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FEED FORWARD PROGRAMMING OF CAR DRIVERS' EYE MOVEMENT BEHAVIOR: A SYSTEM THEORETICAL APPROACH

FINAL TECHNICAL REPORT VOLUME II

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This volume presents the results of two experiments; 1) Driving on the Road, and 2) Observing the Traffic Circumstances in the Laboratory, both dealing with car drivers' pattern of eye fixations. Further experiments deal with successive eye fixations and acquisition of information, the stability of eye movement behavior, the time discrete process model, and visual search strategy while driving around curves and along straight sections.

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SUMMARY

The Final Report consists of two volumes. The first volume is concerned with contemporary research and theory of eye movement behavior in driving. Its goal is to present the single studies within an unique frame and, thereby, to emphasize the essential paramters which influence the driver's visual search strategy. The Final Report's second volume, herewith presented, is devoted to the experimental work. The experimental work done should, essentially, be presented as a succession of single studies. Because the theoretical framework was already given in the Final Report's first volume, it is limited within this context to essential aspects only.

The investigational goal of predicting the car driver's future eye fixations in their successive order is a challenge, actually, at the present state of knowledge, a rather difficult job to achieve.

KEY WORDS

1. Eye movement behavior
2. Driving
3. Driver
4. Environment
5. Information input
6. Time discrete process model

FIGURE LEGENDS

TABLE LEGENDS

Chapter 1

INVESTIGATIONAL GOALS

1. INTERDEPENDENCE BETWEEN SUCCESSIVE FIXATIONS

Eye movement behavior represents an indicator of visual input of discrete "packages of information" (GAARDER, 1975), which are integrated then in the central nervous system to a holistic perception. The pattern of eye movements partly depends on the observed stimuli, the person observing and his prior knowledge (YARBUS, 1967), as well as his psychophysical condition (KALUGER and SMITH, 1970; BELT, 1969). Also, analysis of eye movements indicates that the coming fixation point is known prior to the beginning of the movement of the eye (PÖPPEL, 1974), during which visual information input is hardly possible (VOLKMANN, 1962; RITTER, 1975). The analysis of fixated points indicates, furthermore, that the next fixation point must have been selected through parafoveal vision prior to the beginning of each eye movement. Those points in the environment are mainly fixated which contain a relative high amount of information, i.e., unpredictable contours, as against those seldom fixated spots which consist mostly of redundant elements (MACKWORTH and MORANDI, 1967; ANTES, 1974). It is therefore assumed that in every fixation of the eye some information is picked up out of the environment and integrated within a modifiable, meaningful context to which the information from the coming fixation should be related. Vision is regulated by dynamic aspects, i.e., the person's schema (NEISSER, 1976) in relation to his processing capacity. From a theoretical,as well as a pragmatical,point of view, therefore, the order of eye fixations must be a rather important variable in studying eye movements as an peripheral indicator for central processing.

1.1. Visual input and environment

In the traffic situation there is a rapid change of the visual field, within which different elements of the road are distributed. They change their relative localization to the driver as a function of his driving velocity, as well as their position within his visual field.In this dynamic situation, the same element of the road, e.g., road narrowing, is for the driver of variable importance for steering a car from different distances. Road narrowing,as an example, might be of greatest relevance while planning to change the path of driving and less so from a greater distance, or from proximity after an adaptive sensomotoric activity has been finished. Therefore no element of the road has a constant static value of importance for driving, neither subjectively nor objectively, but a dynamic one, always depending on temporal,as well as spatial circumstances. The relative importance of a specific target must be always considered for this reason within the framework of the global traffic situation.

2. INVESTIGATIONAL INQUIRIES

The investigational goal of this study is to find a causal relationship between successive eye fixations of car drivers and to describe them as a mathematical model, which in turn must be verified. The existence of such a model would indicate the existence of a feed-forward program governing the movements of the eye. Its importance is analogous to senso-motorics where STELMACH (1976) stressed the necessity of a feed-forward program for a successful activity. Knowing a causal dependency between successive eye movements could be of theoretical interest and an aid in investigations of their functional relationship. A mathematical model that describes the causal relationship between successive fixations is also of practical interest, as it takes into account not only the variables of the subject but those of the environment,as well as the changes occurring. Therefore through systematical modification of the environment, it must be possible to find a well-defined design through which the eye will be "voluntary" guided toward a target, this being of special importance for correct steering.

In order to achieve the final investigational goal, future considerations must be subdivided into the following statements of the general problem:

a) Determining individual models: Sequences of eye fixations of experienced, as well as inexperienced, drivers while steering a car on two different routes will be analyzed in order to develop time-discrete models which describe the respective observed individual pattern of eye fixations.

b) Intra- and inter-individual differences: The previously found models should be analyzed with regard to intra- and inter-individual differences.

c) Role of information quantity to be processed on causality between successive eye fixations: Information input through foveal vision is necessary while driving on a complicated route as against a road consisting only of redundant elements. It is of interest to study whether a causal relationship between successive eye movements exists, even while driving on a road of the last type.

d) Determining model validity: After individual models are known, the validity of each of them must be verified by comparing a predicted pattern of eye fixations with an observed one.

3. STATEMENT OF WORK

In order to achieve the experimental goals mentioned above, it is of importance to determine the experimental conditions which are most suitable for investigating eye movement behavior. The question addressed in the first experiment is whether eye movement behavior can be studied under laboratory as opposed to field conditions. This issue is of importance mainly because the experimental conditions (i.e., the independent variables) can better be manipulated and controlled when using a laboratory design than when driving under daily traffic conditions. On the other hand, it is questionable as to whether laboratory conditions can suitably reflect real driving conditions.

The theoretical treatment of the data should be accompanied in each experiment by conventional data evaluation. In this way further research goals can be achieved such as evaluating the relationship between the preferred driving speed (when a great work load is involved) and the associated parameters of eye movement behavior. Further research goals can be achieved via conventional data analysis and include the consideration of the role of repeated driving on the same road segment and general driving experience in modulating the driver's visual search strategy. These experiments should be carried out under a great range of environmental conditions. Each single study should be treated holistically with individual evaluations facilitating the development of particular conclusions.

The system theoretical approach, on the other hand, involves the development of a time discrete process model which describes eye movement behavior as a function of the information that the driver has picked up in relation to the task oriented information available in the forward field (as described in chapter 3). The experiment reported there clearly indicates that a causal relationship exists between the successive fixations of the eye and, further, that eye movement behavior can be accurately described by individual time discrete process models at the phenomenological level. Further efforts must then be carried out in other directions. First, the model used requires a partition of time into discrete intervals. The developed methodological approach requires equal time intervals, as were used in the experiment reported in the third chapter. The fixation times have discrete intervals but with variable durations. There is therefore a discrepancy between the requirement of discrete time intervals for the model development and the intrinsic characteristics of fixation times. As a consequence, a methodological attempt must be made to use the time discrete process models, whose discrete intervals are of variable durations and which correspond to the respective fixation times.

Secondly, the development of this model should not only result in accurate description of the eye movement behavior, but must also facilitate the prediction of the next eye fixation if this model is to be validated. This objective is clearly a primary experimental goal.

A third general issue of the present research, related to the system theoretical approach is to improve our understanding of the mechanisms underlying the mechanism governing the movements of the eye. The initial data analysis did not greatly clarify the mechanisms of eye movement, except that such movements are interdependently related to the driver's momentary schema, as well as to the task-oriented importance of the oncoming targets. The conclusions of the third chapter have, therefore, an inductive character. The approach used in the last experiment, which is described in the sixth chapter, describes the concrete structure of the model which accounts for the movements of the eye toward a next target of fixation. These conclusions therefore have a deductive character.

The investigation carried out is presented subsequently in the form of single experiments. Each of these experiments was carried out to meet a particular goal. Finally, the present research findings have been integrated and an overview presented.

Chapter 2

CAR DRIVERS PATTERN OF EYE FIXATIONS ON THE ROAD AND IN THE LABORATORY

SUMMARY

Car drivers' eye fixations were registered when driving a car on the road and when viewing a slide in the laboratory which shows the same traffic situation. Although subjects of the second group were instructed to observe the presented slide as if they were driving there, they fixated their eyes on well-defined targets with quite different frequencies than those subjects who actually drive the car on the road. Furthermore, in the laboratory there was a tendency toward prolonged fixation times as compared to on-the-road driving conditions. The results suggest that the subjects on the road fixated more task-oriented targets and also picked up more information than their counterpartners in the laboratory.

1. INTRODUCTION

Investigations into the pattern of eye fixations are of interest when studying the peripheral mechanisms of information input in relation, for instance, to the subject's task. The reason is that the patterns of the saccads in relation to the separate fixations of the eye reflect also the cognitive activities which govern the program of eye movements in obtaining information required (MACKWORTH and BRUNER, 1970). Therefore the measureable peripheral activity of the eye is assumed to correspond with central processing mechanisms. For example, YARBUS (1967) showed that the way people observe pictures depends on the target presented, the person observing it as well as on the task the subject is engaged with. He suggests therefore that there is a relationship between thinking and seeing.

Although a relationship between the subject's task and his visual search strategy was already shown, nevertheless, only a little is known about the relationship between patterns of fixations observed in real conditions, e.g., when steering a car, and observing a similar optical array in the laboratory. This issue can also be considered within a more general framework. Every experimental paradigm in the laboratory represents an artificial situation but the design should, nevertheless, reflect reality. By operationalizing the crucial variables, the general issue arises as to whether the obtained relationship between the considered variables in the laboratory condition are also valid in real circumstances.

The two present experiments were designed in order to compare car drivers' visual search activity in a dynamic situation (when driving), with a more static one (when observing a slide of the same traffic conditions). The main goal of this study was to find out whether car drivers fixate similarily in both conditions on the well defined elements of the road. Any difference obtained would indicate that the subject weights the importance of the elements of the road depending on the experimental paradigm. Furthermore, the question of whether any difference occurs in the subjects' processing rate between these designs was also to be investigated.

The importance of these considerations is related in general to the question whether the experimental design in field condition is a necessary precondition to the study of the driver's eye movement behavior in a reliable way. The alternative hypothesis would be to study the driver's visual input in the laboratory because the experimental design could be achieved with better perfection in the laboratory, provided that the driver's eye movement behavior remains constant.

2. GENERAL METHOD

Two experiments were carried out in order to compare the obtained pattern of eye fixations under different conditions. Common to both experiments was registration of eye fixations. The registration of eye fixations was carried out by using a NAC III Eye-Marc-Recorder connected to a videorecorder within a visual field of 30°. The records were played on Grundig Slow-Motion-Apparatus with the capacity for a single frame analysis with a frequency of 50 frames each per recorded second.

3. EXPERIMENT 1: DRIVING ON THE ROAD

3.1. Experimental design

The drivers negotiated unexpectedly a building site, consisting principally of a crane which totally blocked the one way road the drivers used. In order to pass the building site, the subject had to drive for a distance on the road after which it then became necessary to drive on the left side-walk by utilizing a small "ramp" as shown in Figure 1. A more detailed description is given elsewhere (COHEN, 1976); therefore only the essential characteristics of the road elements will be given here. These were (1) the road, (2) the ramp, (3) the side-walk, (4) the wall of the building on the left, (5) the crane and (6) elsewhere. Fixation times and rates were analyzed.

3.1.1. Subjects

The five subjects participating in this experiment were between 22 and 32 years of age.No subject was told that he was going to be faced with a building site. Of course, no instructions were given other than to drive the car as told 15 minutes beforehand.

3.2. Results

The results indicate that no differencesin fixation times were obtained between all of the six categorized elements of the road (X^2=3.87; df=4, $p > 0.05$). The Spearman rank correlation coefficient indicates a relationship between fixation times and rates (r_s=0.97; df=5, $p < 0.05$). It was discerned that as the number of fixations on a target increased, so did the total fixation time. The average fixation time of all fixations amounted to 0.41 s.

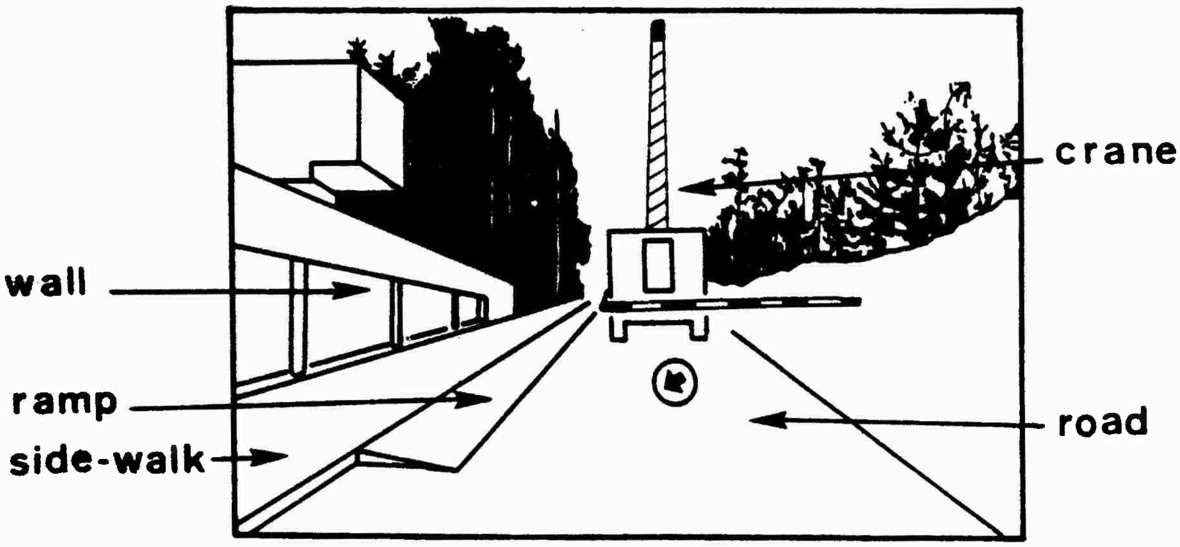


Figure 1: The building site which a group of subjects (N=5) passed when driving a car and which another group of subjects (N=9) observed as a photographed slide in the laboratory. The targets of fixations are indicated by arrows.

Even though no significant differences were obtained among the six categories of road elements, it is surprising that the small ramp was fixated on for the longest relative time (31.9 %) and that the obviously obstructive crane received the shortest fixation (9.9 %; see Fig. 2a). When considering not only the obstructiveness but the importance of the ramp for driving, this finding is reasonable. Even though the ramp is physically a small element, it had the effect of determining the driver's path of driving due because he had to drive on it in order to avoid the crane.

4. EXPERIMENT 2: OBSERVING THE TRAFFIC CIRCUMSTANCES IN THE LABORATORY

4.1. Experimental design

The second experiment was designed differently in two respects from the first one. In the laboratory, an artificial situation was created. Therefore the subjects' perceptual activity did not fulfill its primary function, that is, to survive. The subjects were not required to carry out any sensomotoric activity and did not therefore receive any proprioceptive information. They fulfilled only the tasks given. Another essential difference between both experiments concerns the nature of visual information presented. In this experiment, the subjects were presented with a slide of the real situation as the drivers in Experiment 1 saw it from one well defined position only. Therefore the information presented was of a static nature.

The results of Experiment 1 were considered in order to choose the specific slide to be presented. Because the ramp was fixated on most frequently, that view of the building site was used of all photos taken, where the ramp was most emphasized (see Fig. 1). Because of this emphasis, it was assumed that the possibility of fixating on the ramp should be increased.

The selected slide was presented at a distance of 135 cm from the subjects, corresponding to a visual angle of 22°.

The subjects were told that a slide would be presented, for only a short time, that would show a traffic situation. Their task was to observe this slide as if they had to drive in that same situation.

For data evaluation, a period of observation of approximately five seconds was considered. The analysis began within the first fixation after the onset of the stimuli occurred and ended after five seconds were analyzed, but prolonged until the ending of the ongoing fixation. A total of 2422 frames were considered.

4.1.1. Subjects

Nine licensed subjects participated in this experiment (a tenth subject was excluded, because he had no license). Their ages ranged between 18 and 27 years and all of them had normal visual acuity.

4.2. Results

The six categories of road elements were fixated in this experiment with a significantly varying number of fixation between them,as well as for different total durations (X^2=19.61; df=5, $p < 0.05$ and respectively X^2=403.7; df=5, $p < 0.05$). For the slide, the crane was the target of fixation having the longest total time (13.68 sec) followed by "elsewhere" (11.34 sec), the sidewalk (10.54 sec), the wall (8.64 sec), the ramp (2.84 sec) and the road (1.40 sec). The respective relative fixation times are shown in Figure 2. The total fixation times on each target do not correspond significantly with the total number of fixations on the same element of the road (r_s=0.89; df=5, $p > 0.05$) because the average fixation times on the sidewalk (0.72), as well as on the crane (0.59) were quite long. The average duration of all fixations amounted to 0.52 s.

5. COMPARISON BETWEEN BOTH EXPERIMENTS AND DISCUSSION

An obvious difference between both experiments is shown in Figure 2 which clearly indicates that a significant difference in fixation times on the various elements of the road was obtained (X^2=1064.3; df=5, $p < 0.01$). This result indicates that the time sharing between different targets is completely different when a subject is actually driving than when he is observing the same traffic situation in the laboratory. On the road, the drivers fixate most frequently on the small ramp but this is not so in the laboratory. When the subjects were presented with a slide, they fixated most frequently on the obstructive crane which was seldomly fixated in the real situation. When driving, the crane seemed to direct the drivers' attention toward the path of driving in contrast to the laboratory conditions. It therefore seems that those subjects who drove a car directed their attention to the more important, task specific targets than did the subjects in the laboratory. However, it might be possible that under real driving conditions, because of a great load of foveal information input, the extrafoveal input was quite limited, as compared to the laboratory condition. Nevertheless, it is clear that a driver's visual search strategy on the road can not be replicated in the laboratory when viewing a static picture.

Further support to the notion that there is less task oriented visual input in the laboratory can be derived from analyzing the frequencies with which the targets were fixated. It seems that the subjects in the laboratory fixated on the targets which corresponded to their general interest rather than to their importance for driving, as compared to real driving conditions (see Fig. 2).

A further difference between both experiments relates to the observed fixation durations. The mean fixation time in field conditions amounted to 0.41 s as compared to 0.52 s in the laboratory conditions. Even though the difference between the average durations is approximately 25 %, it is not significant because of the broad distribution of single fixation times. The greater fixation rate on the road might be attributed to a correspondingly greater rate of information picked up which, presumably, correlates to the rate of information processed. This assumption is also supported by the fact that in Experiment 1 those drivers who had a shorter fixation time, on the average,

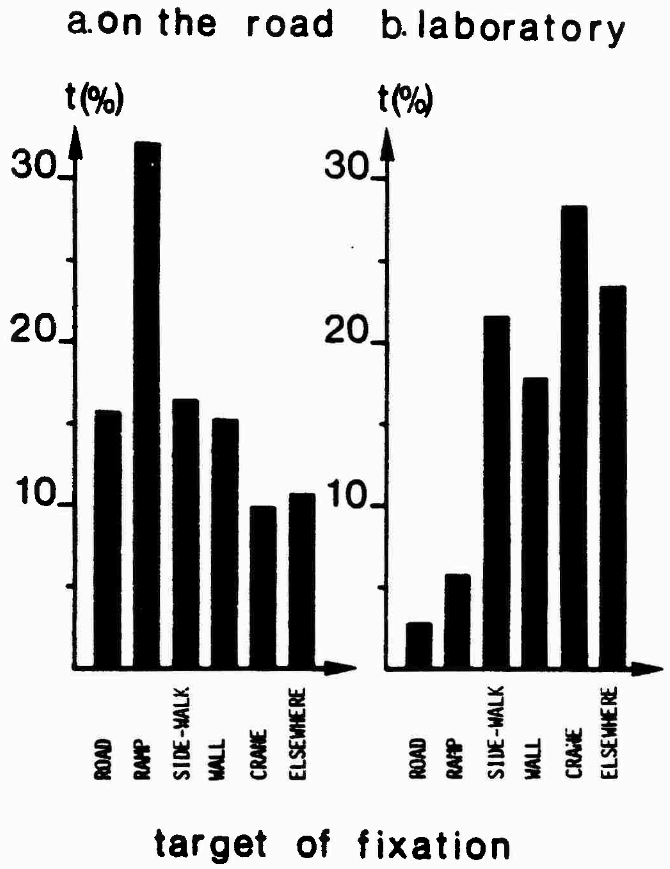


Figure 2: The total fixation time in percentage devoted to well-defined targets (a) on the road and (b) in the laboratory.

preferred to drive their car faster. Presumably they did so because they could process the information required for correct driving more rapidly than could the other subjects who manifested, on the average,longer fixation times (see next chapter). This suggested relationship between the mean fixation times and the processing capacity is supported by studies in which the central processing mechanisms were inhibited by, for example, alcohol (BELT, 1969; MORTIMER and JORGESON, 1972), by carbon-monoxide (SAFFORD, 1971; cit. in BHISE and ROCKWELL, 1971) or by fatigue or sleep deprivation (KALUGER and SMITH, 1970). In all of these studies, prolonged fixation times were observed. Furthermore, children, who presumably still possess less developed processing centers than do adults, also have a slight tendency toward prolonged fixation times (e.g., MACKWORTH and BRUNER, 1970).

The results of both experiments discussed above indicate a discrepancy between the real and the simulated situations as observed in terms of visual search strategy. Several reasons might account for the obtained differences. The most obvious experimental variable is the use of a static optical array in Experiment 2 as compared to real movement in Experiment 1. These differences lead also to dissimilar tasks in both experiments. The closed loop circuit - driver-vehicle-road - is completely broken in Experiment 2, where the subjects did not have to carry out any sensomotoric activity. A further reason might be that drivers use a task-specific visual search strategy in field situations which, presumably, can not be replicated due to verbal instructions. It is also possible that subjects can not recognize in the laboratory the task oriented importance of different targets as adequately as drivers on the road do even though the slide presented was taken from a perspective where the ramp was most emphasized.

6. CONCLUSIONS

In both experiments, similar yet different situations were compared. It might therefore be assumed that in simulations of field situations to be used as experimental designs in the laboratory, a discrepancy, as compared to reality, might exist. Of course, the more sophisticated an experimental simulation is,the better correspondance between field and experimental conditions might be assumed. Nevertheless, the assumed discrepancy between both situations can only be reduced but hardly totally excluded because simulations are only approximations of reality. For example, appropriate accelerations can hardly be achieved in the laboratory, while crashes with their consequences are totally excluded. Also, the subject has a different motivational approach to an experiment done in field conditions as compared to one carried out in the laboratory, because the first one might have serious consequences for himself while the second one does not have any. The clear conclusion of this study is therefore to prefer studying human abilities in reality rather than in the laboratory, whenever the implications of real circumstances are required. Findings from experiments done in the laboratory, on the other hand, are of questionable value in generalizing to natural conditions.

As a final remark, two studies should be mentioned which indirectly support the above conclusions. ALLEN, SCHROEDER and BALL (1978) investigated the eye movement behavior and motor reactions of drivers in a laboratory setting. Their main finding was that licenced drivers consistently made more steering operations than their unlicenced counterparts. Furthermore, the licenced drivers made more errors than the unlicenced subjects. The licenced drivers had, as a consequence, more simulated collisions than their unlicenced counterparts. This finding not only contradicts everyday experience, but also other experimental results that demonstrate that driving skills were developed as the result of long-term perceptual learning. Similarly, records of accident frequency show that the probability of a collision decreases as the number of years of practice increases. Therefore the discrepancy between these facts and the findings of ALLEN et al (1978) may be a consequence of the laboratory conditions used.

Laboratory conditions, even when using a perfect simulation, can never exactly portray reality as it occurs under field conditions. Even when the physical conditions in the laboratory duplicate those under field conditions, the subject may have a different relation to these experimental conditions and as a consequence exhibit different behavior. Within this context, the study of WELTMAN and EGSTROM (1966) should be mentioned. They investigated the effective field of vision in novice divers when diving under artificial conditions or in the ocean. They pointed out that their effective field of vision did not narrow under artificial conditions in contrast to diving in the ocean.

These two studies clearly illustrate that experiments carried out in the laboratory can reflect the influence of such artificial conditions on the behavior of the subject. Such results emphasize the value of studies done in the field which are relative unaffected by such influences and thus are more directly applicable to real-life situations.

Chapter 3

SUCCESSIVE EYE FIXATIONS AND AQUISITION OF INFORMATION

SUMMARY

The eye fixations of five drivers were analyzed when passing an unexpected building site. The faster speed of traveling resulted in shorter mean fixation duration. The total number of their fixations varied only at random. It is hypothesized that information is picked up in discrete "packages of information" and therefore those drivers who had shorter fixations on the average might need less total time to process similar amounts of information.

As to pattern of eye fixations, they were adequate for picking up relevant information for planning future path of driving ahead. By contrast, fixations were seldom devoted to unimportant but "attractive" features of the road. Furthermore, by applying system theoretical analysis, it could be shown, for every driver individually, that the pattern of his successive eye fixations can be described exactly by a time discrete process model. This result suggests not only that every eye movement is planned ahead but also that such a program is determined by prior information input, as well as by the relative importance of roads' features at any specific moment.

1. INTRODUCTION

By analyzing the patterns of a car drivers' eye fixations, it is hoped that some regularities in peripheral information input will be observed, which can be related to central processing mechanisms. In studies on eye movements, special attention is devoted to points of fixation ; extra foveal visual input is most often neglected in the data analysis. The following five reasons justify the analysis of eye fixations in order to understand the corresponding visual information input. According to the physiology of the eye, (1) only fixated objects can be perceived in detail, but also (2) the highest rate of information input is facilitated by the fovea. Moreover, (3) those points that correspond to the instantaneous focus of visual attention are successively fixated (e.g., SCHOILDBORG, 1969; FESTINGER, 1971). Furthermore, (4) the greatest percentage of the fixations are devoted to targets which are characterized by a relativly high amount of information (MACKWORTH and MORANDI, 1967; ANTES, 1974). Finally, (5) the movements of the eye are programmed by a central mechanism. Therefore a relationship between successive fixations of the eye might exist. A proof of this statement is one of the central objectives of this experiment.

The pattern of eye movements and the eye's fixations is therefore assumed to be a peripheral attribute of central processing mechanisms functioning in relation to the subject's cognition. Nevertheless, a single eye fixation on a defined target should not necessarily be attributed to its actual perception. THOMAS (1968) illustrates this exceptional fact: A driver who actually fixates on a red traffic light does not stop his car but continues to drive on. Presumably, even though the relevant information is available, the driver does not process it. The fact that the experimentator can not recognize the actual meaning of single eye fixation represents a limitation to the understanding of the functional meaning of observed eye movements behavior. Therefore instead of dealing with single fixations, the main attention is devoted to regularities of observed patterns of eye fixation. The logic behind this assumption is that regularities in the eye fixation or their sequences correspond to the visual information input as well as to the information processing.

The visual information input is assumed to be up to approximately 90 % of the total relevant information processed when driving (e.g., HARTMAN, 1970; ROCKWELL, 1971; FISCHER, 1974). Vision is therefore the crucial ability needed for car driving. While steering a car, visual information is needed for survival. This is the main advantage of field experiments in contrast to laboratory experiments, where the subject has to be instructed to solve an artificial task. Therefore, investigations carried out in real situations might, presumably, contribute to safety research as well as to theoretical considerations more than do those that are simulated in the laboratory.

Vision can also be considered in general as a perceptual performance, which might be described by the amount of processed information within a constant time interval. In such a case one can either refer to the information entailed in stimuli itself (i.e., ATTNEAVE, 1965) or to its subjective complexity (i.e., PATRY, 1975) or to a combination of these two possibilities. MILLER (1956) pointed out that the capacity for information processing depends not only on stimulus properties but also on the manner in which the subject encodes and decodes the presented information, e.g., by chunking.

The first investigational goal of this experiment was to study the relationship between the preferred speed of driving and the mean duration of eye fixations. The underlying hypothesis is that the mean duration of eye fixations can be attributed to visual performance. The shorter the mean duration of eye fixations (but long enough to permit adequate information input), the more objects can be fixated within a period of time, and therefore the more information is available for processing (see GOULD, 1976).

The second question of interest is whether a causal relationship exists between successive eye fixations. If there is a relationship, than it will indicate not only a feedforward program of eye movements, but also a contextual integration of already processed information. In such a program, two kinds of variables must be considered simultaneously: those of the subject and those of the environment.

From the subject's point of view, it is believed that the information picked up is in "discrete 'packages' of information" (GAARDER, 1975). Furthermore, it is assumed that a sequence of fixations representsan irreversible process, as the information already processed modifies the subject's cognitive schema (NEISSER, 1967, 1976). The momentary cognitive contex, on the other hand, should always influence the selection of the next target to be fixated. According to YARBUS (1967), the next fixation will be directed toward that specific target, which contains or might contain essential information for observational purposes. Furthermore, MACKWORTH and BRUNER (1970) suggest that the pattern of eye movements is "governed by a program for 'constructing' a perceptual world".

As for environmental variables, it is assumed that the relative importance of each element of the road to the driving task, e.g., the meaning of a well defined target of fixation, depends not only on its static and its objective features (e.g., measureable properties in terms of information theory), but also on the driver's ability to chunk, as well as on the information he has already processed. Furthermore, two fixations on the same element of the road occurring from a different viewpoint of the driver, correspond with information input of different relevances for the momentaneous steering operations. Therefore the importance of an element of the road has not a constant, but rather a variable importance. These considerations suggest that car drivers' patterns of eye fixations should not be analyzed exclusively by using conventional statistical methods. The analysis of the dynamic component of the eye fixations pattern might be a more suitable method for investigating sequences of eye fixations.

2. EXPERIMENT

2.1. Driving route

The driving route was characterized by a complicated traffic pattern as shown in Figure 3. Immediately after driving through an underpass, the driver had to turn to the left, as required by a traffic sign. As he turned, he could suddenly see that the road was totally blocked by a slewing crane approximately 100 m away. The only available way to continue driving was to steer the car on the road and, at a short distance from the building site, to drive over to the sidewalk on the crane's left side. This possibility was indicated by an appropriate traffic sign.

