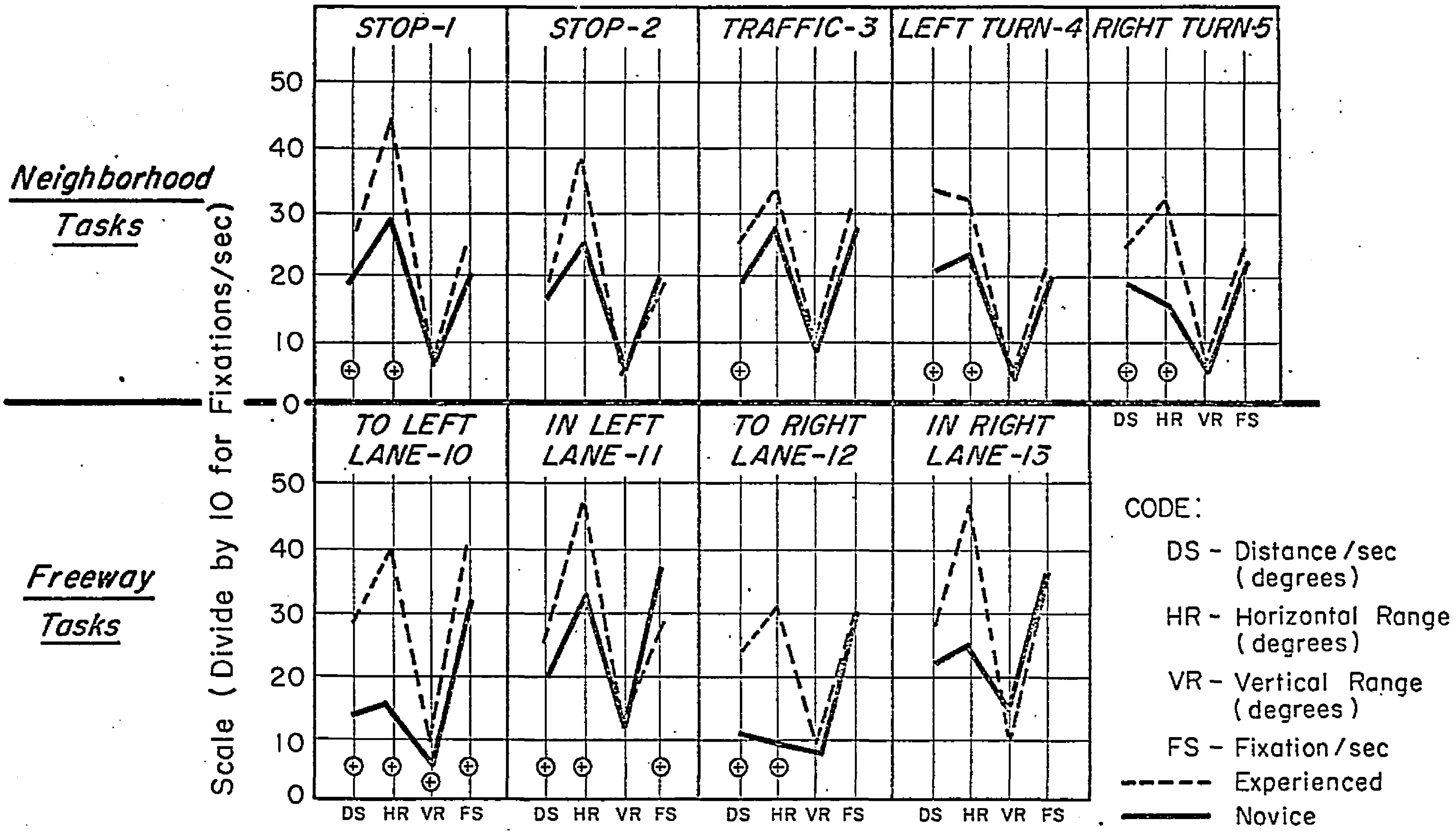

Figure 9. Average distance per second, average range of horizontal fixation locations, average range of vertical fixation locations, and fixations per second by driving tasks for the novice and experienced group.

to be very different were selected for graphing. In Figure 10 relationships between the activity measures are shown for all the tasks for novice drivers C and F. Comparisons with the performance of the novice and experienced groups can be made by referring to Figure 9 which is in the same scale.

Note that on the neighborhood tasks the fixation rate of driver F was always less than that of driver C, yet on the freeway driving tasks driver F increased his sampling rate so that it almost equaled that of driver C. Thus, driver F has the capability of sampling faster when driving in the neighborhood, but apparently chose not to do so. The lower sampling frequency and smaller horizontal range for driver F suggests a slow sampling pattern.

Median of Horizontal Fixation Locations

The place where a driver samples to obtain his information also reveals an important part of his visual sampling strategy. The median was used as the measure of central tendency because of the skewness of the data and the small sample sizes. Positive values of the horizontal median indicated the drivers were looking to the right, and negative values to the left. For the vertical median positive values indicated looking straight ahead or at the sky, while negative values indicate looking at the ground or road surface. For both the neighborhood and freeway tasks, there were no shifts in the median of horizontal fixation locations with increased driving experience by the novice drivers.

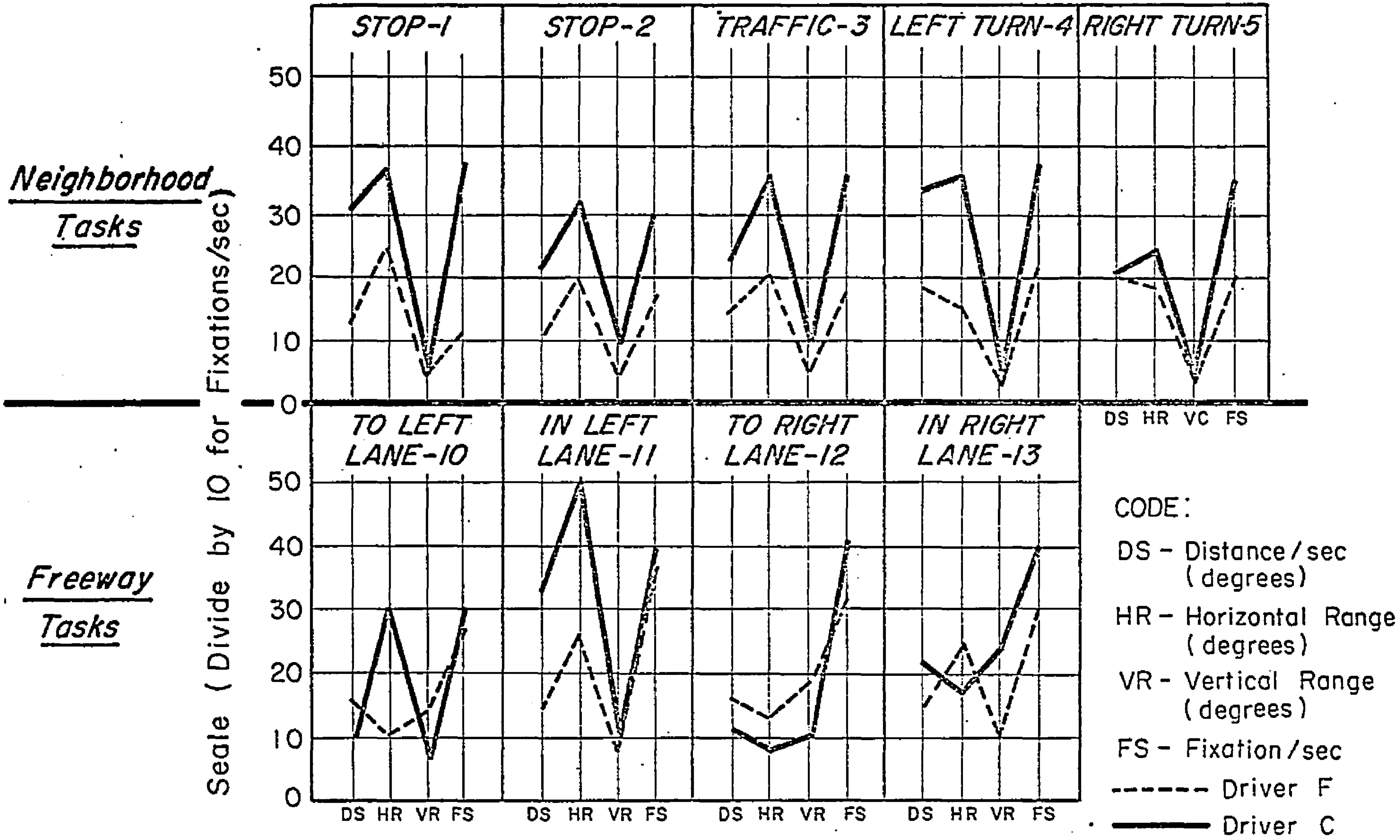

Figure 10. Average distance per second, average range of horizontal fixation locations, average range of vertical fixation locations, and fixations per second by driving tasks for novice drivers C and F.

However, the medians of location appeared to shift as deceleration maneuvers were being completed. In order to investigate this shifting each run of the neighborhood tasks was divided into two sections of equal time. Then medians were computed separately for the first and last sections. Analysis of variance tested the sections effect and showed that there were no significant interactions between task sections and training levels.

In Figure 11 are the median horizontal locations by task sections for the novice and experienced groups. For the freeway tasks no first and last divisions were made. Considering the differences between the first and last half sections the following tasks had significant differences for the novice group:

1. approach to Stop Sign 1($p < .05$)
5. approach to Right Turn ($p < .01$)

and the tasks below had significant differences for the experienced group:

4. approach to Left Turn ($p < .05$)
5. approach to Right Turn ($p < .01$)

The median horizontal location shifted to the right during the last half of the Stop Sign 1 and Right Turn Tasks. For the Left Turn Task it shifted to the left. It is most apparent in Figure 11 that the median horizontal location of the novice group was always to the right of that for the experienced group in the neighborhood driving situations.

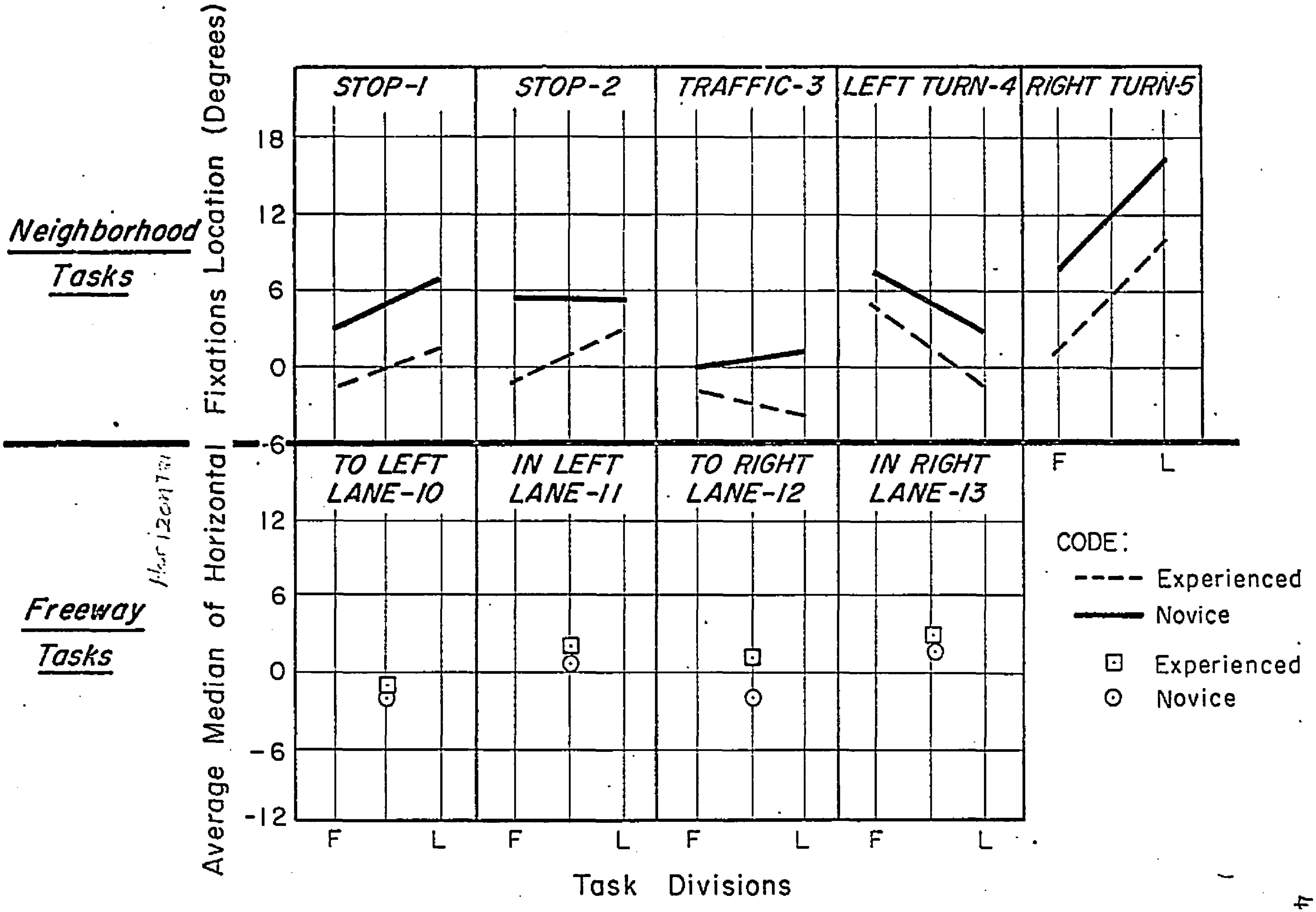

Figure 11. Average median of horizontal fixation locations for the freeway tasks and by first and last task divisions for the neighborhood tasks for the novice and experienced groups.

Tests for differences were made between groups for both the first and last half sections, since it appears that the sections do reflect different sampling patterns in terms of fixations locations. The following significant differences between the novice and experienced groups were found using the Mann-Whitney U Test:

1. first half-stop #1 ($p < .005$)
2. first half-stop #2 ($p < .01$)
3a. first half-traffic light ($p < .019$)
3b. last half-traffic light ($p < .01$)
5. last half-right turn ($p < .086$)

There were no significant differences between groups for the freeway driving tasks.

Median of Vertical Fixation Locations

In Figure 12 the vertical fixation location medians are presented by first and last half task sections. The following tasks had significant first and last half differences for the novice group.

1. approach to Stop 1 ($p < .05$)
5. approach to Right Turn ($p < .01$)

For the experienced group the only significant difference was for the Approach to Right Turn Task ($p < .05$). All the above differences were in the direction of lower (closer in front of the vehicle) fixation locations during the last half of the deceleration maneuvers.

The median vertical fixation locations of the novice

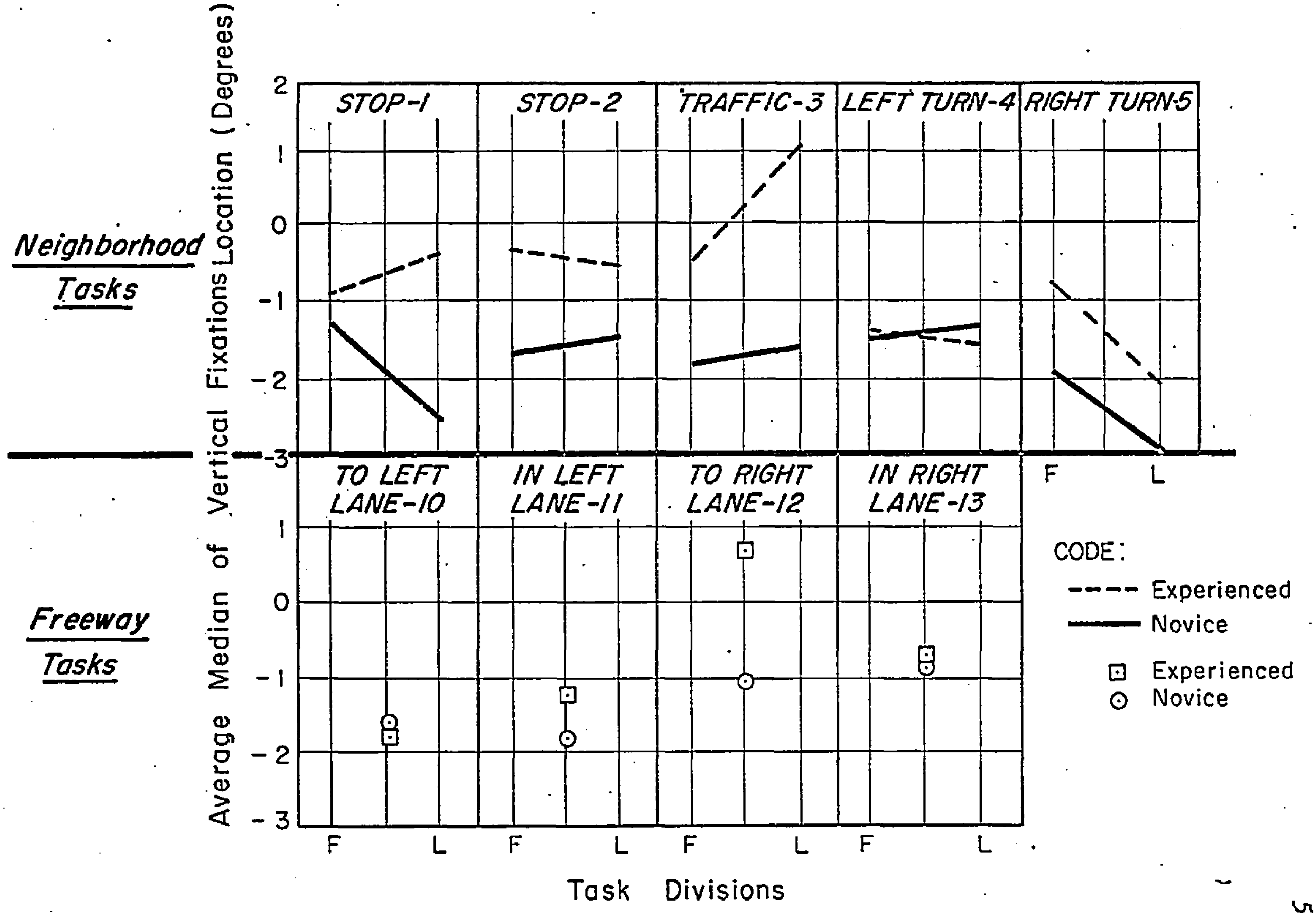

Figure 12. Average median of vertical fixation locations for the freeway tasks and by first and last task divisions for the neighborhood tasks for the novice and experienced groups.

group were lower than those of the experienced group on Tasks 1, 2, 3, 5, 11, and 12. Significance tests between the groups revealed the following results:

1. last half-stop #1 ($p < .057$)
2. first half-stop #2 ($p < .086$)
3a. first half-traffic light ($p < .086$)
3b. last half-traffic light ($p < .057$)
12. change to right lane ($p < .019$)

Summary and Individual Differences of Location Measures

The tendency of the novice drivers to look farther to the right and closer in front of the vehicle than the experienced group suggests that they are concerned with the pick-up of vehicle lane position information.

The finding of their looking lower and farther to the right for the approach to the traffic light was surprising in view of their frequency of sampling on the traffic signal. However, as shown in Figure 13, the experienced drivers sampled the light more during the last portion of the run. Since, when the vehicle is close to the light a greater visual angle is required to sample it, this partially accounts for the higher median location of the experienced drivers on Task 3.

In Figure 14 the shifts in both the median of vertical and the median of horizontal locations are shown for novice drivers C and F as a function of first and last task sections. On every driving task the median location of the gaze of

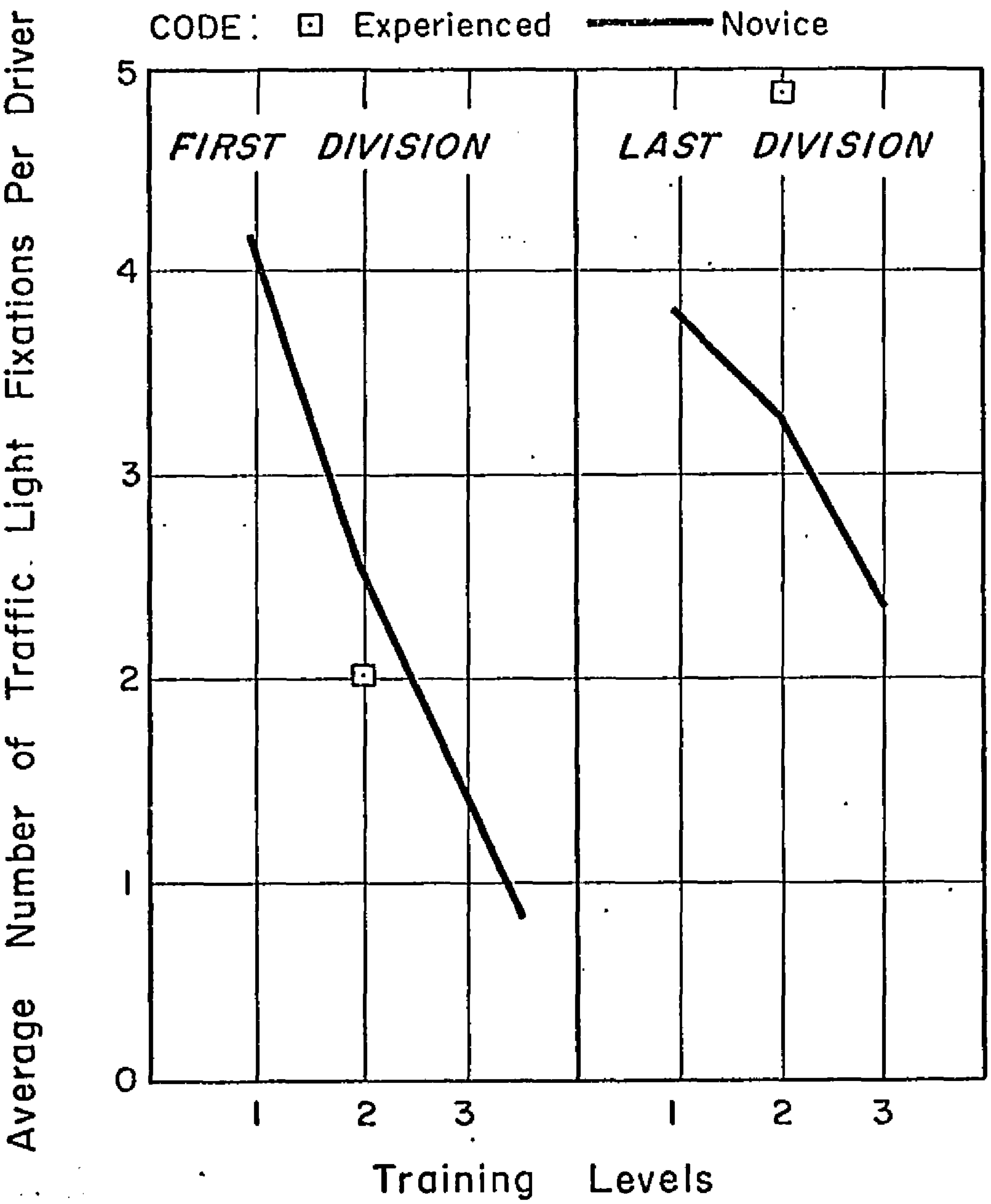

Figure 13. Average number of traffic light fixations by task divisions for the experienced group and by training levels and task divisions for the novice group.

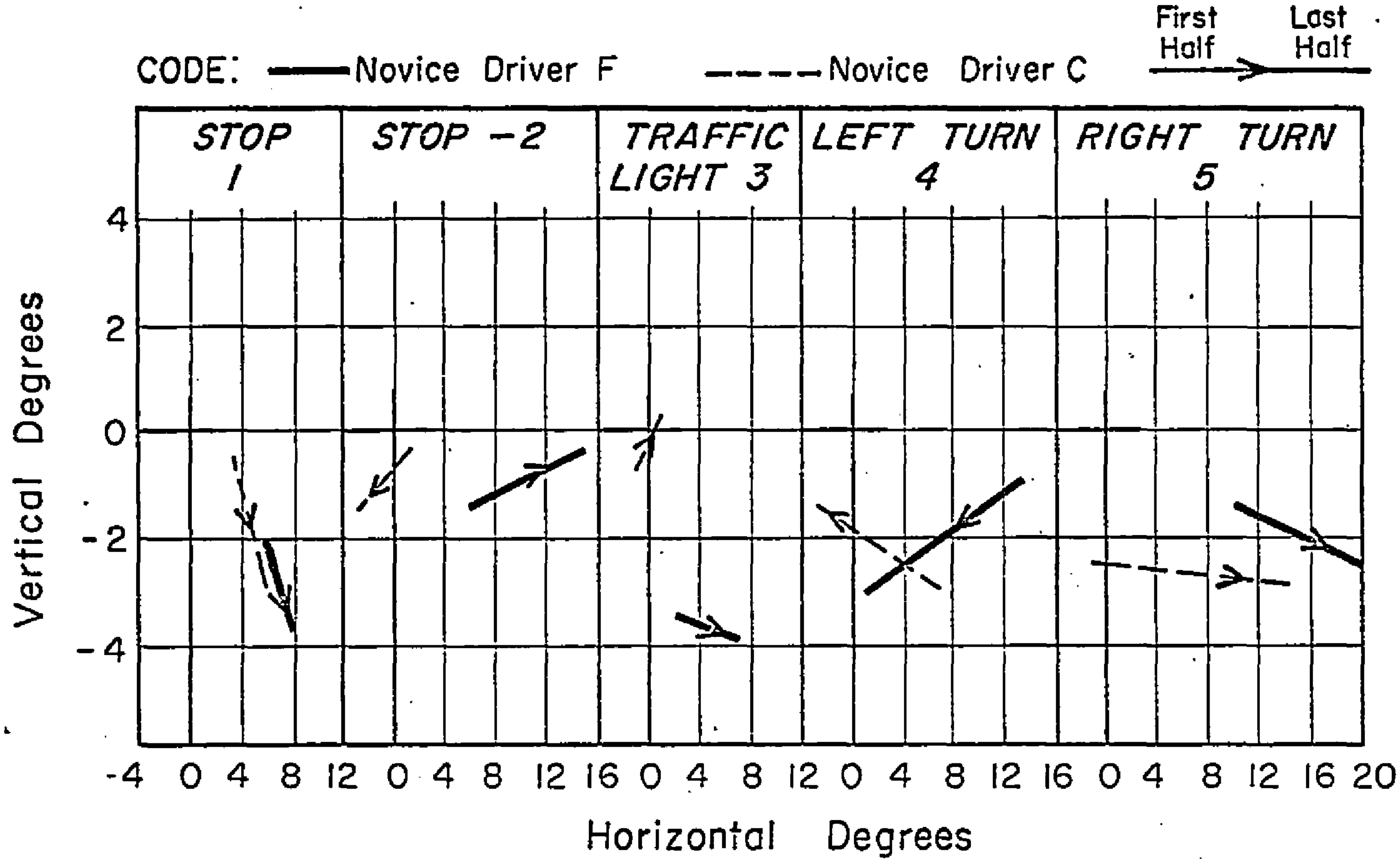

Figure 14. Shifts in the median location of central gaze as a function of first and last half task divisions for novice drivers C and F.

driver C was to the left of driver F for both the first and last sections. When compared with the median of the experienced group the shifts of driver C are similar in the horizontal direction, but not in the vertical direction. In particular on the approaches to Stop Signs 1 and 2 driver C shifted downward during the last half division while the experienced drivers either looked higher or straight ahead.

CHAPTER V

RESULTS - MIRROR AND SPEEDOMETER GLANCES, PURSUIT EYE MOVEMENTS, EYE BLINKS, AND HEAD MOVEMENTS

Mirror and Speedometer Glances

Both mirror and speedometer glances appear to be controlled by learned voluntary commands of the driver. There is no built-in mechanism that will make a driver automatically glance at the vehicle's mirrors or speedometer. Presumably, when a driver feels a need for information from these sources, a command will be initiated to the eye to travel to the mirror or speedometer. However, the large eye movements necessary to sample the mirrors and the speedometer are unnatural to the normal relationship between head and eye movements. Usually an eye movement of 15 degrees or greater is accompanied by a corresponding head movement. In a Cartesian coordinate system with the zero-zero point at the focus of expansion, the following locations were found for the vehicle's mirrors and speedometer:

1) Side Mounted Mirror: -52 Horizontal, -12 Vertical degrees
2) Rear View Mirror: +40 Horizontal, +5 Vertical degrees
3) Speedometer: 0 Horizontal, -18 Vertical degrees

Both the necessity for large eye movements and the voluntary control aspect may contribute to the difficulty that novice drivers appear to have in integrating mirror and speedometer glances into their search and scan strategies.

The data for the freeway and neighborhood sections are presented below for a fixed portion of the route. This was done, in place of presenting the data by tasks, in order to increase the sample size and eliminate variations due to the exact time a glance was executed. The freeway section examined contained three lane changes and was about 2.5 miles long. The neighborhood section was a straight section that was .5 miles long and ended at a stop sign. Figure 15 shows a comparison of the neighborhood and freeway sections by groups. The neighborhood section had a low frequency of both mirror and speedometer sampling. It is interesting to note that at training level 3, the novice groups did very little mirror or speedometer checking.

Considering the mirror glances on the freeway, the experienced group clearly had a larger number per run than the novice group. However, the novice drivers made more use of their speedometers than the experienced drivers.

The frequency of sampling for individual drivers is shown in Figure 16. For the rear view mirror category, only one novice subject, driver C, approached the rate of the experienced group. Note that novice driver D did not ever sample his rear view mirror. The side view mirror was hardly used at all by drivers in the novice group.

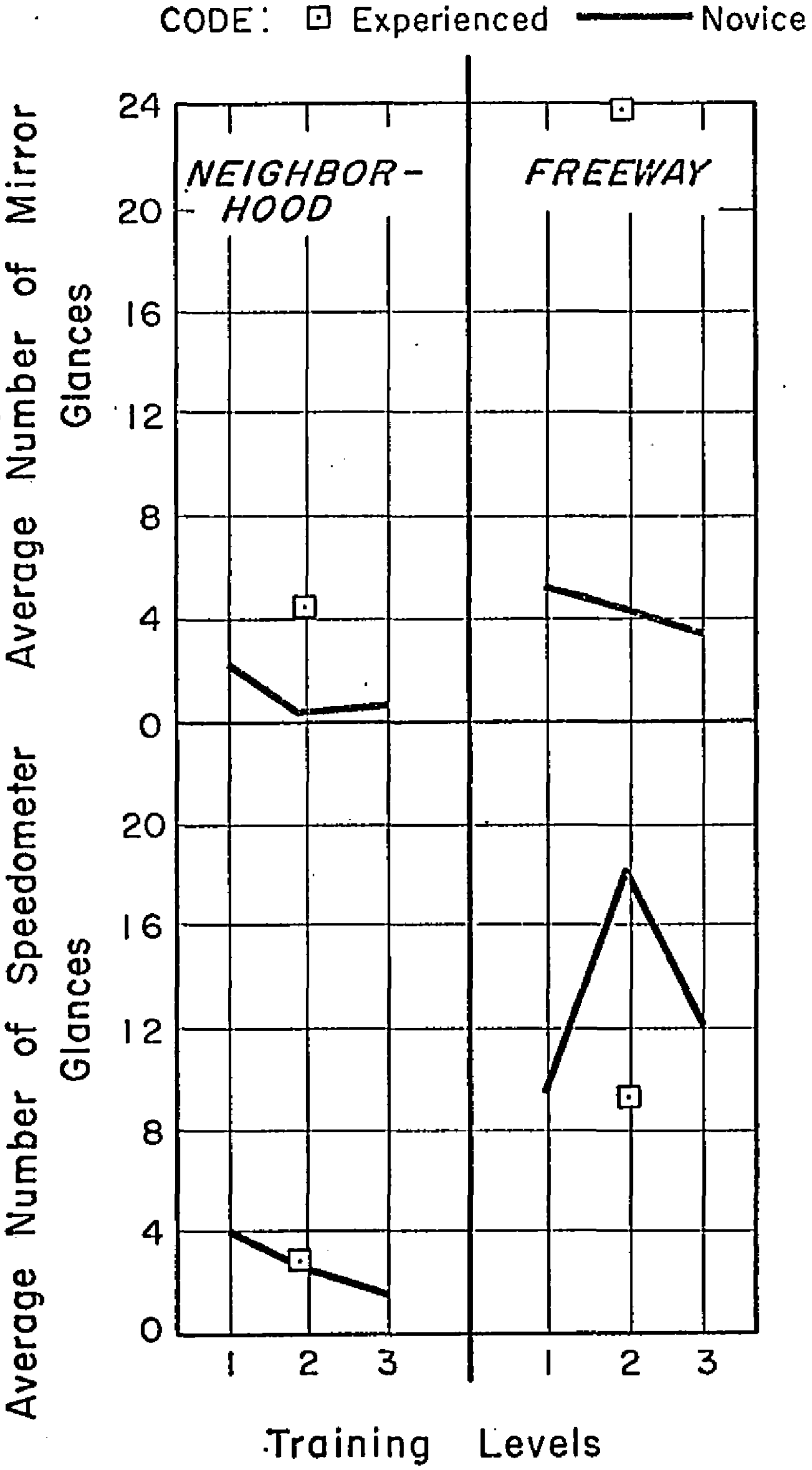

Figure 15. Average number of mirror and speedometer glances for the experienced group and by training levels for the novice group.

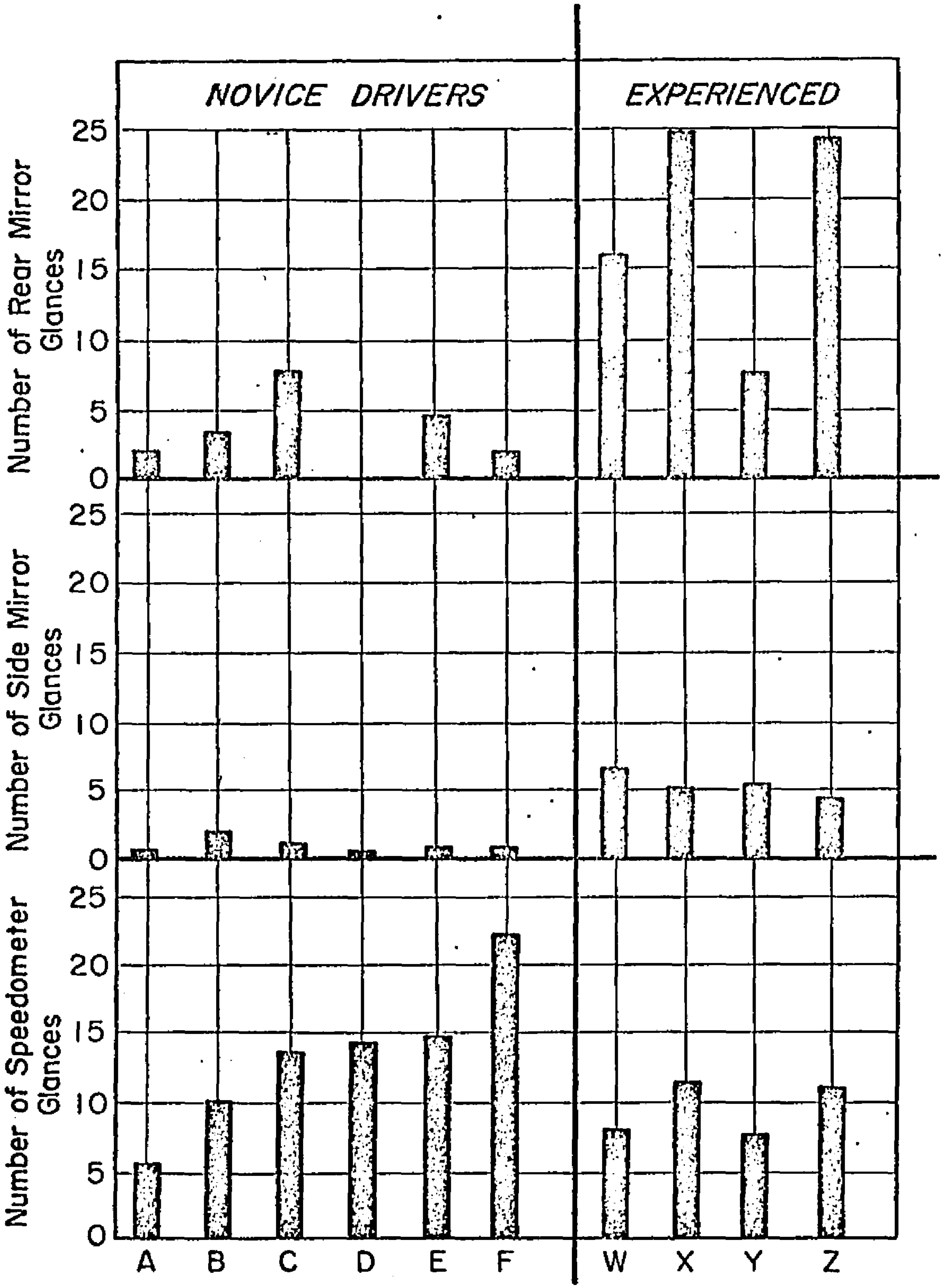

Figure 16. Frequency of mirror and speedometer sampling by individual drivers with neighborhood and freeway data combined.

Frequency of speedometer sampling showed the largest differences among novice drivers. These individual differences may relate to the drivers psychophysical capabilities to estimate vehicle velocity. On the other hand, a low rate of speedometer sampling may mean a driver is visually overloaded, while a high rate suggests the driver has spare visual capacity.

Because of the low frequencies of the mirror and speedometer glances for the neighborhood section, duration data were only calculated for the freeway section. In Figure 17, mean glance duration is graphed for the rear view mirror, side mirror, and speedometer. A surprising result was the short duration of the side mirror fixations by the novice group. Since the side mirror was located about 52 degrees to the left of center and 12 degrees down, it had a large eye travel distance associated with it. This in conjunction with the eye possibly reaccommodating, suggests the novice drivers received little information from their infrequent glances to the vehicle's side mirror. They did manage to use their rear mirrors, however.

The lower mean glance duration of the speedometer samples by the experienced group suggests that they have become skilled in its use.