The road was connected with the sidewalk by means of a small "ramp", which accessed the driver up to the causeway and, once past the crane, back to the road. At the pass the left side of the driving path was limited by the wall of a building and the right one by the building site. On the road's far right side, an embankment also limited the driver's lateral sight.

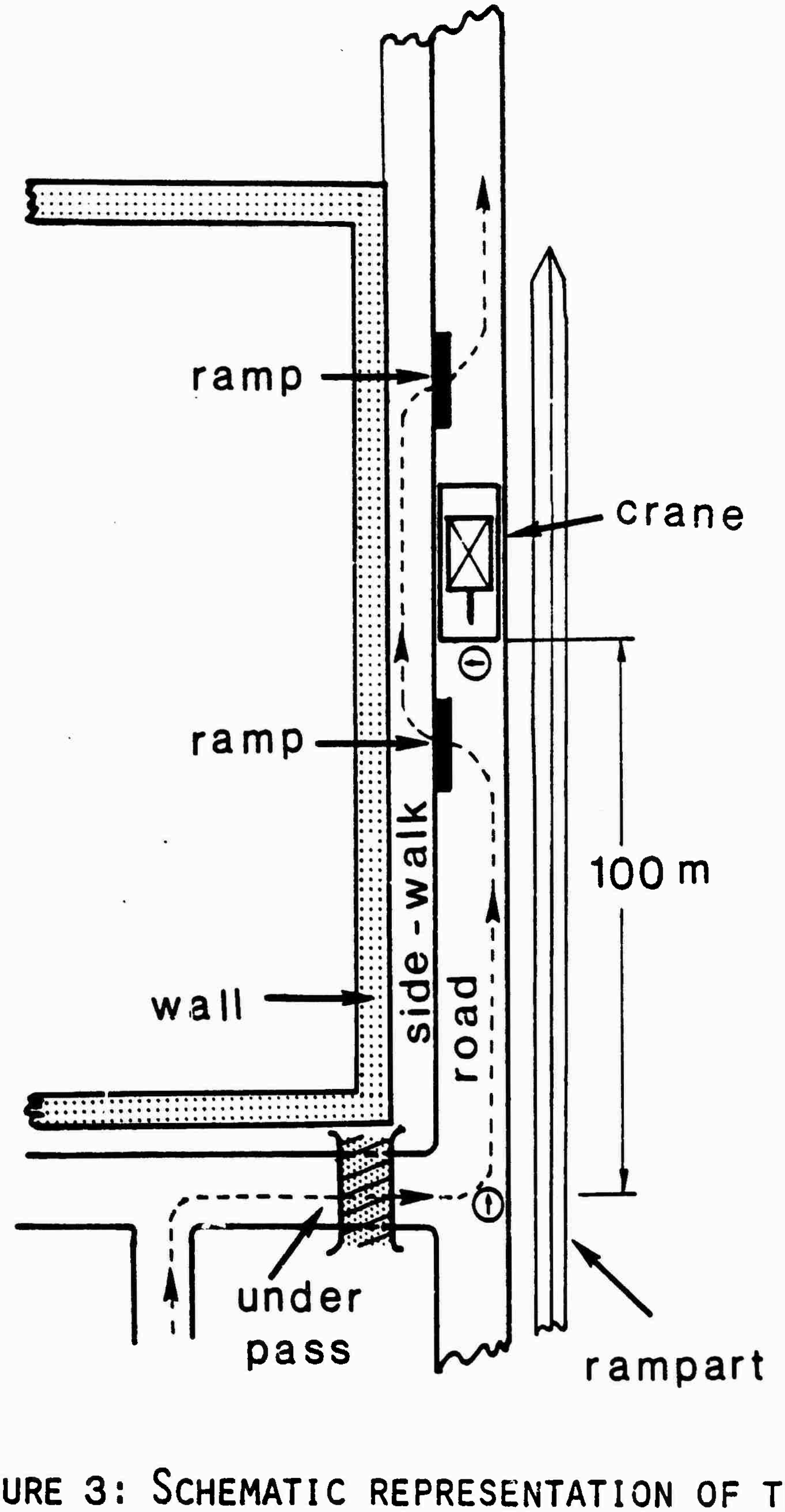


FIGURE 3: SCHEMATIC REPRESENTATION OF THE BUILDING SITE (BIASED SCALE).

When approaching and passing this building site no other car or pedestrian was in sight. All subjects faced this situation so suddenly that none of them could anticipate the path of driving ahead. Under these conditions, the experimental requirement of presenting a great load of information input connected with the necessity of processing it was fulfilled. Furthermore, no verbal instructions were needed.

2.2. Subjects

Five subjects between 22 and 32 years old, with driving experience of between 4 and 14 years, participated in this experiment. None of the subjects knew anything about the existence of the building site to be passed. They also did not receive any instruction as to how they were to drive. Actually, all of the subjects believed that the experiment has previously been finished on another route and that they are just steering the car back to the starting point.

2.3. Data registration

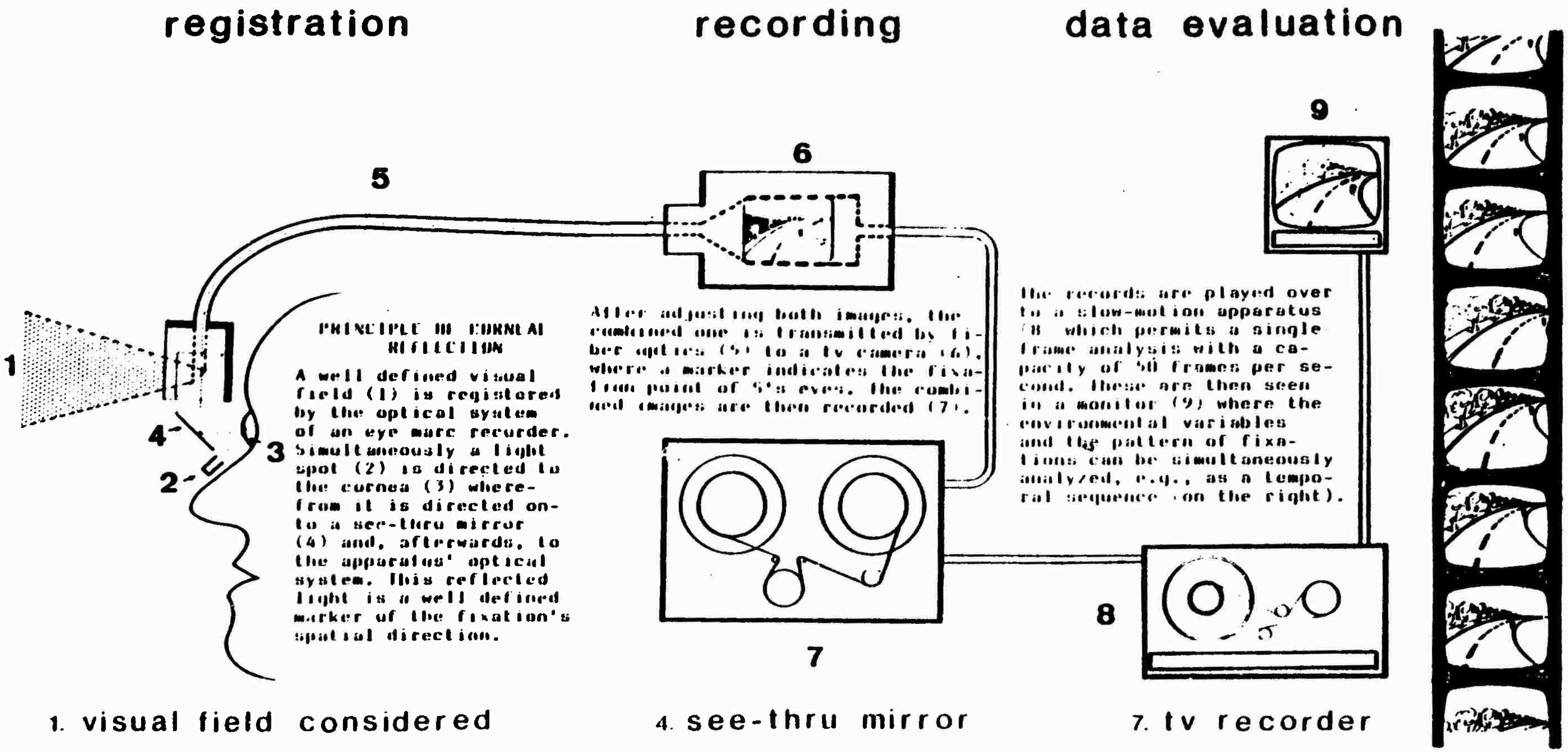
The eye fixations were registered with a NAC III Eye-Marc-Recorder, connected to a portable AKAI-videorecorder. Every subject could move his head freely. This apparatus allows the recording of eye fixations within a horizontal visual scenery of

30^{o}. The records were played over on a GRUNDIG-slow-motion-apparatus, which permitted a single frame analysis with a frequency of 50 frames per second (see Fig. 4). Each single frame therefore corresponds to an observational period of 20 msec.

3. DATA TREATMENT

A sequence of 24 schematic pictures of the driving path was prepared from successive points of view (see Fig. 5). In every schematic picture all relevant elements of the road were included. For each subject the data of eye movements, e.g., the temporal order, the durations and the targets of each eye fixation, was registered on the prepared sheet. Figure 5 shows respectively, a subject's sequence of fixations. Unfortunately, individual head movements could not be considered.

For a <u>conventional statistical analysis</u> of the data, non-parametric methods were used because the requirements of parametric methods were not fulfilled. For every subject the duration of each fixation and the target fixated on were evaluated. The targets of fixations considered were the following elements of the road: (1) road, (2) ramp, (3) sidewalk, (4) wall, (5) crane and (6) elsewhere (see Fig. 4 and Fig. 5). From this



PRINCIPLE OF CORNEAL REFLECTION

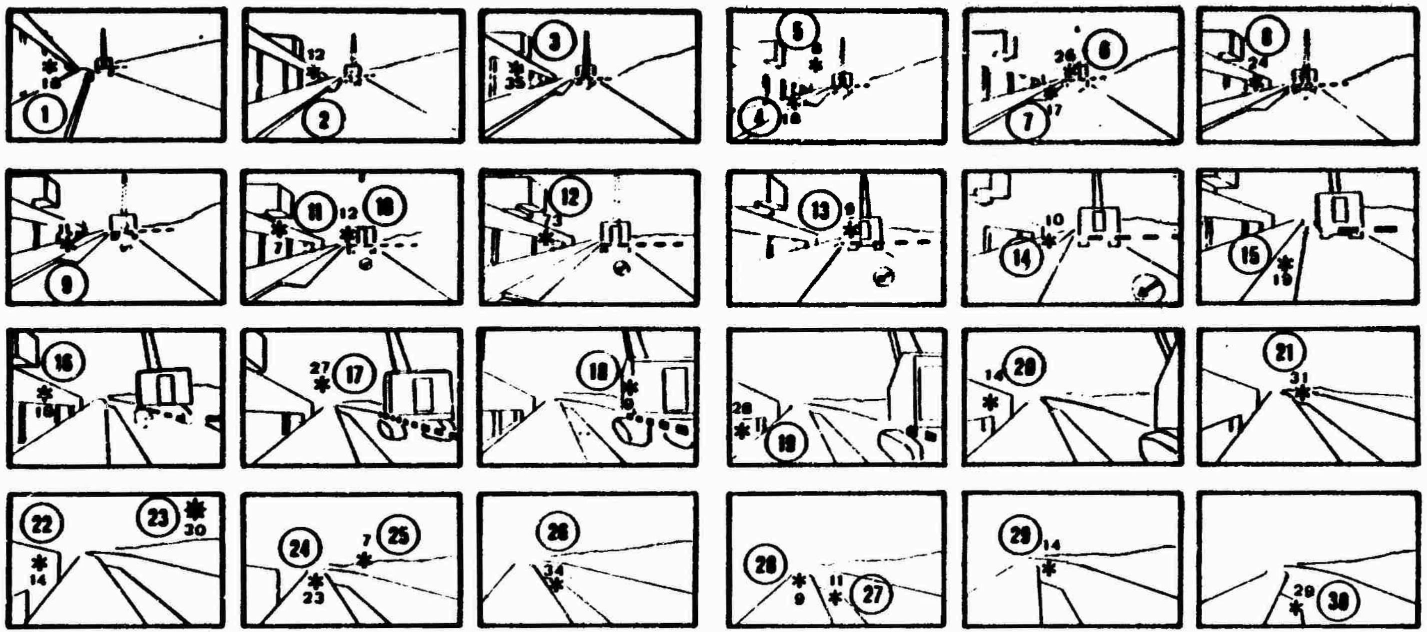
A well defined visual field (1) is registered by the optical system of an eye mark recorder. Simultaneously a light spot (2) is directed to the cornea (3) wherefrom it is directed onto a see-thru mirror (4) and, afterwards, to the apparatus' optical system. This reflected light is a well defined marker of the fixation's spatial direction.

After adjusting both images, the combined one is transmitted by fiber optics (5) to a tv camera (6), where a marker indicates the fixation point of S's eyes. The combined images are then recorded (7).

The records are played over to a slow-motion apparatus (8) which permits a single frame analysis with a capacity of 50 frames per second. These are then seen in a monitor (9) where the environmental variables and the pattern of fixations can be simultaneously analyzed, e.g., as a temporal sequence (on the right).

1. visual field considered
2. spot lamp
3. cornea
4. see-thru mirror
5. fibre optics
6. tv camera
7. tv recorder
8. slow-motion-apparatus
9. monitor

FIGURE 4: THE MEHTOD USED FOR REGISTERING AND RECORDING THE DRIVERS' EYE FIXATIONS AS WELL AS THE TECHNIQUE USED FOR DATA EVALUATION.



* fixation point ⑦ fixation's running number

✱ target of fixation outside of the schematic picture

19 fixation time (in units of 20 msec)

✱ not evaluable fixation

FIGURE 5: SEQUENCE OF 24 SCHEMATIC ENVIRONMENTAL VIEWS AS SEEN BY THE CAR DRIVER IN DISCRETE TIME INTERVALS. THE TARGETS OF FIXATIONS, THEIR TEMPORAL ORDER AND THE RESPECTIVE FIXATION TIMES ARE GIVEN FOR S No 5.

set of data, the total number of fixations, the total fixation time on each target, as well as the total driving time needed to pass the experimental route could be derived. Each subject's driving time represents reciprocally the average speed of his driving because the route had a constant distance.

For a system theoretical analysis of the data, a slightly different categorization of the road's elements, i.e., targets of fixations was necessary. These were: (1) fixation on the driving path in the near distance, (2) fixation on the driving path at a longer distance, (3) fixation on the path's limitation to the left, (4) fixation on the path's limitation to the right, and (5) elsewhere. The categories of eye fixations in short vs long distance were operationalized by a horizontal division of the schematic pictures, the upper part of which was two times greater than the lower part. If the fixation was observed on the driving path in the lower part of the picture, then it was ordered to the first (near distance) or otherwise to the second category (long distance).

In order to describe the eye fixations in terms of time sequences, the registration period was divided into discrete time intervals of 0.5 s each. For each subject and for each successive time interval, the relative observation time of the five categories of road elements was calculated in percentages. The distribution of eye fixations of the i'th subject in the N'th interval of observation can then be described by the following variables and the respective notation:

$X_{i1}(N)$: relative fixation time (in percent) on driving path in short distance;

$X_{i2}(N)$: relative fixation time (in percent) on driving path in long distance;

$X_{i3}(N)$: relative fixation time (in percent) on limitations to the left;

$X_{i4}(N)$: relative fixation time (in percent) on limitations to the right;

$X_{ij}(N)$: relative fixation time (in percent) elsewhere;

whereby, i represents the subjects' index number.

As the temporal distribution of eye fixations on "elsewhere" $X_{ij}(N)$ is well defined by the other four parameters, it can be neglected from further consideration. Its value is always complementary to 100 percent.

$$X_{ij}(N) = 100 - \left[X_{i1}(N) + X_{i2}(N) + X_{i3}(N) + X_{i4}(N)\right]$$

In order to describe the eye fixation process of each subject by means of a process model, one also needs the deviations of $X_{i1}(N)$, $X_{i2}(N)$, $X_{i3}(N)$ and $X_{i4}(N)$ in successive observational intervals. These deviations are defined also as state variables. The corresponding notation is:

$X_{i5}(N) = X_{i1}(N) - X_{i1}(N-1)$

$X_{i6}(N) = X_{i2}(N) - X_{i2}(N-1)$

$X_{i7}(N) = X_{i3}(N) - X_{i3}(N-1)$ and

$X_{i8}(N) = X_{i4}(N) - X_{i4}(N-1)$

The variables $X_{i1}(N)$ to $X_{i8}(N)$ fully describe the pattern of eye fixations and the respective deviations in each observation interval (N). These variables will be denoted as the <u>state variables</u> of the eye fixation process. Table 1 illustrates the sequence of the state variables for the first 10 observation intervals observed on Subject No. 5. The corresponding fixations are shown in Figure 5.

On the route past the building site, the targets of fixation, i.e., each of the five road elements, were of changeable relative importance to the task of steering the car. The relative importance of a road element depends mainly on the targets itself, but also on the driver's relative position to the target,as well as on the information the driver has already processed. This relative importance of every element of the road in observation interval (N) is denoted as an <u>environmental variable</u>.

		OBSERVATION INTERVAL									
	N =	1	2	3	4	5	6	7	8	9	10
STATE VARIABLE	X_{51}	0	40	32	0	0	0	0	0	0	0
	X_{52}	0	0	32	32	36	44	0	0	0	20
	X_{53}	100	60	0	0	64	32	76	100	100	44
	X_{54}	0	0	36	68	0	24	24	0	0	36
	X_{55}	0	40	-8	-32	0	0	0	0	0	0
	X_{56}	0	0	32	0	4	8	-44	0	0	20
	X_{57}	0	-40	-60	0	64	-32	44	24	0	-56
	X_{58}	0	0	36	32	-68	24	0	-24	0	36

TABLE 1: THE TEMPORAL ORDER AND THE MAGNITUDE OF THE STATE VARIABLES OF S No 5 FOR THE FIRST TEN OBSERVATION INTERVALS IN PERCENTAGE.

In order to estimate the importance of every element of the road in each time interval, ten additional experienced drivers (experts) were individually presented with the sequence of the 24 schematic pictures of Figure 5. Of course, no data on eye fixations were included. The task of these experts was to score the relative importance of every one of the above listed road elements in every schematic picture by using a number between zero (not important at all) and three (very important). The experts began with the left upper picture and continued scoring according to their rational sequence. The obtained scores, i.e., the respective sums of all experts in each of the six first schematic pictures for every well defined element of the road, are given in Table 2.

The observation intervals used in the data analysis were always 0.5 s. As the subjects drove with different velocities, every subject "passed" in each interval a different number of the schematic pictures (or a part of them). A prior temporal analysis of the schematic pictures was required in order to determine which schematic pictures a subject "passed" in every interval of observation (N).The estimation of the relative importance of the road elements in each observation interval (N) was based on the interpolation of the respective experts'

CATEGORY PICTURE	1	2	3	4	5	6
DRIVING PATH IN NEAR DISTANCE	7	5	6	9	11	17
DRIVING PATH IN LONG DISTANCE	18	20	22	23	23	22
LIMITATION TO LEFT	10	12	12	12	12	15
LIMITATION TO RIGHT	5	4	4	6	6	4

TABLE 2: SCORES OF IMPORTANCE OF THE FOUR ELEMENTS OF THE ROAD AS JUDGED FOR THE FIRST SIX SCHEMATIC PICTURES OF FIGURE 5 (UPPER ROW).

scores (e.g., when the defined observation interval extended over two successive schematic pictures). Those variables (i.e., elements of the road) that describe for the i'th subject the relative importance of the environment are called <u>environmental variables</u> which are defined as follows:

$W_{i1}(N)$: relative importance of the driving path at short distances

$W_{i2}(N)$: relative importance of the driving path at longer distances

$W_{i3}(N)$: relative importance of the limitations to the left, and

$W_{i4}(N)$: relative importance of the limitations to the right

for every observation interval (N) for each subject No. i, individually, in scored values.

Note that at this point all <u>state</u>, as well as all <u>environmental variables</u> were well defined for each subject and for all observation intervals (N).

To simplify the notations, all the state variables in the observation interval (N), i.e., $X_{i1}(N)$ to $X_{i8}(N)$, can be understood to be components of a state vector $\underline{X}_i(N)$ defined for subject No. i as:

$$\underline{X}_i(N) = \left[X_{i1}(N),\ X_{i2}(N),\ X_{i3}(N),\ X_{i4}(N),\ X_{i5}(N),\ X_{i6}(N),\ X_{i7}(N),\ X_{i8}(N) \right]^T.$$

The observed pattern of eye fixations of Subject No. i in observation interval (N) is, therefore, fully described by the <u>state vector</u> $\underline{X}_i(N)$. In a similar way, the environmental variables, i.e., $W_{i1}(N)$ to $W_{i4}(N)$ for the same subject No. i will be summarized in an <u>environmental vector</u> $\underline{W}_i(N)$ as follows:

$$\underline{W}_i(N) = \left[W_{i1}(N),\ W_{i2}(N),\ W_{i3}(N),\ W_{i4}(N) \right]^T$$

The environmental vector $\underline{W}_i(N)$ includes, therefore, the importance of all the considered road elements in observation interval (N). To illustrate this notation, Table 3 shows all components of the state vector $\underline{X}_i(N)$, as well as those of the environmental vector $\underline{W}_i(N)$, for the ten first observation intervals of Subject No. 5 (i=5).

After the data had been prepared for a system theoretical analysis, the main question then was whether the state vector $\underline{X}_i(N+1)$ of the next observation interval (N+1) could be predicted, e.g., by means of the momentary state vector $\underline{X}_i(N)$ and the environmental vector $\underline{W}_i(N+1)$. If an unknown but time invariant mathematical steady relationship F_i exists between

ENVIRONMENTAL AND STATE VECTORS AND THEIR COMPONENTS

OBSERVATION INTERVALS

	N =	1	2	3	4	5	6	7	8	9	10
$\underline{X}_5(N)$	X_{51}	0	40	32	0	0	0	0	0	0	0
	X_{52}	0	0	32	32	36	44	0	0	0	20
	X_{53}	100	60	0	0	64	32	76	100	100	44
	X_{54}	0	0	36	68	0	24	24	0	0	36
	X_{55}	0	40	-8	-32	0	0	0	0	0	0
	X_{56}	0	0	32	0	4	8	-44	0	0	20
	X_{57}	0	-40	-60	0	64	-32	44	24	0	-56
	X_{58}	0	0	36	32	-68	24	0	-24	0	36
$\underline{W}_5(N)$	W_{51}	6	7	10	11	14	14	23	24	24	22
	W_{52}	21	23	23	23	23	23	23	24	24	23
	W_{53}	12	12	12	12	13	16	21	24	24	24
	W_{54}	4	5	6	6	8	4	6	7	7	12

TABLE 3: COMPONENTS OF THE STATE AND OF THE ENVIRONMENTAL VECTORS IN THE FIRST TEN OBSERVATION INTERVALS OF S No 5.

$\underline{X}_i(N+1)$ as output and $\underline{X}_i(N)$ and $\underline{W}_i(N+1)$ as input variables, then F_i can be approximated by means of a set of mathematical functions f_i. By denoting with $\hat{\underline{X}}_i(N+1)$ the prediction for $\underline{X}_i(N+1)$, the process model can be formulated by

$$\underline{X}_i(N=1) = \underline{X}_i(1); \text{ and}$$

$$\hat{\underline{X}}_i(N+1) = f_i \left[\underline{X}_i(N), \underline{W}_i(N+1)\right]$$

f_i represents the simplest set of functions that allows an accurate approximation of F_i.

The deviation between the predicted and the observed state vector can be described by an error vector $\underline{e}_i(N+1)$, which gives a score for the reliability of the model's prediction for the time interval (N+1)

$$\underline{e}_i(N+1) = \hat{\underline{X}}_i(N+1) - \underline{X}_i(N+1).$$

As a score for the model's reliability over the sequence of N_{end} intervals, the root of the quadratic mean of the prediction errors in percentages was used. Therefore, the model's prediction error E was calculated as follows:

$$E = \sqrt{\frac{1}{n \cdot N_{end}} \cdot \sum_{N=1}^{N_{end}} \sum_{j=1}^{n} e_i(N+1)^2}$$

N_{end} = number of observation interval

n = number of state variables

Figure 6 shows schematically how a process model of simple order predicts the state vector for the (N+1)'th interval by means of $\underline{X}_i(N)$ and $\underline{W}_i(N+1)$.

By means of these time sequences, it was thought possible to find for each subject, a time discrete dynamic process model for an accurate description of the observed sequences of eye fixations. The theoretical background of the identification method used, its possibilities, as well as its limitations, are described in detail in HIRSIG (1974a, 1974b). Therefore only the principal aspects of the data evaluation will be described here. The identification method used for determining f_i is based on LJAPOUNOV's stability theory (e.g., SCHAUFELBERGER, 1972) but it can not be described here in detail. Nevertheless, the essential characteristics should be mentioned briefly:

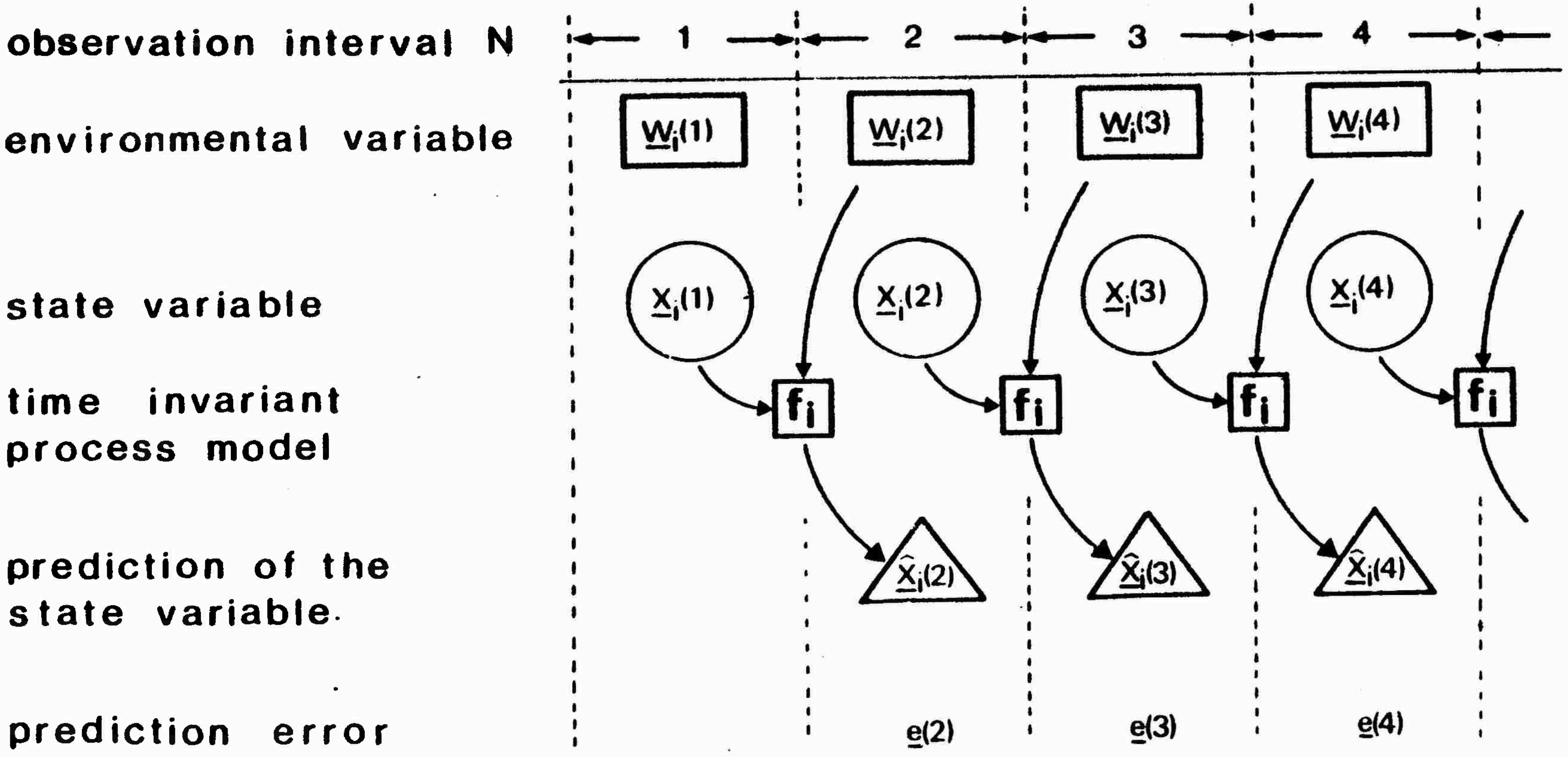


FIGURE 6: A SIMPLE RELATIONSHIP BETWEEN INPUT AND OUTPUT VARIABLES OF THE PROCESS MODEL AS USED IN THE FIRST APPROACH (VALID IN THIS FORM FOR THE Ss No 2 AND No 3 ONLY).

1) The set of functions f_i can be called a process model of the observed eye fixations behavior only if the predicted and the observed state vectors deviate in all observation intervals only within an a priori defined limit of tolerance.

2) A process model can be found only if all relevant variables have been experimentally considered, measured and taken into account while developing the process model.

3) If the prediction error is greater than the prescribed level of tolerance, then it means either
   a) that not all of the relevant variables have been considered, or
   b) that the essential suppositions of a time invariant and steady mathematical relationship between the input and output variables had not been fulfilled.