Pursuit Eye Movements

The most interesting phenomenon found in the data was pursuit or following eye movements. The purpose of the

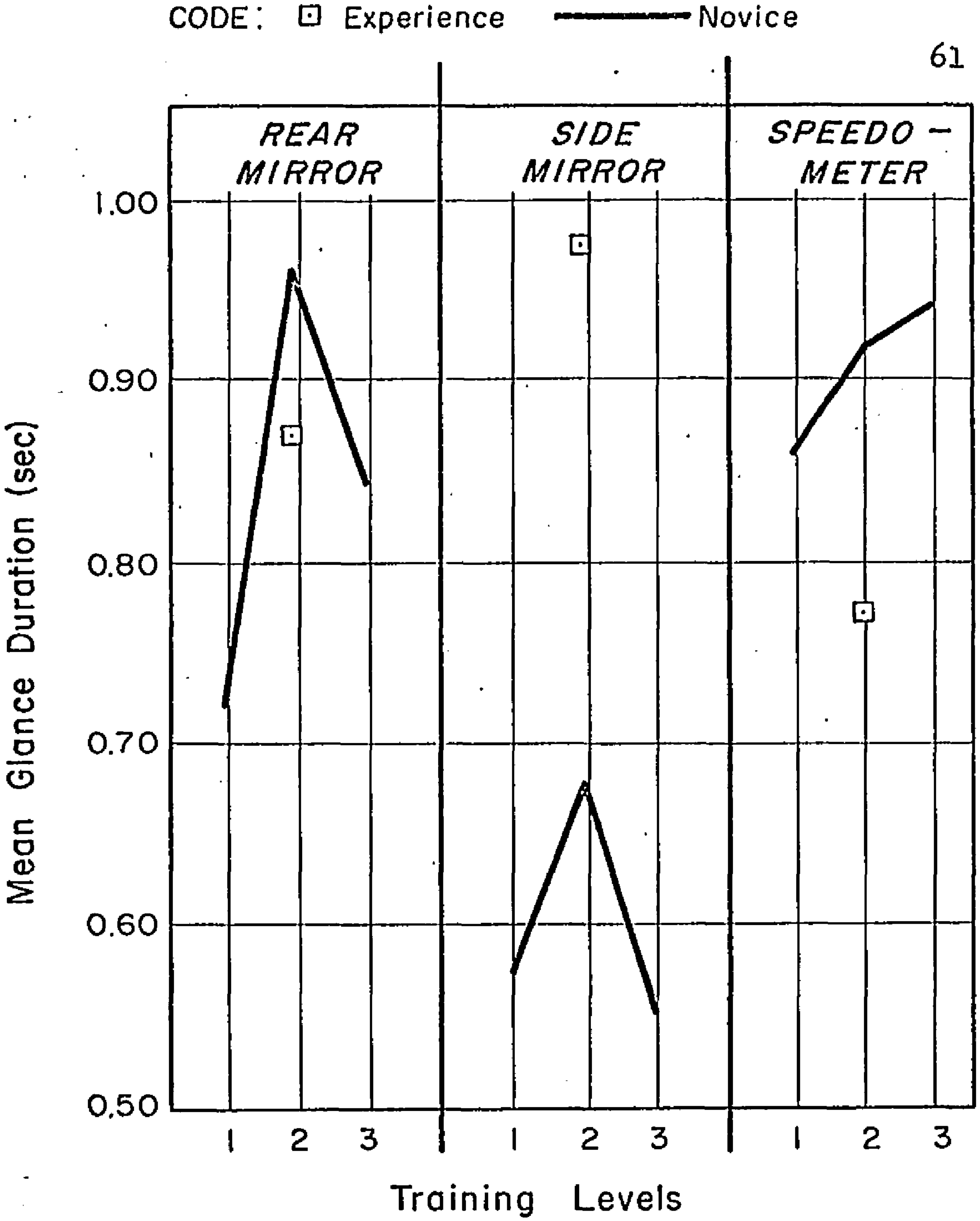

Figure 17. Mean rear mirror, side mirror, and speedometer glance durations for the freeway run for the experienced group and by training levels for the novice group.

pursuit is to stabilize, as much as possible, the retinal image with respect to the retina. This enables the observer to continuously observe the object for a relatively long time period. If a driver would look only very close in front of the vehicle when traveling at freeway speeds, then optokinetic nystagmus would occur. Optokinetic nystagmus are involuntary, conjugate, rhythmical movements which contain a pursuit phase that alternates with quick return jumps. This is not the type of phenomenon observed in the data. Between every two pursuit movements observed there was at least one regular fixation.

Almost every fixation that occurs in the driving environment has a pursuit component. In Table 2 angular velocity is shown in degrees/second as a function of distance ahead of a vehicle and lateral distance to the side of the vehicle. It is assumed the vehicle is traveling at 50 m.p.h.

Distance Ahead (feet)	Lateral Distance From Side 5 feet	15 feet	50 feet
1000	.02	.06	.21
500	.08	.25	.83
300	.23	.70	2.3
100	2.1	6.1	16.0
50	8.3	23.1	42.1
0	840.0	280.0	84.0

Table 2. Angular Velocity by Distance Ahead and to the Side of the Vehicle (degrees/second).

Note that at a distance far ahead of the vehicle, the greatest angular velocity occurs at 50 feet to the side of the vehicle, while at a close distance in front of a vehicle the greatest angular velocity would occur directly in front of it. Since pursuit eye movements are possible when the speed of the object reaches the drift velocity of the eye (about 5 min/sec or .083 deg/sec) they commonly occur when driving. Therefore, to clearly differentiate the pursuit phenomenon from the regular saccades, only following movements of 400 milliseconds or greater have been classified as pursuit eye movements. Data of a 2.5 mile stretch of the Freeway Driving situation (vehicle velocity = 70) were examined for pursuit eye movements. In Figure 18, are the frequencies, medians and ranges of pursuit eye movements for five novice drivers. Also included is the percent of pursuit movements as a function of total fixation time. The experienced drivers, one novice driver (subject C) and the special novice driver did not make any pursuit eye movements. The average median duration over all subjects was 1.0 seconds. The percent of time or volume of pursuits was in correspondence with that found by Kaluger and Smith (1970) for fatigued drivers.

Pursuit eye movements occurred on a variety of objects in the driving environment. In Table 3 frequencies of pursuits are listed by type of object and subject. Assuming that looks at the guard rail, left edge, right edge, and

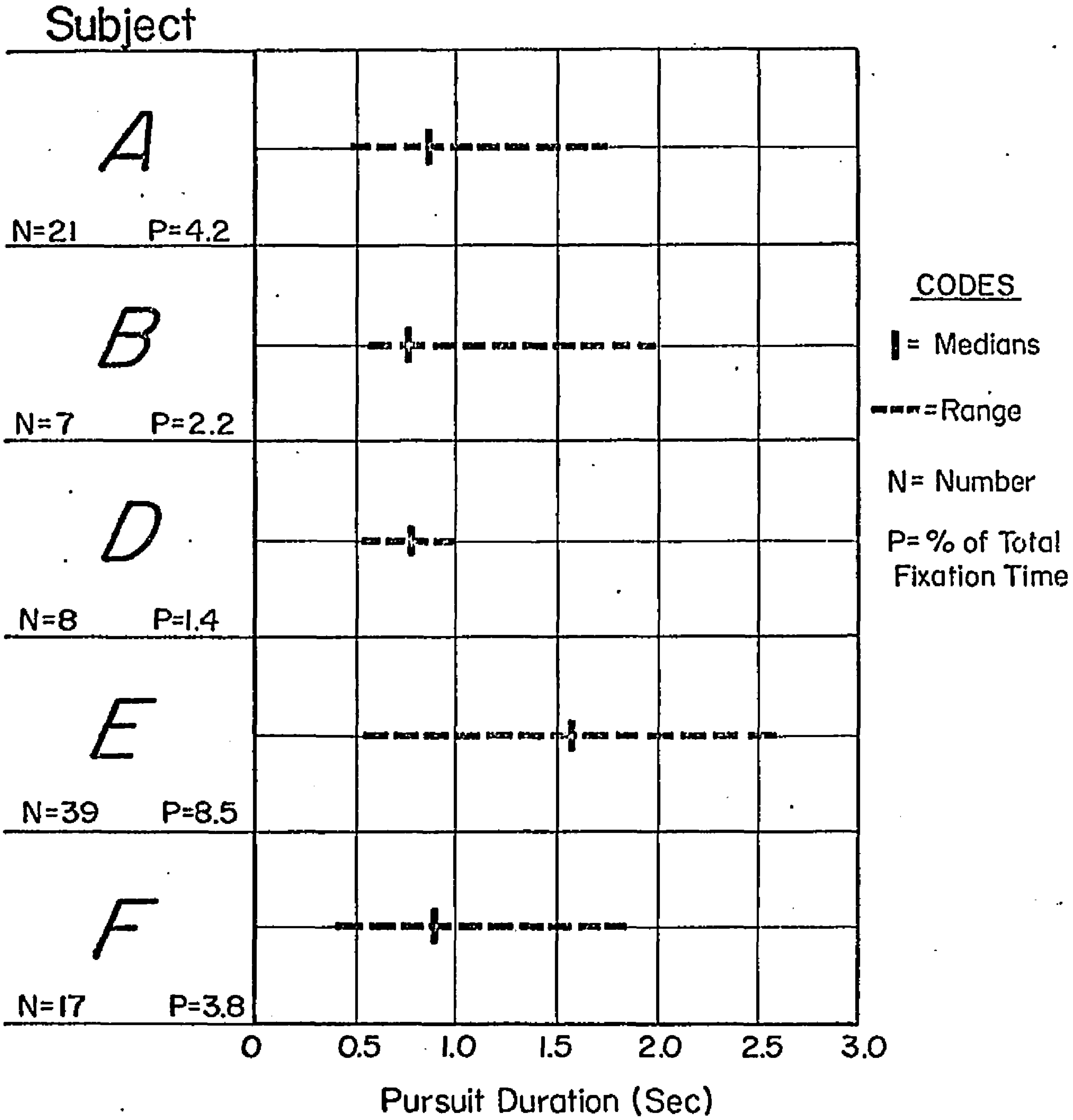

Figure 18. Frequency, median, range, and percent of total fixation time of pursuit eye movements for five novice drivers.

center lane markers all provide information to the driver as to his lateral position, then 70 percent of the pursuit eye movements were for that purpose.

Objects/Subjects	A	B	D	E	F	Total
Left Edge Marker	3	1	1		5	10
Center Lane Marker	18		7		1	26
Right Edge Marker				15	7	22
Guard Rail				6	3	9
Bridge				5	1	6
Road Signs		2		1		3
Vehicles		3			1	4
Landscape		1			11	12
Total	21	7	8	27	29	

Table 3. Frequencies of Pursuit Eye Movements by Subjects and Objects.

There was also some evidence for frequency of pursuits to decrease as a function of training levels. At training level 1 the five novice drivers made 42 pursuits; at training level 2, 33; and training level 3, 17.

According to Alpern (1962) the eye muscle actions during pursuit are typical of many unskilled movements such as might occur when a child learns to write. These unskilled movements are classified as slow-tension movements because they are the result of only a sight difference in tension between the agonist and antagonist. Apparently these slow-tension movements disappear with motor-skill training. It appears that they also disappear with increased perceptual skill when driving.

Driver Eyeblink Rates

One of the functions of any eyeblink is to keep the eyes functionally active. Every eyeblink is accompanied by tear secretion. The eyelid closing distributes this secretion over the surface of the cornea. There are three types of eyeblinks; voluntary, periodic, and reflexive. The reflex blink occurs as part of the response to sudden loud or bright stimuli. The rate of periodic blinking is controlled by the central nervous system and varies widely among individuals. King and Michels (1957) found the average rate of blinking to be 12.5 blinks/min. Taking into account that the eyelid is closed for a period of 130 mscs. per blink, (Gordon, 1951) result is a pattern of 4,870 mscs. of light followed by 130 mscs. of darkness. Most people are unaware that their visual input is interspersed by these short periods of darkness.

The possible interference of blinking with visual tasks has been studied by Lawson (1948), Drew (1950) and Poulton and Gregory (1952). Lawson suggested that blinking may be "a primary cause of proneness to accident" in driving and flying. Drew, however, reported that the blink rate varies with the difficulty of the task, and found no differences in task accuracy between rapid and infrequently blinking subjects. A finding of Drew's that is relevant to the present study is that four automobile drivers averaged 1.0

blinks/minute in heavy traffic and 8.2 blinks/minute while driving in the country. Thus, the most difficult task had the lowest blink rate.

Poulton and Gregory found that blink rate varied inversely with the difficulty of a tracking task. Listed below are the mean numbers of blinks per minute for the conditions reported by Poulton and Gregory:

"Resting" before experiment	17.6
Immediately before tracking	23.5
Tracking straight course	8.6
Tracking curved course	2.7
Immediately after tracking	41.6
"Resting" after experiment	21.6

Thus, the difficulty of tracking the curved course substantially reduced the blink rate.

The Poulton and Gregory study indicates that when the situation requires a lot of information to be extracted in a short time period, one response of the visual system is to reduce the rate of blinking. This puts the eye under some degree of stress due to the cornea not being as frequently lubricated by the tear secretion. It also detracts from the statement of Lawson's that blinking is associated with accident proneness, since regardless of the initial blink rate, blinking is inhibited when the situation demands it. Apparently, people's visual systems are tailored to operate at approximately equal efficiency levels while having widely different blink rates.

In the present experiment, blinks were counted over part of the neighborhood and freeway driving situations. The neighborhood section was straight, and ended at a stop sign. It took 70 seconds to travel at 25 miles per hour. The freeway section was also straight but it involved three vehicle lane changes. At 70 m.p.h. it took 170 seconds to complete the route.

In Figure 19 blink rates are presented by individual drivers for the neighborhood, and freeway routes. Large individual differences in the periodic blink rate are quite apparent. Consider the blink rates at training level 1 of the novice drivers. Here subjects B, C, D, and E had higher blink rates on the neighborhood tasks than the freeway tasks. This suggests that traveling at 70 m.p.h. is difficult for the novice drivers, and the need for more information inhibited their blink rate. No such reduction in freeway blink rates was found for the experienced drivers. In fact, on their first runs, all the experienced drivers had a lower blink rate on the neighborhood route than the freeway route.

It is also interesting to note that three novice drivers, B, D, and E had a lower blink rate on trial 3 of the nieghborhood route than trial 1. This may indicate that on trial 1 their blink rate was "normal" and by trial 3 it had adapted to the needs of the situation.

In order to further test the association between task difficulty and blink rate the blinks were counted for the

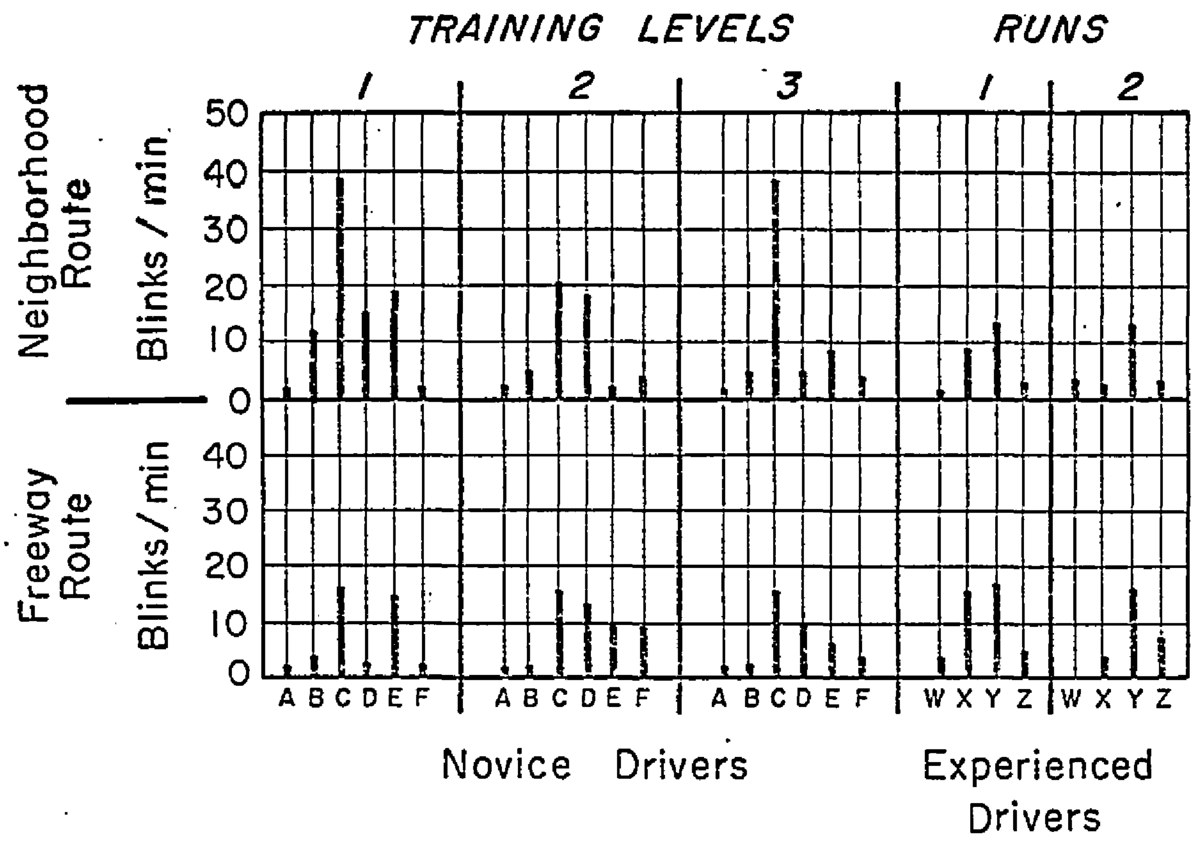

Figure 19. Eye blinks per minute by training levels for the novice drivers, and by runs for the experienced drivers.

freeway lane change (Tasks 10, 11, and 12 combined). These results are reported in Table 4 below.

	Novice Drivers						Experienced Drivers				
	A	B	C	D	E	F	W	X	Y	Z	
Training Level 1	14.0	0	4.6	5.4	4.0	0	6.6	0	7.0	16.0	Run 1
Training Level 3	0	0	16.4	9.0	4.0	3.0	3.3	0	24.0	0	Run 2

Table 4. Blink Rates for Freeway Lane Change (Blinks/Min)

One exception to the rule of decreased blinking with increased task difficulty can be seen in driver A's data. During his freeway run which lasted 175 seconds, he made six eyeblinks, yet four of these occurred in a 17 second period when he was changing lanes. Apparently, in some cases a stressful task may increase the blink rate. At the other extreme, subject C who had an overall blink rate of 16 blinks/minute reduced his blink rate to 4.6 blinks/minute during the freeway lane change at training level 1. Considering the large individual differences found between driver's blink rates on the lane change maneuver, it seems reasonable to conclude that the task of vehicle lane position monitoring on high-speed freeways is not analogous to the laboratory curve tracking tasks such as studied by Poulton and Gregory.