4. RESULTS

A total of 2903 video frames were analyzed. As a first step in conventional data treatment, the total fixation time of all subjects on each element of the road was calculated. The respective fixation times on the road, the ramp, the sidewalk, the wall (on the left), the crane and elsewhere (including fixations on rear view mirror etc.) were, respectively, 9.2 sec (15.8 %), 18.5 sec (31.9 %), 9.6 sec (16.5 %), 8.9 sec (15.3 %), 5.7 sec (9.9 %) and 6.2 sec (10.6 %). The total fixation duration on an element of the road corresponds to the number of fixations on this element ($r_s = 1.00$; df = 1.00; $p < 0.01$). The longer the total fixation time, the greater the number of fixations on the same target. This finding clearly indicates that the subjects more often considered their path of driving than an "attractive" target such as the crane. The fact is surprising in that, for the first moment, the driver's attention was most often directed to the relatively small and unattractive ramp. When considering the importance of this element of the road for determining the subject's path of driving, this result seems to be reasonable. Even though the crane completely blocked the road, it seems that the subjects were less concerned with the cause of the obstruction and more with searching for their future path of driving. Therefore the crane as an obstacle might have directed the drivers' visual attention toward their actual path of driving.

The driving times with which the subjects needed to pass the building site, ranging from 8.7 to 17.2 s (see Fig. 7), where significantly different between subjects ($X^2 = 204.9$; df = 4; $p < 0.01$). As these values were observed over a constant distance, it can be concluded that the subjects drove with different average velocities. The higher a subject's driving speed, the shorter the average durations of his fixations ($r_s = 1.00$; df = 1; $p < 0.01$). Nevertheless, the total number of eye fixations observed on the experimental route varied only randomly between subjects. No relationship could be established between a subject's preferred speed of traveling and his driving experience ($r_s = 0.2$; df = 4) as compared to his mean fixation times.

In the <u>system theoretical analysis</u>, two different kinds of models were determined for every one of the five subjects individually (first and second model approach). In all models, f_i represents a system of second order potential series of the given arguments in Table 1 and, respectively in Table 2. All prediction errors range between 0.0 % and 2.6 %. They do not exceed the prescribed limit of tolerance of 5 %. Therefore it might be concluded that the sequences

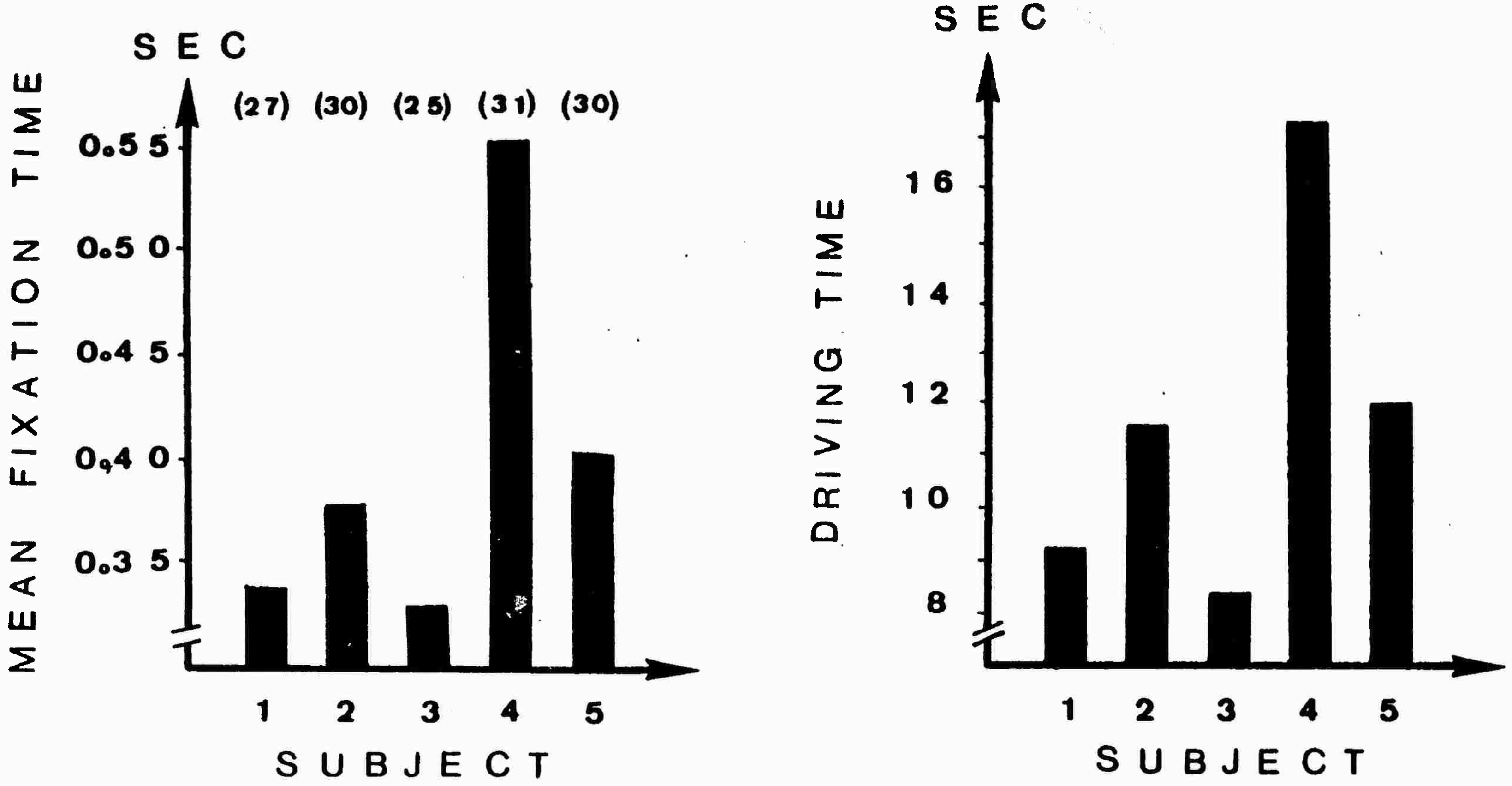


FIGURE 7: THE MEAN FIXATION TIME OF EVERY S (LEFT) AND THE NUMBER OF FIXATIONS OBSERVED (BRACKETS ABOVE) AS WELL AS THE RESPECTIVE DRIVING TIME (RIGHT)

of eye fixations can be fully described by the established process models.

The models in the first model approach (Table 4) predict the state vector of the next interval by means of the present state vector and by a defined number of environmental vectors which, nevertheless, vary from subject to subject. These results indicate that a causal relationship exists between successive fixations of the eye. Furthermore, the environmental variables ahead on the road are an integral part of the program governing the movements of the eye. Nevertheless, there is inter - individual variability as indicated by the different number of "environmental-information" intervals needed to predict the following fixations of the eye of different subjects.

The models of the first approach show that a causal relationship between successive eye fixations can be derived as a function of the present information input and the road elements' importance in the future observation intervals. The question arose, at this point, as to whether any evidence could be found for the suggestion that the perceptual system is a self-regulating one, i.e., whether the information already picked up determines the future information to

S No	PREDICTION MODEL	PREDICTION ERROR
1	$\hat{\underline{X}}_1(N+1) = \underline{f}_1 \left[\underline{X}_1(N), \underline{W}_1(N+1), \underline{W}_1(N+2), \underline{W}_1(N+3), \underline{W}_1(N+4)\right]$	2,6%
2	$\hat{\underline{X}}_2(N+1) = \underline{f}_2 \left[\underline{X}_2(N), \underline{W}_2(N+1)\right]$	0 %
3	$\hat{\underline{X}}_3(N+1) = \underline{f}_3 \left[\underline{X}_3(N), \underline{W}_3(N+1)\right]$	0 %
4	$\hat{\underline{X}}_4(N+1) = \underline{f}_4 \left[\underline{X}_4(N), \underline{W}_4(N+1), \underline{W}_4(N+2), \underline{W}_4(N+3)\right]$	1,4%
5	$\hat{\underline{X}}_5(N+1) = \underline{f}_5 \left[\underline{X}_5(N), \underline{W}_5(N+1), \underline{W}_5(N+2), \underline{W}_5(N+3)\right]$	0,2%

TABLE 4: FIRST MODEL APPROACH: INDIVIDUAL PREDICTION MODELS OF THE STATE VARIABLES ACCORDING TO PRESENT STATE VECTOR AND THAT OF ENVIRONMENT IN A WELL DEFINED NUMBER OF FUTURE OBSERVATION INTERVALS.

be obtained. If so, then the already known information input in the observation intervals (N-m) to (N) should have been sufficient to predict accurately the state vector in the next observation interval, i.e., $\hat{\underline{X}}_i(N+1)$. Therefore in the models of the second approach, the environmental variables should not have been directly considered. They were, nevertheless, implicitly included in the prior sequence of eye fixations, because under a great load of information, every subject fixates only on the most important target at any given moment.

The results show (see Table 5) that the analysis of the known present and prior information inputs (state vectors) was sufficient for determining a process model, which can predict with sufficient accuracy the next state vector in observation interval (N+1). Table 5 indicates that for one subject the present $\underline{X}_i(N)$ and two past state vectors $\underline{X}_i(N-1)$ and $\underline{X}_i(N-2)$ of information input and for the four other subjects, the present $\underline{X}_i(N)$ and one past state vector $\underline{X}_i(N-1)$ were needed to predict accurately the relative time sharing of relative fixation times on defined targets in the next observation interval (N+1).

S No	PREDICTION MODEL	PREDICTION ERROR
1	$\hat{\underline{X}}_{\underline{1}}(N+1) = \underline{f}_{\underline{1}}\,[\underline{X}_{\underline{1}}(N),\ \underline{X}_{\underline{1}}(N-1),\ \underline{X}_{\underline{1}}(N-2)]$	0 %
2, 3 4, 5	$\hat{\underline{X}}_{\underline{i}}(N+1) = \underline{f}_{\underline{i}}\,[\underline{X}_{\underline{i}}(N),\ \underline{X}_{\underline{i}}(N-1)]$	0 %

TABLE 5: SECOND MODEL APPROACH: INDIVIDUAL PREDICTION MODELS OF THE STATE VARIABLES ACCORDING TO PRESENT AS WELL AS PAST STATE VECTORS.

5. DISCUSSION

In requiring the drivers to pass the building site, three essential experimental conditions were fulfilled in guaranteeing the reliability of using the pattern of analyzed eye fixations as a proper criterion of information input.First,no subject could anticipate the complicated traffic situation which he was suddenly faced with from a relative short distance away. Therefore all relevant information input needed for the correct steering of the car on this route could be recorded and analyzed. Second, the road elements were properly categorized. Third, the subject's processing capacity was loaded, so that he had to concentrate on relevant cues. This is seen, for example, in the fact that the small ramp was fixated very frequently and for a long time, e.g., as compared to response to the great and "attractive" screwing crane. This finding indicates that the subject's attention was directed mainly toward the relevant cues needed for the driving task and not toward the targets of general interest. This finding supports the suggestion that the greater percentage of information input occurred foveally and that the role of peripheral vision might have been essentially limited for programming the future movements of the eye. Furthermore, this suggestion is also supported by the fact that targets which had no immediate importance for driving were seldom fixated, as this fact is also indicated by analyzing the observed sequences of fixations (see Fig. 5).

A reason for this fact derives from the complicated traffic situation, i.e., the information load which had to be processed within a short period of time. It can be assumed therefore that all subjects mainly used their central vision, which facilitates not only the most detailed but also the fastest information input rate possible, in contrast to peripheral vision (e.g., BHISE and ROCKWELL, 1971). Nevertheless, extra foveal vision remains important, especially for guiding the eye to the next target of fixation.

The observed relationship between the mean durations of eye fixations and the preferred driving speed of a subject, must be discussed in more detail. The results show that the higher a subject's preferred velocity was, the shorter were his average fixation times, i.e., the more fixations ocurred within a defined period of time. Nevertheless, the total number of fixations varied only randomly between the subjects. The question then arises as to whether those subjects who had shorter average fixation times might possess an increased capability to process the relevant information that allows him to drive faster.

GAARDER (1975) suggests that information input occurs in the form of "discrete 'packages' of information". It is assumed that the eye remains fixated on a target until the information searched for is picked up (e.g., NEISSER, 1976). Then the eye changes its position immediately to the next target of interest. This notion is in accordance with YARBUS (1967) who suggests that the eye will be directed to details which carry or might carry the relevant information searched for. In this connection the findings of MACKWORTH and BRUNER (1970) are also of importance. They found slightly longer fixation times in children than in adults. For children and adults the mean fixation times increased when viewing blurred compared to sharp pictures. The authors explain this result with the argument that fixation times "can be used to assess how far people have progressed toward memorizing a visual pattern". The <u>average fixation times</u> might, therefore, also indicate how fast the Ss can perceive the traffic situation ahead. <u>Single fixation time</u>, however, does not adequately refer to the information input occurring (COHEN, 1977). Single fixation times might be influenced by random factors but they also depend on the magnitude of the previous eye movement (e.g., SCHOILDBORG, 1969). Nevertheless, drivers who had a shorter mean fixation time have, presumably, a greater processing capacity. The underlying assumption to this statement is that the average amount of information input corresponds to the number of changes in the fixated state of the eye within a defined time interval. Actually, the total number of fixations on the experimental route varied only randomly between subjects passing the building site. The subjects therefore might have adjusted their preferred traveling speed to their processing capacity, i.e., a subject with a higher processing capacity would drive his car faster because he would need less time to pick up "discrete packages of information" for correct steering. This skill must be attributed more to a subject's individual ability and less to his driving experience, because the experimental route represents an uncommon traffic situation.

This interpretation is supported by additional empirical data. Other investigations show that there is a tendency toward prolonged fixation times when the driver is under the influence of alcohol (BELT, 1969), carbonmonoxid (SAFFORD, 1971), sleep deprivation or when he is fatigued (KALUGER and SMITH, 1970). In these situations, the general visuomotoric skills are presumably inhibited; a fact that is manifested in longer fixations of the eye. Further support for this suggestion is reviewed in GOULD (1976).

These findings, nevertheless, do not suggest a general relationship between a subject's mean fixation time and his processing capacity as manifested in the driver's preferred speed of driving. Such a relationship might only be observed if the three following conditions are fulfilled:

(1) if the subject is loaded with a great amount of information which he must process in a short time, (2) when the subject cannot anticipate the future path of driving and (3) when information input occurs mainly through foveal, in contrast to peripheral, vision.

The capability for processing information might depend on short term memory. Even when the information input occurs in single successive fixations, i.e., in "discrete packages", they are integrated to a subjectively continuous representation of the environment. At the same time a modification of the subject's cognitive schema occurs which in turn might determine the next fixation. This process might depend on the way a subject encodes and decodes the information available. MILLER (1956) pointed out that a proper chunking strategy "is an extremely powerful weapon for increasing the amount of information that we can deal with". This reasoning is in accordance with the discussed inter-individual differences observed while drivers passed the building site.

A further central issue of this study concerns the succession of eye fixations. The causal relationship found between the successive fixations of the eye, as established for each subject individually, indicates a feed forward programming of the eye movements. The targets to be fixated in the next observation interval (N+1) could be predicted according to the fixated targets in the present interval (N) and the importance of the environmental variables in future intervals (see Table 4). Analysis of these two kinds of variables is sufficient in order to predict the future fixation. Therefore the target to be fixated on next is determined by the present information input (presumably in connection with the subjects' cognitive schema), as well as by the importance of the elements on the road ahead. This finding supports NEISSER's (1976) assumption that "each eye movement will be made as a consequence of information picked up, in anticipating more". This interpretation leads to the conclusion that every successive fixation of the eye is carried out in a manner influenced by prior eye fixations. It is therefore suggested that the order of information input as reflected by the driver's visual search strategy might correspond to a rational sequence of required modifications in the driver's cognitive schema in order to set up anticipatory programs for future sensomotoric activities (e.g., SCHMIDT, 1976).

The individual differences obtained in the first model approach (see Table 4) refer to the number of environmental vectors which had to be considered in order to establish an accurate model of the observed behavior of the eye. The total number of the observation intervals considered varies between the subjects from one (Subject No. 2) to five (Subject No. 1) which corresponds to the durations of 0.5 s to 2.5 s. It is possible that the number of observation intervals to be considered for establishing the subject's individual model, can also represent his effective preview time.

The existence of a causal relationship between successive eye fixations was also determined in the second model approach. Because past and present information input determines the next state vector, it is clear that the next target to be fixated is determined before the eye begins to move. This finding supports the suggestion of BHISE and ROCKWELL (1971) that the eye is functioning as a two channel processor. While foveal information input corresponds with conscious information input, peripheral vision might be attributed in the present experimental conditions essentially to a selection of the target to be fixated on next. This conclusion contradicts the opinion that there are fixations strictly devoted either only for exploring or for information processing. It is, nevertheless, possible that the proportional sharing between information picked up for exploration and for processing might differ from one fixation of the eye to another. These proportions might alter according to environmental conditions, the task to be done, the subject's motivation, his task specific abilities and so on.

An additional theoretical importance of the discussed causality between the successive fixations of the eye can be related to different theoretical models of eye movements. A relationship between following movements of the eye (each leading to the next fixation) has been frequently suggested. The results presented here empirically support this important presupposition.

In discussing the second model approach it was pointed out that advance targets of fixation can be predicted according to the information already picked up. Even though in this second model approach the environmental variables were not considered directly in the model, these are included implicitly, because the subjects fixate targets of importance and because targets to be fixated ahead are selected by peripheral vision when the eye is focused in another direction. In line with this reasoning, it might also be assumed that the temporal control of information input might be achieved by a proper visual layout of the driver's near environment.

The experimental route used was only of a short distance. Therefore the subjects could complete the experimental task quickly, i.e., within a small number of observation intervals. Because of this, the limited numbers of observational intervals that lead to the development of the two model approaches discussed precluded validation. The goal of the next experiment is to establish time discrete process models for driving on a longer section. Then a first attempt should be made for predicting future eye fixations on an independent set of data.

Chapter 4

SUCCESSIVE EYE FIXATIONS AND THE STABILITY OF EYE MOVEMENT BEHAVIOR

SUMMARY

The eye movement behavior of seven subjects was recorded during driving - twice on the same experimental route - in order to collect two sets of independent data. The comparisons of these sets of data showed in general that there was no significant difference between the two runs in regard to fixation times, saccade amplitude and targets of fixations. When considering the individual level, however, some intra-individual tendencies toward fluctuations were obtained. Nevertheless, different subjects did not manifest equal tendencies. The fluctuations observed, however, did not prohibit the use of these two sets of independent data for the system theoretical approach.

For the system theoretical approach the discrete time intervals were defined in correspondence with each fixation's duration by using an interpolation method. The first set of data was used for establishing time discrete process models and the second set for their validation. The models' validation was not perfect, probably because the drivers' processing capacity was not completely loaded. However, because a great part of future eye fixations could be predicted successively, it is supposed that more accuracy can be obtained under different environmental conditions, encompassing a greater sensomotoric load.

1. INTRODUCTION

The car driver orients himself in his environment mainly through visual information input and its adequate processing. These processes are a precondition for the sensomotoric control and guidance of the car on the road, and of its movement parameters in lateral and longitudinal directions. Furthermore, this information input also facilitates the anticipation of future possible events as well as the actual realization of suitable reactions. The information input needed to fulfill both requirements, i.e., control and anticipation, is characterized by DONGES (1978) as information for stabilization and for guidance, respectively.

The driver's visual search for traffic-relevant and task-oriented information is principally manifested by the succession of saccadic movements and each subsequent fixation of the eye. These two main alternating states of the eye, i.e., the saccade and the fixation, characterize essentially the driver's eye movement behavior. They play different functional roles in gathering the necessary information.

The saccadic movement's essential purpose is to bring a target of special momentary interest, within the shortest time possible, into projection on the fovea (e.g., CARPENTER, 1977).

During the saccadic movement, however, the information input is rather inhibited (e.g., VOLKMANN,1976). On the other hand, when the eye is in its fixated state, essential information input occurs. Meanwhile, the most rapid as well as the most detailed information input is facilitated by the fovea in opposition to the peripheral regions of the retina. Therefore the different points, i.e., targets, which the driver fixates successively correspond essentially with the actual sequence of information picked up in detail.

The driver who travels at rather high velocities has neither the opportunity nor the obligation to fixate all present targets completely (i.e., cue theory, e.g., KOLERS, 1968). Because he acts under a limit of time and processing capacity, he must carefully concentrate his visual attention on picking up the most important part of the information available at each moment. As a result, the points of fixation are not distributed stochastically on the road and its near surroundings. On the contrary, the program governing the saccadic movements must always guide the eye toward targets of instantaneous importance. This requirement, which guarantees adequate information input, is in accordance with theories on the central programming of eye movements (e.g., FROST and POEPPEL, 1976; RAYNER and McCONKIE, 1976).

The ongoing information input includes two interrelated dimensions. These are the spatial and the temporal extensions. The spatial extension includes more than information about the road characteristics ahead. It provides, additionally, information about the present objects, their sizes, directions etc. The temporal extension, on the other hand, facilitates making a one-dimensional time estimation. Due to the interaction of both these dimensions, the driver recognizes changes of the objects' relative locations, i.e., motions within time. This facilitates the perception of the objects' relative velocities as well as that of their respective directions.

The dual characteristic of the information processed in relation to the driver's cognition makes it possible for him to anticipate future traffic circumstances. He can then set up sensomotoric programs for control and guidance operations.

The eye movement behavior can be characterized analogously also by spatial and temporal variables. The spatial variable includes the specific targets which the driver fixates. The temporal variable, on the other hand, refers to the fixations' respective durations,as well as to the succession of fixations on available targets.

The spatial characteristics of the fixation points were investigated mainly under laboratory conditions, e.g., while viewing static pictures. MACKWORTH and BRUNER (1970) have demonstrated that an optical array's informative parts, i.e., those which contain unpredictable features, are most often fixated. Less informative details, on the other hand, are fixated seldom or not at all. This result is confirmed also by ANTES (1974) as well as LOFTUS and MACKWORTH (1978). The pattern of eye fixations depends, however, not only on the characteristics of the optical array, but also on the subjects cognition. YARBUS (1967) showed that a change of the subject's instructions in regard to the viewing purpose correspondingly altered his fixation pattern. Accordingly, the driver's intention with respect to his motoric task might influence his eye movements behavior (e.g., see chapter 2). The driver's visual search strategy is actually quite different when driving a car as compared to merely observing the same scene in the laboratory.

Under free viewing conditions, e.g., when no instructions are given, it might be assumed that the observer directs his goal of viewing intrinsically. The subject does not intend, therefore, to cover the whole optical array with his effective field of view. Instead, the viewer uses a visual search strategy leading him to refixation vis-à-vis overlaps at some details, while other parts of the picture remain unfixated (e.g., SAIDA and IKEDA, 1979).

When driving a car in dynamic situations the subject also manifests spatial regularities in his visual search strategy. The relationship between environmental parameters and the visual search strategy have been summarized elsewhere (COHEN, 1980).

The <u>temporal</u> <u>dimension</u> of eye movement behavior during information input from a continuously changing dynamic situation is a rather neglected field of research. Even when using static optical arrays, e.g., pictures, the temporal course of the successive fixation is seldom considered by the investigation (e.g., ANTES, 1974). More attention is directed, however, toward descriptive values like average fixation times. It is known, for example, that the fixations' mean duration tends to increase when the information density increases (GOULD, 1976), when the subject is fatigued (KALUGER and SMITH, 1970), or when he is under the influence of alcohol (MORTIMER and JORGESON, 1972). Also young children tend toward longer fixation times than adults, perhaps because their information processing mechanisms are not yet fully developed (MACKWORTH and BRUNER, 1970). These and other findings on fixation times are of importance. However, when one summarizes the respective durations of a sequence of fixation in a single value like mean fixation times, a rather great part of the dynamics, as manifested in the visual search strategy, is lost.

A first attempt to analyze the sequences of car drivers' eye fixation, with simultaneous consideration of spatial as well as temporal variables in relation to the driver's actual information input, was possible by applying a system-theoretical approach (see the previous chapt.). However, the data had to be prepared in accordance with the three following essential aspects:

- First, the temporal continuity was divided into a succession of arbitrarily chosen discrete time intervals (N) of 0.5 s each.

- Second, the road characteristics, obtained from a limited number of well-defined road elements, were denoted as environmental variables $W_{ij}(N)$ after their task oriented importance was scored by experts for each single time interval (N). The integrated significance of all separate environmental variables $W_{ij}(N)$ for each single time interval (N) was denoted as an environmental vector $\underline{W}_j(N)$, which indicated the respective instantaneous importance of all defined road elements.

- Third, the driver's actual information input from the defined road elements during the time interval (N), and the respective alternations occurring between the present time interval (N) and the previous one (N-1), were denoted as state variables $X_{ij}(N)$. Their integrated effect was denoted as state vector $\underline{X}_i(N)$. The state vector $\underline{X}_i(N)$ indicates, therefore, the instantaneous information input and the alternation occurring.

The delineated data preparation facilitated the determination of two kinds of time discrete process models of each driver's sequence of eye fixations, individually. Both of the kinds of models obtained describe each driver's sequence of fixations accurately.

In the first kind of model approach it was pointed out that the instantaneous state vector $\underline{X}_i(N)$ and the environmental vectors ahead, e.g., from $\underline{W}_i(N+1)$ to $\underline{W}_i(N+m)$, are completely sufficient for mathematically describing a driver's pattern of fixations. This finding indicates that the next information input, meaning the next target of fixation, depends on previous information input, i.e., the driver's cognitive schema in relation to the path of driving ahead.

The second kind of model approach pointed out that the previous information input of the past time intervals (N-k) to (N) determines the next target of fixation. This finding suggests that the information a driver has already acquired determines the information he is seeking.

However, the data evaluated facilitated the acquisition of prediction models only. Because no further set of independent data was available, the obtained models could not be validated. Therefore one goal of the present study was to evaluate two sets of independent data. One of them was required for the development of time discrete process models, as done previously. The second set of data was to serve in making an attempt to validate the prediction models to be obtained from the set of data.

In the previous study all essential conditions for reasonable analysis of eye movement behavior were fulfilled (e.g., (COHEN, 1980). The road designer, however, does not consider such scientific requirements when projecting the path of the road. On the contrary, he makes efforts to reduce the driver's workload and to increase his preview time, i.e., his anticipation. Therefore it is also of interest to study the driver's eye movement behavior under conditions which do not completely fulfill the theoretical requirements for data analysis but rather correspond with more common traffic circumstances. The decrease of drivers' workload, however, might allow him a spare capacity for picking up information which is of no direct significance for steering a car. Furthermore, a decrease of information density causes an increase of the effective field of view (e.g., GOULD, 1976). It is therefore assumed that the less information a driver has to process, the greater is the role of his peripheral as compared to central vision (e.g., BHISE and ROCKWELL, 1971). This consideration suggests that under conditions of a moderate or low workload, the input of relevant information might compete with the input of non-relevant information. In this study, however, an experimental route, characterized by a rather moderate load of information, was to be used.

The methodological approach used previously endeavored to divide the temporal continuity into arbitrarily chosen, discrete time intervals. These intervals, of course, did not necessarily correspond to the durations of eye fixations. Therefore the defined instantaneous information input in each time interval (N) was considered according to the fixations occurring during this time which entailed either whole fixations or their weighted parts. A methodological attempt was also to be made concurrently in order to avoid, or at least to reduce, an arbitrary division of the temporal continuity into discrete time intervals. They were required, nevertheless, to correspond exactly to each fixation's respective duration, which is a more suitable rate for the definition of each time interval (N).

A last question of importance regards the stability of eye movement behavior. Even though it is a central issue in investigating the parameters of car drivers' eye movement behavior, it is still a rather neglected area of research. However, some evidence for the stability of car drivers' visual search strategy is given in a previous study of ROCKWELL and BHISE (1971). They concluded that fixation times, directions of sight and the magnitude of the saccades does not alter for repeated driving over the same route. However, the subjects were acquainted in advance with the experimental path of driving. Therefore whether eye movement behavior alters on a strange road between a first and a second trial should be investigated. This comparison should be carried out by using conventional statistical methods.

2. EXPERIMENT

In the present experiment each subject had to drive on the same road twice in order to collect two sets of independent data. One set of data was required for establishing individual time discrete process models, which describe each eye movement behavior accurately. The second set of data was required to permit an attempt at validating the individual models established. At the same time these two sets of data served also to investigate the stability of eye movement behavior.

The experimental route was characterized by a moderate load of information, which the driver had to process. Nevertheless, a continuous visual search for traffic relevant information was required.

2.1. Driving route

The subjects arrived at the experimental route after a driving period of 15 to 20 minutes, during which they could accustom themselves to the Eye-Marc-Recorder. The driving route was an infrequently used suburban road, characterized by a rather slight curve to the left. The experimental route began just before negotiating a pedestrian crossing and ended upon reaching a subsequent one in the form of an intersection. On each side of this road a bus stop was located. In the different runs, the presence of pedestrians or traffic from the opposite direction was not controlled in order to maintain natural field conditions. (Due to the system-theoretical method of data evaluation the importance of such differences were taken into account and remained balanced.)On the other hand, no driver followed another car, because a leading car influences the follower's eye fixations (e.g., MOURANT and ROCKWELL, 1970).

Under these driving conditions it might be assumed that the processing capacity of no driver was overloaded. Each of them could also anticipate the advance path of driving from a rather great distance, even though none of them was familar in advance with the route. Furthermore, there was very little need to carry out unpredictable motor activities, such as changes of direction or of velocity.

2.2. Subjects

Seven subjects participated in this experiment. Each of them used his own car, in order to preserve the driver's motor habits. Therefore different subjects used different middle-class cars. Essential data concerning the subjects are summarized in Table 6. None of the subjects knew the goal of this experiment and they were also told that there were no norms in "good visual search strategy", in order to encourage them to maintain their usual eye movement behavior.

subject No.	age	sex	driving experience		number of accidents	type of car
			in km	in years		
1	27	♀	12'000	3	1	VW Rabbit
2	24	♀	51'000	3	0	C2V
3	29	♂	200'000	8	3	Fiat 127
4	31	♂	80'000	11	0	Renault 4
5	30	♀	50'000	4	0	Toyota/ Corina
6	35	♂	200'000	17	1	Alfa-Julietta
7	27	♂	120'000	9	2	Renault 4
$\bar{X}$	29		102'000	7.9	1	

Table 5: The driver's characteristics, his experience, and the cars used.