The eye blinks that were associated with mirror and speedometer glances were not included in the above data. Following 85 percent of the mirror glances and 82 percent of the speedometer glances was an eye blink. During the period of the blink the eye usually traveled back to some point ahead of the vehicle. Since this type of blinking occurred with such regularity it does not fall in the category of an involuntary periodic blink. Thus it appears that the visual system has compensated for the difficulty in abstracting mirror and speedometer information by refreshing the eye with a blink. It would be interesting to investigate whether eye blinks are associated with the reading of a well designed digital speedometer. When considering mirror and speedometer glance durations, about 200 mscs. should be added to the values presented in Chapter VI to account for the accompanying eye blink.

Head Movements

The miniature TV camera, which viewed the road scene ahead, was firmly attached to the stabilization unit that was mounted on the driver's head. Thus, when the driver moved his head, the miniature TV camera moved with it. A particular point on the hood of the vehicle was used as a reference point, and driver head movements were mapped around that point. A computer program calculated the amount of head movement for the five neighborhood deceleration tasks and the four freeway tasks.

In Figure 20 are the mean ranges of head movements for the novice and experienced groups. On only one task, the approach to Stop Sign 1, was the decrease in range of head movements as a function of training levels significant

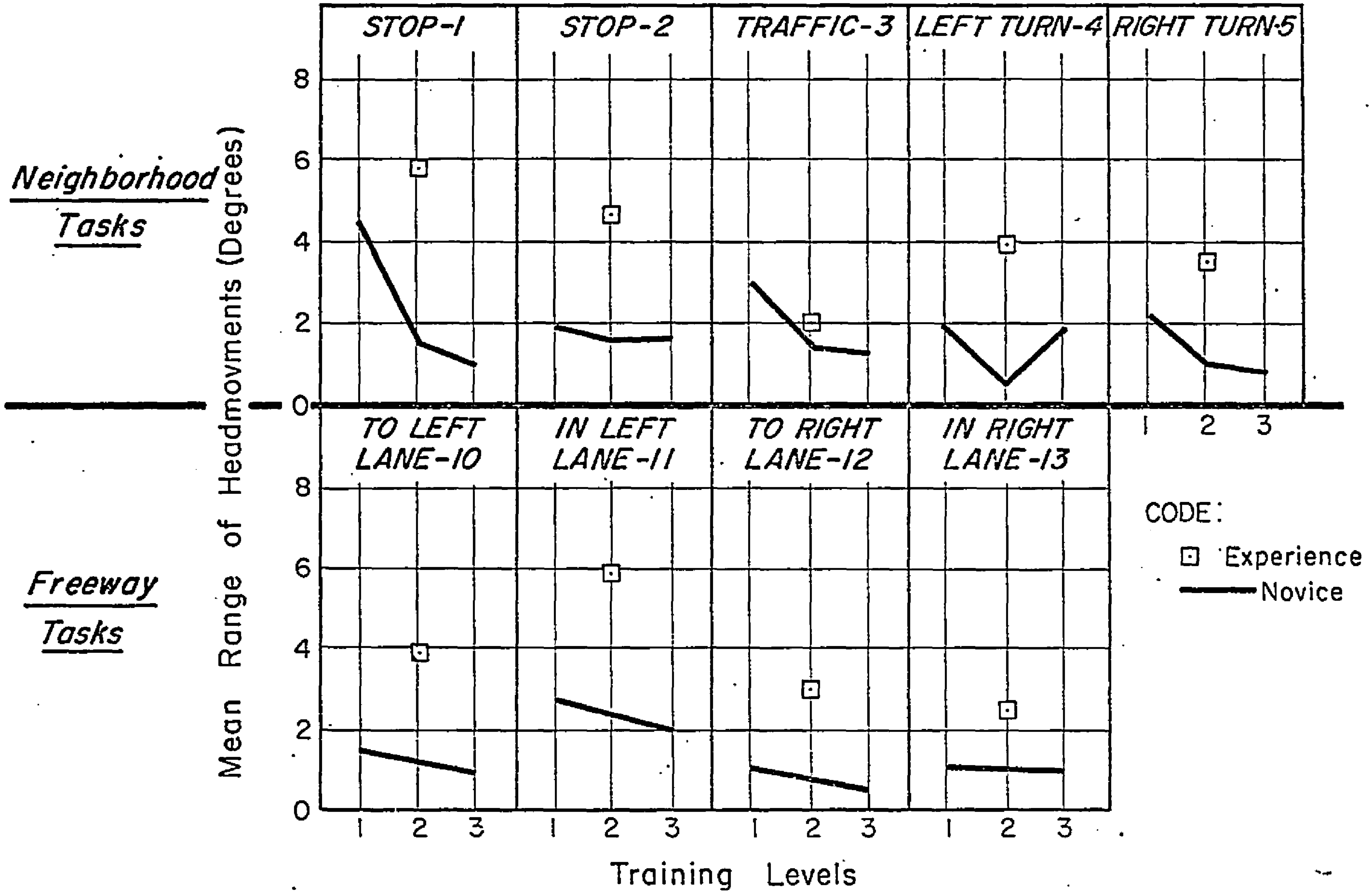

Figure 20. Mean ranges of head movements by driving tasks and training levels for the novice group and by driving tasks for the experienced group.

($p < .10$). This was somewhat surprising in view of the significant decreases in ranges of horizontal fixation locations previously reported for the novice drivers.

The ranges of head movements for the experienced drivers were found to be significantly greater than those of the novice drivers on the following tasks.

1. approach to Stop Sign 1 ($p < .057$)
2. approach to Stop Sign 2 ($p < .057$)
4. approach to Left Turn ($p < .032$)
10. change to Left Lane ($p < .005$)
11. driving in Left Lane ($p < .057$)

Although the ranges of the experienced drivers were higher than those of the novice drivers on all the other driving tasks, the differences were not statistically significant.

Large differences between subjects were found for both the novice and experienced groups in terms of range of head movements. In Figure 21 the mean ranges are shown averaged over the five neighborhood tasks by individual drivers, and also averaged over the four freeway tasks by individual drivers. As can be seen, novice drivers A and C and experienced drivers W and Z all made large head movements relative to the other drivers. It also appears that the freeway tasks tended to inhibit the head movements of the novice drivers but not of the experienced drivers.

The smaller range of head movements of the novice

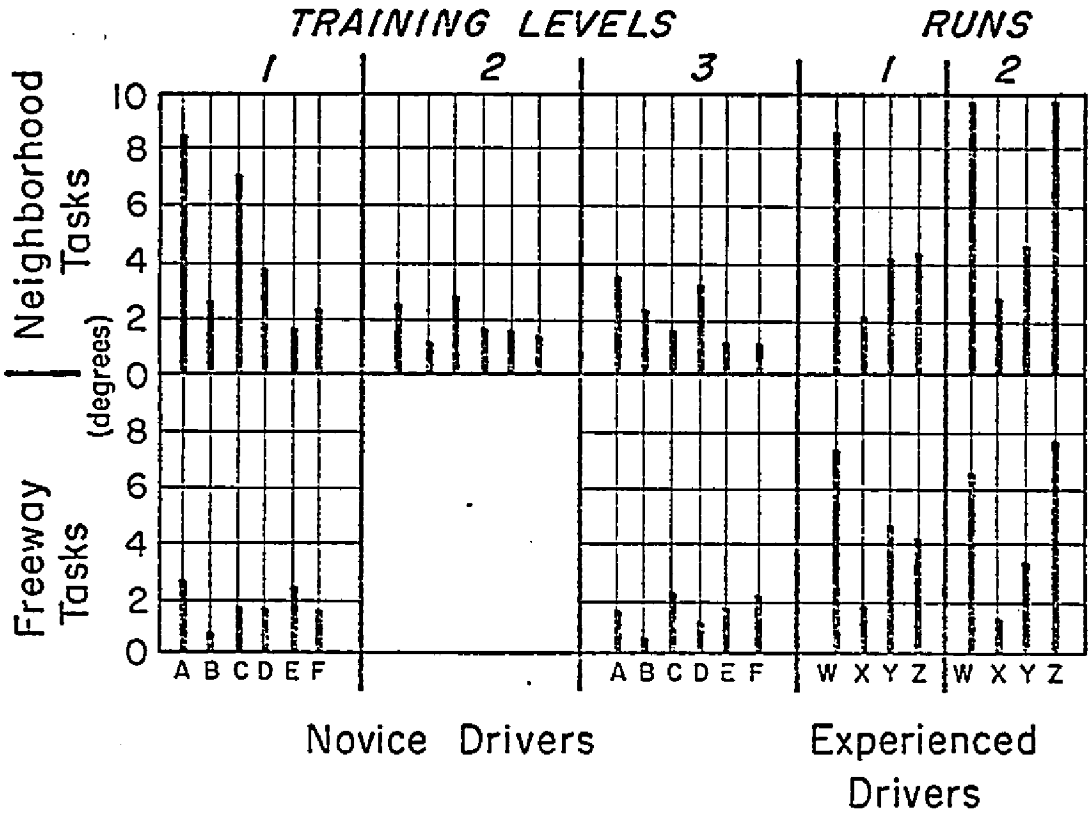

Figure 21. Mean ranges of head movements by training levels for the novice drivers and by runs for the experienced drivers.

drivers may be due to their smaller range of eye fixation locations. Some relationships between head movements and eye movements have been reported by Sanders (1963). Sanders conceptualized the functional visual field as shown in Figure 22.

He found that when a display was in the stationary field (0 to 30 degrees) it could be responded to without any eye movement, but in the area from about 18° to 30° (Area A) eye movements were preferred. If the display was between 30 and 90 degrees, eye movements were necessary for a response, and beginning at 72° (Area B) eye movements were accompanied by head movements. If the display was located at 90° or greater from the center then both head movement and eye movements were necessary.

Such relationships between the stationary field, eye field, and head field of course depend on the intensity and complexity of the display. However, Sanders data clearly indicate that for some tasks the eyes travel as far as 72° unaccompanied by head movements.

Data from the present study indicate that drivers make small head movements (0 to 3 degrees) regardless of where they are fixating. Head movements greater than 3° accompanied eye fixations that were greater than 60° from straight ahead. Thus drivers' glances at their mirrors and speedometers are usually only accompanied by small head movements.

In contrast with the findings of the present study and

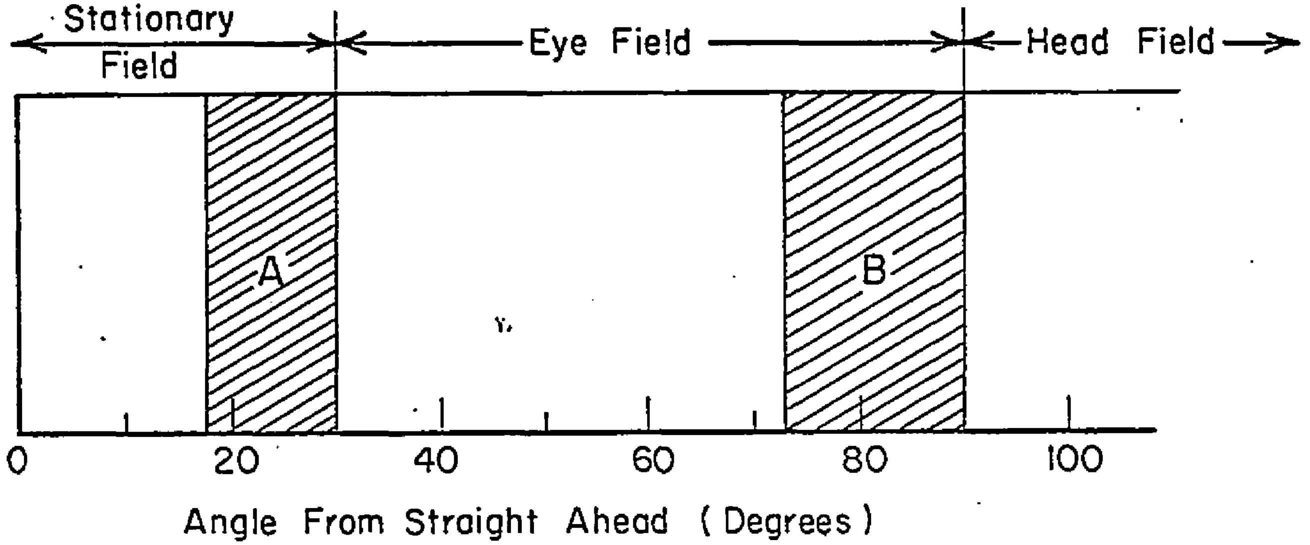

Figure 22. Sanders' conceptualization of the functional visual field.

those of Sanders are data recently reported by Robinson, <u>et. al.</u> (1971). They reported that head movements simply laged the eye movements by about 50 mscs. when the eye fixated on targets 40, 60, and 80 degrees from straight ahead. They then assumed that it was possible to study drivers search behavior by recording head movements. That large eye movements (30 to 70 degrees) are possible without corresponding head movements has been demonstrated by Sanders and the present study.

CHAPTER VI

RESULTS--SPECIAL NOVICE DRIVER

In order to investigate whether training would aid in the development of visual search and scan patterns, one additional novice driver was given special instruction. In Figure 23 is an outline of the experimental treatment given the special novice driver. It was identical to that of the other novice drivers except for the feedback and instruction training given just prior to testing at training levels 2 and 3.

The first phase of the training consisted of having the subject view the search and scan patterns of an experienced driver, and then view his own search and scan patterns. The second phase consisted of giving the driver verbal instructions as to where to look. The special novice driver was told the following:

1) Scan wider in the horizontal direction.
2) Look far ahead. Don't look at the road just in front of the vehicle.
3) Sample your mirrors more frequently.

These instructions were based on differences found between the novice and experienced drivers search and scan patterns and are reported in Chapters IV and V. An attempt

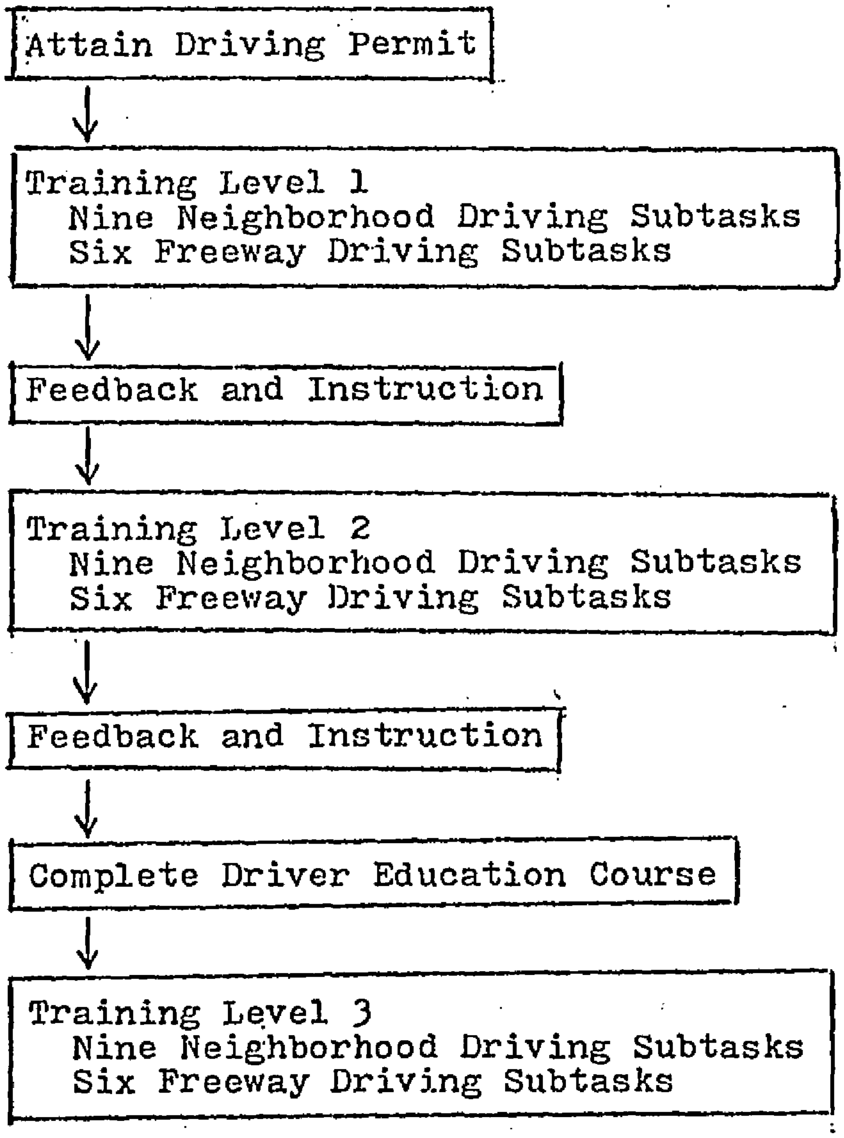

Figure 23. Experimental Plan -- Special Novice Driver

was made to keep the instructions simple, and the number of them small.

The technique used to display the special novice driver's results in relationship to the other novice drivers was as follows. First, the results for the special novice driver were plotted as a function of training levels. Then at each training level, the range of values found for the other six novice drivers was graphed.

Travel Distance Per Second and Horizontal Range

In Figure 24 are the values of travel distance per second for the special novice driver for the neighborhood and freeway driving tasks together with the range of values for the other six novice drivers. For the freeway driving task it can be seen that at training level 3, as compared to training level 1, the average travel distance per second for the special novice driver always had a higher value in relationship to the range of the novice group. For example, for Task 12, the special novice driver's value fell in the middle of the novice group's range at training level 1, as compared to being at the top of the range at training level 3. The same result was found for all the neighborhood driving tasks, except the Approach-to-Right-Turn. This suggests that one of the effects of the special instructions was to counteract the downward trend of activity over training levels that was found for the novice group.