2.3. Data registration

Each driver's eye fixations were registered in his environmental surroundings with a NAC Eye-Marc-Recorder, and recorded on an AKAI-video-recorder. This record permitted the evaluation of data on targets of fixation, the amplitude of the saccades and duration of fixations, as well as consideration of the specific traffic conditions. During each experimental run the environment was simultaneously photographed with an NIKON 2 FS motor camera using a frequency of approximately two shots per second. These photos were needed for presenting situation sequences to traffic experts, in order to judge the task oriented importance of defined elements of the road from the same discrete places which the driver crossed.

2.4. Scoring the relative importance of the road elements

The driving path was beforehand divided into four categories, i.e., elements of the road, as follows:

1. focus of expansion, which was defined as the furthest place where the driver could still determine his advance path of driving (surrounded by an area of approximately 2^{o} around it, which corresponds to the extension of central vision),

2. left of the path, which included the area to the left of his own path of driving, i.e., left of the (real or imaginary) middle lane line,

3. path of driving itself, limited in a lateral direction by the road's (real or imaginary) middle lane line and the sidewalk on the right. In a longitudinal direction the path of driving was limited by the road's focus of expansion,

4. right of the road, which included the spatial area to the right of his own path of driving, and

5. elsewhere, which was a fifth category in the conventional data analysis, used when the subject looked toward the sky or fixated on the rear view mirror etc. This category was, however, complementarv to the four mentioned ones.

This partition of the driving path into discrete elements of the road corresponded to the environmental variables to be considered. Therefore it is necessary to know the task oriented relative importance of every element of the road in relation to the driver's position on the road, as well as to other traffic occurrences.

For scoring the relative importance of the road elements defined, five experts were individually presented a letter-case containing a total of 14 sequences of photos taken (with a frequency of two per second) while executing each experimental run. Of course, none of the photos included any data on eye fixations. The number of single photos within each sequence varied among the runs according to the driver's speed of traveling as well as the actual start and end of the photographic record. At a short distance from the negotiated intersection, the subjects made especially rapid coordinated eye-head-movements, which prohibited further continuous data evaluation.

The task of the five experts engaged was to score every element of the road in every single photo according to its task-oriented relative importance for safe driving. They were instructed to use a rating scale which ranged from the value 1 to 7. They scored an element of the road with the value 1 if it was of greatest importance for driving, i.e., when its perception was necessary for being able to drive correctly. If an element of the road had no importance at all, then the value 7 was used. The intermediate values were used for graduations between the scores 1 and 7. All experts' scores were summed up for every experimental run and every element of the road, in each photo. The scores of each element could therefore range between a minimum of 5 and a maximum of 35 (see Table 7).

2.5. Data treatment in the system theoretical approach

The system theoretical analysis of the data strives to determine and validate, for each driver, a dynamic process model that allows the successive prediction of the driver's eye fixations. As single eye fixations were to be predicted successively, the state and environment variables had to be defined in a different way than described previously. The model building method itself, however, remained the same.

State variables:

To describe the location of the eye fixations, four categories of road elements were considered: 1) focus of expansion, 2) left side of the road, 3) driving path, 4) and right side of the road, as defined above.

In order to get a metric measure for the location of the eye fixations, each fixation was also described by its coordinates in a x/y-plane representing an artificial visual field of the driver (see Fig. 8).

This artificial visual field was arbitarily divided into four sectors, each of them summarizing all possible fixations on one of the four categories. Each eye fixation of the i'th subject could then be described by the following state variables:

$X_{i1}(N)$: X-coordinate of the N'th eye fixation

$X_{i2}(N)$: Y-coordinate of the N'th eye fixation

$X_{i3}(N)$: duration of the N'th eye fixation

$X_{i4}(N)$, $X_{i5}(N)$, $X_{i6}(N)$ describe the deviation of X_{i1}, X_{i2} and X_{i3} in successive observations.

$$X_{ij}(N) = X_{ij}(N)-X_{ij}(N-1); \; j = 1, 2, 3$$

To simplify the notation, all state variables were understood as components of a state vector $\underline{X}_i(N)$.

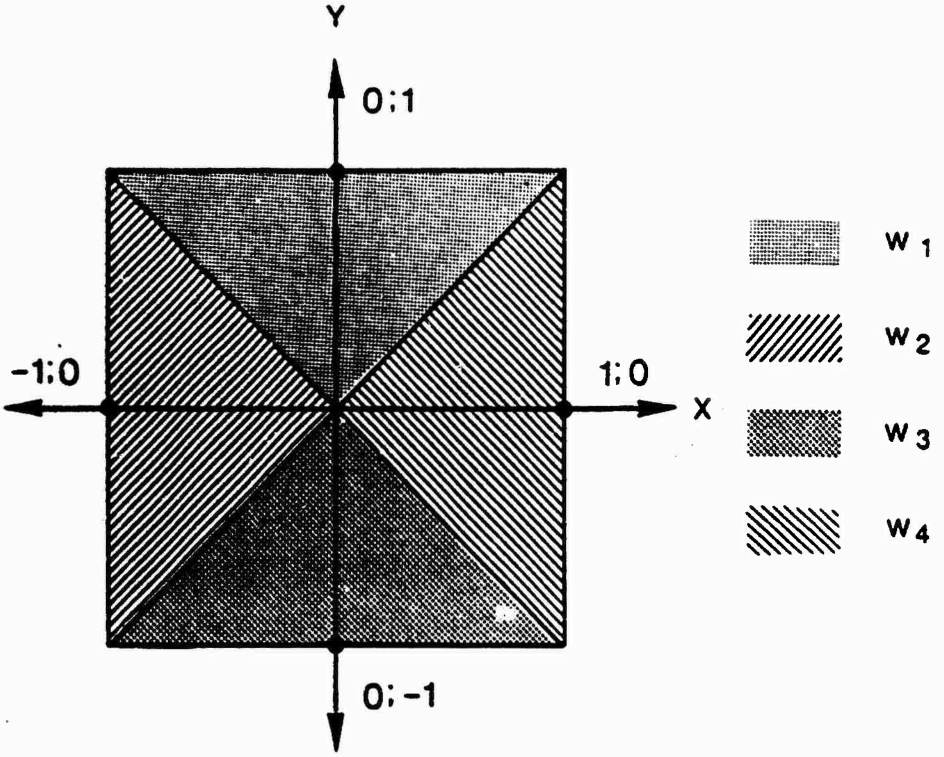


Figure 8: Car driver's artificial visual field.

Environment variables:

Each of the four road elements exerts a specific dynamic importance for the task of ste ring the car. This relative importance of the road elements wer described by environmental variables.

In order to estimate the varying importance of the road elements while a subject was steering the car, the street was photographed in 0.5 sec intervals for each run of each subject. An estimate of the relative importance of the road elements could be found by summarizing the corresponding scores of the experts for each eye fixation. For a run of the i'th subject, the environment variables were defined as follows:

$W_{i1}(N)$: relative importance of the driving path over a long distance during the N'th fixation.

Similarily, $W_{i2}(N)$, $W_{i3}(N)$, $W_{i4}(N)$ describe the relative importance of the other road elements (see Fig. 9).

Summarizing all environment variables in an environment vector $\underline{W}_i(N)$ allowed a simplification of the notation.

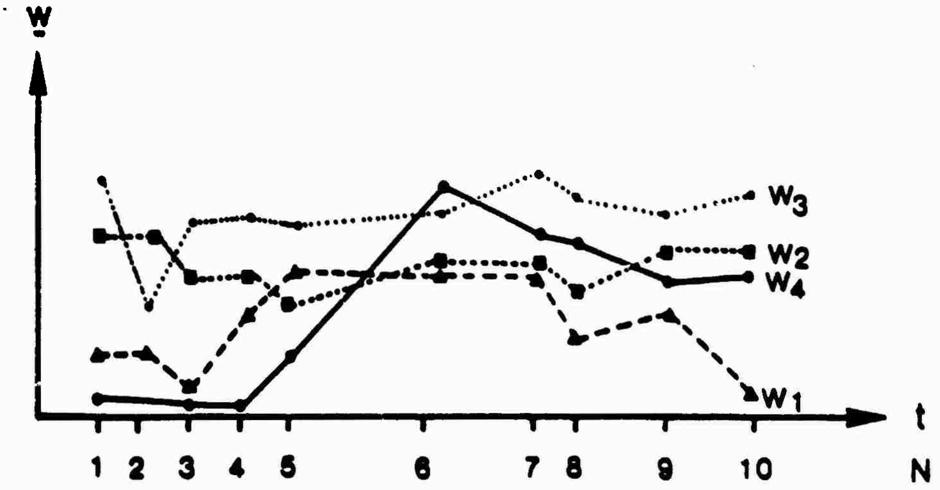


Figure 9: Schematic sequence of the environmental variables W_j which represent the task oriented importance of defined road elements vs that of $\underline{W}$.

A run of the i'th subject could then be fully described by the sequence of state vectors (giving the coordinates of the successive eye fixations) and the sequence of environment vectors (describing the varying importance of the road elements).

Each of the seven subjects had to evaluate two runs on the same route; for each subject we received two independent sets of data. On the first set, a prediction model was developed, and the second set was used to validate the model.

The prediction model:

A prediction model aimed to give a good prediction $\underline{X}_i(N+1)$ for the (N+1)'th state vector (eye fixation), given the momentary and previous eye fixations and a number of environment vectors lying ahead $\underline{W}_i(N+K)$; $K = 0, 1, 2, \ldots K_{end}$.

If an unknown but time invariant mathematical steady relationship F_i exists between $\underline{X}_i(N+1)$ as output and $\underline{X}_i(N)$ and $\underline{W}_i(N+K)$ as input variables, then F_i can be approximated by a set of mathematical function f_i. The prediction model, giving predictions for $\underline{X}_i(N+1)$ basing on the observed $\underline{X}_i(N)$ and $\underline{W}_i(N+K)$, can be formulated by

$$\hat{\underline{X}}_i(N=1) = \underline{X}_i(N=1)$$

$$\hat{\underline{X}}_i(N+1) = f_i\left(\underline{X}_i(N-I),\ \underline{W}_i(N+K)\right) \text{ with}$$

$\hat{\underline{X}}_i$ denoting a prediction for $\underline{X}_i$ and f_i standing for the simplest set of functions that allow an accurate approximation of F_i.

The model building procedure differed in two points from the method described in the previous chapter.

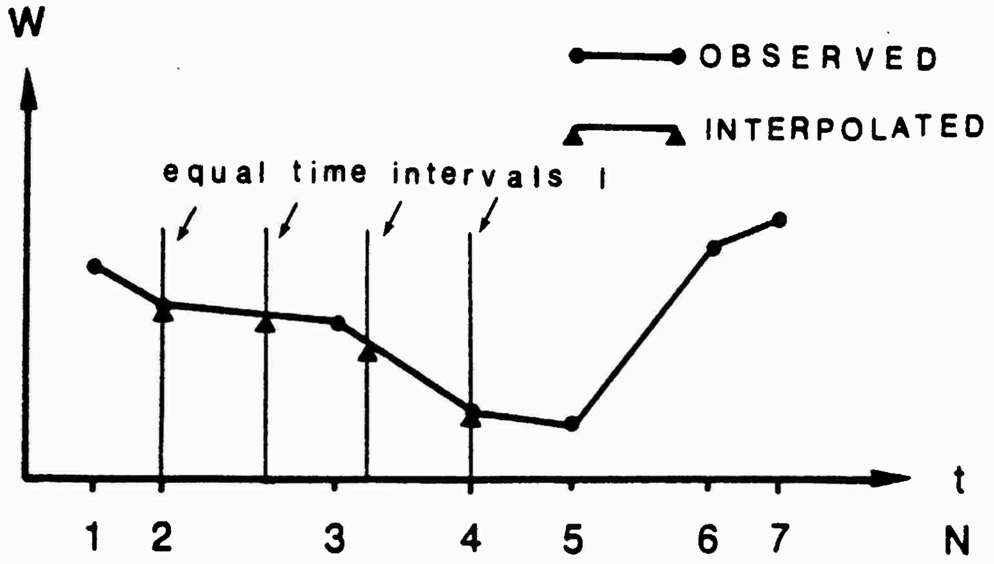
1) Validation of the model: We consider a process model a prediction model, when it can be validated on an independent set of data.

Thus, for each subject the data of the first run were used to determine a process model, and the data of the second run were used to check the validity of the process model as a prediction model.

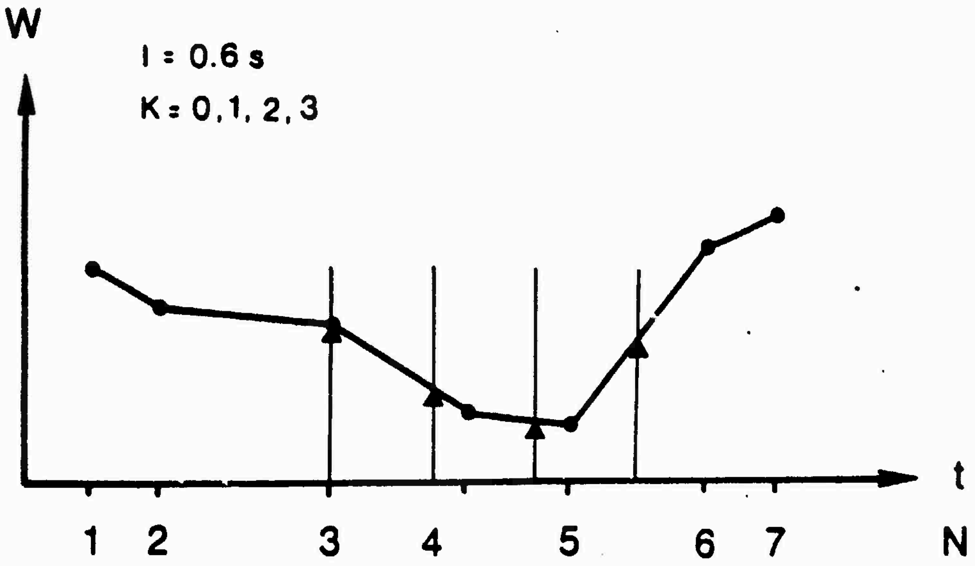
2) The model predicts single eye fixations of different duration. As the environmental vectors were defined for the duration of the corresponding eye fixations, the $\underline{W}_i(N+1)$, $\underline{W}_i(N+2)$, ... $\underline{W}_i(N+K)$ were not defined for equal time scale intervals.

In order to use, for each prediction, an equal duration of preview time vs the "environment ahead", the environmental vectors were linearly interpolated for each fixation as schematically shown in Figure 10.

By this procedure the prediction of the (N+1)'th state vector (eye fixation) could be based on a unique section of environment lying ahead.



Interpolation of the variable W_1 for the second eye fixation



Interpolation of the variable W_1 for the third eye fixation

Figure 10: Schematic representation of the interpolation method.

3. RESULTS

The two independent sets of each subjects' data were needed for establishing individual time, discrete prediction process models, and for their respective validation. Figure 11 and Figure 12 illustrate the environmental conditions as well as the sequence of eye fixation of Subject No. 2 during his first and, respectively, second run. Each fixation is marked with a black disk, which indicates also its actual running number. The disk's diameter corresponds approximately with the central vision's extension. Supplementary data, indicating the respective fixation times, is given in Table 7.

Before attempting model establishment and validation, however, it was necessary to test the stability of eye movement behavior over the two runs. This important precondition could be examined by using conventional statistical methods. The three following parameters of eye movement behavior were of particular importance: the fixation times, the saccade amplitudes, and the targets of fixations. The specific traffic conditions, however, also had to be considered.

Fixation times:

Figure 13 shows every subject mean fixation time and the

first run						second run					
N	t	W_1	W_2	W_3	W_4	N	t	W_1	W_2	W_3	W_4
1	22	24	22	20	17	1	28	23	21	22	17
2	22	24	22	20	17	2	68	23	21	22	17
3	18	24	22	20	17	3	44	21	19	21	17
4	16	24	22	20	17	4	66	21	19	21	17
5	46	22	20	16	15	5	22	22	24	20	16
6	30	21	21	18	20	6	48	22	24	20	18
7	20	21	21	18	20	7	22	21	20	23	21
8	26	18	21	20	18	8	18	21	20	23	21
9	16	18	21	20	18	9	40	20	19	21	18
10	22	18	21	20	18	10	38	20	19	21	18
11	24	22	22	22	19	11	28	18	20	21	17
12	26	22	22	22	19	12	42	18	20	21	17
13	18	18	22	21	21	13	26	16	18	19	20
14	36	18	22	21	21	14	26	16	18	19	20
15	52	18	23	22	24	15	32	17	19	22	21
16	20	21	21	23	21	16	16	18	18	21	21
17	20	21	21	20	21	17	30	18	18	21	21
18	6	21	21	20	21	18	18	18	16	22	21
19	14	21	21	20	21	19	44	18	16	22	21
20	22	21	22	21	18	20	30	17	18	22	20
21	18	21	22	21	18	21	24	17	17	22	19
22	20	19	22	20	17	22	20	17	17	22	19
23	28	19	22	20	17	23	34	18	18	23	20
24	54	19	20	21	17	24	22	18	18	23	20
25	28	19	20	22	16	25	28	17	17	21	18
26	24	19	20	22	16	26	22	17	17	21	18
27	24	18	19	23	16	27	52	17	20	22	20
28	16	18	19	23	16	28	32	17	18	20	19
29	22	18	19	23	16	29	36	17	18	20	19
30	38	16	18	21	20	30	24	16	16	20	17
31	34	16	18	21	20	31	22	16	19	20	15
32	24	16	22	20	20	32	24	16	19	20	15
33	24	15	21	21	21	33	34	15	19	19	11
34	22	15	21	21	21	34	26	15	19	19	11
35	24	15	21	21	21	35	22	15	20	16	15
36	16	16	22	21	18	36	18	15	20	16	15
						37	28	15	19	18	10
						38	40	15	19	18	10

Table 7: Scores of the four defined elements of the road which are focus of expansion (W_1), left of the path (W_2), path of driving (W_3) and right of the road (W_4) for each time interval N and each experimental run of Subject No. 2 as well as the respective fixation times (t) in 1/100 s (compare Fig. 4 and Fig. 5).

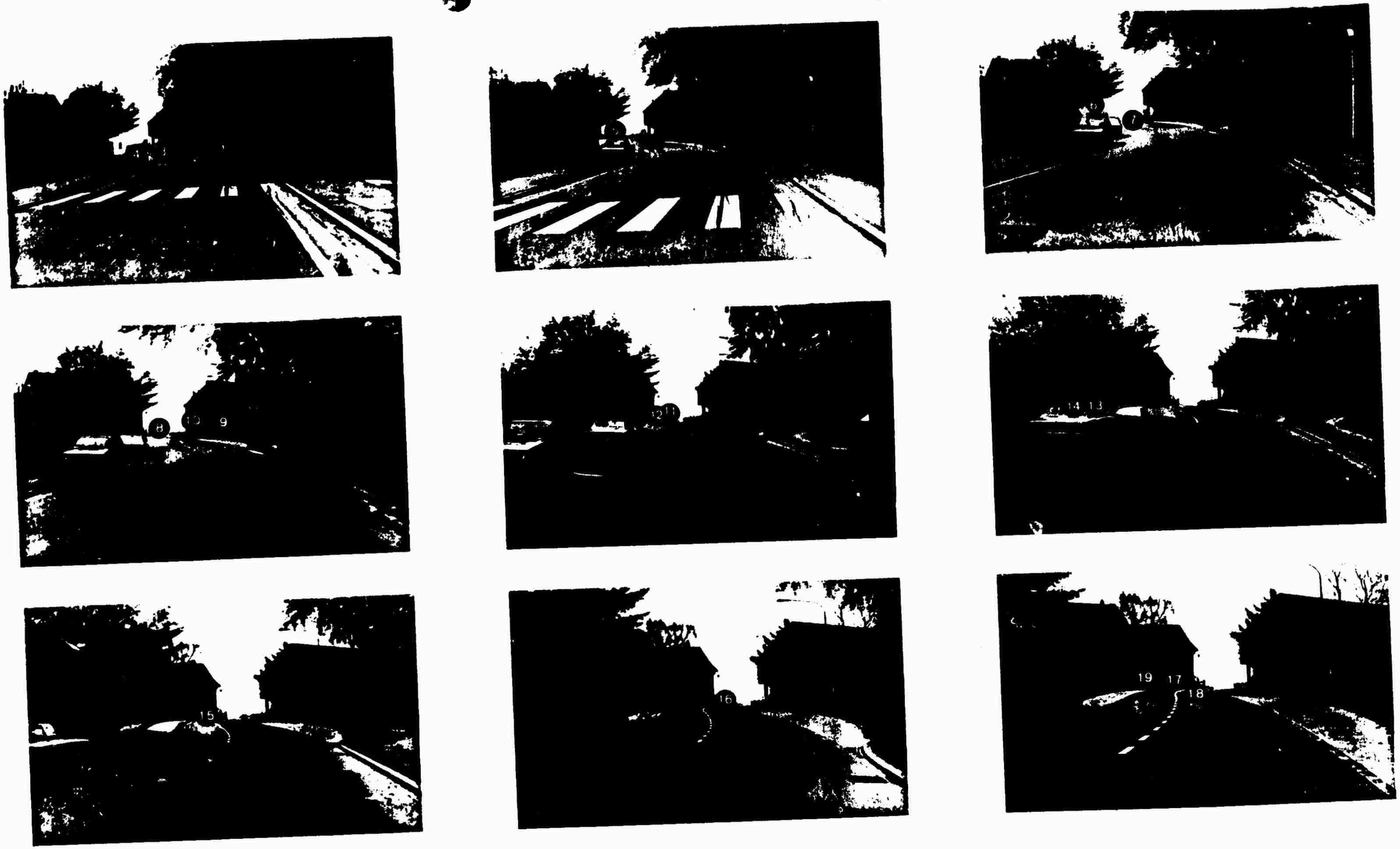


Figure 11: Fixation sequence during the first run (Subject No. 2)

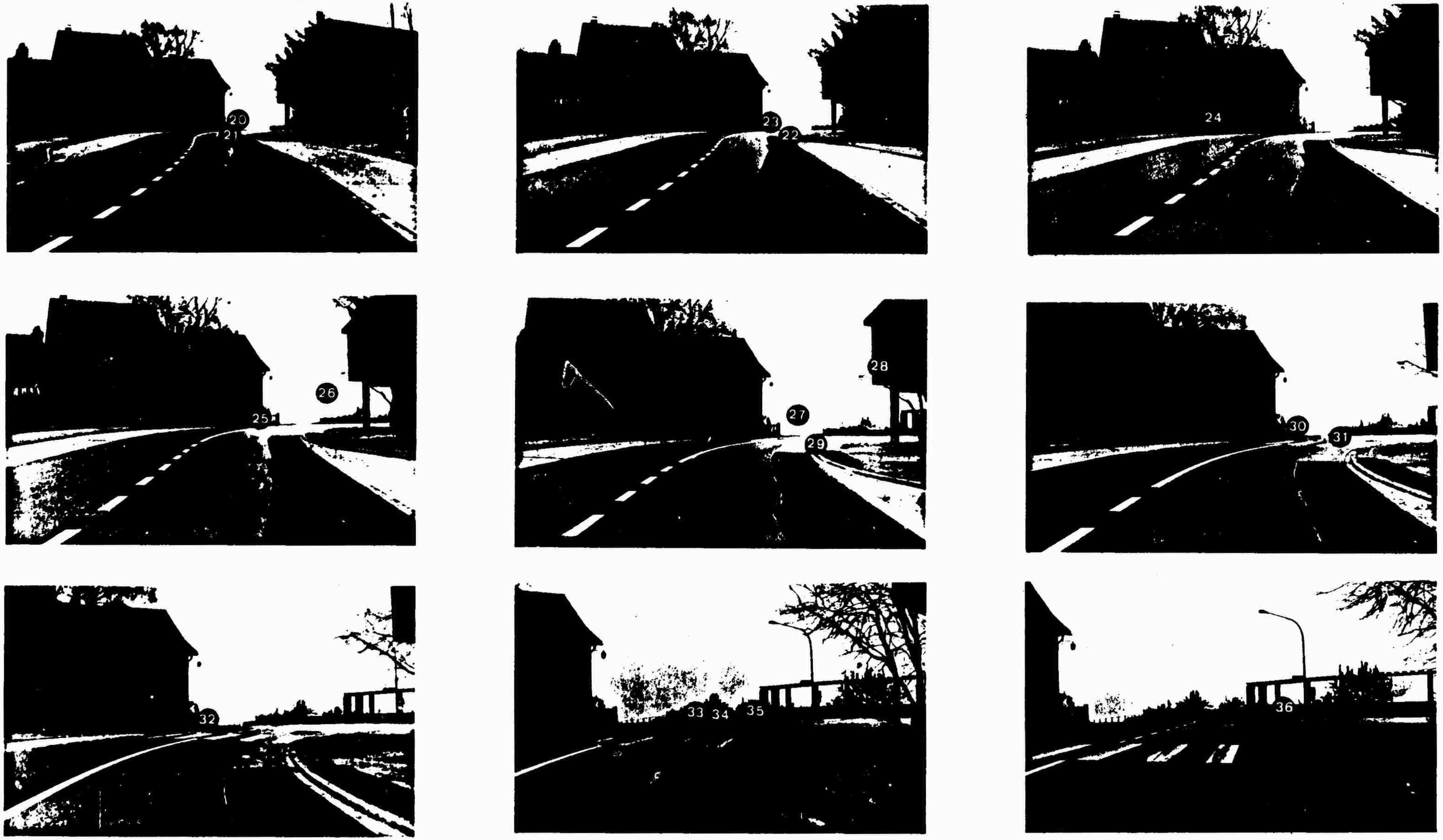


Figure 11: continued

Figure12: Fixation sequence during the second run (Subject No. 2)

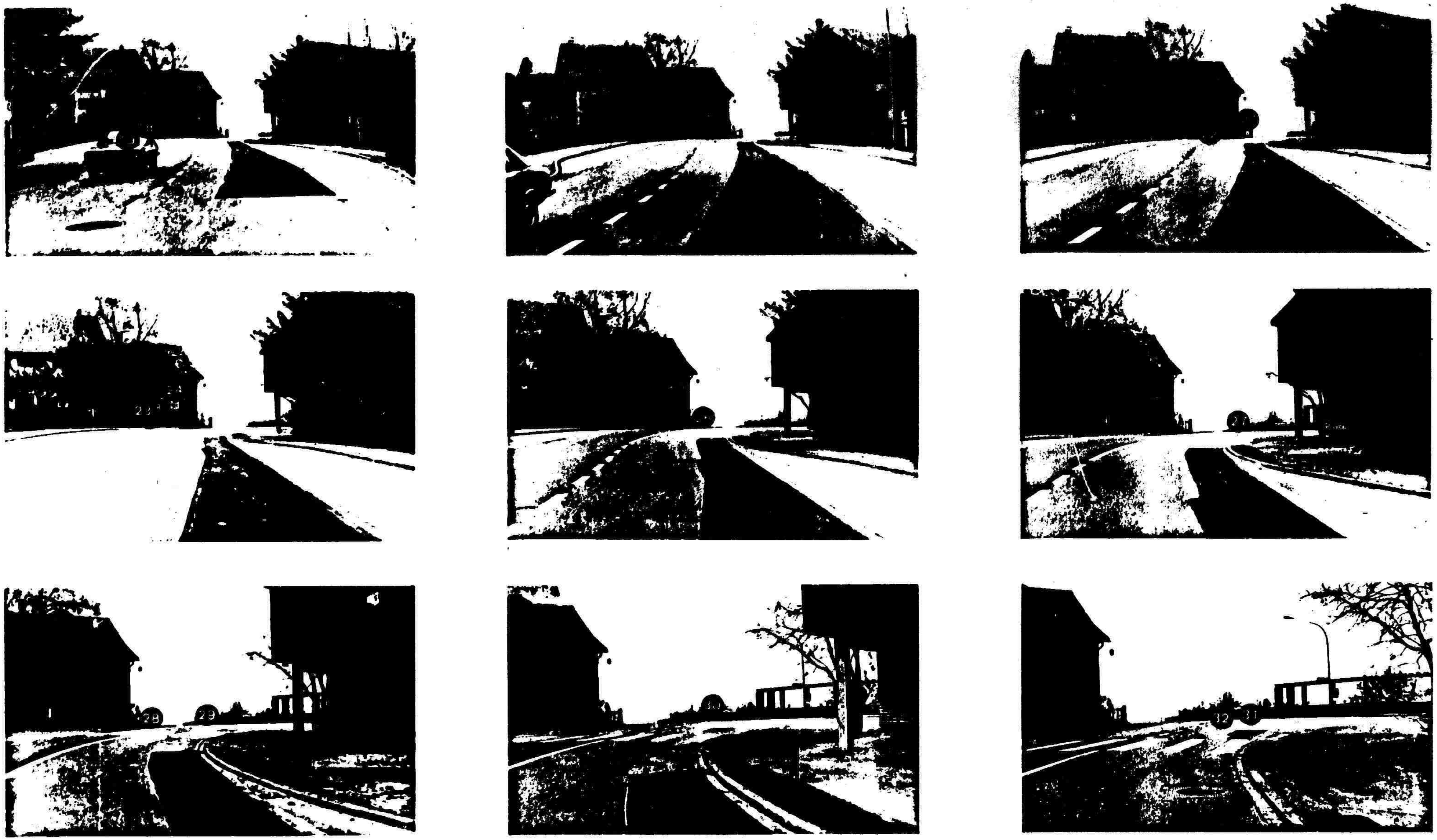


Figure 12: continued

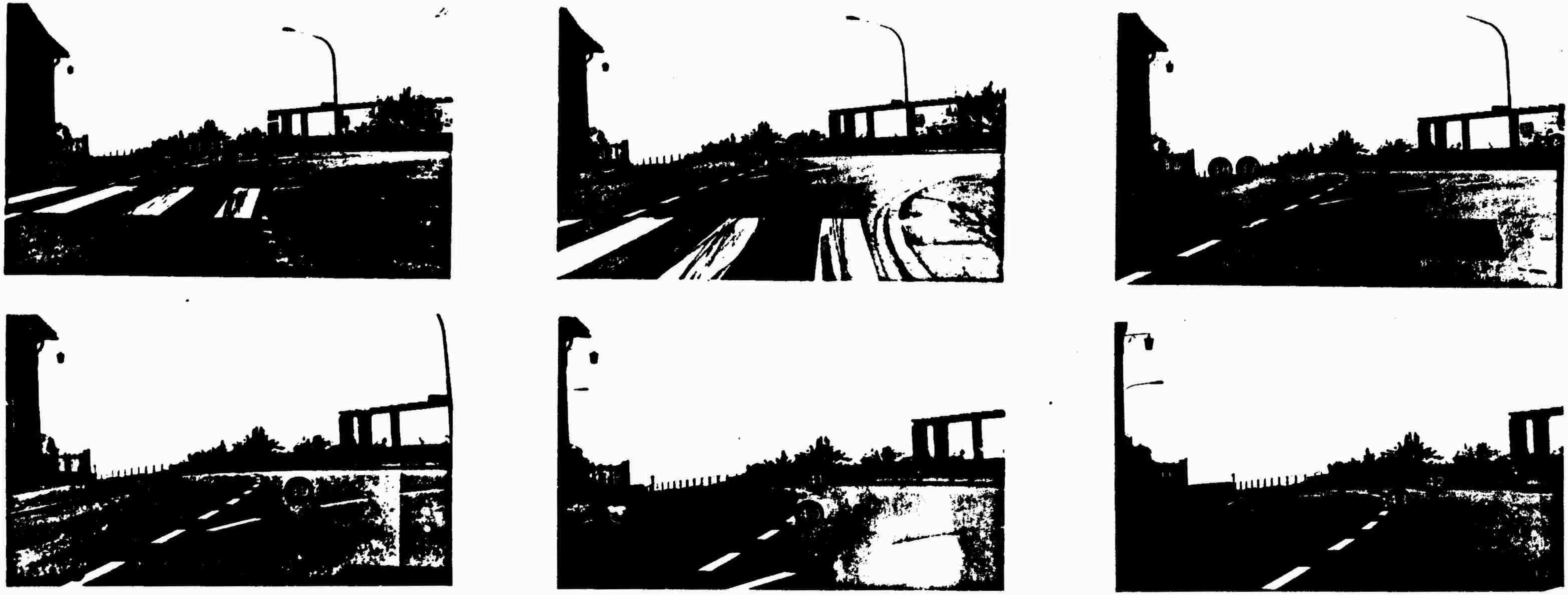


Figure 12: continued

respective standard deviation for each run. A further differentiation is given in Table 8, where the targets of fixations are also shown.

The original data were transformed in order to approximate the normal distribution for fulfilling the requirements of parametric testing methods. Afterwards, a three factorial analysis of variance was carried out. The results indicated a significant difference among the subjects ($F_{6,317} = 4.26$; $p < 0.01$). Their average fixation times over both runs ranged from 0.30 s to 0.39 s. Furthermore, there was also an intra-individual fluctuation between both runs as indicated by the significant interaction between subjects and runs ($F_{6,317} = 3.01$; $p < 0.01$). The intra-individual differences were to be considered later. Furthermore, the mean fixation time did not depend on the element of the road fixated. The differences varied between them only at random ($F_{4,317} = 1.48$; $p > 0.20$).

Saccade's amplitudes:

The saccade amplitudes refer to the magnitude of those eye movements which lead the eye toward a target to be fixated next. The average saccade amplitudes and their respective standard deviations are shown in Figure 14 for each subject and every

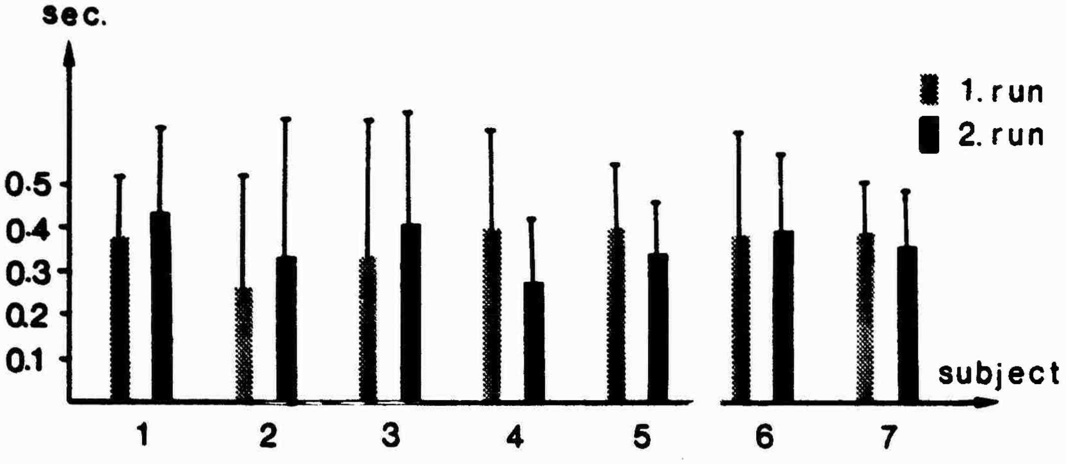


Figure 13: Individual mean fixation times and the corresponding standard deviations in each run.

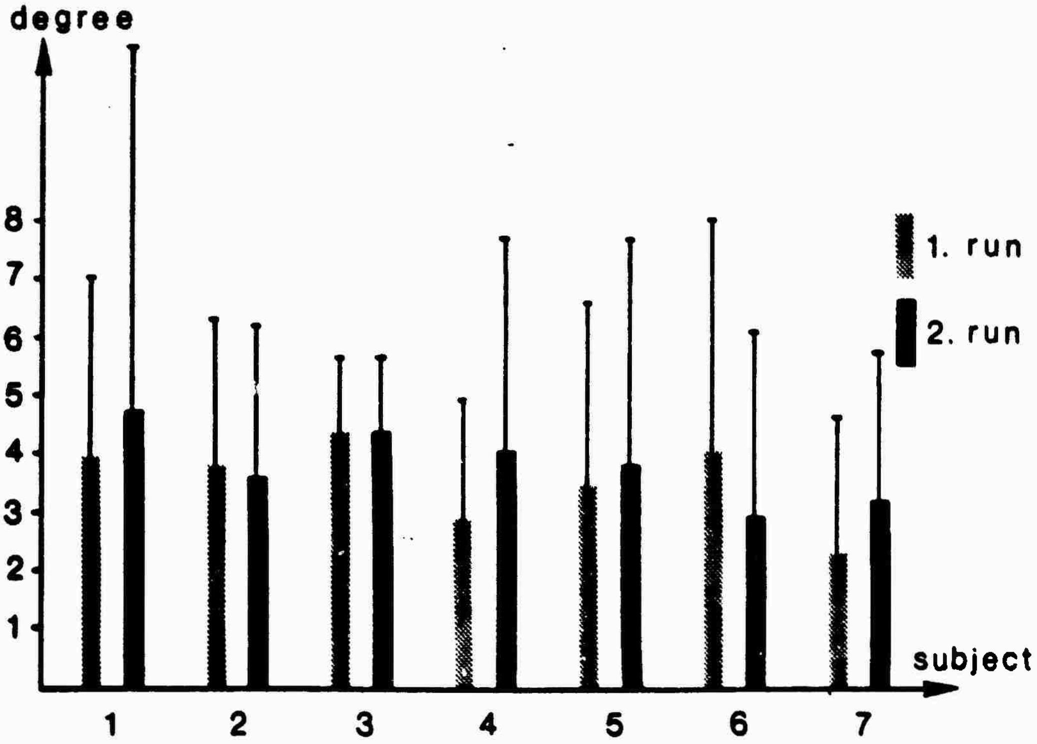


Figure 14: Individual saccade mean amplitudes and the corresponding standard deviations in each run.

	first run						second run						
road element	1	2	3	4	5	$\bar{X}_1$	1	2	3	4	5	$\bar{X}_2$	$\bar{X}_{12}$
subject													
1	37 (3)	48 (1)	36 (22)	39 (6)	- (0)	37 (32)	57 (6)	18 (1)	37 (6)	33 (4)	60 (1)	43 (18)	39 (50)
2	28 (9)	32 (9)	22 (12)	19 (4)	29 (5)	26 (39)	29 (12)	34 (12)	34 (17)	30 (2)	- (0)	32 (43)	30 (82)
3	38 (10)	34 (5)	24 (12)	22 (2)	- (0)	32 (29)	34 (4)	55 (8)	33 (7)	18 (1)	- (0)	41 (20	36 (49)
4	44 (3)	38 (5)	36 (8)	48 (6)	28 (1)	41 (25)	28 (2)	26 (11)	35 (6)	26 (4)	12 (1)	28 (24)	34 (49)
5	42 (1)	38 (8)	43 (10)	20 (1)	- (0)	40 (20)	35 (7)	32 (4)	36 (15)	31 (4)	- (0)	35 (30)	37 (50)
6	25 (2)	35 (6)	47 (11)	27 (4)	- (0)	39 (23)	42 (6)	22 (1)	39 (14)	45 (3)	- (0)	40 (24)	39 (47)
7	44 (9)	34 (11)	41 (6)	36 (1)	- (0)	39 (27)	37 (4)	42 (5)	25 (5)	24 (5)	38 (5)	33 (24)	36 (51)
	37 (37)	35 (45)	35 (81)	35 (26)	28 (6)	35 (195)	37 (41)	39 (42)	36 (70)	30 (23)	37 (7)	35 (133)	35 (378)

Table 8: Each subject's mean fixation time (in 1/100 s) and the respective number of fixations (in breaks) on every element of the road in each experimental run.

target of subsequent fixations. Their respective total number, on each element of the road, is also indicated in Table 9.

In general, the mean saccade amplitude varied between the first run (3.28°), and the second run (3.58°), at random ($F_{1,317} > 1$). The saccade amplitude depends, however, on the subsequently fixated road element ($F_{4,317} = 4.10$; $p < 0.01$). The following amplitudes were observed when the driver fixated subsequently right of the road (4.83°), left of the road (3.87°), road (3.37°), elsewhere (3.00°) and at the focus of expansion (2.75°). The differences seen have been caused, however, by road characteristics which represented a slight curve to the left.

A significant difference was observed among the subjects ($F_{6,317} = 3.57$; $p < 0.01$). Their respective mean amplitudes ranged between 2.20° (subject No. 3) and 4.23° (subject No. 1). On the other hand, no difference was observed between the both runs ($F_{1,317} < 1$). Also, no interaction was obtained between subjects and runs ($F_{6,317} = 1.39$; $p > 0.05$). This finding means that the saccade magnitude remained stable over both runs, and that this may have reflected individual visual search strategies.

	first run							second run						
road element	1	2	3	4	5	$\bar{X}_1$	road element	1	2	3	4	5	$\bar{X}_2$	$\bar{X}_{12}$
subject							subject							
1	3.75 (3)	3.90 (1)	3.30 (22)	6.56 (6)	- (0)	3.92 (32)	1	2.75 (6)	2.70 (1)	4.82 (6)	2.81 (4)	2.78 (1)	4.73 (18)	4.23 (50)
2	3.51 (9)	3.71 (9)	3.22 (12)	5.19 (4)	5.10 (5)	3.84 (39)	2	2.97 (12)	3.67 (12)	4.13 (17)	3.38 (2)	- (0)	3.65 (43)	3.74 (82)
3	1.68 (10)	2.13 (5)	2.50 (12)	3.15 (2)	- (0)	2.20 (29)	3	1.65 (4)	1.91 (8)	2.27 (7)	6.08 (1)	- (0)	2.19 (20)	2.20 (49)
4	1.28 (3)	[illegible] (5)	3.23 (8)	2.70 (6)	2.70 (1)	2.95 (25)	4	3.94 (2)	2.97 (11)	2.99 (6)	7.52 (4)	9.38 (1)	4.07 (24)	3.49 (49)
5	2.93 (1)	2.47 (8)	3.72 (10)	9.60 (1)	- (0)	3.27 (20)	5	3.94 (7)	7.58 (4)	2.57 (15)	4.86 (4)	- (0)	3.86 (30)	3.71 (50)
6	3.94 (2)	3.86 (6)	3.81 (11)	5.04 (4)	- (0)	4.05 (23)	6	2.14 (6)	2.40 (1)	3.31 (14)	3.43 (3)	- (0)	2.99 (24)	3.51 (47)
7	1.66 (9)	2.01 (11)	3.55 (6)	4.50 (1)	- (0)	2.35 (27)	7	4.88 (4)	3.81 (5)	4.86 (5)	2.21 (5)	1.98 (5)	3.49 (24)	2.89 (51)
$\bar{X}$	2.38 (37)	2.83 (45)	3.30 (81)	4.90 (26)	2.83 (6)	3.28 (195)	$\bar{X}$	3.08 (41)	3.33 (42)	3.46 (70)	4.13 (23)	3.15 (7)	3.58 (183)	3.43 (378)

Table 9: Each subject's mean amplitude of his saccades (in degrees) leading to fixation on every defined element of the road and the corresponding number of eye movements in each run (breaks).

Targets of fixation:

Figure 15 shows the relative frequency of fixation on each defined element of the road, in every experimental run. It is obvious that the distribution of fixations is, in general, similar over both runs. The five elements of the road were, however, fixated with different rates ($X^2 = 138.2$; df = 4; $p < 0.01$). The greatest part of fixations over both runs was devoted to the individual's path of driving (40.0 %) followed by fixation on the left of the road (23.0 %), focus of expansion (20.6 %), right of the road (13.0 %) and elsewhere (3.4 %).

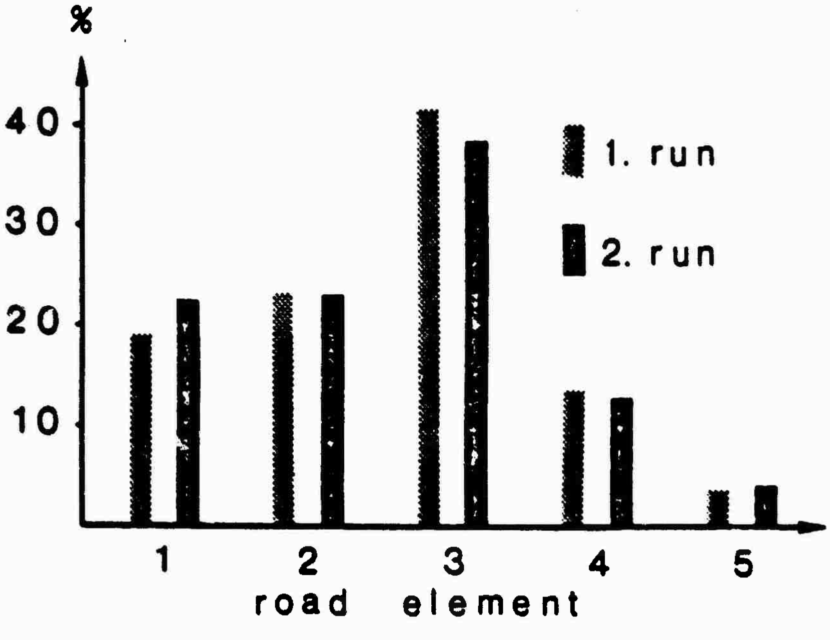


Figure 15: Fixation rates on defined elements of the road in each run.

Each subject's driving time was measured between the pedestrian crossings. Because the distance was constant, these times also reflect the average driving speed. The Spearman rank correlation coefficient was calculated for the mean fixation time and driving speed, which were neither for the first nor for the second run, significant
($r_s = 0.2$ and $r_s = -0.2$ respectively).

The individual level:

Although no significant differences were observed over the two runs regarding fixation times, saccade magnitudes and targets of fixations, it was of importance to analyze the individual levels. For example, despite the fact that the defined elements of the road were fixated across all subjects with similar frequencies, that did not mean that there were no individual tendencies toward shifts of attention between both runs. Also, it could not be expected that a subject would always fixate the elements of the road with equal frequency while repeatedly negotiating the same site.

Fixation times:

The intra-individual variations in fixation times over the two runs did not show equal tendencies. Some subjects prolonged their mean fixation times in the second run, as compared to the first one, while others shortened them. Also, the fixation times' standard deviation did not show an equal tendency (see Fig. 13).

The t-test was carried out for comparing each subject's fixation times between the two runs. A significant intra-individual difference was, however, obtained with Subject No. 2 only, who prolonged his fixation times in the second run (see Tab.10).

Saccade's amplitudes:

The saccade amplitudes also didn't change systematically over both runs. The standard devidations were rather great in comparison to the mean saccade amplitude. A significant prolongation of the saccade amplitudes was observed only with subject No. 7 (see Tab.10).

	fixation times	saccades' amplitude	targets of fixation
coefficient	t	t	X^2
subject			
1	1.89 x (48)	0.89 (48)	8.27 x (4)
2	3.28 ** (80)	0.49 (80)	7.21 x (4)
3	0.99 (47)	0.02 (47)	4.62 (3)
4	1.72 x (47)	1.89 x (47)	4.05 (4)
5	1.18 (48)	0.83 (48)	6.91 x (3)
6	0.18 (45)	1.44 (45)	6.06 x (3)
7	2.22 x (49)	2.35 * (49)	8.36 x (4)

Table 10: Coefficients indicating intra-individual differences between the two experimental runs for fixation times, saccade amplitudes and targets of fixation. (The numbers in breaks indicate the degrees of freedom.)

* $p < 0.05$

** $p < 0.01$

x $p - 0.10$

Targets of fixations:

There were no significant intra-individual differences between the targets of fixations during the first run as compared to the second run. Nevertheless, five out of seven subjects manifested a tendency toward shifts of attention.

The intra-individual fluctuations in the descriptive values described above do not seem to depend only on the specific traffic conditions. For example, Subject No. 4 drove the car twice under similar conditions but, nevertheless, there was a tendency toward variations of fixation times as well as amplitude magnitude. On the other hand, Subject No. 3 negotiated an oncoming car in the second run only, but none of the mentioned variables varied even to a level indicating a tendency (i.e., $p \sim 0.10$). Therefore it does not seem to be of importance to describe further individual cases. In concluding these considerations use of these two sets of independent data for the system-theoretical analysis would seem to be justified.

System theoretical approach:

The data of each subject's first run were used to determine an individual process model of the following form:

$$\hat{\underline{X}}_i(N=1) = \underline{X}_i(N)$$

$$\hat{\underline{X}}_i(N+1) = f_i\left(\underline{X}_i\ (N-I), \underline{W}_i(N+K)\right)$$

$$I = 0, 1$$

$$K = 0, 1, 2, \ldots\ldots 6$$

f_i represents a system of second order potential series of the given arguments.

The data of the subject's second run were then used to check the validity of the models. That means that no information was used for the model building. The models' predictions were adjoined to one of the four categories of the road elements depending upon the location in the artificial visual field (see Fig. 8). As an example, Table 11 shows the observed and the predicted targets of fixations for the first and the second run of Subject No. 2, respectively. The model was built on the first set of data and its validation was carried out on the second set. It may be anticipated, of course, that more fixations can be correctly predicted on the first set of data, which was also used for the model building, than on the first run

N	sequence of targets fixated	
	observed	predicted
1	4	4
2	3	3
3	3	3*
4	2	2*
5	1	1*
6	2	3
7	3	3*
8	1	2
9	4	4*
10	4	4*
11	1	1*
12	1	1*
13	2	2*
14	2	2*
15	2	2*
16	1	1*
17	2	3
18	3	3*
19	2	2*
20	1	1*
21	3	3*

second run

N	sequence of targets fixated	
	observed	predicted
1	4	4
2	3	3
3	3	3*
4	2	2*
5	1	1*
6	2	3
7	1	3
8	1	3
9	2	2*
10	2	2*
11	3	2
12	1	1*
13	2	4
14	1	3
15	4	3
16	3	1
17	1	3
18	2	3
19	2	3
20	2	2*
21	1	1*
22	2	2*
23	2	3
24	2	2*

Table 11: Sequence of observed and predicted targets of fixation for the first and the second runs (Subject No. 2). The two first fixations were used for the model building.

N obervation interval
1 focus of expansion
2 left of the path
3 path of driving
4 left of the road
* correct prediction

second independent set.

subject No.	1	2	4	5	6	7
percentage of correct predictions	44	45	37	57	45	50

Table 12: Percentage of correct sequential predictions of the targets of fixations for each subject.

A question of importance, at this point, is whether the prediction models established for each subject individually were also valid for each driver's second set of data. All drivers' individual models were, however, from the same mathematical structure. The sequential prediction of each subject's order of eye fixations on defined elements of the road were calculated for the second run according to the models established beforehand, i.e., as done for Subject No. 2. However, Subject No. 3 had too few fixations in the second run. Therefore, his individual prediction model could not be validated (see Table 12).

subject No.	1	2	4	5	6	7
percentage of correct predictions	88	68	50	64	45	50

Table 13: Percentage of correct sequential predictions of the targets of fixations for each subject (after the categories "focus of expansion" and "path of driving" were united into the category "track").

The results obtained were not completely satisfactory. The close-up analysis showed that a rather great part of prediction errors were a result of the difficulty to distinguish correctly between fixation at the focus of expansion (W_1) and at the path of driving (W_3). When these two categories of the road elements were combined to a new category called "track", the percentage of the sequential correct predictions was much better (see Table 13).

4. DISCUSSION

The results presented are a direct continuation of the previous study (see chapter No. 3). The central issues of the present report were the investigation of eye-movement-behavior stability, inprovement of the system theoretical approach in relation to the time interval durations used, and an attempt toward the validation of the established individual time discrete process models.

The conventional data analysis showed that the drivers' eye movement behavior remained stable at the general level. When considering the individual level, there were some intra-individual fluctuations over the two runs in fixation times, the saccade magnitudes and targets of fixation. These intra-individual variations were rather small and seldom reached a level of significance (see Table 10) or indicated constant tendencies (see Fig. 13 and Fig. 14). These intra-individual fluctuations might have been caused by the fact that the drivers did not have a continuously great load of relevant information to process. (However, the term information load can not, at present, be operationalized in a satisfactory way.)

No significant relationship was obtained between a subject's mean fixation times and his average traveling speed (as measured by the needed traveling time over a constant distance). This finding does not contradict the finding of the previous experiment. In the present study it seems that the subjects adjusted their speed of driving to prescribed limitations of velocity, and not to their own processing capacity. It can also be assumed that the subjects had a reserve capacity which might have been used for picking up information that did not have a primary task-oriented character. Because the intra-individual differences did not reach a level of significance, there is no prohibition to the use of these two sets of independent data for the comparisons required.

For the system theoretical approach, progress was made in relation to the duration of the discrete time intervals used. These correspond at present exactly to each fixation's durations. Therefore one can now consider single fixations and not their distribution within a predetermined time interval. The underlying methodological approach was achieved through data interpolation.

The attempt toward model validation showed that the prediction models established on the first set of data could be used for successive predicting of the sequence of eye fixations on the second set of independent data. The relative number of eye fixations correctly predicted, however, ranged between 37 % and 57 %.

The drivers' individual models, which were all of the same underlying structure, were especially inaccurate for the distinction between the related categories of the road elements' "focus of expansion" and "path of driving". If these categories are united into one category called "track", then the prediction rates for the fixations' succession range between 45 % and 88 %. This higher prediction rate, although not yet completely satisfying, represents a first attempt (at any laboratory, to date) toward successive prediction of advance targets of fixations based upon past information input and the importance of the road elements ahead. If the condition under which these prediction rates were obtained is considered, this finding then encourages further investigations which strive to achieve better prediction accuracy.

One of the environmental conditions which might have led to the rather low rate of correct predictions is the fact that no driver's processing capacity was continuously and completely loaded with traffic-relevant information. The driver might have also picked up interfering information which was, nevertheless, considered in the model building and in the model validation. In the next experiment it will be necessary therefore to use an experimental route where a continuous and detailed information input is absolutely required.

Furthermore, in this present experiment the subjects drove their cars on the same route twice. While they did not know this route during the first run, this was not the case in the second run. This fact might have therefore led them to modify the dynamics of their visual search strategy. The suggestion for the next study would be to use two routes with which the subjects are either completely acquainted or not at all acquainted. Furthermore, if the models to be found under these conditions are validated satisfactorily, then the problem of how the process of becoming acquainted with a driving route influences a subject's visual search strategy can also be studied.

In conclusion it must be stated that the models found could not be perfectly validated. Nevertheless, the fact that a large part of the future fixations could be successively predicted for the first time is encouraging for further investigations under different environmental conditions, e.g., as described in COHEN (1980).

The evaluation of the results presented depends on the reader's point of view. Although all subjects' predictions are much higher than chance level, one can say that the models established are still not accurate enough. One might still point out that it is - for the first time - possible to predict a sequence of fixations in a dynamic field situation.

Chapter 5

TIME DISCRETE PROCESS MODEL ESTABLISHED ON DATA FROM TWO ROUTES: A CASE STUDY

SUMMARY

The next experiment, a case study, was conducted to investigate whether the data on eye movement behavior observed on two different driving routes could be accurately described by a single prediction process model. Such a model was found to be quite accurate for a set of dependent data, i.e., 95 % of the fixation targets were predicted. However, the model's accuracy in predicting fixations for an independent set of data was poorer, yet predicted 41 % of the fixations correctly (9 out of 22). This result is, nevertheless, comparable with previous findings where data from only one driving route was used in establishing the model. The discrepancy between the rate of correct predictions for dependent as compared to independent data is probably the result of interfering information input and parafoveal information input rather than to any change in the driver's central mechanism that control his eye movements.

1. INTRODUCTION

The causal relationship existing between the successive eye fixations of the car driver is determined by two kinds of variables: (1) the information previously received and (2) the task-oriented importance of the road elements ahead. These two factors are sufficient to describe a car driver's sequence of fixations adequately and accurately, i.e., as a mathematical time discrete prediction process model.

The value of the discrete process model is related to its heuristic use in predicting the future fixations of an automobile driver on the basis of the information he has previously received and the known road characteristics ahead. Because the task oriented importance of the road elements ahead partly determine the future target of fixations, then changing the visual environment would causally influence the sequence of fixations. Studying the process governing the sequential movements of the eye is a precondition for achieving the main investigational goal, which is to redesign the visual characteristics of the road according to this process model. Such systematic redesigning of the visual features of a road should facilitate guiding the eyes of a driver sequentially toward the targets of primary importance for driving safely. However, before this goal can be achieved it is necessary to test the accuracy of the time discrete process model in predicting a driver's future targets for visual fixation.

An initial attempt for sequentially predicting the drivers' future visual fixation targets has been reported in the two preceeding chapters. The results obtained in this earlier investigation supported the system theoretical approach applied to predicting the future targets of fixations. It was shown that a subsequent fixation target could be predicted accurately from an individual process model previously derived for the driver. This finding represents a step of considerable progress in studying the eye movements of a driver and emphasizes the potential applied value of this theoretical approach in improving driving safety.

From a pragmatic point of view, it is necessary not only to point out the theoretical possibility of predicting future targets of fixation but it is also necessary to achieve a high level of accuracy in making such predictions. It is important to study whether data on eye movement behavior collected while driving on <u>different routes</u> can be combined for establishing <u>a single time discrete process model</u>. Ideally such a general model can be derived for use in many driving situations. The predictive value of this general model would be expected to be comparable to that on previously reported findings, that is, when a second set of data is collected for the same driving route. Due to the preliminary nature of the current study, data were collected from only one subject.

2. EXPERIMENT

2.1. Method

The present experiment is a case study conducted to determine whether two sets of independent data collected concerning eye movement behavior occurring during driving on two completely different routes can be described by means of a single discrete prediction process model. This model should also be tested, i.e., by means of predicting the future sequence of fixations on the two sets of data used in establishing the model. Furthermore, the model's validity should also be tested by means of sequentially predicting the future eye fixations for a third set of independently collected data on one of the two routes previously used. This approach is shown schematically in Figure 16.

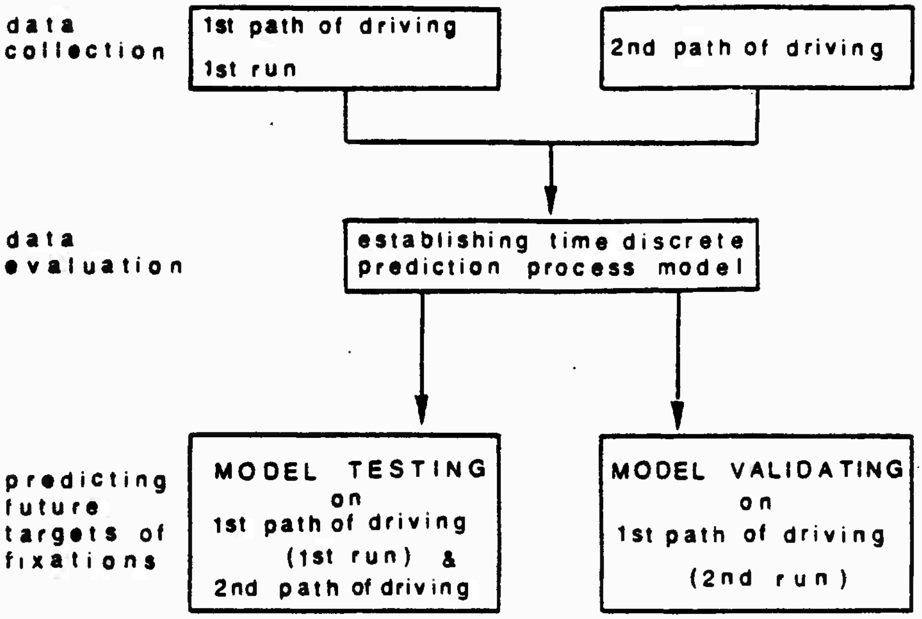


Figure 16: Schematic representation of the experimental design.