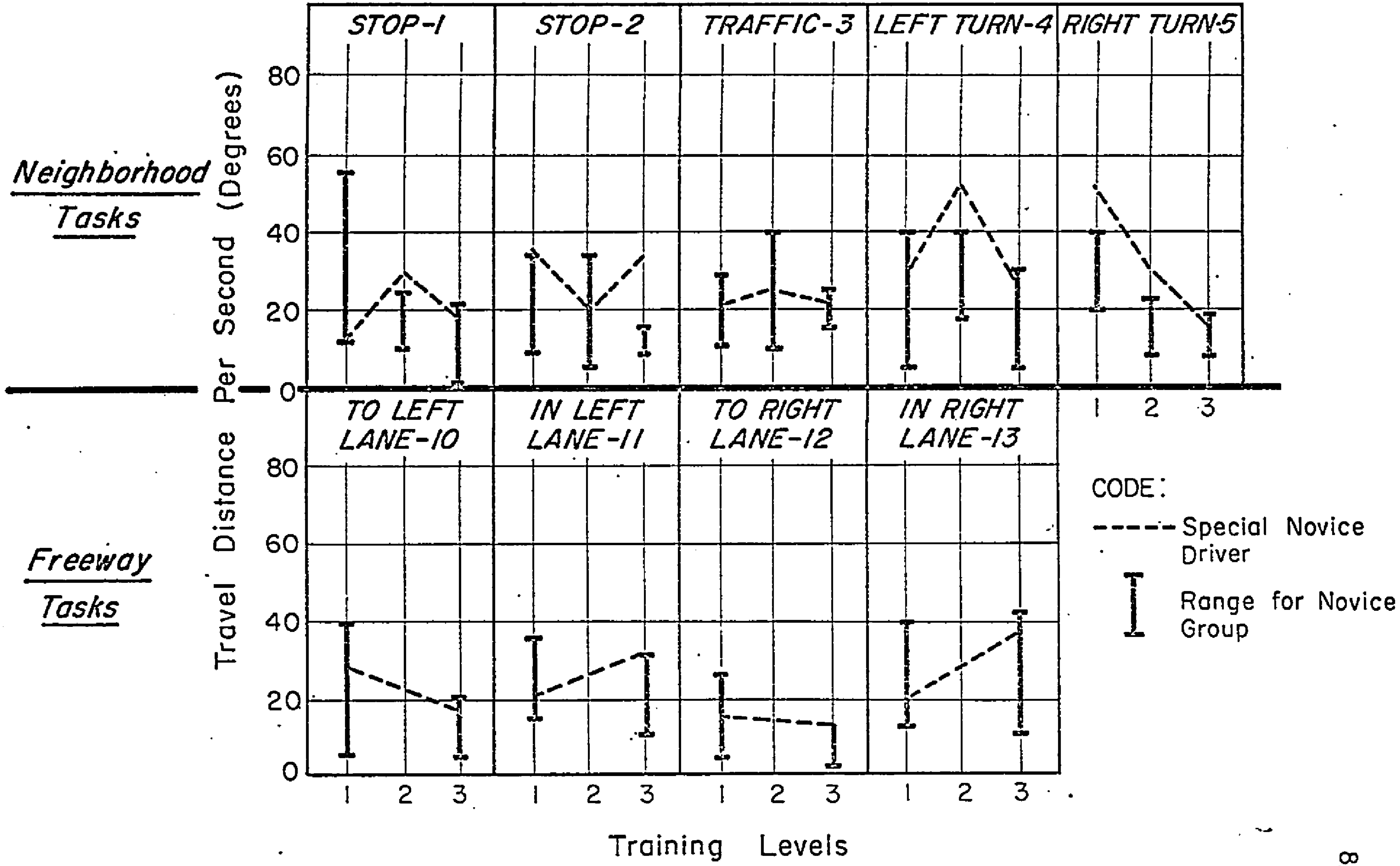

Figure 24. Travel distance per second for the novice group (ranges) and for the special novice driver by training levels and driving tasks.

The ranges of horizontal fixation locations for the special novice driver are shown in Figure 25. For seven of the nine driving tasks at training level 3, the special novice driver scanned wider in the horizontal direction than any of the other novice drivers. In contrast at training level 1, when the special novice driver had not received any instruction, his horizontal range was smaller than that of any of the other novice drivers on three of the driving tasks. Thus, it appears that the instructions to scan wider in the horizontal direction were followed by the special novice driver.

Locations of Fixations in the Vertical Direction

The instruction to the novice driver to look far ahead of the vehicle may have had an effect on his median vertical fixation. In Chapter IV significant differences were reported in terms of first and last half divisions of some neighborhood driving tasks for the median of vertical fixation locations. Hence, the results here are shown by first and last half task divisions as well as by training levels.

In Figure 26 the medians of vertical fixation locations are shown for the first division of the neighborhood driving tasks. Again, the trend that the special novice driver's values are lower than that of some of the regular novice drivers at training level 1, and higher than those of any of the novice drivers at training level 3 is readily apparent. Thus, the instruction to look further ahead appears to have

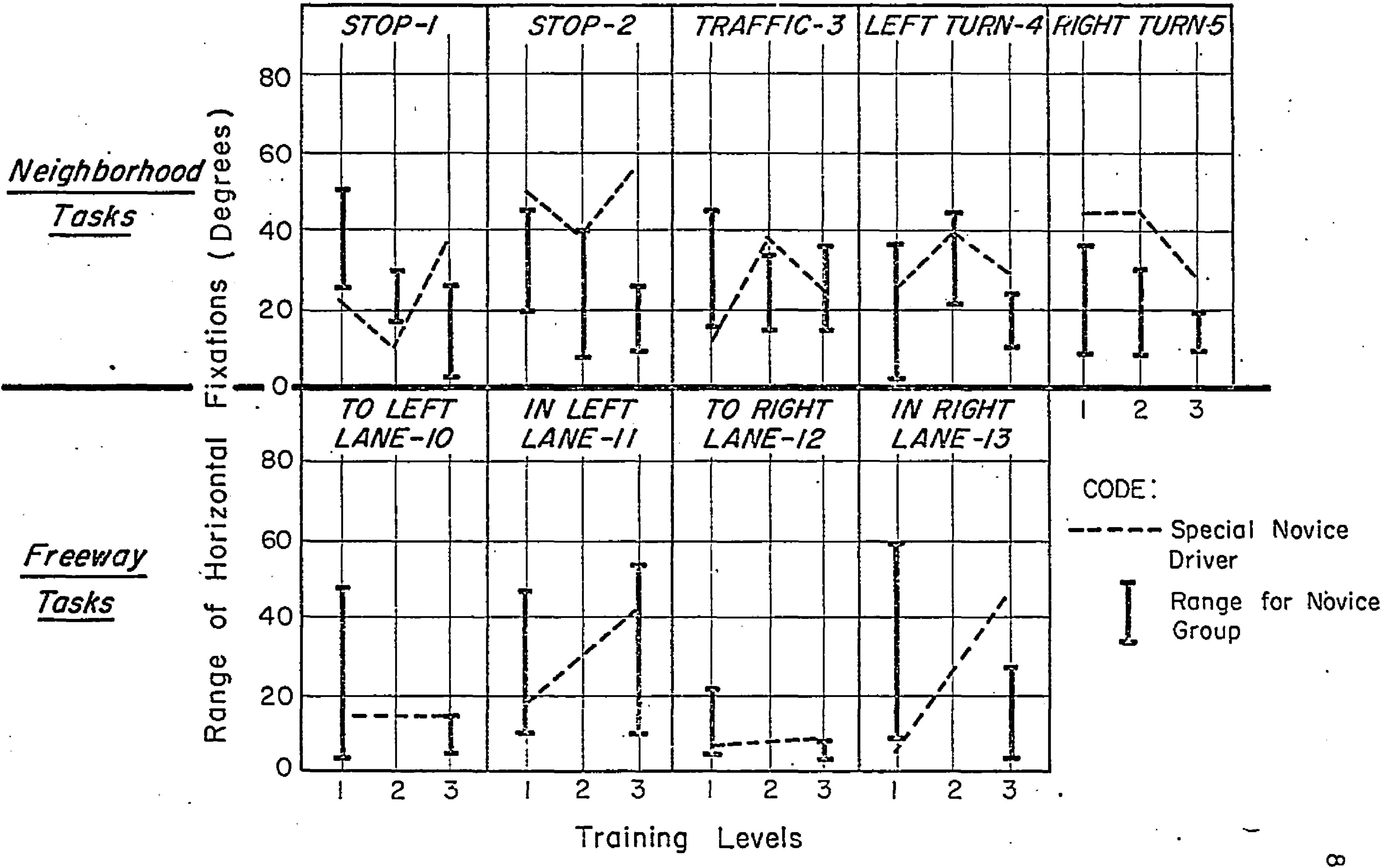

Figure 25. Range of horizontal fixation locations for the novice group (ranges) and for the special novice driver by training levels and driving tasks.

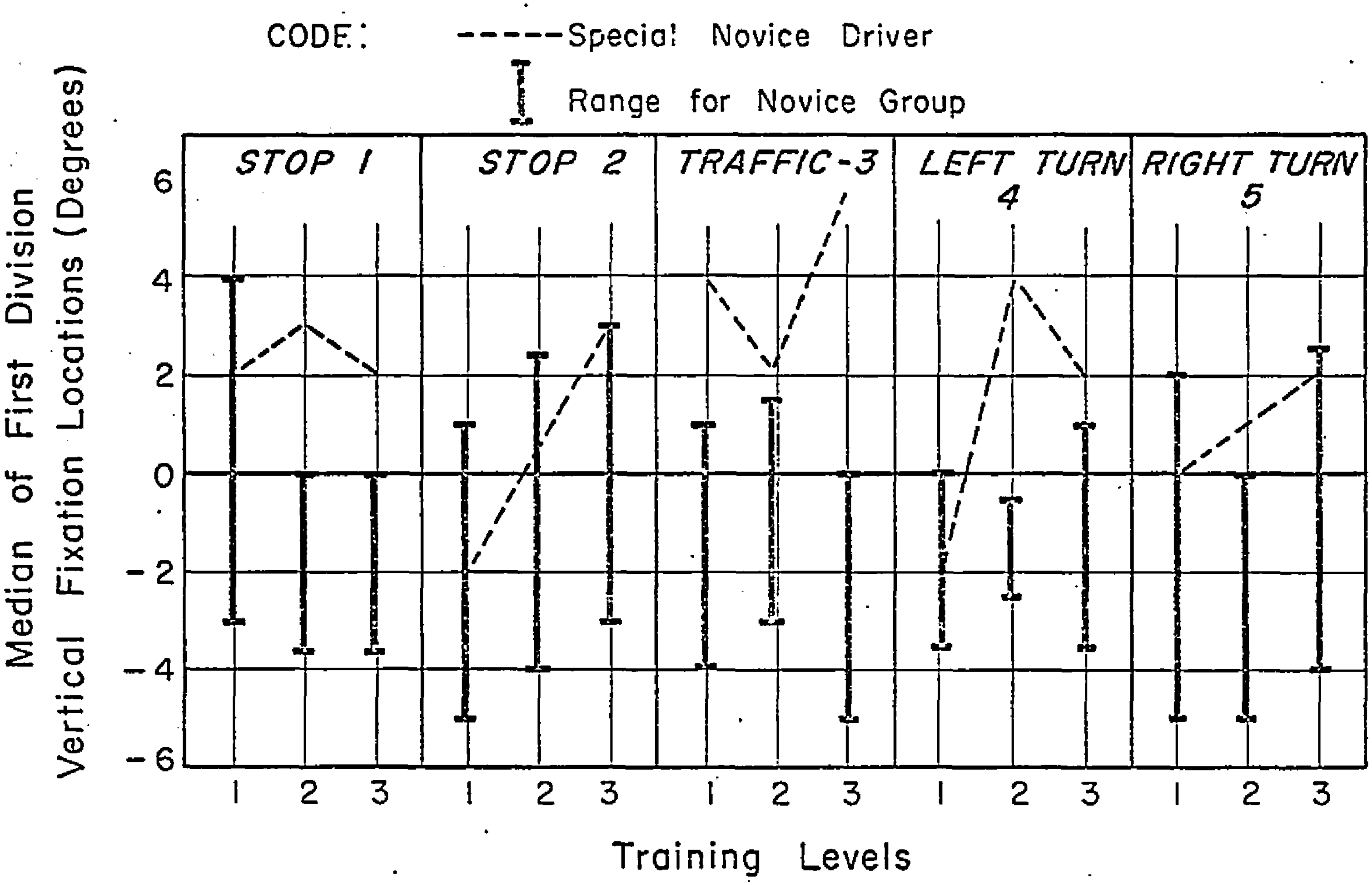

Figure 26. Median of first division of vertical fixation locations for the novice group (ranges) and for the special novice driver by the neighborhood tasks.

been responsible for the high median of vertical fixation locations of the special novice driver for the first half divisons of the neighborhood tasks. In Figure 27 are the corresponding measures for the second division of the neighborhood tasks. Here, the increase in the median of vertical fixation locations over training levels is not quite so apparent for the special novice driver. However, at training level 3, the special novice driver's median is higher or equal to that of all the other novice drivers except for the Approach-to-Stop-Sign-2 task. In Figure 28 are the medians of vertical fixation locations for the freeway driving tasks. Between training levels 1 and 3 the special novice driver had a rise in median vertical location for all the driving tasks. This suggests that the training given to the special novice driver affected how far he looked ahead of the vehicle.

Mirror Glances

In Table 5 are the number of mirror glances for the freeway run by subjects and training levels. It appears that the special novice driver (SN) was already a frequent mirror sampler at the first training level. It is interesting to note, however, that at training level 3, the special novice driver had more than twice as many mirror glances as any other novice driver. The corresponding frequencies for the neighborhood run are in Table 6. Here, the effect of

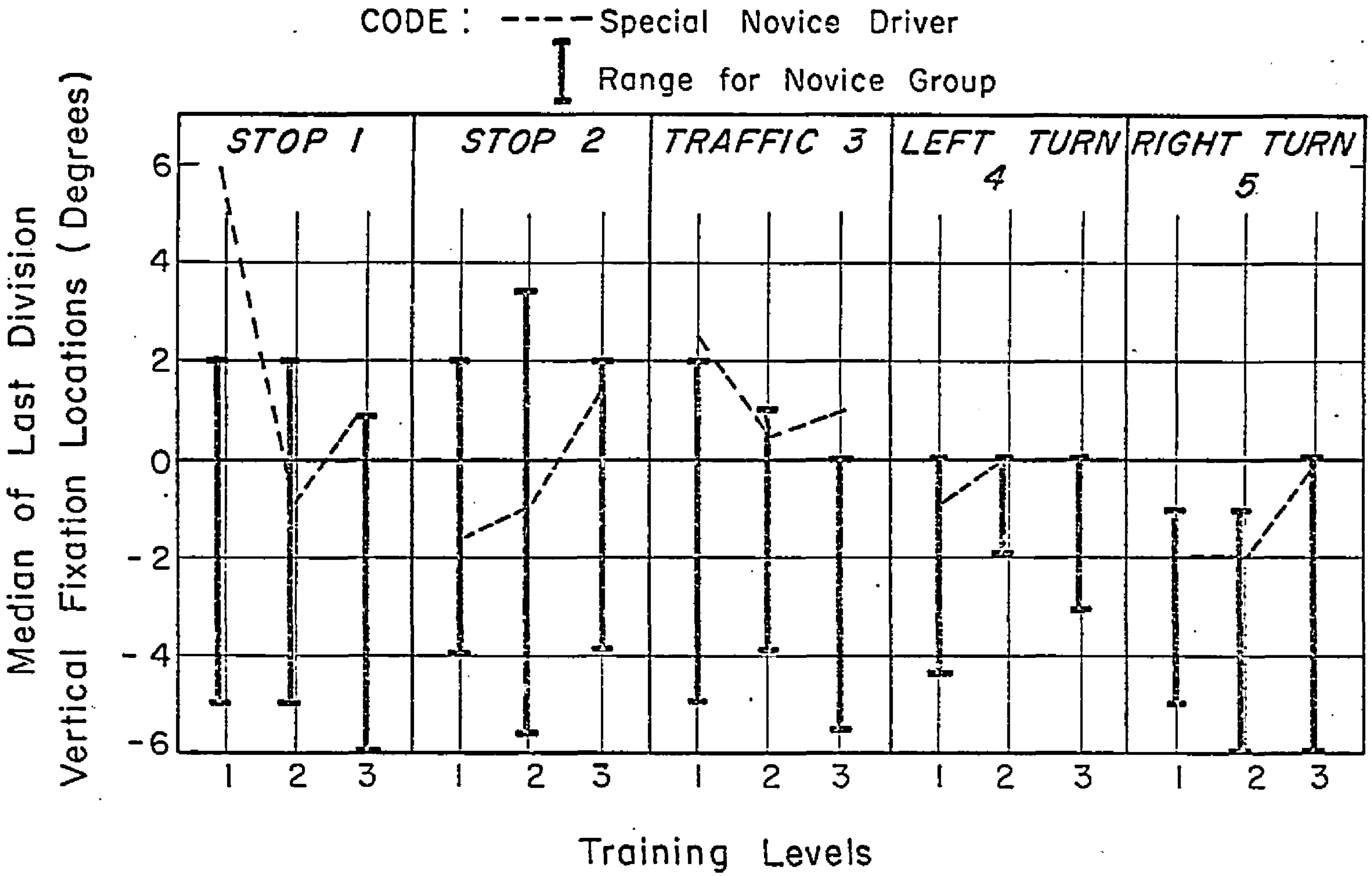

Figure 27. Median of last division of vertical fixation locations for the novice group (ranges) and for the special novice driver by the neighborhood tasks.

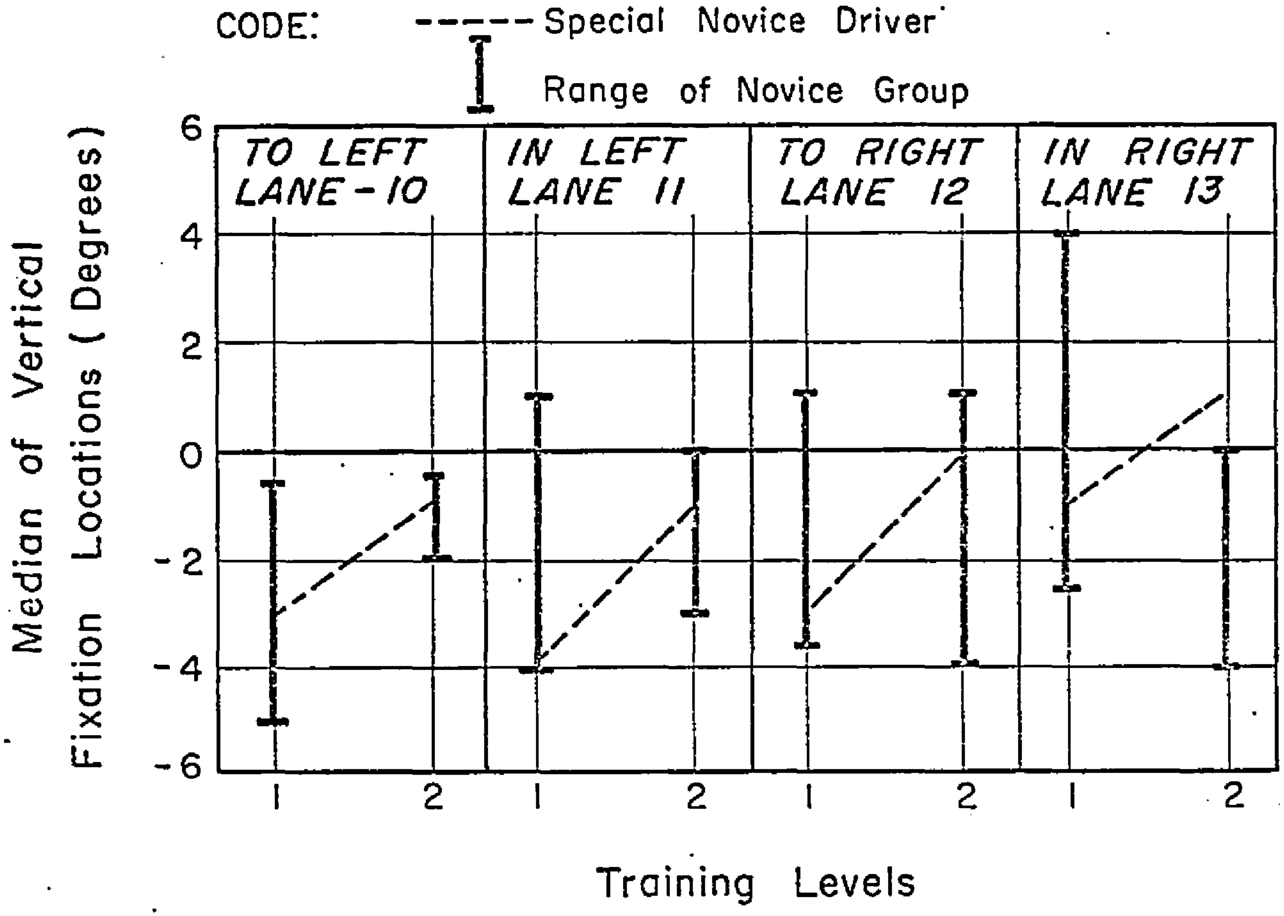

Figure 28. Median of vertical fixation locations for the novice group (ranges) and for the special novice driver by freeway tasks.

the instructions is apparent with the special novice driver having zero mirror glances at training level 1.