2.1.1. Driving routes

The first driving route was identical to that used in a previous study (see chapter 4, Figures No. 9 and 10). The second path of driving characteristics is shown in Figure 17, which also includes data on observed eye fixations. This second route began after the driver had completed negotiating a sharp curve to the right and ended just before arriving at an intersection.

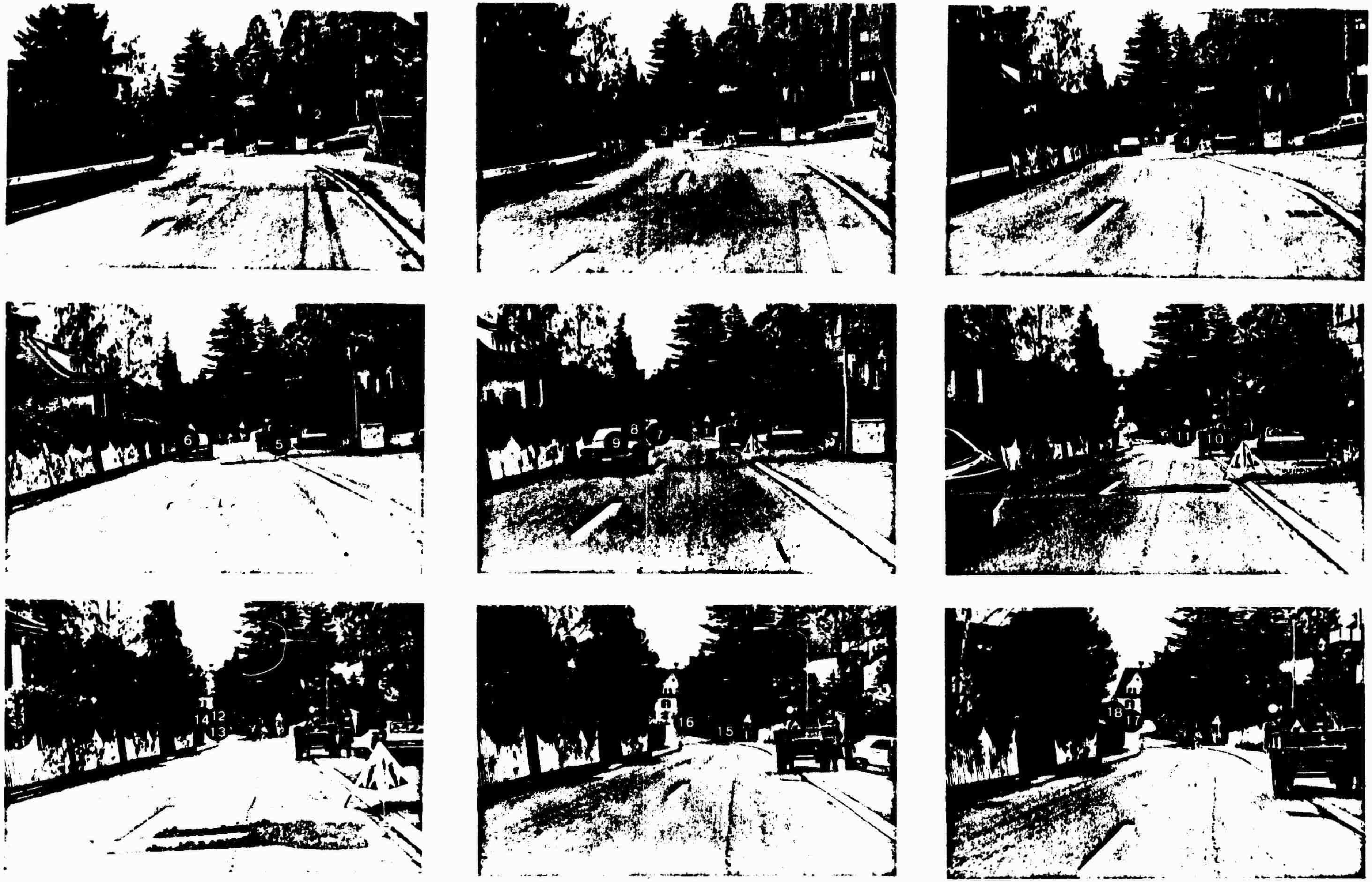


Figure 17: The driver's sequence of fixations on route No 2 (in part).

2.1.2. Subject

The female subject who participated in this experiment was not acquainted with the experimental driving routes. She was 24 years old and had driven a car daily for more than three years. During the experiment, the subject spontaneously noted that the driving route was rather complicated. Such a statement, as HICKS and WIERWILLE (1979) have pointed out, is probably a sensitive measure reflecting the driver's work load.

2.1.3. Data registration and evaluation

The data registration and evaluation were accomplished as in the previous experiment (see chapter No. 4), except that in the present experiment the order of the highway pictures which five experts rated for road elements importance was random.

3. RESULTS

The data on the subject's eye movement behavior observed on the first (i.e., first run) as well as on the second path of driving were computed together in order to establish a combined time discrete prediction process model. The model established was of the following structure:

$$\hat{\underline{X}}\,(N+1) = [\,\underline{X}\,(N-1),\ \underline{X}\,(N),\ \hat{\underline{W}}\,(N+K)\,]$$

$$K = 0,\ 6$$

whereby

$\hat{\underline{X}}\,(N+1)$	is the prediction of the next target of fixation,
N	is the eye fixations running number, each corresponding with a time interval which is equal to that of fixation time,
$\underline{X}\,(N)$	is the N'th observed target of fixation, and
$\hat{\underline{W}}\,(N)$	is the interpolated importance of the road element for the N'th fixation of the eye (see p. 37 ff.).

The model derived from the data was then used with a dependent set of data, as well as an independent one to establish its validity. The targets of fixation observed and the environmental scores for each element of the road and every time interval considered in the model are provided in Tables 14, 15 and 16 for the three independent sets of data, respectively.

3.1. Model testing

For testing the model's accuracy it was decided to predict the sequential targets of fixation for one of the two sets of data used before. Thus, the model testing was carried out on a dependent set of data. It was decided to use the data of the first (i.e., first run) and the second experimental route because of the high comparability with earlier results. The model established for the two rather different routes was found to be quite accurate. Thirty-six out of a total of 38 targets of fixation (95 %) were correctly predicted.

running number	W / N	0	1	2	3	4	5	6	Target	t(1/100s)
1	W1	24.0	24.0	21.1	18.0	22.0	18.0	19.0	4	22
	W2	22.8	22.8	20.9	21.0	22.8	22.0	22.3		
	W3	20.0	20.0	17.8	20.0	22.0	21.0	22.3		
	W4	17.0	17.0	19.6	18.0	19.0	21.0	23.0		
2	W1	24.0	21.9	21.0	18.0	22.0	18.0	20.3	3	22
	W2	22.0	20.1	21.0	21.0	22.0	22.5	21.5		
	W3	20.0	16.2	18.0	20.0	22.0	21.5	22.8		
	W4	17.0	15.6	20.0	18.0	19.0	22.4	21.7		
3	W1	24.0	21.4	19.5	19.5	18.3	18.1	21.0	3	18
	W2	22.0	20.6	21.0	21.4	22.0	22.9	21.0		
	W3	20.0	17.1	19.0	20.7	21.1	27.0	21.5		
	W4	17.0	17.8	19.0	18.4	20.8	23.9	21.0		
4	W1	24.0	21.0	18.0	22.0	18.0	19.2	21.0	2	16
	W2	22.0	21.0	21.0	22.0	22.0	22.2	21.0		
	W3	20.0	17.9	20.0	22.0	21.0	22.4	20.0		
	W4	17.0	19.8	18.0	19.0	21.0	22.8	21.0		
5	W1	22.0	21.0	18.0	22.0	18.0	20.1	21.0	1	46
	W2	20.0	21.0	21.0	22.0	22.4	21.6	21.0		
	W3	16.0	18.0	20.0	22.0	21.4	22.7	20.0		
	W4	15.0	20.0	18.0	19.0	22.1	21.9	21.0		
6	W1	21.0	18.0	22.0	18.0	19.3	21.0	21.0	2	30
	W2	21.0	21.0	22.0	22.0	22.2	21.0	22.0		
	W3	18.0	20.0	22.0	21.0	22.4	20.0	21.0		
	W4	20.0	18.0	19.0	21.0	22.7	21.0	18.0		
7	W1	21.0	18.0	20.0	18.0	21.0	21.0	19.0	3	20
	W2	21.0	21.0	22.0	22.8	21.0	21.5	22.0		
	W3	18.0	20.0	21.5	21.8	23.0	20.5	20.0		
	W4	20.0	18.0	20.0	23.4	21.0	19.5	17.0		
8	W1	18.0	21.3	18.0	18.7	21.0	21.0	19.0	1	26
	W2	21.0	21.8	22.0	22.5	21.0	22.0	21.6		
	W3	20.0	21.6	21.0	22.2	20.0	21.0	20.2		
	W4	18.0	18.8	21.0	23.3	21.0	18.0	17.0		
9	W1	18.0	22.0	18.0	20.2	21.0	19.9	19.0	4	16
	W2	21.0	22.0	22.4	21.5	21.0	22.0	20.0		
	W3	20.0	22.0	21.4	22.7	20.0	20.4	21.1		
	W4	18.0	19.0	22.3	21.8	21.0	17.4	16.9		
10	W1	18.0	19.7	18.0	21.0	21.0	19.0	19.0	4	22
	W2	21.0	22.0	22.8	21.0	21.6	22.0	20.0		
	W3	20.0	21.4	21.8	27.7	20.6	20.0	21.4		
	W4	18.0	20.2	23.5	21.0	19.3	17.0	16.6		
11	W1	22.0	18.0	18.9	21.0	21.0	19.0	19.0	1	24
	W2	22.0	22.0	22.4	21.0	22.0	21.3	20.0		
	W3	22.0	21.0	22.3	20.0	21.0	20.4	21.8		
	W4	19.0	21.0	23.1	21.0	18.0	17.0	16.2		
12	W1	22.0	18.0	20.3	21.0	19.7	19.0	19.0	1	24
	W2	22.0	22.5	21.5	21.1	22.0	20.0	20.0		
	W3	22.0	21.5	22.8	20.1	20.3	21.1	22.0		
	W4	19.0	22.4	21.7	20.8	17.3	16.9	16.0		
13	W1	18.0	18.2	21.0	21.0	19.0	19.0	18.7	2	18
	W2	22.0	22.8	21.0	21.9	22.0	20.0	19.7		
	W3	21.0	22.1	21.2	20.9	20.0	21.6	22.3		
	W4	21.0	23.8	21.0	18.2	17.0	16.4	16.0		
14	W1	18.0	19.3	21.0	21.0	19.0	19.0	18.0	2	38
	W2	22.0	22.2	21.0	22.0	20.9	20.0	19.0		
	W3	21.0	22.4	20.0	21.0	20.6	21.9	23.0		
	W4	21.0	22.7	21.0	18.0	17.0	16.1	16.0		
15	W1	18.0	21.0	21.0	19.0	19.0	18.8	18.0	2	52
	W2	23.0	21.0	21.8	22.0	20.0	19.8	19.0		
	W3	22.0	21.8	20.8	20.0	21.5	22.2	23.0		
	W4	24.0	21.0	18.6	17.0	16.5	16.0	16.0		
16	W1	21.0	21.0	19.0	19.0	19.0	18.0	16.0	1	20
	W2	21.0	21.5	22.0	20.0	20.0	19.0	18.0		
	W3	23.0	20.5	20.0	21.3	22.0	23.0	21.0		
	W4	21.0	19.5	17.0	16.7	16.0	16.0	20.0		
17	W1	21.0	21.0	19.0	19.0	18.3	16.9	16.0	2	20
	W2	21.0	22.0	21.6	20.0	19.3	18.5	19.4		
	W3	20.0	21.0	20.2	21.7	22.7	21.9	20.6		
	W4	21.0	18.0	17.0	16.3	16.0	18.2	20.0		
18	W1	21.0	20.6	19.0	19.0	18.0	16.0	16.0	3	10
	W2	21.0	22.0	20.1	20.0	19.0	18.0	21.8		
	W3	20.0	20.8	20.9	22.0	23.0	21.0	20.1		
	W4	21.0	17.8	17.0	14.0	16.0	20.0	20.0		
19	W1	21.0	19.9	19.0	19.0	18.0	16.0	15.8	2	28
	W2	21.0	22.0	20.0	20.0	19.0	18.0	21.8		
	W3	20.0	20.4	21.1	22.0	23.0	21.0	20.2		
	W4	21.0	17.4	16.9	16.0	16.0	20.0	20.2		
20	W1	21.0	19.0	19.0	18.6	17.5	16.0	15.0	1	22
	W2	22.0	22.0	20.0	19.6	18.7	18.7	21.0		
	W3	21.0	20.0	21.6	22.4	22.5	20.8	21.0		
	W4	18.0	17.0	16.4	16.0	17.1	20.0	21.0		
21	W1	21.0	19.0	19.0	18.0	16.0	16.0	15.0	3	18
	W2	22.0	20.4	20.0	19.0	18.0	21.3	21.0		
	W3	21.0	20.8	22.0	23.0	21.0	20.2	21.0		
	W4	18.0	17.0	16.0	16.0	20.0	20.0	21.0		

Table 14: The first 21 fixations observed on the 1. route (1.run), the corresponding interpolated environmental variables for 7 next fixations (N), targets of fixation and the respective durations (the numbers 1, 2, 3 and 4 represent the road elements horizon, left of the road, path and right of the road).

running number	W / N	0	1	2	3	4	5	6	Target	t(¥100s)
1	W1	20.0	23.1	20.9	20.9	28.0	27.6	17.6	4	46
	W2	19.0	21.3	20.1	20.2	12.0	14.4	19.9		
	W3	17.0	15.4	15.0	15.0	12.0	11.5	15.9		
	W4	12.0	9.7	12.1	13.4	22.0	20.2	10.3		
2	W1	20.0	21.7	19.9	25.8	28.0	22.4	16.0	4	18
	W2	19.0	20.6	19.6	15.3	12.0	22.9	19.0		
	W3	17.0	15.0	15.0	13.1	12.0	11.9	17.0		
	W4	12.0	11.3	13.7	18.7	22.0	11.3	10.0		
3	W1	24.0	20.7	21.1	28.0	27.3	16.0	22.8	4	90
	W2	22.0	20.0	20.4	12.0	16.7	19.0	25.0		
	W3	15.0	15.0	15.0	12.0	10.9	17.0	12.5		
	W4	9.0	12.3	13.3	22.0	18.4	10.0	10.8		
4	W1	19.0	22.5	28.0	26.0	16.0	24.7	24.6	4	42
	W2	19.0	20.2	12.0	25.0	19.0	25.3	16.9		
	W3	15.0	14.7	12.0	9.0	17.0	12.3	16.3		
	W4	14.0	13.8	22.0	12.0	10.0	11.3	17.1		
5	W1	22.0	28.0	26.2	16.0	25.0	24.2	25.0	4	16
	W2	21.0	12.0	23.8	19.0	27.0	20.2	14.0		
	W3	15.0	12.0	9.3	17.0	11.0	15.5	17.0		
	W4	13.0	22.0	12.9	10.0	11.0	13.8	20.0		
6	W1	22.0	28.0	26.0	16.0	24.8	24.6	23.9	2	22
	W2	21.0	12.0	25.0	19.0	25.9	17.3	14.0		
	W3	15.0	12.0	9.0	17.0	11.9	16.2	18.1		
	W4	13.0	22.0	12.0	10.0	11.2	16.7	21.1		
7	W1	28.0	28.0	19.6	19.0	24.0	25.0	21.6	1	32
	W2	12.0	12.0	21.1	21.7	22.0	14.0	14.0		
	W3	12.0	12.0	14.1	15.0	15.0	17.0	20.4		
	W4	22.0	22.0	10.7	10.3	12.0	20.0	23.4		
8	W1	28.0	26.0	16.0	25.0	24.5	24.6	19.0	2	30
	W2	12.0	25.0	19.0	27.0	18.4	14.0	14.0		
	W3	12.0	9.0	17.0	11.0	15.9	17.4	18.0		
	W4	22.0	12.0	10.0	11.0	15.6	20.4	18.0		
9	W1	28.0	18.9	19.8	24.0	25.0	21.4	20.7	2	22
	W2	12.0	20.7	22.3	22.0	14.0	14.0	16.0		
	W3	12.0	14.7	14.5	15.0	17.0	20.6	17.3		
	W4	22.0	10.6	10.4	12.0	20.0	23.6	19.4		
10	W1	26.0	16.0	25.0	24.3	25.0	19.6	22.0	4	18
	W2	25.0	19.0	27.0	19.8	14.0	14.0	17.5		
	W3	9.0	17.0	11.0	15.5	17.0	18.9	16.8		
	W4	12.0	10.0	11.0	14.2	20.0	19.8	20.4		
11	W1	26.0	16.0	24.6	24.7	23.5	19.6	23.0	3	28
	W2	25.0	19.0	24.8	16.5	14.0	14.7	18.8		
	W3	9.0	17.0	12.8	16.4	18.5	17.8	16.4		
	W4	12.0	10.0	11.4	17.5	21.5	18.5	21.2		
12	W1	16.0	22.8	24.0	25.0	20.7	21.2	24.5	1	18
	W2	19.0	25.0	22.0	14.0	14.0	16.6	17.4		
	W3	17.0	12.5	15.0	17.0	20.5	17.1	14.4		
	W4	10.0	10.8	12.0	20.0	23.1	19.7	22.5		
13	W1	16.0	25.0	24.4	25.0	19.3	22.2	25.5	1	24
	W2	19.0	27.0	19.1	14.0	14.0	17.8	12.6		
	W3	17.0	11.0	15.7	17.0	18.5	16.7	11.6		
	W4	10.0	11.0	14.9	20.0	18.9	20.5	23.5		
14	W1	16.0	24.0	24.9	22.5	20.1	23.5	26.2	2	24
	W2	19.0	22.0	14.7	14.0	15.4	19.5	11.8		
	W3	17.0	15.0	16.8	19.5	17.5	16.2	10.8		
	W4	10.0	12.0	19.3	22.5	18.9	21.6	22.5		
15	W1	25.0	24.1	25.0	20.2	21.5	24.8	26.5	4	18
	W2	27.0	21.3	14.0	14.0	17.0	15.8	15.0		
	W3	11.0	15.2	17.0	19.8	17.0	13.5	12.3		
	W4	11.0	12.7	20.0	21.7	20.0	22.8	19.9		
16	W1	25.0	24.5	24.4	19.1	22.5	25.8	26.7	4	18
	W2	27.0	18.0	14.0	14.1	18.2	11.1	17.3		
	W3	11.0	16.0	17.6	18.0	16.6	10.6	13.3		
	W4	11.0	16.0	20.6	18.1	20.8	23.8	18.0		
17	W1	24.0	24.9	22.5	20.1	23.5	26.2	26.9	1	20
	W2	22.0	14.7	14.0	15.4	19.5	11.8	19.7		
	W3	15.0	16.8	19.5	17.5	16.2	10.8	14.4		
	W4	12.0	19.3	22.5	18.9	21.6	22.5	16.1		
18	W1	24.0	25.0	20.5	21.3	24.6	26.4	25.2	1	44
	W2	22.0	14.0	14.0	16.7	16.8	14.5	20.3		
	W3	15.0	17.0	20.3	17.1	14.1	12.0	14.6		
	W4	12.0	20.0	22.6	19.8	22.6	20.4	14.6		
19	W1	25.0	22.1	20.4	23.8	26.2	26.9	22.0	3	32
	W2	14.0	14.0	15.6	19.7	12.4	20.2	19.0		
	W3	17.0	19.9	17.5	16.1	11.1	14.6	14.0		
	W4	20.0	22.9	19.1	21.8	22.1	15.6	14.0		
20	W1	25.0	19.3	22.2	25.5	26.6	22.4	22.0	4	36
	W2	14.0	14.0	17.8	12.6	16.5	19.1	19.0		
	W3	17.0	18.5	16.7	11.6	13.0	14.1	21.0		
	W4	20.0	18.9	20.5	23.5	18.6	14.1	19.0		
21	W1	21.0	20.9	24.3	26.3	26.3	22.0	21.8	1	26
	W2	14.0	16.3	18.4	13.7	20.7	19.0	17.8		
	W3	21.0	17.2	15.1	11.7	14.9	19.8	17.9		
	W4	24.0	19.5	22.3	21.9	14.9	18.2	16.4		

Table 15: The first 21 fixations observed on the 2. route, the corresponding interpolated environmental variables for 7 next fixations(N), targets of fixations and the respective durations (the numbers 1, 2,3 and 4 represent the road elements horizon, left of the road, path and right of the road).

running number	W / N	0	1	2	3	4	5	6	Target	t(¥100e)
1	W1	23.0	22.1	21.0	21.6	21.8	20.9	19.8	4	28
	W2	21.0	20.1	19.0	22.0	23.0	19.9	19.1		
	W3	22.0	21.5	21.0	20.4	20.8	22.8	21.0		
	W4	17.0	17.0	17.0	17.6	18.7	20.7	17.9		
2	W1	23.0	21.2	21.1	22.0	21.2	20.0	18.3	3	68
	W2	21.0	19.2	19.6	24.0	20.7	19.0	19.8		
	W3	22.0	21.1	20.9	20.0	22.5	21.0	21.0		
	W4	17.0	17.0	17.1	18.0	20.5	18.0	17.2		
3	W1	21.0	21.2	22.0	21.0	20.0	18.0	16.4	3	44
	W2	19.0	20.2	24.0	20.0	19.0	20.0	18.4		
	W3	21.0	20.8	20.0	23.0	21.0	21.0	19.4		
	W4	17.0	17.2	18.0	21.0	18.0	17.0	19.4		
4	W1	21.0	21.9	21.3	20.0	18.7	17.1	16.4	2	66
	W2	19.0	23.5	21.3	19.0	19.6	19.1	18.4		
	W3	21.0	20.1	27.0	21.0	21.0	20.1	20.2		
	W4	17.0	17.9	20.0	18.0	17.4	18.3	20.4		
5	W1	22.0	21.2	20.0	18.4	16.9	16.6	18.0	1	22
	W2	24.0	20.8	19.0	19.8	18.9	18.6	17.9		
	W3	20.0	22.4	21.0	21.0	19.9	20.8	21.1		
	W4	18.0	20.4	18.0	17.2	18.7	20.6	21.0		
6	W1	22.0	21.0	20.0	18.0	16.0	17.4	18.0	2	48
	W2	24.0	20.0	19.0	20.0	18.0	18.6	16.4		
	W3	20.0	23.0	21.0	21.0	19.0	21.6	21.8		
	W4	18.0	21.0	18.0	17.0	20.0	21.0	21.0		
7	W1	21.0	20.0	18.0	16.4	17.0	18.0	17.5	1	22
	W2	20.0	19.0	20.0	18.4	19.0	17.2	17.1		
	W3	23.0	21.0	21.0	19.4	22.0	21.4	22.0		
	W4	21.0	18.0	17.0	19.4	21.0	21.0	20.5		
8	W1	21.0	19.9	18.0	16.0	17.7	18.0	17.0	1	18
	W2	20.0	19.1	20.0	18.0	18.3	16.0	17.9		
	W3	23.0	21.0	21.0	19.0	21.3	22.0	22.0		
	W4	21.0	17.9	17.0	20.0	21.0	21.0	19.9		
9	W1	20.0	18.9	17.3	16.2	13.0	17.9	17.0	2	58
	W2	19.0	19.5	19.3	18.2	18.0	16.2	17.3		
	W3	21.0	21.0	20.3	19.7	21.0	27.0	22.0		
	W4	18.0	17.5	18.0	20.2	21.0	20.9	19.3		
10	W1	20.0	18.0	16.0	17.6	18.0	17.0	17.3	2	38
	W2	19.0	20.0	18.0	18.4	16.0	18.0	17.3		
	W3	21.0	21.0	19.0	21.4	22.0	22.0	22.3		
	W4	18.0	17.0	20.0	21.0	21.0	20.0	19.3		
11	W1	18.0	16.5	16.9	18.0	17.5	17.0	18.0	3	28
	W2	20.0	18.5	18.9	17.3	17.0	17.0	18.0		
	W3	21.0	19.5	21.8	21.3	22.0	22.0	23.0		
	W4	17.0	19.3	20.9	21.0	20.5	19.0	20.0		
12	W1	18.0	16.0	17.8	18.0	17.0	17.6	17.2	2	42
	W2	20.0	18.0	18.2	16.0	17.8	17.6	17.2		
	W3	21.0	19.0	21.2	22.0	22.0	22.6	21.4		
	W4	17.0	20.0	21.0	21.0	19.8	19.6	18.4		
13	W1	16.0	17.3	18.0	17.3	17.0	18.0	17.0	2	26
	W2	18.0	18.7	16.7	17.5	17.0	18.0	18.4		
	W3	19.0	21.8	21.7	22.0	22.0	23.0	21.5		
	W4	20.0	21.0	21.0	20.3	19.0	20.0	18.9		
14	W1	16.0	18.0	18.0	17.0	18.0	17.0	17.0	1	26
	W2	18.0	18.0	16.0	17.5	18.0	17.0	19.5		
	W3	19.0	21.0	22.0	22.0	23.0	21.0	21.5		
	W4	20.0	21.0	21.0	19.5	20.0	18.0	19.7		
15	W1	17.0	18.0	17.5	17.0	18.0	17.0	17.0	4	32
	W2	19.0	17.2	17.1	17.0	18.0	17.3	18.5		
	W3	22.0	21.4	22.0	22.0	23.0	21.1	20.5		
	W4	21.0	21.0	20.5	19.0	20.0	18.2	19.2		
16	W1	18.0	18.0	17.0	17.4	17.0	17.0	17.0	3	16
	W2	18.0	16.0	17.6	17.9	17.0	19.5	18.0		
	W3	21.0	22.0	22.0	22.9	21.0	21.5	20.0		
	W4	21.0	21.0	19.6	19.9	18.0	19.8	19.0		
17	W1	18.0	17.7	17.0	18.0	17.0	17.0	16.9	1	30
	W2	18.0	16.5	17.1	18.0	17.0	18.9	17.8		
	W3	21.0	22.0	22.0	23.0	21.0	20.9	20.0		
	W4	21.0	20.7	19.1	20.0	18.0	19.5	18.8		
18	W1	18.0	17.0	17.2	17.5	17.0	17.0	16.1	2	18
	W2	16.0	17.9	17.2	17.5	19.7	18.0	16.1		
	W3	22.0	22.0	22.2	22.1	21.9	20.0	20.0		
	W4	21.0	20.0	19.2	19.1	19.8	19.0	17.1		
19	W1	18.0	17.0	18.0	17.0	17.0	17.0	16.0	2	44
	W2	16.0	17.5	18.0	17.0	19.4	18.0	16.7		
	W3	22.0	22.0	23.0	21.0	21.4	20.0	20.0		
	W4	21.0	19.5	20.0	18.0	19.7	19.0	16.5		
20	W1	17.0	17.3	17.5	17.0	17.0	16.0	16.0	2	30
	W2	18.0	17.3	17.5	20.0	18.0	16.0	18.6		
	W3	22.0	22.3	21.9	22.0	20.0	20.0	20.0		
	W4	20.0	19.3	18.9	20.0	19.0	17.0	15.2		
21	W1	17.0	18.0	17.0	17.0	16.8	16.0	16.0	1	26
	W2	17.0	18.0	17.0	18.8	17.7	17.3	19.0		
	W3	22.0	23.0	21.0	20.8	20.0	20.0	20.0		
	W4	19.0	20.0	18.0	19.4	18.7	16.1	15.0		

Table 16: the first 21 fixations observed on the 1. route (2. run), the corresponding interpolated environmental variables (W) for 7 next fixations (N), targets of fixations and the respective durations (the numbers 1, 2, 3 and 4 represent the road elements horizon, left of the road, path and right of the road).

3.2. Model validation

After it was shown that the model accurately predicts from a dependent set of data, it was also of importance to know the rate of correct predictions for an independent set of data. This was done for the subject's second run on the first experimental route in order to facilitate a comparison with previous results. The rate of correct predictions for this second run was 41 % or 9 out of a total of 22 fixations observed. Even though this rate is lower for the independent, as compared to the dependent data, this prediction rate is, nevertheless, comparable to previous results (see chapter No. 4, Table 12). This finding means that combining data collected from two different routes facilitates establishing a single time-discrete process model, whose accuracy is comparable to a model obtained from only one path of driving (i.e., set of independent data).

4. DISCUSSION

The results presented above were based on a single subject. Any possible conclusion must therefore be considered tentative. The results showed that the data on eye movement behavior obtained from two rather different driving routes can be combined to establish a single time discrete prediction process model. Because the model testing resulted in somewhat greater accuracy for the identification of targets of fixation using a dependent set of data, it seems that the model fits the eye movement behavior underlying the model development. Furthermore, if one model adequately describes the successive targets of fixation relating to driving on two different routes, it seems probable that the mechanism governing the driver's eye movements is not greatly dependent on the specific road characteristics per se but on the momentarily relative importances of its elements.It is possible that a driver maintains an individual visual search strategy over long periods of time. This strategy of eye movement behavior is, of course, also governed by the road elements' task-specific relative importance. The fixation strategy of a driver, nonetheless, is based on both the individual visual capability and the momentary task oriented importance of the visual target.