		Subjects						
		A	B	C	D	E	F	SN
Training Levels	1	5	4	11	1	9	1	13
	2	1	7	8	0	4	6	12
	3	3	5	7	0	4	3	16

Table 5. Number of Freeway Mirror Glances by Training Levels and Subjects.

		Subjects						
		A	B	C	D	E	F	SN
Traing Levels	1	2	4	3	0	2	1	0
	2	0	0	0	0	0	1	5
	3	0	0	3	0	0	0	3

Table 6. Number of Neighborhood Mirror Glances by Training Levels and Subjects.

CHAPTER VII

RESULTS--CONTROL PERFORMANCE

Control Behavior During the Neighborhood Deceleration Tasks

There were five sections of the neighborhood runs on which all drivers decelerated the vehicle. At Stop-Sign-1 and 2 the vehicle came to a complete stop. The vehicle's final velocity at the traffic signal depended upon whether it was red or green. Of the 26 approaches made to the signal, the vehicle came to a complete stop at 19 of them. On both the Approach to the Left Turn and to the Right Turn the vehicle always slowed down but never came to a complete stop.

The computer output of the analysis of velocity included a plot of velocity over time. Using this plot the portion of the curve over which the deceleration was approximately constant was chosen for analysis. This always included at least the middle two-thirds of the deceleration maneuver straight line was then fitted to the data using the BMD05R Regression Analysis Program. The slope of the fitted line was taken to be the vehicle's deceleration rate for that maneuver.

In Figure 29 the mean deceleration rate is plotted for the novice and experienced groups. An analysis of variance of the novice drivers' data over all tasks indicated that

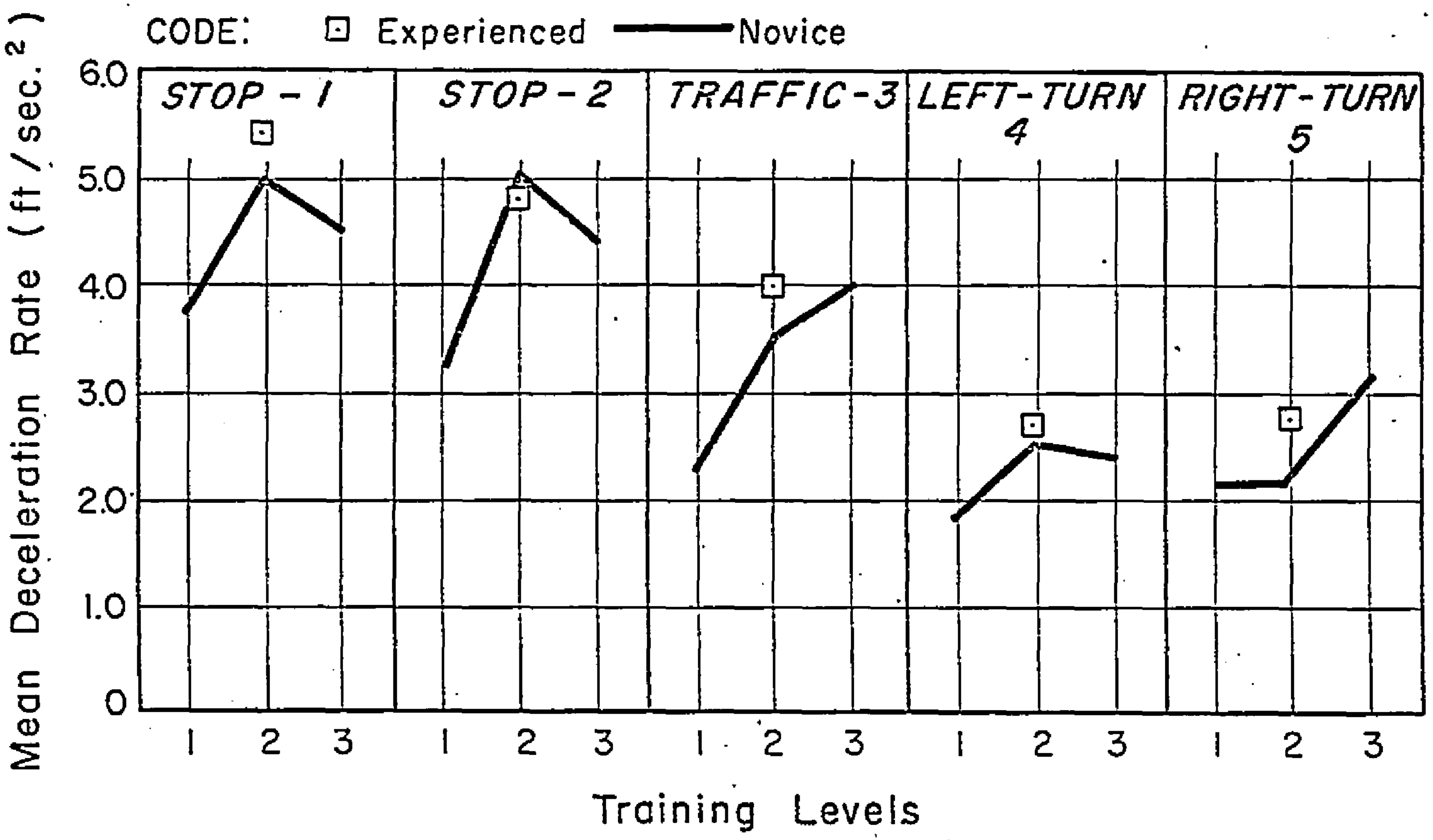

Figure 29. Mean deceleration rate (neighborhood tasks) for the experienced group and by training levels for the novice group.

training level was statistically significant ($p < .05$). For Tasks 1, 2, 3, and 4, the deceleration rate increased between training levels 1 and 2 while for Task 5, it increased between training levels 2 and 3. This result indicates that at zero level of experience the novice drivers were very cautious when applying the vehicle's brakes.

Because of the increases of deceleration with trials, significance tests between the novice and experienced groups were made using only the training level 3 data for the novice group. For the Stop-Sign-1 task the novice drivers had significantly lower deceleration rates than the experienced group ($p < .086$ Mann-Whitney U Test). The greater deceleration rate of the experienced group on the Stop-Sign-2 task approached significance ($p < .129$).

Another statistic of importance during vehicle deceleration is maximum lateral acceleration. This is shown in Figure 30 for the novice and experienced groups. Considering the novice drivers' data, the decrease over training levels for the Approach-to-Traffic-Light Task was the only significant effect ($p < .01$). This may be due to the novice drivers being somewhat nervous about the traffic signal as shown by their numerous foveal fixations to check its status.

Using the data at training level 3 for comparisons between the novice and experienced drivers, there were no significant differences between groups for the maximum lateral acceleration statistic. It appears that maximum lateral

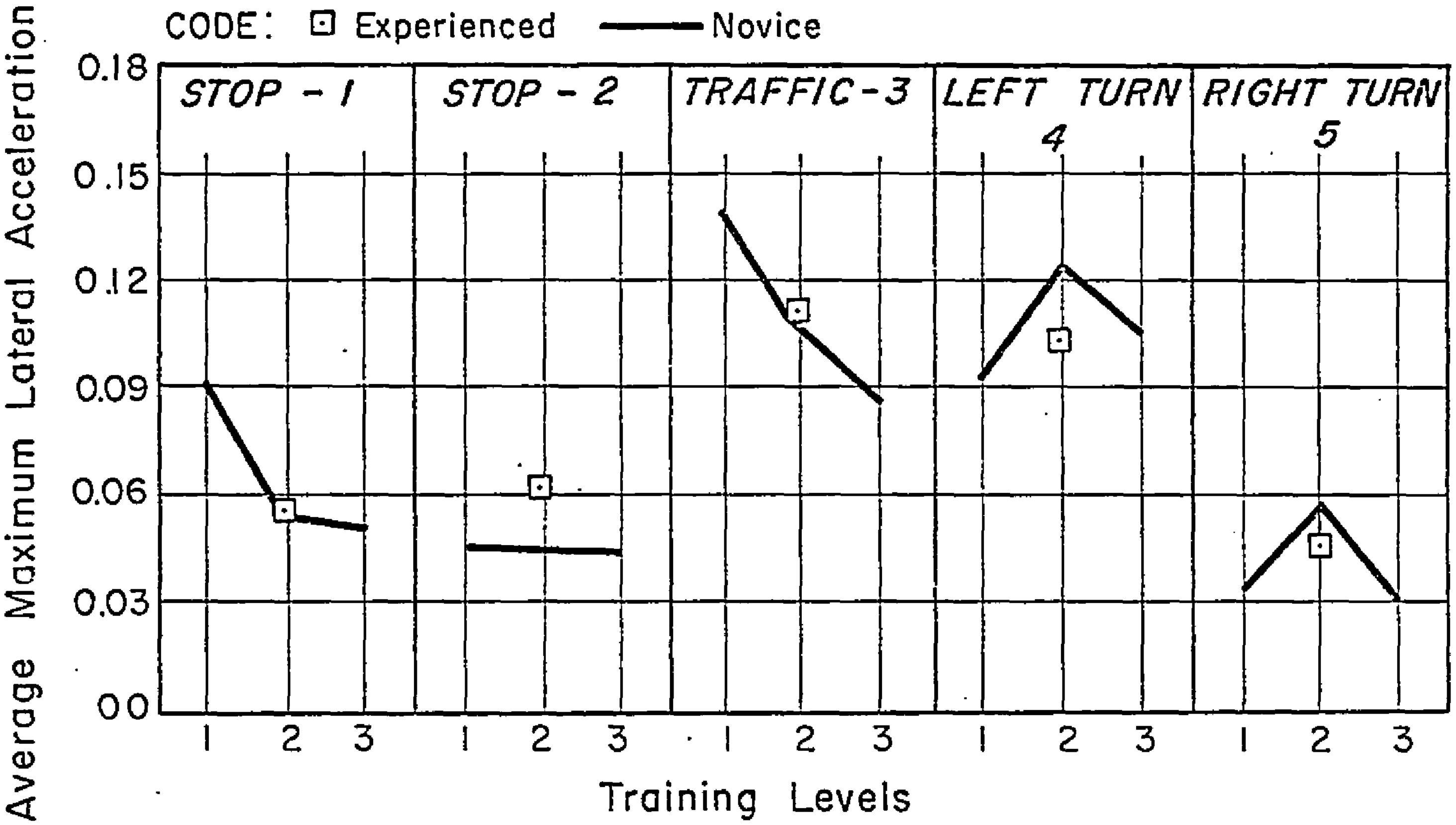

Figure 30. Average maximum lateral acceleration (neighborhood tasks) for the experienced group and by training levels for the novice group.

acceleration during deceleration maneuvers is not a good discriminator between novice and experienced drivers.

Control Behavior During the Neighborhood Turning Tasks

Two of the neighborhood turning tasks after coming to a complete stop, numbers 6 and 9, were right and left turns, respectively. The other two tasks, numbers 7 and 8, were continuous right and left turns, respectively. For each run the maximum lateral acceleration and its corresponding velocity value were found. Analyses of Variance and Mann-Whitney U Tests on that data indicated no significant effects over training levels, and no significant differences between the novice and experienced groups.

Another measure of driver performance on curves has been illustrated by Herrin (1970). This measure was designated "effective curvature", and is dependent upon lateral acceleration, vehicle velocity, and the vehicle understeer coefficient, K. Using the relationship that:

$$A = MV^2 + b \text{ where}$$

A = maximum lateral acceleration,

V = velocity associated with maximum lateral acceleration, and

$M = (1+K)(11.67 \times 10^{-6}\ C)$

The effective curvature C can be found if M is known, since a derived value for K is about .2 as shown by Herrin.

By groups and for each of the four neighborhood turning tasks a straight line was fitted to a plot of maximum lateral acceleration versus velocity squared. The slope of this line was the value of M, and thus permitted the calculation of C, effective curvature. In Table 7 are values of effective curvatures for the turning tasks.

	Tasks	Experienced Group	Novice Group
#6	Right Turn From Stop	25.0	52.8
#7	Continuous Right Turn	84.3	94.3
#8	Continuous Left Turn	31.4	67.1
#9	Left Turn From Stop	10.7	25.7

Table 7. Effective Curvature by Turning Tasks and Groups (degrees)

For all the turning tasks the effective curvature of the experienced group was always less than that of the novice group. This indicates that the experienced drivers "cut" the corners more than the novice drivers. For the Continuous-Right-Turn, note that the magnitude of the difference between the groups was small. This was due to the environmental constraint of avoiding vehicles that may have been coming from the direction into which the subject's vehicle was turning.

Control Behavior During the Freeway Driving Tasks

There were six freeway driving tasks, but for the purpose of analyzing the control data they were divided into four. Tasks 10, 11, 12 were combined as one unit due to the small number of data points that were sometimes associated with Tasks 10 and 12. The new unit will be called the lane change task, #16. Vehicle velocity was of importance to the drivers, because of instructions given to the subjects (maintain about 70 m.p.h.), and due to the danger of traveling too fast on the freeway. Therefore, one of the statistics analyzed was average velocity. Another statistic that was investigated was the standard deviation of lateral acceleration. This was chosen because of the large number of eye fixations and eye pursuit movements made to obtain lateral position information by the novice drivers. Due to recorder difficulties no control data were collected for two of the novice drivers.

In Figure 31, average velocity is presented for each of the four freeway driving tasks by novice and experienced groups. Although the novice drivers showed a trend toward increasing velocity for all tasks, this was not statistically significant. Therefore, tests for differences between the novice and experienced groups were made using the training level 3 data of the novice drivers. Here the novice group had significantly higher ($p < .10$) average vehicle velocity for the Traveling-In-Right-Lane and Freeway Deceleration Tasks. Clearly, the novice drivers were no longer fearful of traveling a little too fast on the freeway.

In Figure 32 is the Average Standard Deviation of Lateral Acceleration for the novice and experienced groups. Again,

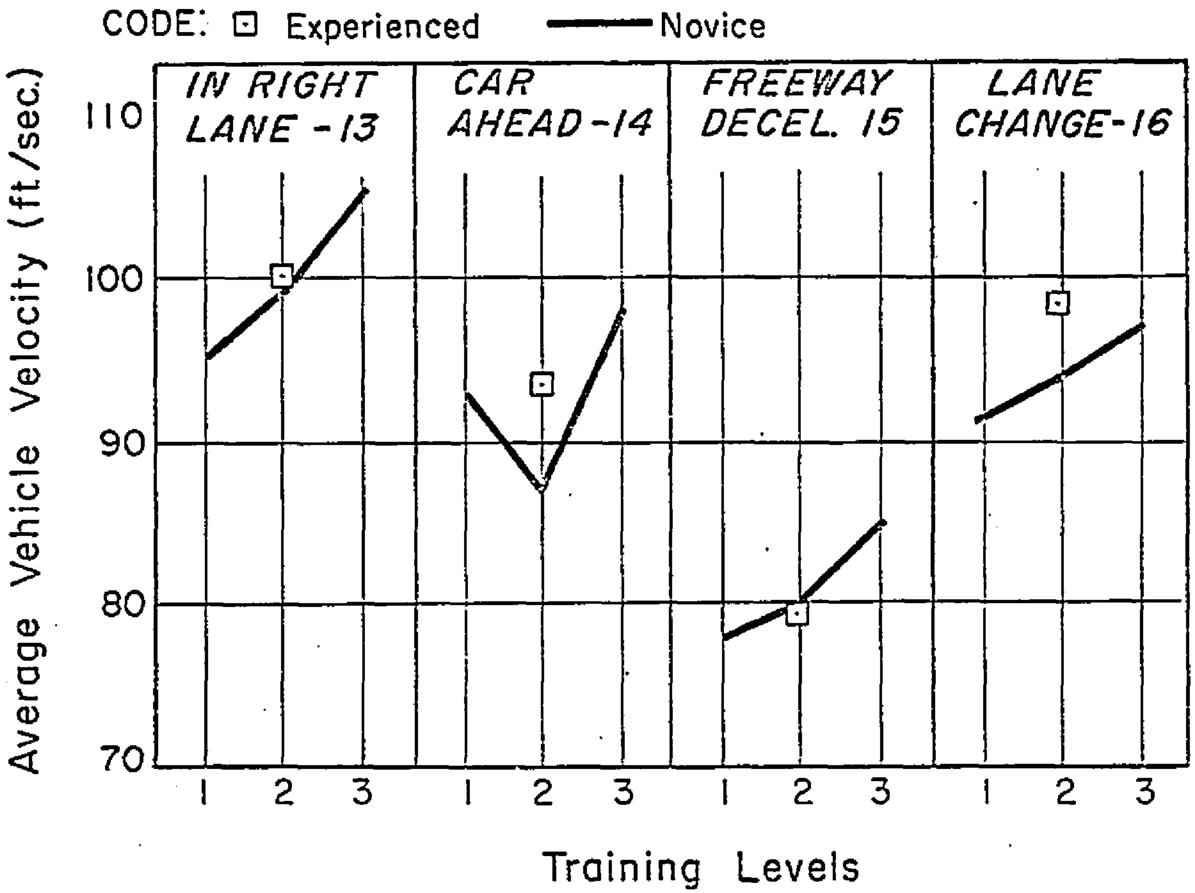

Figure 31. Average vehicle velocity (freeway tasks) for the experienced drivers and by training levels for the novice drivers.

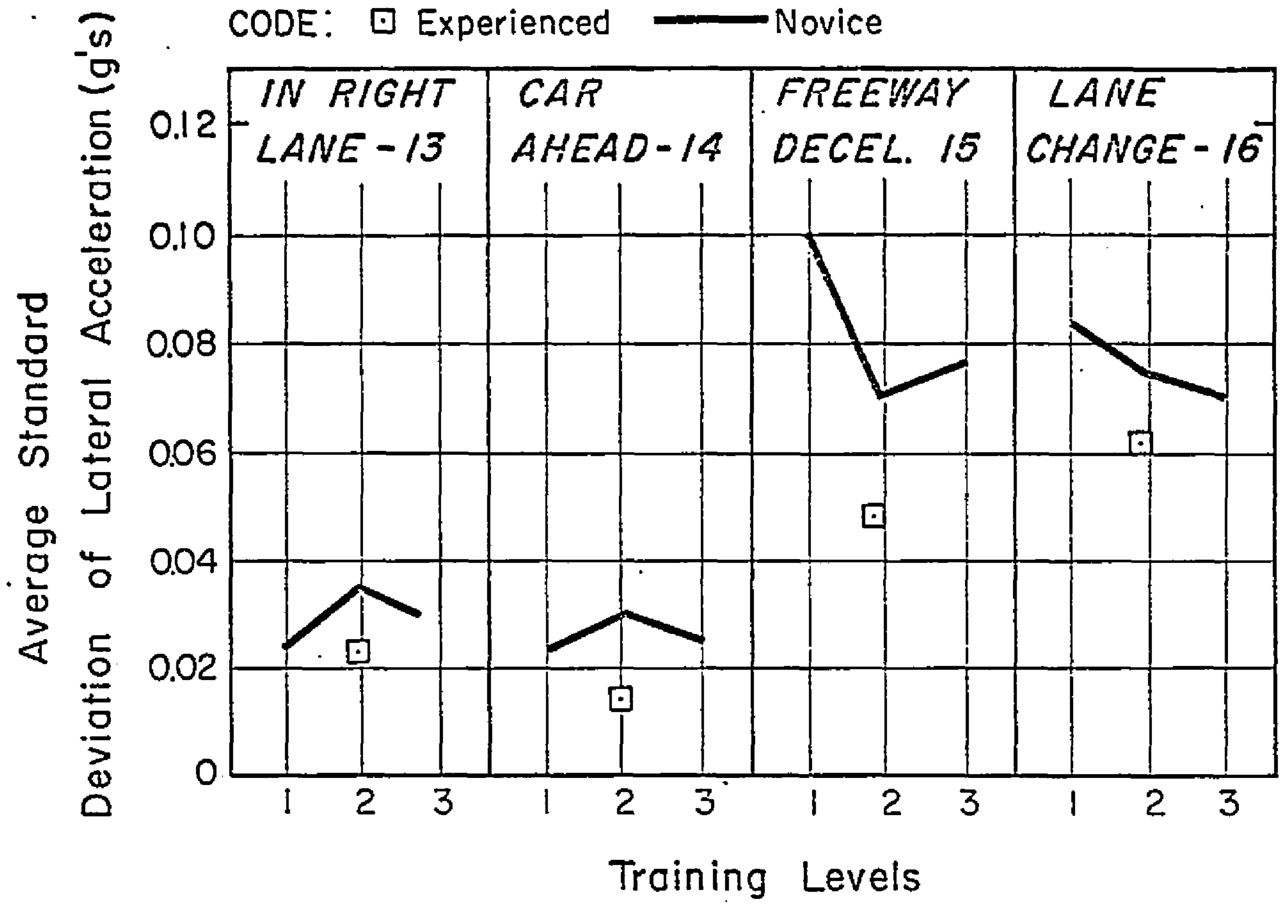

Figure 32. Average standard deviation of lateral acceleration (freeway tasks) for the experienced drivers and by training levels for the novice drivers.

analysis of variance indicated no significant differences in the novice drivers' data due to training levels. Hence, training level 3 data was used for comparisons between the novice and experienced groups. In the Freeway Deceleration Task the higher variance in the lateral acceleration of the novice group was significant ($p < .05$). Also, for the Car-Ahead-Freeway Task (#14) the novice group had higher variance of lateral acceleration than the experienced group ($p < .10$).

CHAPTER VIII

DISCUSSION

Summary of Results

Neighborhood Driving

Differences between the novice and experienced groups for the neighborhood tasks are summarized in Table 8. A large portion of the differences in activity are related to the differences in ranges of horizontal fixations. The experienced drivers had a mean horizontal range of 26°, while at training level 3 the novice drivers averaged only 12°. The smaller range of scanning found for the novice group is similar to a result reported for drivers under the influence of alcohol by Belt (1970). Belt found that a Concentration Index (the amount of eye fixation time spent in the most populous $3^\circ \times 3^\circ$ grid block) increased as the drivers' blood alcohol level increased. Mackworth and Bruner (1970), in a study comparing the scanning of adults and children, found that the children's search and scan patterns lacked adequate coverage of the display. In the same manner it appears that novice drivers lack adequate coverage of the neighborhood visual scene.

Table 8 also indicates differences in the medians of horizontal and vertical fixation locations. For the novice

Table 8. Summary of Neighborhood Results Between Novice and Experienced Groups

	Stop Sign-1	Stop Sign-2	Traffic Light - 3	Approach Left Turn - 4	Approach Right Turn - 5
Eye Travel Distance/sec	Less for Novice	---	Less for Novice	Less for Novice	---
Range of Horiz Fixations	Less for Novice	---	---	Less for Novice	Less for Novice
Range of Vert. Fixations	---	---	---	---	---
Fixation Duration	---	---	---	---	---
Median of Horiz Locations	Novice looked more to right (1st half)		Novice looked more to right	---	Novice looked more to right (2nd half)
Median of Vert. Locations	Novice looked lower (2nd half)		Novice looked lower	---	---
Mirror Sampling	Novice drivers sampled mirrors less frequently.				
Speedometer Checks	Novice checked while braking. Experienced checked while traveling near the speed limit.				
Deceleration Rate	Lower for Novice		---	---	---
Maximum Lateral Acceleration	---	---	---	---	---
Blink Rate	---	---	---	---	---
Turning Corners	Novice drivers made sharper turns than the experienced drivers.				

group at training level 3, the central direction of gaze was 1.5 degrees lower and 4 degrees further to the right than that of the experienced group. It appears that this location was due to the novice drivers' frequent sampling of the curb in order to verify and/or estimate vehicle lane alignment.

In a study of driving fatigue Kaluger and Smith (1970) also found that drivers looked more to the right and closer in front of the vehicle. This occurred after several hours of driving. The compensating strategy of fatigued drivers appears to be a regression toward the visual scan behavior of novice drivers in neighborhoods.

Freeway Driving

A summary of freeway results between the novice and experienced group is presented in Table 9. Here the differences in activity relate to fixation duration, the range of vertical fixation locations, and the range of horizontal locations. Over all freeway tasks, the experienced drivers had a mean horizontal range of 42°, while at training level 3 the novice drivers' horizontal range averaged only 16°. In addition to the horizontal range effect, the two freeway lane change tasks also had differences in vertical ranges. There the experienced drivers range was 9° while the novice drivers' range averaged 5.5° at training level 3. These findings support Zell's (1970) result that even after several

Table 9. Summary of Freeway Results Between Novice and Experienced Groups

	10 Change to Left	11 In Left	12 Change to Right	13 In Right
Eye Travel Distance/sec	Less for Novice	Less for Novice	Less for Novice	---
Range of Horiz Locations	Less for Novice	Less for Novice	Less for Novice	---
Range of Vert Locations	Less for Novice	---	---	---
Median of Horiz Locations	---	---	---	---
Median of Vert Locations	---	---	Lower for Novice	---
Fixation Duration	Greater for Novice	Less for Novice	---	---
Mirror Sampling	Novice sampled less frequently.			
Speedometer Checks	Novice sampled more frequently.			
Pursuit Eye Movements	Five of the six novice drivers made tracking eye movements -- none of the experienced did.			
Mean Vehicle Velocity	Novice faster for task 13 and when decelerating.			
Variance of Lateral Accel.	More for novice drivers on freeway car-following and deceleration tasks.			

months of driving experience novice drivers scanned the surrounding visual field less frequently than experienced drivers.

The novice drivers also had a lower median of vertical fixation locations than the experienced drivers on the change to right lane task. This in conjunction with the smaller range of vertical fixation locations suggests that the novice drivers had an urgent need to know the vehicle's heading with respect to the road when changing lanes. These results support the recent finding of Bhise (1971) that drivers who have been deprived of visual input sample lane markings foveally because of the urgent need for such information.

The finding of only one difference in medians of horizontal and vertical fixation locations for the freeway tasks (Table 9) contrasts markedly with the result for the neighborhood tasks. Some novice drivers did, however, display a compensating behavior, that of eye tracking movements, in order to increase their in-take of visual information while traveling at 70 m.p.h. In Kaluger and Smith's study both the duration and frequency of pursuit movements increased with amount of sleep deprivation. Kaluger and Smith also reanalyzed Zell's data and found that novice drivers also made pursuit eye movements. Because of the motion of the vehicle, pursuit eye movements are related to how close the driver is foveally sampling in front of the car. Thus pursuit eye movements on the lane markings may indicate the most critical times at which a driver is concerned with the vehicle's lane position and direction of travel.

Summary Over Training Levels

Table 10 is a summary of the results found over training levels for the novice group. The finding of decreases in travel distance per second with increased driver education and behind the wheel experience was most surprising. Driver education texts usually stress the searching for critical events, and The Smith System of Driving (1958) advocates that a driver should keep his eyes moving. Yet at training level 1 for the neighborhood tasks the novice drivers had an average horizontal range of 28° while at training level 3 three range was only 12°. The corresponding figures for freeway driving were 24° and 16°. Accompanying the decrease in horizontal range for the freeway lane changing tasks was an increase in mean fixation duration (.25 sec. to .37 sec.). This suggests trying to abstract more information while changing lanes. For the neighborhood decelerations just prior to the execution of turns, there was a decrease in mean vertical range over training levels. Taken together, the decreases in horizontal and vertical ranges, and the increases in fixation durations indicate that at training level 3 the novice drivers had learned where to look for vehicle control information, and were spending a good deal of their time abstracting such information. This large amount of attention

Table 10

Summary of Results Over Training Levels
for the Novice Group

	Neighborhood Tasks					Freeway Tasks			
	1	2	3	4	5	10	11	12	13
Eye Travel Distance/Sec	decr.	decr.	--	--	decr.	--	--	decr.	--
Range of Horiz Locations	decr.	decr.	decr.	decr.	--	--	--	--	--
Range of Vert Locations	--	Lower at tr. level 2	--	decr.	decr.	--	--	--	--
Fixation Duration	--	--	--	--	--	incr.	--	incr.	--
Medians of Horiz & Vert Locations	--	--	--	--	--	--	--	--	--
Mirror Glance Duration						Increased			
Speedometer Glance Duration						Increased			
Pursuit Eye Movements						Decreased			
Eye Blink Rate	Decreased					Inhibited at Tr. Level 1			
Deceleration Rate	incr.	incr.	incr.	incr.					
Max. Lateral Acceleration			decr.						
Vehicle Velocity						Trend toward faster			

being paid to visual cues that aid in vehicle control may be responsible for their being no significant differences in vehicle lateral deceleration on may of the driving tasks. At the same time it creates a search and scan pattern that appears to be unsafe in terms of its ability to detect critical events.

It is generally recognized that the initial stage in the development of search and scan patterns is the isolation of informative areas (Zinchenko et.al. 1963). Clearly the novice drivers had isolated what areas to search by training level 3. The second stage in the development of scan patterns, that of recognition is linked to decreases in fixaation duration since the information contained in the objects becomes more redundant with practice.

However, in the driving environment, the scene is constantly changing and the recognition of invariant cues that are redundant appears to be a difficult task for the novice to learn.

The relationship of mirror fixations to the novice drivers narrow zone of scanning is simple. They regarded mirror checking as non-essential. Possibly because it interfered with their monitoring of vehicle lane position. The amount of mirror sampling as a measure of driving skill has been suggested by Quenault (1969). He found that mirror usage was the best discriminator between a group of drivers convicted of careless driving and a control group. The present study indicates that the number of mirror glances is a good discriminator between novice and experienced drivers.

Comparisons Between Individual Novice Drivers and the Experienced Group

In Table 11 differences among the novice drivers are

Table 11. Differences Between the Experienced Group's Average Performance and Individual Novice Drivers.

Novice Drivers	Grade of Control Performance (Driver Ed Course)	Rating of Control Skill by Experimenter	Neighborhood Eye Travel Distance Per Second	Neighborhood Mean Fixation Duration	Neighborhood Median of Horizontal Fixation Location	Trial 3-Freeway Number of Mirror Fixations	Trial 1-Freeway Number of Tracking Eye Movements
A	B	4	-10	-.13	0.0	-9	+18
B	B	5	-10	+.03	+5.0	-7	+ 7
C	B	1	0	-.15	+0.5	-5	0
D	C	7	- 1	-.06	+5.3	-12	+ 4
E	B	3	- 9	+.02	+4.7	- 8	+10
F	C	6	-12	+.24	+6.9	- 9	+10
Special	B	2	- 2	-.10	+4.0	+ 4	0

presented in relationship to the average performance of the experienced group for several selected measures. A plus indicates that the novice driver was above the mean of the experienced drivers and a minus below the mean. Also shown is the grade given by their driver education instructor for their control performance at the end of the course. The ranking of the experimenter was for the driving performance at training level 3.

While driving on the freeway at training level 3 all the novice drivers, except the one given special instruction, sampled their mirrors less frequently than the average of the experienced group. At training level 1 all the novice drivers, except Driver C and the special driver, displayed tracking eye movements while freeway driving.

On the neighborhood tasks only novice Drivers A and C had about the same median of horizontal fixation location as the experienced group. It is interesting to note that they both had faster sampling rates than the experienced group. Novice Driver C also was given the best rating of control skill by the experimenter. Novice Drivers B and E both sampled at the same rate as the experienced drivers, but looked further to the right and had less overall visual activity. Novice Driver D who only differed from the experienced group in median of horizontal fixation locations was rated the poorest in terms of control skill by the experimenter. Novice Driver F sampled at a much slower rate than the experienced group and the other novice drivers. He also sampled the furthest to the right and was given a grade of C for his control performance by his driver education instructor.

Clearly the neighborhood driving tasks permitted a wide range of visual sampling strategies for the novice drivers. In the next section the general strategy of how the experienced drivers acquired visual information is discussed.

Strategies of Information Pick-Up

Three characteristics of the visual patterns of the experienced drivers, 1) wide scanning in the horizontal direction, 2) fixations far ahead of the vehicle, and 3) many mirror fixations, suggest that they are actively seeking a large amount of information. Gibson (1966) has proposed a theory of information pick-up and suggested that drivers use their perceptual systems to hunt information until they achieve clarity. Since an automobile is constantly moving through a continuous stream of information, the driver only achieves clarity for short periods of time. He must at frequent intervals sample new information to re-establish the relationship between the vehicle and the roadway. This could account for the experienced drivers relatively active search and scan behavior.

The large differences between the novice (at training level 3) and the experienced drivers search patterns suggest that the novice drivers were inefficient in their pick-up of information. This may be partially accounted for by the novice drivers being unskilled as to the acquisition of non-verbal material. Arnheim (1970) deplores this "pictorial illiteracy" in adults and suggests it is because of a lack of formal training in how to examine visual displays. However, beginning with the first grade, and continuing through the education process, the student is taught and encouraged to read verbal material quickly and efficiently. Thus, the inexperienced driver can be considered to be unprepared to perform the task of searching for pictorial information that controlling a vehicle demands.

The changes in the novice drivers visual search strategies over time indicate that they are trying to achieve some degree of clarity in their sampling of the environment. In Figure 1 (page 15) it was noted that the initial familiarization phase of skill acquisition (Fitts and Posner, 1967) is characterized by active exploration to discover the relevant sources of information. This appears to be the same strategy that the novice drivers used when tested at training level 1. The second stage in Figure 1, that of recognition, is characterized by a detailed examination of selected sources of information. This was reflected in the novice drivers eye patterns becoming quite compact when tested at training levels 2 and 3. At the end of their driver education training, the low activity level of the novice drivers search patterns indicate they had not yet advanced to the third stage of learning, where much of the visual information becomes redundant and is largely ignored.

Thus, learning to visually sample the driving environment is characterized by a long recognition stage as compared to other skill learning. This may be due to several factors, one being that the many different types of information that a driver must sample are only available for brief periods due to the motion of the vehicle. Thus, a driver must make many fixations on a stimulus pattern, at discontinuous points in time in order to learn what features of it are redundant. Another factor may be that the novice drivers' primary task appeared to be maintaining of control over the vehicle, and the psychomotor feedbacks loops of relating vehicle changes in direction and velocity with control movements may take more time to develop into perceptual reflexive responses than is generally realized. A third explanation is that the long recognition stage may be due to the complex interaction between foveal and peripheral vision that is demanded by automobile driving. As previously mentioned a novice driver samples foveally a lot of information that the experienced driver obtains through peripheral vision. Thus novice drivers must learn to recognize objects and relationships with peripheral vision. Unfortunately little is known about how long it takes to learn to use peripheral vision.

A Model of the Driving Task with Recommendations for Future Research

In Figure 33 is a model of the driving task. A driver's congnitive behavior can be described in terms of perceptual capabilities, internal perceptual models, and executive control habits. The perceptual capabilities of drivers have been studied by researchers for several years. Rockwell and Snider (1965) have done extensive research on the psychophysical capabilities of drivers. Burg (1971) has reported the dynamic visual acuity and its relationship to automobile driving for over 17,000 drivers. Speed of information processing for drivers has not been researched per se but may be related to fixation duration. The internal perceptual models may be aggregates of data about objects (Gregory, 1970) and/or representations of experience which preserve temporal and spatial relations (Kagan, 1970). These models are formed and revised by information from many sensory modalities, although while driving, vision is the primary source of information. The executive control habits provide connections and interfaces between current perceptual processing and overall goals of the automobile driver, i.e., driving safely and arriving at the proper destination.

The road scene, which the driver monitors by visual sampling, is composed of highway geometry features and the driver's vehicle (Figure 33). Based on information obtained from visually sampling the road scene and the driver's cognitive processes, a decision is made as to when and what control actions to take. The driver receives feedback of his actions through visual and proprioceptive cues. Two other feedback loops which are due to visually sampling the road scene ahead provide information that may be used to construct and modify the driver's internal perceptual models and executive control habits.