The accuracy of the model derived in this experiment is greater for subsequently predicting the sequence of fixations on a dependent set of data than for predicting fixation points for an independent set of data. Insofar as these hypotheses are correct, the question arises as to the cause of the discrepancy between the rate of correct subsequent predictions for dependent and independent sets of data. A possible explanation may be the interfering information involved resulting in a tendency to fixate on targets other than those related to driving. This can occur especially when the subject's processing capacity is not completely used for traffic-relevant information. On the other hand, traffic-relevant information can also be picked up (to a limited extent) due to parafoveal vision, which can not be evaluated in the data analysis. Because these two kinds of interference are better considered in the dependent than in the independent set of data, it is possible that this resulted in a higher rate of correct predictions for successive fixation targets for a dependent set of data. This assumption is in accordance with earlier conclusions.

In summarizing the results of this case study, it can be stated that the model generated is accurate for the data used in its development. However, its accuracy for an independent set of data is poorer. The model was established using data from driving over two different routes and its accuracy is comparable to that of an earlier model derived from driving over only a single route. This comparison indicates the invariance of the mechanism controlling the visual fixations of an automobile driver.

Chapter 6

VISUAL SEARCH STRATEGY WHILE DRIVING AROUND CURVES AND ALONG STRAIGHT SECTIONS

1. INTRODUCTION

Curves are necessary road elements for connecting straight sections. They are, from the ergonomist point of view, associated with an increased motor, as well as sensoric work load.

When traveling around curves, the driver has to change the car's movement parameters in longitudinal, as well as in lateral, directions (e.g., velocity as compared to steering wheel angle) in response to environmental conditions. When traveling along a straight section, the driver stabilizes the vehicle's movement parameters and keeps the same state, provided that no obstacles are present. This comparison points out the simplified relationship between the road's geometry and the motorist's work load which increases with increased irregularities of the road's structure.

Sensoric work load is partly determined by the required motor activity, that is by the information needed to set up adequate feed-forward motor programs (e.g., KELSKO and STELMACH, 1976). This relationship is related to the fact that guided behavior, like driving, is mainly facilitated through feedback information. The rate of information input depends, on the other hand, on the amount of the available information. In this line of reasoning the available information, which can, theoretically, be defined as the amount of alternations within a defined time interval, is greater while traveling around curves as compared to straight roads. As an example, the road's focus of expansion should be mentioned. SHINAR, McDOWELL and ROCKWELL (1977) emphasized that the focus of expansion remains, perceptually, in an unchanged position on a straight road, that is,it does not depend on the driver's position. On the other hand, when traveling around curves, the road's focus of expansion is also closer and continuously changes its spatial position in relation to the motorist's direction of driving. Because of the decreased view distances, there is also an increased probability of environmental alternations as the driver's forward sight is limited. When targets are already detected, there is usually little spare time for changing the car's movement parameters. As a consequence, the motorist has to react under a greater preasure of time while driving around curves as compared to straight roads.

These considerations showed that the driver has to pick up a rather great amount of information while traveling around curves, where he also has to carry out more motor activity than on straight roads. Furthermore, the limited view distances in curves must be compensated for by increased vigilance in order to readjust, if necessary, the vehicle's movement parameters to the continuously alternating environmental conditions.

The high task requirements while driving around curves, as compared to straight roads, can presumably, be associated with accident frequency. Accident records on rural roads clearly point out that the number of crashes is much greater on curves than on straight road sections. If one considers the driver's limited processing capacity, then the increased accident frequency might be related to his increased work load or, in other words, to his insufficient ability to perceive his future path of driving adequately in advance. From the point of view of road safety it is therefore of importance to study the way in which the information input occurs when driving around curves, as indicated by the driver's eye fixations and to relate them to the environmental conditions.

Contemporary research pointed out that the accident frequency in curves does not only depend on their physical properties but also on their perceptability during their negotiation. SHINAR (1977), for example, emphasized that the accident frequency is radically increasing in illusive curves, meaning curves whose radius is underestimated during their approach. In this sense, DILLING (1973) emphasized the importance of curve approaching zone characteristics to permit accurate perception in advance.

Studies on eye movement indicated that the driver's visual search activity increases just before entering the curve (COHEN and STUDACH, 1977). Furthermore, the variability of the visual search strategy is already increasing when one negotiates a curve (SHINAR *et al*.,1977).These findings indicate that the driver's visual search strategy alters in an anticipatory way, that is, the driver adjusts his visual search in advance of the road's characteristics ahead.

While driving around curves, the driver's visual search strategy is different from that while traveling along straight road sections (e.g., SHINAR *et al*., 1977). Furthermore, the motorist's eye movement behavior depends also on the curve's handedness. The driver, nevertheless, picks up in both cases, information which is equally related to his subtasks, those being either control or guidance. In other words, it can be stated that in order to pick up information for control or for guidance, he must adapt his eye movement behavior to road geometry (COHEN and STUDACH, 1977).

Furthermore, the driver's visual search strategy is a matter of long-term perceptual learning. Novice drivers, as compared to experienced ones,fixate targets located within shorter distances and they also scan a narrower part of the road (MOURANT and ROCKWELL, 1971, 1972). Furthermore, subjects who have driven 10'000 km have less elaborated visual search strategy than have mature drivers(COHEN and STUDACH, 1977). When driving around curves, the experienced drivers manifested, in general, a more adequate visual search strategy. That driving skills are a matter of long-term perceptual learning is also indicated by the driver's physiological reactions (e.g., HELANDER, 1976).

Studies already carried out on the driver's eye movement behavior used a paradigm of data observed on different curves. Therefore the results might reflect not only the curve's handedness but also any other peculiar characteristics. The first investigational goal of the present study was therefore to analyze the driver's eye movement behavior while he is traveling around the same curve from both directions. From alternated driving directions, the same curve can be considered as a right,as well as a left handed curve. The comparison between the two runs can then indicate the isolated role of the curve's handedness on the eye movement behavior.

A second goal of this study was to investigate the influence of the environmental conditions on visual search strategy while traveling around curves. This notion can be achieved from comparing data observed in curves with equal central radii but with different preview conditions. The preview condition depends on the curve's length as well as objects located alongside the road. As the driver's motor activity depends mainly on the curve's radius, any difference observed between such two curves could be related to the environmental conditions.

A further objective of the present experiment was to analyze the driver's eye movement behavior while driving on straight road sections in relation to the road structure ahead, meaning that one which the subject is just negotiating.

A further question of importance was to find out whether the driver's eye movement behavior is different while driving around curves as compared to straight road sections. However, the straight road sections can always be treated either as an approaching zone of a curve or of an intersection.

A fifth objective of this experiment was to consider the relationship between driving experience and the subject's eye movement behavior. Of special importance was to consider the interdependence between driving experience and environmental conditions in regard to the visual search strategy, that is, whether driving experience influences the subject's eye movement behavior permamently or only in certain conditions.

The experimental design outlined above requires driving repeatedly on the same road. Previous investigations pointed out that repeated driving on the same route has no effect or minimal influence on driver eye movement behavior (BLAAUW and RIEMERSMA, 1975; see also the third chapter), unless the drivers are differently instructed (MOURANT and ROCKWELL, 1970). It can therefore be assumed that repeated driving would have little, if any, influence on the subject's eye movement behavior.

2. EXPERIMENT

2.1. Driving route

Each subject drove his car for approximately 25 minutes before reaching the experimental route. Within this period of time he could accustom himself to the equipment used. The experimental route is shown in Figure 18. As indicated, every driver steered his car one time in each of the two directions. The first run began after turning to the left. In the second run, as indicated in Figure 18, the subject negotiated the experimental route from the opposite direction.

The experimental route was characterized by a narrow road with a width of 5 m. Parked cars further reduced the width to approximately 3 m. This means that two cars, i.e., in the presence of oncoming traffic, had insufficient room to pass and one of the drivers would have to stop and steer his car aside. (However, the experimental route could normally be used only by residents from the neighbourhood, or through special permission from the police. As a consequence this road was only seldom used.)

The road's narrowness required a relatively precise steering operation. Accordingly, the driver was forced, due to envi-

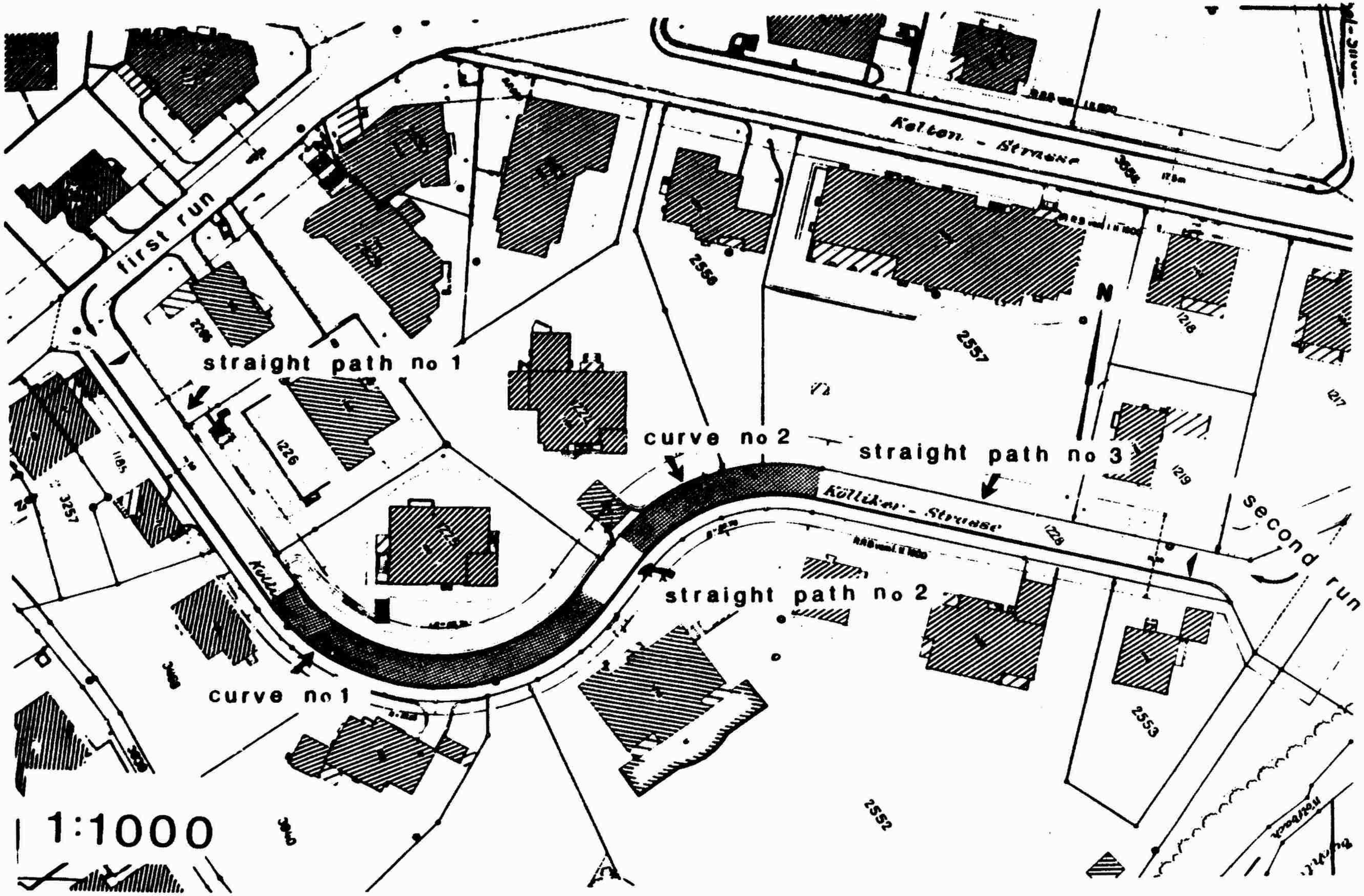


Figure 18: Plan of the experimental route indicating every section and traveling direction in each run.

ronmental conditions, to pick up a relatively great amount of information for lateral control, i.e., to fixate targets at a relatively short distance. On the other hand, the driver had only limited advance viewing possibilities and therefore he also had to pick up information for guidance in order to set adequate plans for his future motor activity. This requirement was increased because of possible oncoming traffic or the presence of pedestrians.

2.2. Subjects

Eight subjects, equally divided into two subgroups according to their driving experience, participated in this experiment. The first subgroup will be referred to as "inexperienced drivers", although only one of them was actually a novice motorist. The other three "inexperienced" drivers had operated a car for 4 to 5 years, although not on a daily basis. Therefore, even though the term "inexperienced" was used, this subgroup of subjects should not be confused with beginners, except for the one driver mentioned. Perceptual learning seems to be a long-term process requiring several years (e.g., COHEN and STUDACH, 1977), thus justifying use of the selected categorization. The 4 drivers of the other subgroup were called "experienced" subjects. They had used their own car daily for 8 or more years. The subjects' essential characteristics are given in Table 17.

			Driving experience	
Subgroup		age	km 10^3	years
Inexperienced	range	23-28	1-50	0.5-5
	mean	25.5	19	3.5
Experienced	range	28-42	100-400	8-23
	mean	34.5	221	12.5

Table 17: The subjects' age and their driving experience for each subgroup.

2.3. Data evaluation

For the conventional data analysis the route was divided into five discrete experimental sections. As Figure 18 indicates, two of them were Curves No. 1 and No. 2 and the remaining three were straight sections. The two curves had the same central radius amounting to 30 m at the roads middle. Curve No. 1 was longer than Curve No. 2 and also turned in the opposite direction. Furthermore, at the north side of Curve No. 1, a wall prohibited viewing its termination from the start of the curve. As this route was driven in both directions, each curve could be treated as a left- as well as a right-handed curve.

The criteria for the conventional data analysis were the fixation times, the saccade amplitudes and the fixation point's angular deviation from the road's focus of expansion in horizontal as well as vertical directions. In order to relate each fixation's horizontal,as well as vertical angular distance from the road's focus of expansion,a variable coordinate system was used. It was divided into fields of 1x1 cm each, i.e., corresponding with an angular extension of 1.5°x1.5°. Because the coordinate system used was a linear instead of a trigonometrical one, it caused a slight inaccuracy. However, this small error can be neglected, as pointed out by COHEN and FISCHER (1977), as it amounts to only less than 5 % even at the coordinate's far sides.

The coordinates' zero-point was adjusted at the beginning of each fixation to the road's focus of expansion. Then the number of fields were encounted lying between the road's focus of expansion and the observed fixation point in horizontal,as well as vertical directions. If the fixation was either to the right of or above the coordinate's zero-point, then the coordinates measured were designated with a "plus" and otherwise with a "minus".

The vertical coordinate indicates the driver view distance but not exclusively. The value "0" corresponds with a fixation at the road's focus of expansion, that is, the maximum preview distance. Values smaller than "0" correspond with fixations at nearer distances, whereas values greater than "0" indicate that the driver fixated targets above the road. In the last case, no clear relationship could be established between the fixation's vertical coordinate and the fixation's distance. Nevertheless, the fixation's vertical coordinates indicate, on the average, the respective fixation distances.

The goal of the system theoretical data analysis was to establish time discrete process models for each subject individually and to validate them on an independent set of data. The two sets of independent data considered were derived from each motorist's first run. The eye movement behavior observed at the run's beginning was used to establish the model, whereas a subsequent set of data was required for its validation.

The general approach applied here is similar to that used in previous experiments. The driver's eye movement behavior is primarily influenced by the information he has already picked up in relation to the importance of the road elements ahead. Therefore, these two kinds of variables are of crucial importance.

Two methodical aspects were introduced in the present data treatment. They are related, first, to the categorization of the environmental variables and, second, to a postulated hypothetical mechanism which governs the movements of the eye.

Environmental variables: During each experimental run the eye movement behavior was recorded and the environment was simultaneously photographed with a motor-camera using a frequency of approximately two shots per second. These photos were used to determine the location of the four most important targets available in each photo, i.e., at the precise moment that the subject was at the same location.One of these four crucial targets was always the road's vanishing point.Because the road's focus of expansion always possessed constant values, it couldnot be considered in the model development separately. The further three elements were related to the environmental conditions, that is,they were variable. They were determined in each picture by experts. These targets were determined by means of their relevance for driving. They were either required to change the vehicle's movement parameters or contained potential danger for safe driving. Their respective locations were defined within the frame of each picture (10.5 cm x 7.4 cm) by means of a coordinate system. Its variable origin (zero-point) corresponded in each picture with the road's focus of expansion.

The location of the remaining three important targets were described by their coordinates (the coordinates' origin also reflected, on the other hand, the driver's location within that visual field). The three pairs of coordinates represent the environmental variables W_1, W_2 and W_3 and the changes occurring between successive time intervals represent the environmental variables W_4, W_5 and W_6.

<u>The state variables</u> correspond with the targets which the driver fixated. Their respective coordinates were calculated in relation to the road's vanishing point. The six following state variables were used for describing the i'th subject's eye fixation:

$X_{i1}(N)$: X-coordinate of the N'th eye fixation

$X_{i2}(N)$: Y-coordinate of the N'th eye fixation

$X_{i3}(N)$: duration of the N'th eye fixation

$X_{i4}(N)$, $X_{i5}(N)$ and X_{i6}: correspond with the respective deviations of X_i, X_2 and X_{i3} between successive intervals, i.e.,:

$$X_{ij}(N) = X_{ij-3}(N) - X_{ij-3}(N-1); \; j = 4, 5, 6.$$

The second change introduced in the present experiment was the postulation of a hypothetical model of information processing. It is based on the assumption that continuous information input is required in driving in order to avoid any discrepancy between the objective traffic conditions and its cognitive representation, i.e., the driver's schema. The driver approximates this goal through his continual recognition of all relevant targets, i.e., through the processing of the available and relevant information. The hypothetical model, shown in Figure 19 as a block diagram suggests that the i'th subject had at each time interval (N) his own current schema S_{ic}. He, on the other hand, had to consider any new event occurring and had to integrate the respective information in his schema, that is, he had to elaborate his schema. This elaborated schema is denoted as S_{ie}.

The i'th driver's current schema S_{ic} is defined as a function of the three last targets of fixations (i.e., their respective coordinates) which are weighted by the fixations' respective durations.

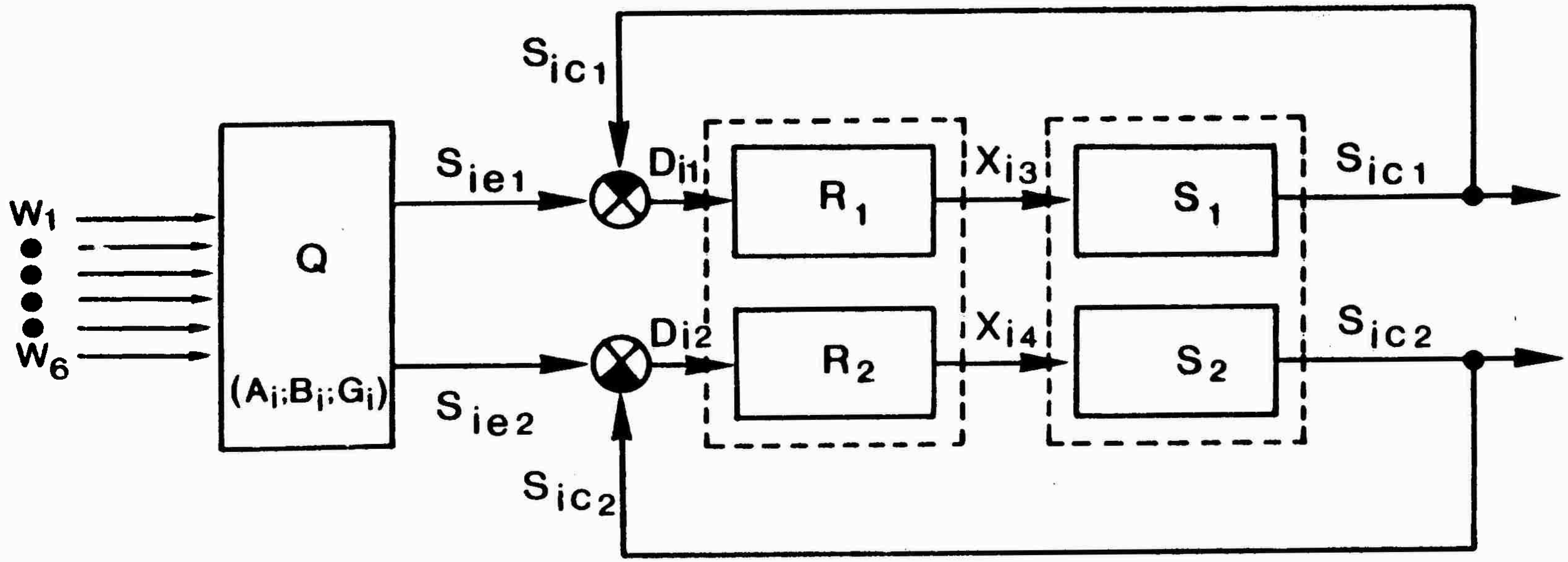


Figure 19: A block diagram illustrating the suggested mechanism governing the movements of the eye.

$$S_{icj}(N) = \frac{\left[X_{ij}(N)\ X_{i3}(N)+X_{ij}(N-1)*X_{i3}(N-1)+X_{ij}(N-2)\ X_{i3}(N-2)\right]}{\left[X_{i3}(N)+X_{i3}(N-1)+X_{i3}(N-2)\right]}$$

$j = 1,\ 2$

This equation describes the transformation of the previous fixations to the present schema of the driver (see block Q in Figure 19).

The driver's elaborated schema S_{ie}, which he possesses in the next time interval (N+1), depends on the environmental conditions, as well as on three individual variables. In an ideal case S_{ie} should correspond perfectly with traffic conditions and the driver's own capabilities. It is defined as follows:

$$S_{icj} = G_i * \left[(A_i*W_{ij}(N+1)+B_i*\ W_{i(j+2)}(N+1)+W_{i(j+4)}(N+1\right]/(A_i+B_i)$$

$j = 1,\ 2$

This equation defines the transformation of the environmental variables to the driver's elaborated schema (see blocks S_1 and S_2 in Fig. 19).

The subject's variables which are considered in this concept are weighting factors, i.e., the motorists' input control

(A_i) and guidance information (B_i). Furthermore, it is supposed that the motorist's efforts to relate his present schema to the available information is a matter of inter-individual variability. This factor, which is denoted as G_i is also an integral part of the model's block Q. It is related to the selection of the available information $\underline{W}_i(N)$ in regard to the driver's present schema.

In the model suggested, any change of eye fixations is attributed to the discrepancy between the motorists' current schema S_{ic} and the elaborated one S_{ie}. This discrepancy is denoted as $D_i(N)$ and is computed as follows:

$$D_{ij} = S_{icj} - S_{ie} \; ; \quad j = 1, 2$$

The mathematical description of the block R, which is shown in Figure 19, is given in the following equation:

$$X_{i(j+3)}(N+1)=C_{ij1}+C_{ij2}*X_{i(j+3)}(N)+C_{ij3}*DX_{i(j+3)}(N)+C_{ij4}*D_{ij}(N)$$

$$DX_{i(j+3)}=X_{i(j+3)}(N)-X_{i(j+3)}(N-1)$$

$s = 1, 2$

C_{ij1} to C_{ij4} denotes weighting factors which are iterated while establishing the model.

According to this transformation law, the change of the eye fixation depends on the corresponding coordinates of D_i and the previous change of the fixation points. In other words, this change, which is the system's output variable, can be treated as a non-ideal P-controller with the difference variable D_i as its input variable. The mathematical description of the whole model suggested is for the i'th subject as follows:

$$S_{icj}(N)= \left[X_{ij}(N)\ast X_{i3}(N)+X_{ij}(N-1)\ast X_{i3}(N-1)+X_{ij}(N-2)\ast X_{i3}(N-2)\right] / \left[X_{ij}(N)+X_{ij}(N-1)+X_{ij}(N-2)\right]$$

$$S_{iej}(N)=G_i \ast \left[(A_i\ast W_{ij}(N+1)+B_i\ast (W_{ij+2}(N+1)+W_{ij+4}(N+1)\right] /(A_i+B_i)$$

$$D_{ij}(N)= S_{iej}(N)-S_{icj}(N)$$

$$DX_{ij+3}(N) = X_{ij+3}(N)-X_{ij+3}(N-1)$$

$$\hat{X}_{ij+3}(N+1) = C_{ij1}+C_{ij2}\ast X_{ij+3}(N)+C_{ij3}\ast DX_{ij+3}(N)+C_{ij4}\ast D_{ij}(N)$$

$$\hat{X}_{ij}(N+1) = X_{ij}(N)+\hat{X}_{ij+3}(N+1)$$

$j = 1, 2$

X_{ij} denotes the observed state variables, and

$\hat{X}_{ij}$ denotes the model's predictions

An estimation procedure was used for establishing the individual models. The method used was similar to that mentioned previously (see p. 37 ff.). The corresponding description of the transformation law to be estimated is

$$\hat{X}_{ij+3}(N=1) = X_{ij+3}(N)$$

$$\hat{X}_{ij+3}(N+1) = f_i \left[X_{ij+3}(N), DX_{ij+3}(N), D_{ij}(N)\right]$$

$$j = 1,\ 2$$

Furthermore, the values of individual factors A_i, B_i and G_i were determined by a trial and error method so that the model established facilitated describing the observed sequence of fixations in the best possible manner.

The models' validity was tested on a second set of independent data. Thereby, a prediction was treated as valid, when the absolute difference between a predicted point of fixation and the observed one was smaller then 10 mm (on the picture's area).

3. RESULTS

The presentation of the results based on conventional data analysis is divided into four essential parts. These are the analysis of eye movement behavior while driving (1) around curves and (2) along straight road sections, followed by (3) the comparison between curved and straight sections and finally, (4) findings based on the system theoretical data treatment.

3.1. Curved sections

Fixation times: The mean fixation times are shown in Figure 20 for each curve, for the subjects' driving experience and for each run. The direction of traveling, i.e., experimental run, determined the curve's handedness. As this figure indicates, neither driving experience ($F_{1,454} = 0.92$; $p > 0.05$) nor the curves' direction significantly influenced the subjects' average fixation times.

The mean fixation time amounted on the average to 0.37 s over the two curves. It was 0.38 s when traveling around Curve No. 1 and 0.35 s when traveling around Curve No. 2. Even though the difference between the curves is statistically significant ($F_{1,454} = 8.40$; $p < 0.01$), it should not be

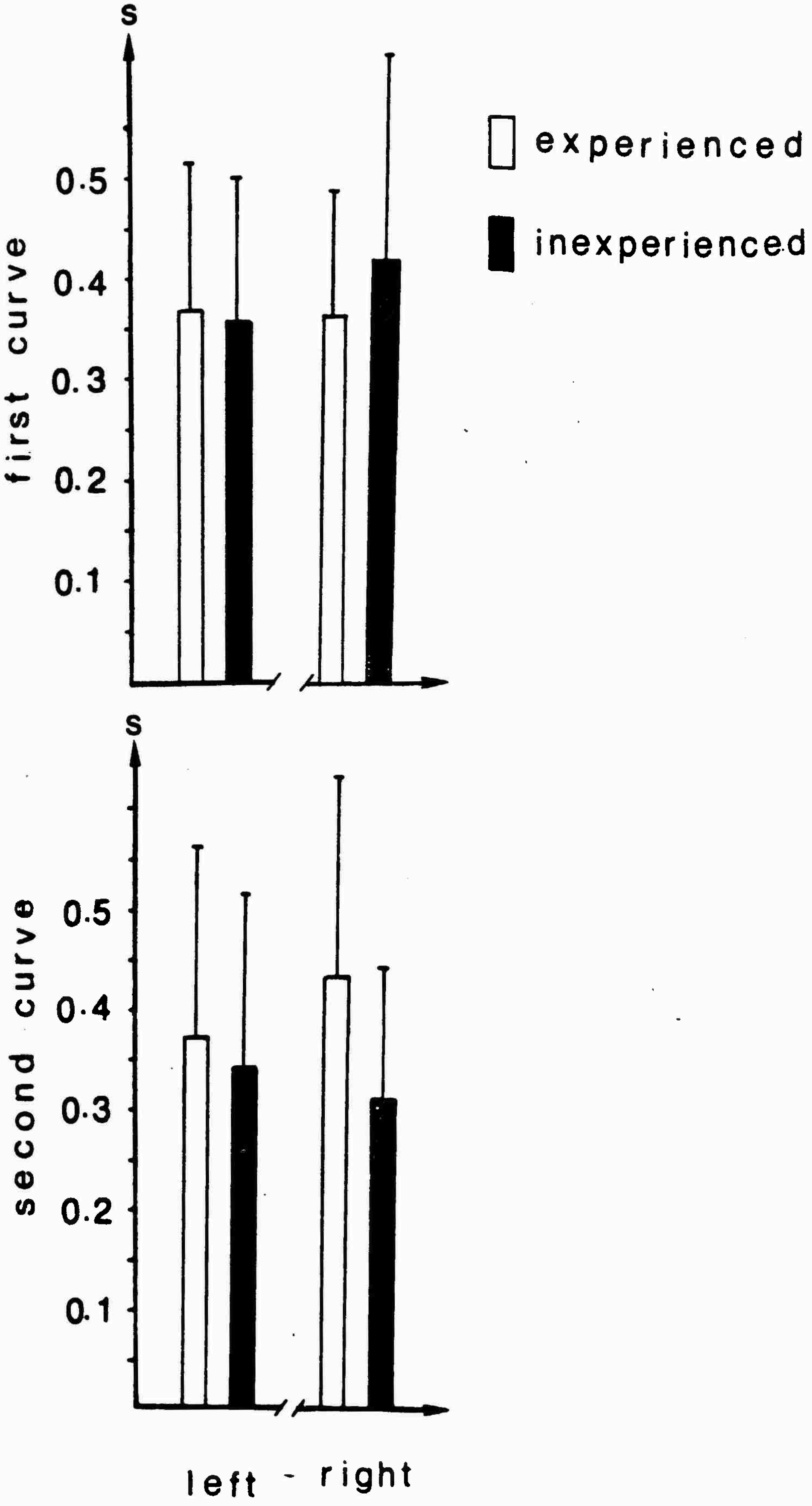


Figure 20: The subjects' mean fixation times in each curve (in seconds) and the respective standard deviations.

further considered, as the absolute difference is rather small.