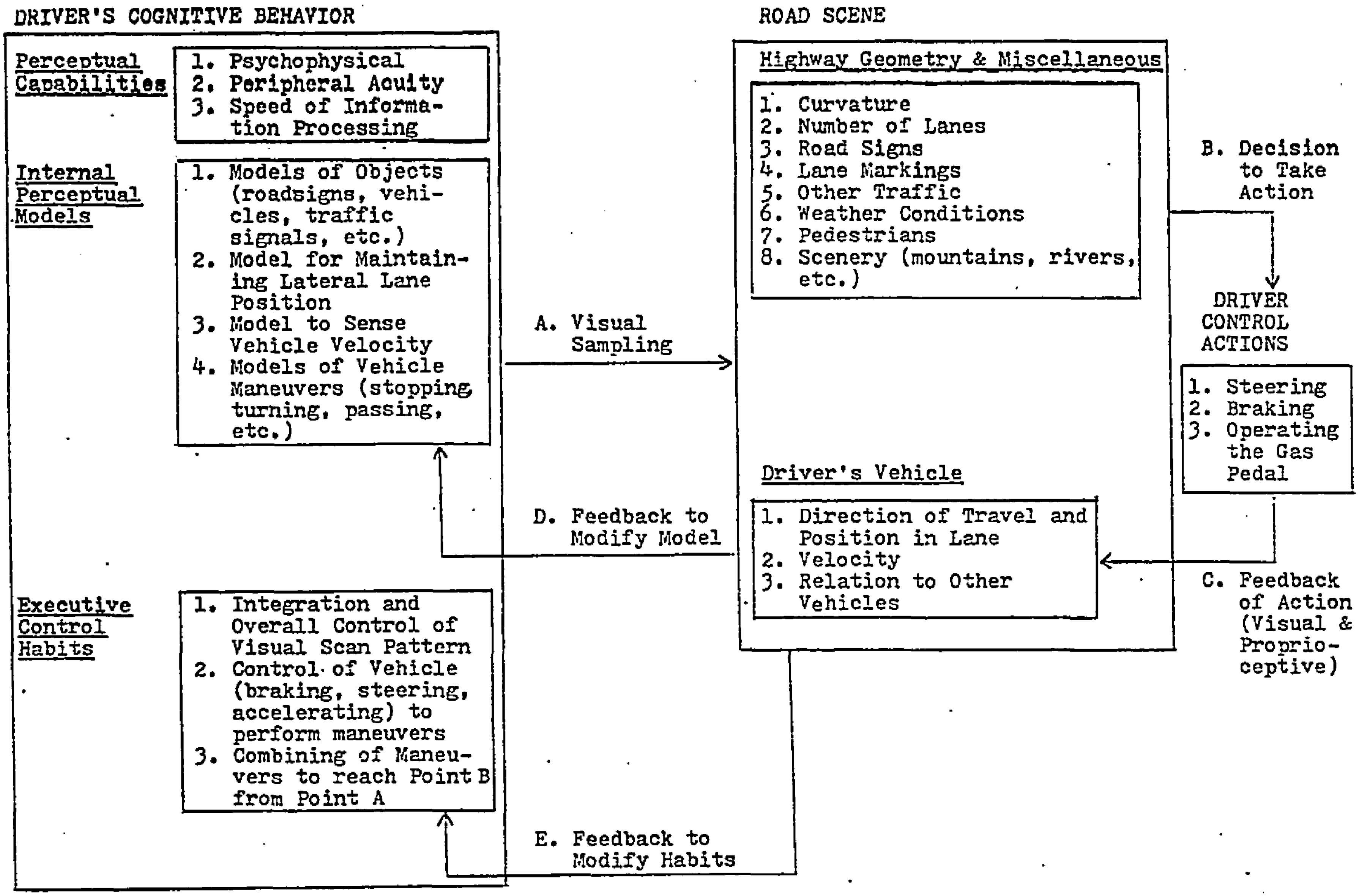

Figure 33. A Model of the Driving Task

By analyzing records of driver's visual scan patterns, inferences are made as to the types of executive control habits and internal perceptual models that drivers have. However, during any given eye fixation the driver may be attending to objects on the foveal part of the retina and/or objects on the peripheral part of the retina, or not attending at all. Hence a critical research need is to study the relationships between peripheral and foveal vision in connection with whether the driver is attending to the visual inputs. A measure of the amount of attention and its variations over time would be a very valuable tool for determining the visual skill of automobile drivers. Pribram (1969) has reported that a recently discovered brainwave, called Contingent Negative Variation, is an indication that the organism is preparing to respond and thus correlates with attention. The recording of such brainwaves in conjunction with eye movements should lead to new insights into the workings of the process called attention.

An experiment that offers more immediate pay off than the examining of physiological measures in conjunction with search and scan patterns is the recording of drivers' eye movements over a longer period of time than in the present study. This would provide evidence as to when drivers begin to use their mirrors more frequently and start to shift their visual patterns upward and straight ahead of the vehicle.

Another obvious need is to study the visual scan patterns of novice female drivers and novice older drivers. More attention should also be given to the relationships between head movements and eye movements while driving. In addition the head movements of drivers should be recorded with and without the stabilization unit on the head of the driver. This would reveal whether the wearing of the equipment has any effect on the number and magnitudes of head movements. Eye movement research especially aimed at providing inputs for teaching driver education is also needed and is discussed in the next section.

Implications for Driver Education

The data clearly indicates that at the end of their driver education course the novice drivers (with the possible exception of Driver C) did not have search and scan patterns that were adequate for the monitoring of low probability events. This was shown by small ranges of horizontal fixation locations, sampling close in front and to the right of the vehicle, and infrequent mirror glances. Such search and scan patterns suggest that the novice drivers considered the vehicle's immediate lateral and longitudinal control to be of primary importance and ignored most other information.

However, having novice drivers on public roads with such compact and unsafe search and scan patterns may be unnecessary. It is possible to train novice drivers in control and perceptual skills before driving in real traffic and hence, to reduce the probability of their being in accidents. An outline of a training program designed to accomplish this should include the following:

1) teaching of basic control skills,

2) practicing and overlearning of basic control skills,
3) training to develop internal perceptual models (see Figure 33),
4) training to develop executive control habits (see Figure 33), and
5) driving on public roads.

The basic control skills of starting, accelerating, braking, turning, and backing are presently being taught in most driver education courses. A standardized test of these driving fundamentals has recently been developed by McKnight (1971). Most schools have parking lots that are adequate for this type of training.

The practicing of the basic control skills should be done in an area closed to other traffic. While driving at speeds of 25 m.p.h. beginning drivers need to have enough practice so that their control actions associated with turning corners, decelerating, and maintaining proper lane position become automatic reflexive behaviors. Once drivers are competent in vehicle handling and control then training of their search and scan patterns may begin.

The development of internal perceptual models could be accomplished by presenting motion pictures at varying frame rates and for increasingly brief time periods (from about 5 to 1 seconds) and having students report what they say. Such a procedure would give the novice drivers practice in picking up information at the fast rates that many driving situations demand. In fact, a series of films showing many driving tasks and situations are needed to develop adequate and complete perceptual models.

Beginning drivers also need practice in developing the executive control skill that is responsible for their overall visual scan patterns. Here films showing how experienced drivers' search and scan various driving situations would give them knowledge of what constitutes good visual scan habits. Practice in looking far ahead of the vehicle, scanning wide in the horizontal direction and sampling the vehicle's mirrors could then follow. It would be valuable if a test could be developed (possibly using a driver simulator) to indicate whether novice drivers are ready to begin driving on public roads. Another function of this test would be to specify possible amounts and types of remedial training.

As shown in Figure 33, the controlling of an automobile involves much cognitive behavior and visual sampling but only a few control actions. The small number of control actions has caused many people to regard learning to drive as a simple and quickly learned task. This study, however, indicates that acquisition of good driving skill requires a great amount of visual perceptual training. The task of sampling a moving visual environment and simultaneously controlling the vehicle was shown to be very difficult for the novice driver.

APPENDIX A

GLOSSARY OF TERMS

alpha rhythms -- found in the normal adult brain when he is awake and relaxed. They have a frequency of ten to twelve cycles per second.

drift -- the tendency of the eye to move away from the fixation point.

eye fixation -- when the eyes appear to be stationary. Actually both drift and tremor occur during fixation periods.

fovea -- the central region of the retina (from 1° to 2°) where visual acuity is the greatest.

focus of expansion -- the point in a moving three dimensional field that appears to be stationary.

pursuit eye movements -- slow involuntary tracking movements which follow moving objects. They do not appear in the absence of moving objects.

retina -- a part of the eye that houses the light-sensitive rod and cone cells that convert light into electrical pulses.

saccadic eye movements (involuntary) -- movements of less than 1° in amplitude which tend to compensate for the eye drift during fixation periods.

saccadic eye movements (voluntary) -- the jumps by which we move our eyes from one fixation place to another. Normally both eyes move together.

tremor -- high frequency low amplitude involuntary eye motion.

visual acuity -- the ability of the eye to resolve detail.

APPENDIX B

VISUAL CHARACTERISTICS OF SUBJECTS

Table 12

Results of Experienced Drivers' Eye Examinations

	W	X	Y	Z
Visual Acuity (far)				
Left	20/18	20/18	20/15	20/20
Right	20/18	20/22	20/18	20/18
Both	20/18	20/22	20/15	20/18
Visual Acuity (near)				
Left	20/18	20/15	20/15	20/15
Right	20/18	20/15	20/15	20/15
Both	20/18	20/15	20/15	20/15
Depth Perception	N	N	N	N
Color Vision	N	N	N	N
Vertical Phoria	N	N	N	N
Lateral Phoria	N	N	N	N

N = normal

Table 13

Results of Novice Drivers' Eye Examinations

	A	B	C	D	E	F	Special
Visual Acuity (far)							
Left	20/15	20/22	20/25	20/20	20/20	20/18	20/20
Right	20/15	20/18	20/18	20/25	20/18	20/15	20/18
Both	20/15	20/20	20/20	20/20	20/15	20/15	20/20
Visual Acuity (near)							
Left	20/15	20/20	20/15	20/15	20/18	20/18	20/20
Right	20/15	20/22	20/15	20/15	20/18	20/20	20/22
Both	20/15	20/20	20/20	20/15	20/18	20/15	20/18
Depth Perception	N	E	N	N	N	N	N
Color Vision	N	N	N	N	N	N	N
Vertical Phoria	N	N	N	N	N	N	N
Lateral Phoria	N	N	N	N	N	N	N

N = normal E = excellent

APPENDIX C

MODELS AND ASSUMPTIONS OF STATISTICAL TESTS

Analysis of Variance

Two factors, training levels and task sections, were considered to be fixed. This implies that inferences may only be made for the particular levels of the factors administered. A third factor, subjects, was considered to be random. For random effects inferences may be made for the entire population. However, because of the small sample size in the present experiment one should use caution in doing this. Every novice driver was tested only once in every experimental condition. Hence, the design may be considered to be a mixed model without replication.

Let A, B, and S represent the factors, training levels, task divisions, and subjects, respectively. Consider a_i equal to the i^{th} level of A, b_j equal to the j^{th} level of B and s_k equal to the k^{th} level of S. Each observed score, X_{ijk}, may then be represented by the following linear model:

$$X_{ijk} = u + \alpha_i + \beta_j + \gamma_k + \alpha_i\beta_j + \beta_{(j)}\gamma_k + \alpha_{(i)}\gamma_k + \alpha_{(i)}\beta_{(j)}\gamma_k$$

where u = the grand mean of all the different treatment combinations and α, β, and γ are effects of sizes 3, 2, and 6 from their respective treatment populations.

In Table 14 are the expected mean squares for the sources of variance.

Table 14

Expected Mean Squares -- Novice Drivers

Source	Expected Mean Squares
Subjects (S)	$36\ Q_s^2 + Q_E^2$
Training Levels (A)	$12\ Q_A^2 + 6\ Q_{AS}^2 + Q_E^2$
Task Divisions (B)	$18\ Q_B^2 + 6\ Q_{BS}^2 + Q_E^2$
AS	$6\ Q_{AS}^2 + Q_E^2$
BS	$6\ Q_{BS}^2 + Q_E^2$
AB	$6\ Q_{AB}^2 + Q_{ABS}^2 + Q_E^2$
ABS	$Q_{ABS}^2 + Q_E^2$

The following F ratios were constructed:

1. $\frac{MS_A}{MS_{AS}}$ 2. $\frac{MS_B}{MS_{BS}}$ 3. $\frac{MS_{AB}}{MS_{ABS}}$

Then, if one is willing to assume that Q_{ABS}^2 is equal to or near zero the following additional tests could be made:

1. $\frac{MS_S}{MS_{ABS}}$ 2. $\frac{MS_{AS}}{MS_{ABS}}$ 3. $\frac{MS_{BS}}{MS_{ABS}}$

The above analysis of variance model includes the assumptions listed below:

1. Numerator and denominator of any F ratio is independent. This is true if scores are randonly sampled from a normal population.
2. Errors e_{ij} are normally distributed for each treatment population. This is equivalent to the assumption of normally distributed scores.
3. Errors e_{ij} have constant variance for each i, j combination.
4. Each score is the <u>sum</u> of the effects in the linear model.

Because of the large number of analyses of variance computed and the F distribution being little effected with balanced cells by lack of normality and heterogeneity of variance (Kirk, 1968), no effort other than a cursory viewing of the data was made to see if the above assumptions were met in the data analyzed.

The same type model was used to analyze the experienced drivers' data with the exceptions that factor A was now called run and had only two levels, and factor S had only four levels.

The Mann-Whitney U Test

This test was used to determine significant differences between the groups of novice and experienced drivers. Its assumptions are that at least ordinal measurement has been achieved, and that the groups tests are independent. Both these assumptions were met in all Mann-Whitney U Tests that were made. This is one of the most powerful non-parametric tests and its power efficiency is close to 95 percent for moderate-sized samples (Siegel, 1956). It was selected to avoid making the assumption that the population variances are homogeneous as required by the T test.

APPENDIX D

ANALYSIS OF VARIANCE TABLES

Codes

For all tables pertaining to the novice drivers the sources of variation are coded as follows:

1 = Subjects,
2 = Training Levels,
3 = Task Sections, and
Residual = Subjects x Training Levels x Task Sections.

For the experienced drivers' analyses, the only change was that source of variance number 2 was equated with runs. None of the freeway data was divided into Task Sections, hence source of variation number 3 is omitted in the freeway ANOVA (analysis of variance) tables.

Tables are presented for only the average travel distanc distance per second measure. The analysis of variance tables for all the other statistics and tables of individual data points are on file at the Systems Research Group, Department of Industrial Engineering, The Ohio State University.

Table 15

ANOVA - Average Travel Distance Per Second

Novice Drivers - Task 1

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUMS OF SQUARES	MEAN SQUARES
1	5	1593.19976	318.63989
2	2	1130.44506	565.22241
3	1	273.79148	273.79126
12	10	1546.71975	154.67197
13	5	109.03166	21.80632
23	2	462.08163	231.04082
RESIDUAL	10	440.14063	44.01405
TOTAL	35	5555.40234	

Table 16

ANOVA - Average Travel Distance Per Second

Novice Drivers - Task 2

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUMS OF SQUARES	MEAN SQUARES
1	5	1714.69006	342.93799
2	2	755.50562	377.75269
3	1	35.60095	35.60095
12	10	1062.76436	106.27643
13	5	1006.31614	201.26321
23	2	334.38446	167.19223
RESIDUAL	10	1144.71094	114.47108
TOTAL	35	6053.96875	

Table 17

ANOVA - Average Travel Distance Per Second

Novice Drivers - Task 3

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUMS OF SQUARES	MEAN SQUARES
1	5	999.66805	199.93361
2	2	14.90162	7.45081
3	1	144.39993	144.39992
12	10	544.30174	54.43016
13	5	350.07114	70.01422
23	2	4.11066	2.05533
RESIDUAL	10	738.78931	73.87892
TOTAL	35	2796.24194	

Table 18

ANOVA - Average Travel Distance Per Second

Novice Drivers - Task 4

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUMS OF SQUARES	MEAN SQUARES
1	4	1581.30050	395.32495
2	2	537.31216	268.65601
3	1	103.41608	103.41608
12	8	1111.50446	138.93805
13	4	1243.19435	310.79858
23	2	714.28026	357.13989
RESIDUAL	8	750.68750	93.83594
TOTAL	29	6041.69141	

Table 19

ANOVA - Average Travel Distance Per Second

Novice Drivers - Task 5

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUMS OF SQUARES	MEAN SQUARES
1	5	134.13799	26.82759
2	2	1221.02301	610.51147
3	1	25.84027	25.84026
12	10	1031.46568	103.14656
13	5	442.01067	88.40213
23	2	673.76375	336.88184
RESIDUAL	10	1066.63428	106.66342
TOTAL	35	4594.87500	

Table 20

ANOVA - Average Travel Distance Per Second

Novice Drivers - Task 10

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUMS OF SQUARES	MEAN SQUARES
1	5	551.62434	110.32486
2	1	248.17004	248.17004
RESIDUAL	5	505.66235	101.13246
TOTAL	11	1305.45654	

Table 21

ANOVA - Average Travel Distance Per Second

Novice Drivers - Task 11

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUMS OF SQUARES	MEAN SQUARES
1	5	599.35820	119.87163
2	1	32.68510	32.68509
RESIDUAL	5	75.16748	15.03350
TOTAL	11	707.21069	

Table 22

ANOVA - Average Travel Distance Per Second

Novice Drivers - Task 12

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUMS OF SQUARES	MEAN SQUARES
1	5	270.53893	54.10777
2	1	285.19564	285.19556
RESIDUAL	5	170.67969	34.13593
TOTAL	11	726.41406	

Table 23

ANOVA - Average Travel Distance Per Second

Novice Drivers - Task 13

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUMS OF SQUARES	MEAN SQUARES
1	5	1036.18602	207.23720
2	1	6.52220	6.52220
RESIDUAL	5	227.40186	45.48036
TOTAL	11	1270.10962	

Table 24

ANOVA - Average Travel Distance Per Second

Experienced Drivers - Task 1

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUMS OF SQUARES	MEAN SQUARES
1	3	689.73676	229.91225
2	1	216.82544	216.82544
3	1	192.51572	192.51572
12	3	1604.49111	534.83032
13	3	583.68193	194.56064
23	1	71.82599	71.82599
RESIDUAL	3	1177.91577	392.63843
TOTAL	15	4536.99219	

Table 25

ANOVA - Average Travel Distance Per Second

Experienced Drivers - Task 2

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUMS OF SQUARES	MEAN SQUARES
1	3	330.99622	110.33206
2	1	50.76542	50.76541
3	1	105.57532	105.57532
12	3	312.82733	104.27577
13	3	714.16694	238.05563
23	1	40.00577	40.00577
RESIDUAL	3	294.85547	98.28516
TOTAL	15	1849.19165	

Table 26

ANOVA - Average Travel Distance Per Second

Experienced Drivers - Task 3

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUMS OF SQUARES	MEAN SQUARES
1	3	559.36732	186.45576
2	1	167.70239	167.70239
3	1	545.22168	545.22168
12	3	72.62766	24.20921
13	3	655.62707	218.54234
23	1	41.60246	41.60245
RESIDUAL	3	474.48633	158.16211
TOTAL	15	2516.63428	

Table 27

ANOVA - Average Travel Distance Per Second

Experienced Drivers - Task 4

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUMS OF SQUARES	MEAN SQUARES
1	3	1772.05560	590.68506
2	1	9.76562	9.76562
3	1	1140.75049	1140.75049
12	3	65.13718	21.71239
13	3	747.09244	249.03081
23	1	534.76607	534.76587
RESIDUAL	3	517.25000	172.41666
TOTAL	15	4786.81641	

Table 28

ANOVA - Average Travel Distance Per Second

Experienced Drivers - Task 5

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUMS OF SQUARES	MEAN SQUARES
1	3	1539.08528	513.02832
2	1	0.33062	0.33062
3	1	177.55573	177.55573
12	3	1270.16110	423.38696
13	3	234.33679	78.11226
23	1	498.40516	498.40503
RESIDUAL	3	515.84473	171.94824
TOTAL	15	4235.71875	

Table 29

ANOVA - Average Travel Distance Per Second

Experienced Drivers - Task 10

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUMS OF SQUARES	MEAN SQUARES
1	3	304.02011	101.34003
2	1	51.01108	51.01108
RESIDUAL	3	1247.94955	415.98315
TOTAL	7	1602.98096	

Table 30

ANOVA - Average Travel Distance Per Second

Experienced Drivers - Task 11

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUMS OF SQUARES	MEAN SQUARES
1	3	154.06133	51.35378
2	1	239.01147	239.01147
RESIDUAL	3	240.33154	80.11050
TOTAL	7	633.40430	

Table 31

ANOVA - Average Travel Distance Per Second

Experienced Drivers - Task 12

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUMS OF SQUARES	MEAN SQUARES
1	3	194.63180	64.87726
2	1	576.94727	576.94727
RESIDUAL	3	862.53540	287.51172
TOTAL	7	1634.11426	

Table 32

ANOVA - Average Travel Distance Per Second

Experienced Drivers - Task 13

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUMS OF SQUARES	MEAN SQUARES
1	3	615.65321	205.21773
2	1	1.22987	1.22987
RESIDUAL	3	374.68115	124.89371
TOTAL	7	991.56396	

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