As Figure 20 indicates, the experienced drivers' mean fixation times were slightly shorter when traveling around Curve No. 1 than that of the inexperienced drivers (0.37 s and, respectively 0.38 s). In Curve No. 2, on the other hand, the experienced drivers' mean fixation times were longer (0.40 s) than those of the inexperienced ones (0.34 s). This represented a significant interaction between curves and driving experience ($F_{1,454} = 6.83$; $p < 0.01$).

<u>Saccade amplitudes:</u> The saccade mean amplitude, as observed over the two curves and the two runs for all subjects, amounted to 4.41°. The data are differentiated in Figure 21 according to the subjects' driving experience, the curves' directions and the two curves.

When inspecting Figure 21 it is immediately obvious that the inexperienced drivers' mean amplitude (4.79^{0}) is greater than that of the experienced subjects (3.88^{0}; $F_{1,453} = 28.76$; $p < 0.001$). This finding is much more pronounced in the longer Curve No. 1 than in the other. Also, the saccade mean amplitude is greater when driving around a left handed curve (5.09^{0}) than around a right handed curve (3.68^{0}; $F_{1,453} = 36.94$;

$p < 0.001$). Furthermore, there is a significant interaction between the curves and their directions ($F_{1,453} = 34.32$; $p < 0.001$). This interaction has been caused by the great influence of the curve's direction in Curve No. 1, as compared to Curve No. 2 on the drivers' amplitude. When considering each curve for itself, the results pointed out that the direction influenced the saccade amplitude significantly in the first curve ($F_{1,310} = 103.13$; $p < 0.001$), depending on the subjects' driving experience ($F_{1,310} = 15.48$; $p < 0.001$). On the other hand, no significant difference was observed in Curve No. 2 either in regard to its direction or to driving experience.

This finding suggests that the driver's visual search strategy does not only depend on a curve's central radius (which partly determines the driver's motor activity, his proprioceptive information etc.), but also on further environmental variables such as advance viewing possibilities.

<u>The fixation points' mean angular distance</u> from the road's focus of expansion is shown in Figure 22 for Curve No. 1, as well as for Curve No. 2 (down). The lateral deviations from the road's focus of expansion will be treated first and then the vertical ones.

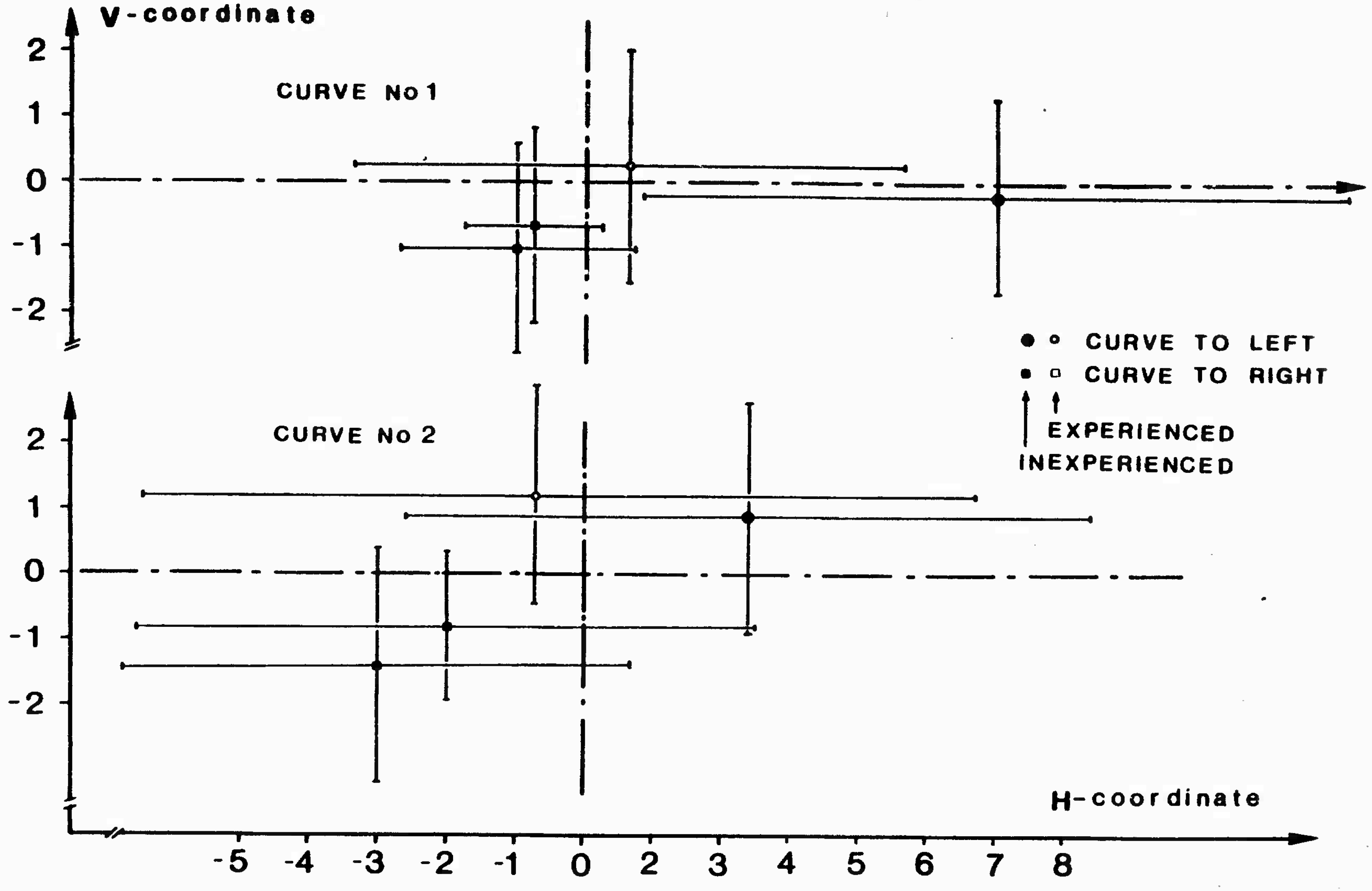


Figure 22: The fixations' mean angular distance from the road's focus of expansion in horizontal (H) as well as vertical (V) directions (one coordinate unit is equal to 1.5°) for each curve and run.

Horizontal coordinate: The fixations' average horizontal distance from the road's vanishing point amounted to 1.07 coordinates (or 1.6°). This means that the drivers slightly tended to fixate the road's right side, as calculated over all subjects, the two curves and the two runs. The fixations' horizontal dwell point depends on the curve's direction ($F_{1,452} = 146.74$; $p < 0.001$), and the specific curve driving around ($F_{1,452} = 33.81$; $p < 0.001$) as well as on the subjects' driving experience ($F_{1,452} = 39.75$; $p < 0.001$). Figure 22 clearly indicates that the fixations' mean dwell point is located to the left when traveling around a curve to the right (-1.67 or -2.5°) and to the right when traveling around a left handed curve (2.17 or 3.2°). This finding indicates that the drivers fixated targets located, on the average, on the opposite side in relation to the curve's direction. This regularity is better pronounced in Curve No. 1 as against Curve No. 2, where the experienced driver fixated the road's left side even more frequently when they were traveling around it toward the left (0.68 or 1.0°). This shift caused a significant interaction between driving experience and the curve's direction ($F_{1,452} = 32.05$; $p < 0.001$).

The fixation points' mean horizontal distance from the road's vanishing point amounted in Curve No. 1 to 1.97 (or 3.0°) and in Curve No. 2 -1.14 (or -1.7°). From an analysis of the data of each curve taken independently, it is apparent that the curve's direction influenced the fixations' mean dwell point significantly in Curve No. 1 ($F_{1,310} = 56.87$; $p < 0.001$), as well as in Curve No. 2 ($F_{1,113} = 89.32$; $p < 0.001$). However, the influence of driving experience was significant in Curve No. 1 only ($F_{1,310} = 14.14$; $p < 0.001$), that is, in contrast to Curve No. 2 ($F_{1,113} = 1.15$; $p > 0.05$). When considering the environmental conditions, it is obvious that the role of driving experience is manifested rather under difficult environmental circumstances and less so under relatively decreased workload (Curve No. 1 in contrast to Curve No. 2). However, the experienced driver's mean fixations' dwell point was, in both curves, regardless of their respective directions, nearer to the road's focus of expansion when compared to corresponding data for the inexperienced driver.

Vertical coordinate: The average vertical coordinate of the drivers fixation points', differentiated according to driving experience, the specific curve and its direction are shown in Figure 22. This figure indicates that the fixation points' mean vertical coordinate varied according to the curve's direction ($F_{1,452} = 85.38$; $p < 0.001$) and the drivers' experience ($F_{1,452} = 19.38$; $p < 0.01$). On the other hand, it did not vary between the two curves beyond chance level ($F_{1,452} = 2.06$; $p > 0.05$).

The fixations' mean dwell point was located 0.43 coordinates (or 0.65°) above the road's focus of expansion for driving to the left and -0.97 coordinates (or 1.44°) for driving around a right handed curve. This result indicates that the drivers fixated their eyes on nearer distances when driving around a curve to the right as compared to driving around a curve to the left.

As mentioned above, the drivers' mean vertical coordinate of their fixations depend on their respective experiences. It amounted in experienced drivers to 0.22 (or 0.33°) and in inexperienced drivers to -0.46 (or -0.69°). The experienced drivers, as these data indicate, tended on the average to fixate targets located slightly above the road's focus of expansion in contrast to the inexperienced drivers.

3.2. Straight road sections

Fixation times: Figure 23 shows the subjects' mean fixation times differentiated for the two levels of driving experience, for the three straight sections, as well as for the two experimental runs. The purpose of the experimental run was, however, to give more than a limited aquaintance with the experimental route. The experimental run determined the road's

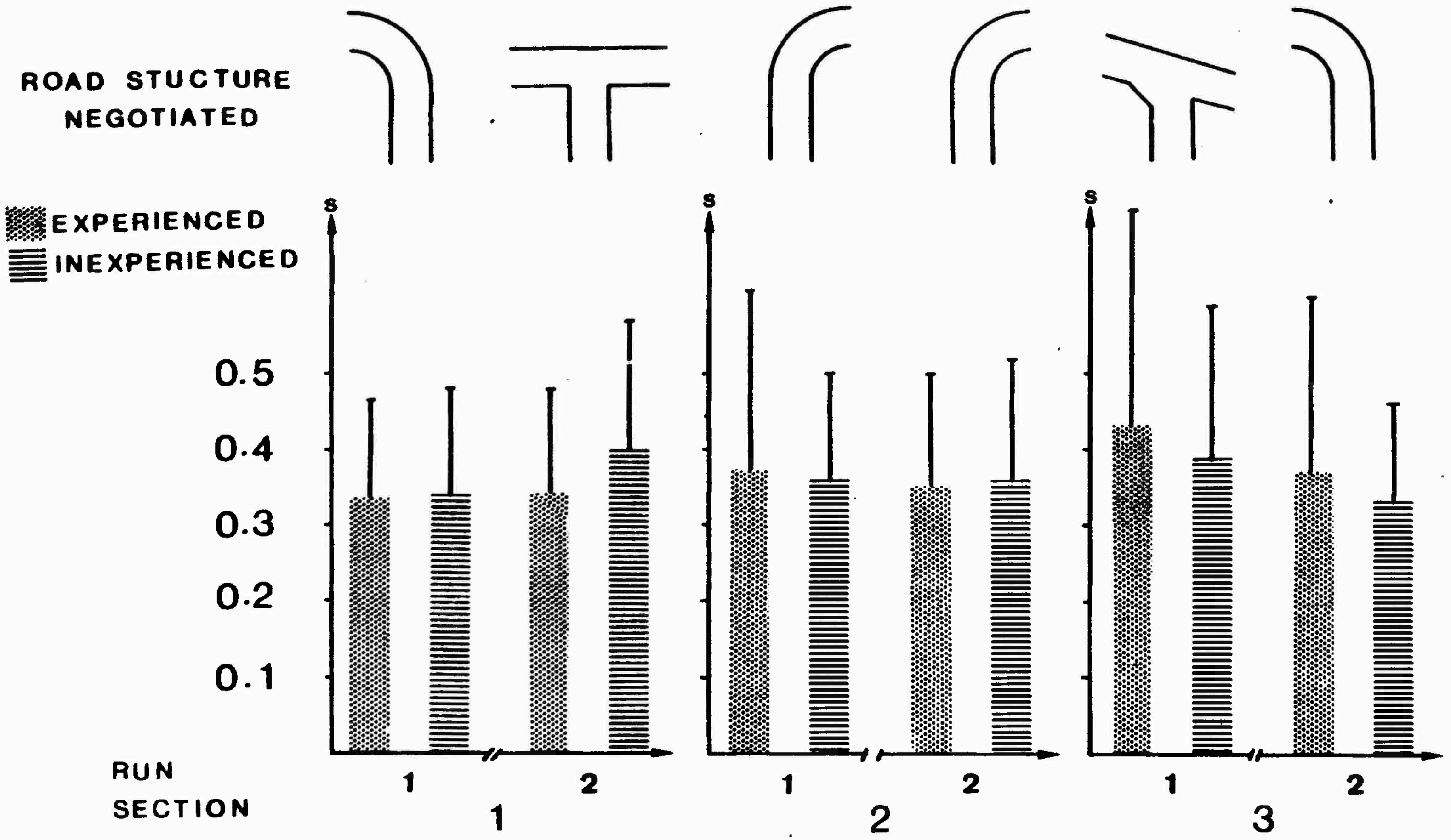


Figure 23: The drivers' mean fixation times (in seconds) for every straight section and each run. The road structure negotiated is shown at the top of the Figure.

structure which the drivers were to negotiate next, as indicated at the top of Figure 23.

The mean fixation time amounted to 0.36 s in total and on Straight Sections No. 1, No. 2 and No. 3, respectively, 0.35 s, 0.36 s and 0.37 s. These slight differences, which were accompanied with the usual rather great standard deviations, did not reach a level of significance ($F_{1,867} > 1$). If considering each straight section individually, then a significant difference can be observed only on Straight Section No. 3. The mean fixation time amounted in the first run to 0.44 s and in the second run to 0.34 s ($F_{1,388} = 7.69$; $p < 0.001$). This difference might depend on the road's structure negotiated. A possible relationship might be demonstrated as follows: The mean fixation times were longer when negotiating a T-formed intersection than when approaching a left handed curve (see Fig. 23 at the top). Comparable environmental conditions were present for driving on Straight Section No. 1. A similar tendency was observed at this section, that is, prolonged fixation times were observed for approaching a T-formed intersection (second run) as opposed to negotiating a left handed curve (first run). On the other hand, the mean fixation time remained unchanged for approaching similar road structures, as occurred for driving along Section No. 2. These results suggest tentatively a relationship between the road's characteristics ahead and the driver's mean fixation times.

Driving experience did not influence the motorist's fixation times significantly ($F_{1,867} < 1$). Furthermore, driving experience did not yield a significant interaction either with the experimental run ($F_{1,867} < 1$) or with the three sections ($F_{1,867} < 1$).

<u>The saccade amplitudes:</u> The mean saccade amplitude amounted to 4.90° over all subjects and experimental runs and on Straight Sections No. 1, No. 2 and No. 3, respectively 4.91°, 4.92° and 4.89° (see Fig. 24). The differences between these sections, as the variance of analysis indicates, vary only at random ($F_{2,864} < 1$; $p > 0.05$). On the other hand, the saccade amplitude is significantly influenced by the subjects' driving experience ($F_{1,864} = 8.76$; $p < 0.01$), as well as by the experimental run ($F_{1,864} = 4.16$; $p < 0.05$). Furthermore, significant interactions were observed between the experimental runs and the three straight sections ($F_{2,864} = 17.83$; $p < 0.001$), as well as the subjects' driving experience ($F_{1,864} = 4.57$; $p < 0.05$).

The inexperienced drivers' mean saccade amplitude was greater (5.15°) than that of the experienced subjects (4.60°).

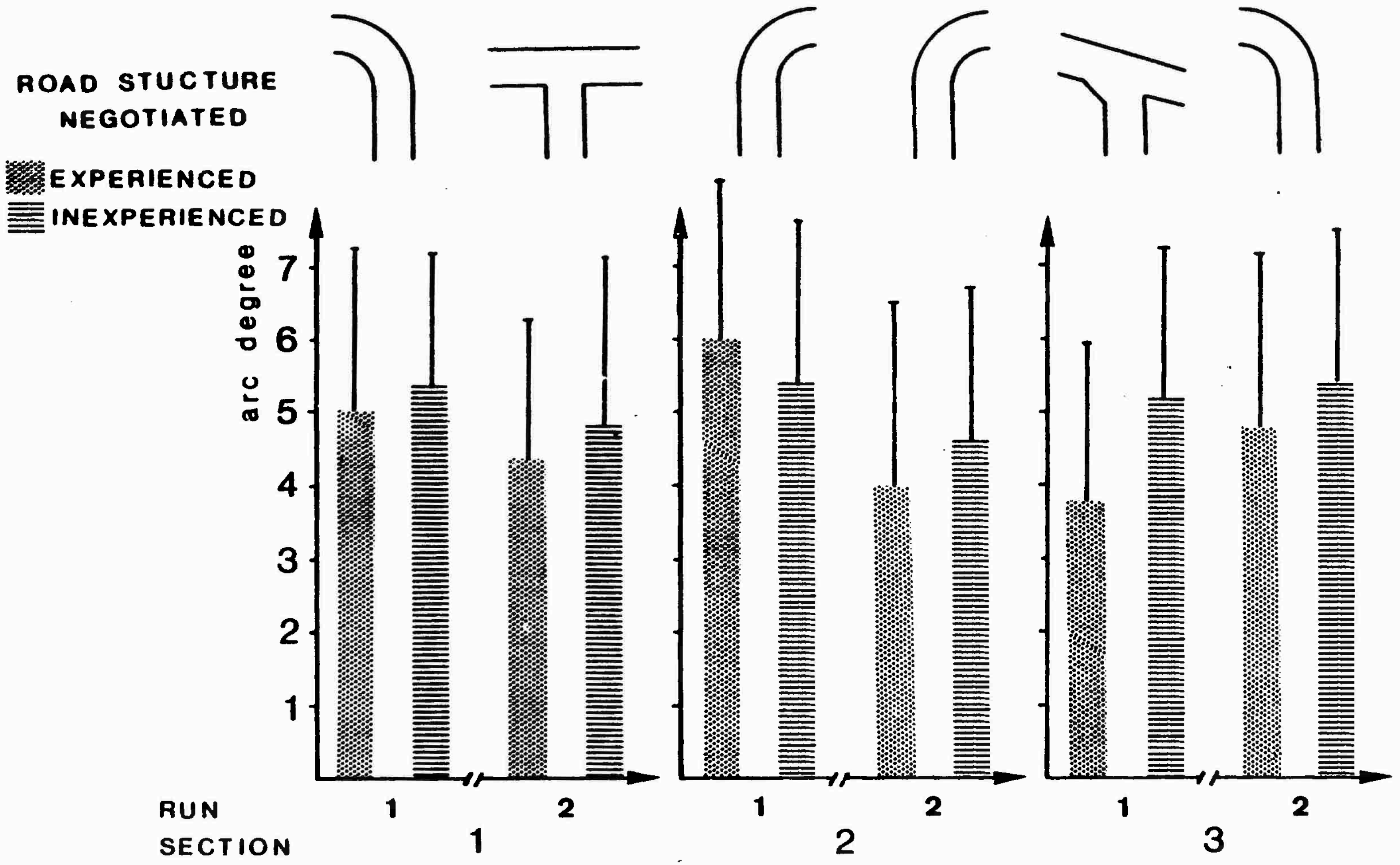


Figure 24: The drivers' mean amplitudes (in arc degree) for every straight section and each run. The respective road structure negotiated is shown at the top of the Figure.

This difference was rather pronounced on Straight Section No. 3 ($F_{1,380} = 12.26$; $p < 0.01$) in contrast to Straight Section No. 2 ($F_{1,123} < 1$).

The experimental runs influenced the drivers' average amplitudes. They were greater in the first (5.0°) than in the second run (4.8°). However, the significant interaction between experimental runs and road sections, as well as driving experience indicates that this difference can not be attributed to the sequence of runs solely.

When considering each straight section for itself, then the saccade mean amplitude tended to decrease for driving on Section No. 1 in the second, as compared to the first run (see Fig. 24), ($F_{1,304} = 3.25$; $0.05 < p < 0.10$) and it decreased significantly on Section No. 2 ($F_{1,123} = 16.12$; $p < 0.01$), on the other hand, it significantly increased while driving on Section No. 3 ($F_{1,386} = 10.55$; $p < 0.001$). These differentiated results must be treated within two different frameworks. First, one can assume that the experimental run per se directly influenced the saccade magnitude, i.e., causing a decreased visual search activity. Second, one can argue that the drivers, while traveling on the same section in opposite directions, negotiated different road structures, i.e., a curve in contrast to a T-formed intersection. As a consequence, the saccade ampl might alter as a result of anticipating the advance of driving. In the following discussion the role experimental run is considered first and then that environmental conditions ahead.

Foring along Straight Section No. 1, as well as along ion No. , there was an environmental difference between two rs with regard to the road structure negotiated, in deaded on the subjects' driving direction, as indicate at top of Figure 24. Furthermore, Straight Section No. entered in the first run after the subject had turned ls to the left. He, on the other hand, entered Straight on No. 3 after turning to the right. In both cases, records qualitative inspection indicate, the dr fixated at the sections start on targets, which were d in short distances, presumably for picking up control ation. These fixations were associated with rather greaitudes. After a short period of driving, the drivers rad decreased the frequency of their fixations during shorences and thereby reduced the saccade amplitudes. On tr hand, when the drivers drove on the same sections bthe opposite direction, that is, when approaching a T-fontersection, the saccade amplitudes increased toward theght sections end. These effects were more pronounce experienced drivers than in experienced ones.

The fixations points' mean angular distance from the road's focus of expansion: The average angular distance between the drivers' fixation points and the roads' focus of expansion, in horizontal, as well as vertical direction is shown in Figure 25 for each straight section separately. These two main spatial directions will be distinctively treated in the following discussion, i.e., the horizontal direction first and then the vertical one.

Horizontal coordinate: The fixation's mean horizontal dwell point, in relation to the road's focus of expansion, depended on the particular straight section driving on ($F_{2,863} = 156.83$; $p < 0.001$) as well as on the experimental run ($F_{1,863} = 14.74$; $p < 0.001$). Driving experience, on the other hand, did not influence the fixations' angular distance from the road's vanishing point ($F_{1,863} < 1$).

To consider each experimental straight section solely, significant differences were observed between the two runs on Straight Section No. 1 1 ($F_{1,304} = 15.53$; $p < 0.001$) as well as on Straight Section No. 2 ($F_{1,123} = 27.16$; $p < 0.001$) but none on Straight Section No. 3 ($F_{1,385} < 1$; $p > 0.05$).

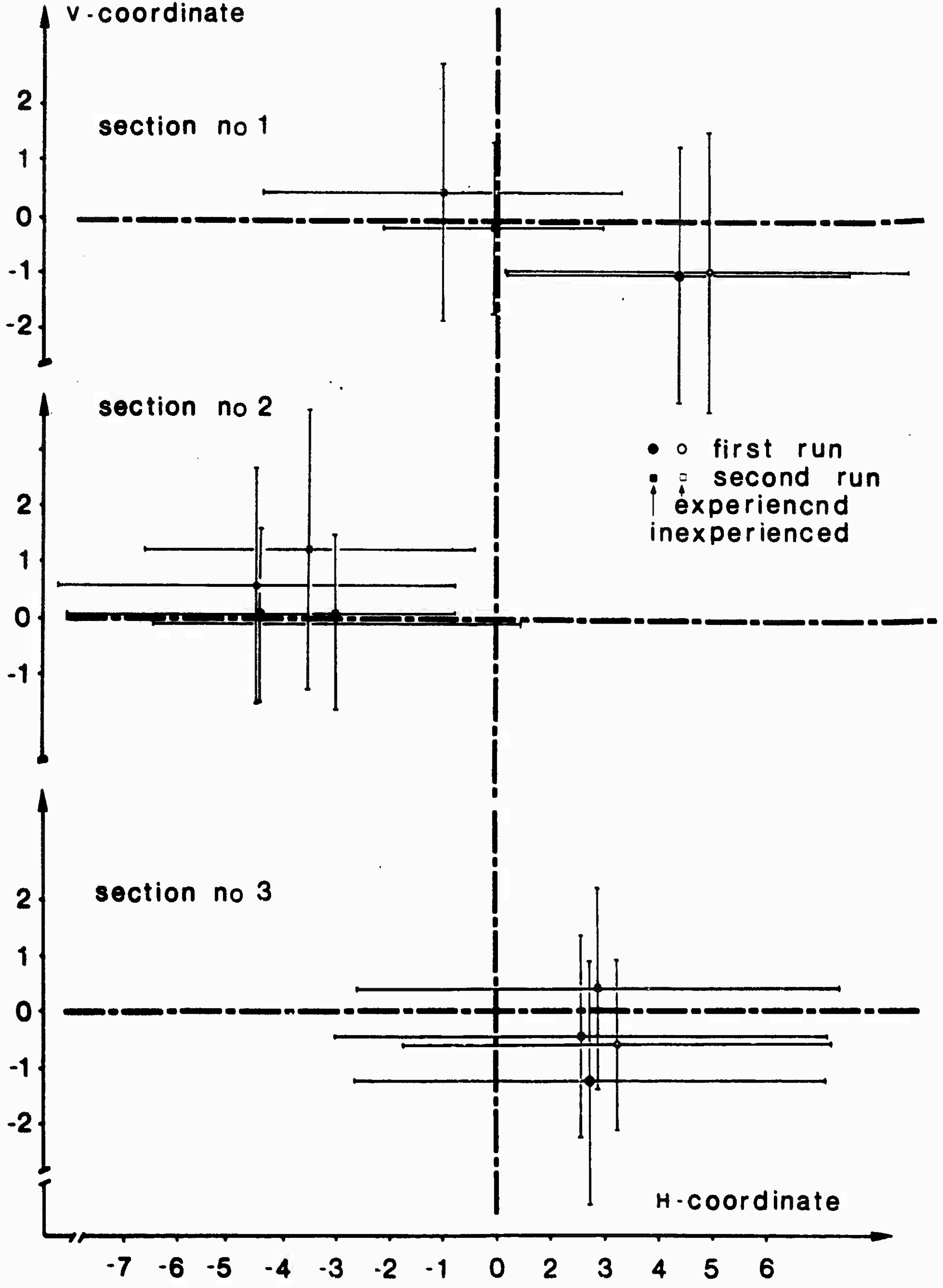


Figure 25: The fixations' mean dwell point in relation to the road's focus of expansion in horizontal as well as vertical direction (one coordinate unit is equal to 1.5^{0}) for every straight section and each run.

<u>Vertical</u> <u>coordinate:</u> The fixations' vertical angular distance from the road's focus of expansion was significantly influenced by the subjects driving experience ($F_{1,874} = 20.01$; $p < 0.001$), by the experimental run ($F_{1,874} = 40.52$; $p < 0.001$) as well as by the particular section being driving up on. Figure 25 clearly indicates that the inexperienced drivers fixated more frequently on targets, which were located lower, as compared to those fixated on by experienced subjects. This result suggests that the inexperienced drivers fixated targets in closer distances, on average, than did the experienced drivers.

The targets fixated on in the first experiment run were associated with closer view distances than in the second run, as the respective vertical coordinates indicate. This effect was quite pronounced on Straight Sections No. 1 and No. 3. In Straight Section No. 2, however, the mean vertical coordinate amounted to greater than zero. This result, however, did not mean, that the drivers could look "beyond" the roads focus of expansion of course. It means they just tended to fixate targets, e.g., fences along the road, at a level which was well above the road's surface.

3.3. Comparison between straight and curved sections

The comparison between straight and curved sections intends to point out any difference which can be attributed to varying road geometry. Therefore the role of the particular sections considered above will not be treated here.

The fixation times were not significantly influenced by the road's geometry ($F_{1,1308} = 1.61$; $p > 0.05$). They amounted to 0.37 s in curves and 0.36 s in straight sections.

The saccade amplitudes were greater for traveling along straight sections (4.90^{o}) than for driving around curves (0.41^{o}; $F_{1,1304} = 51.15$; $p < 0.001$). This result was caused, presumably, as the records quantitative inspection indicates, by an increased alternation between fixations in near and far distances (i.e., between information input for the vehicle's guidance and its lateral control) for driving along straight sections as opposed to traveling around curves. This suggestion is supported by the alternation of the fixation distances, as indicated by the fixations' vertical coordinates.

The fixation points' variability in vertical direction, i.e., its spatial location in relation to the road's focus of expansion, was greater for driving along straight sections (SD = 2.12) than for traveling around curves (SD = 1.78). This difference, however, was not significant.

These findings are surprising, because one could expect that the driver's search activity, as indicated by the amplitudes of his saccades,would be greater while driving around curves than along straight sections. The contrary was, however, observed. This finding might be, however, related to the structure of the road ahead, that is the motorist's anticipation of future events or activities.

The other variables, i.e., the fixation points' angular distance from the road's focus of expansion in vertical or horizontal directions, did not yield any significant differences as a function of the road's geometry. As a concluding remark it can be suggested that the driver's visual search activity did not show essential difference between straight and curved sections. The only difference obtained was related to the saccade amplitudes.

3.4. Time discrete process models

Table 18 shows the values of the six state variables ($X_1, \ldots\ldots, X_6$) as well as those of the six environmental variables ($W_1, \ldots\ldots, W_6$) as computed, for instance, for Sub-

G= 0.80 A= 1.00 B= 0.50

X1	X2	X3	X4	X5	X6	W1	W2	W3	W4	W5	W6
321.	-236.	13.	0.	0.	0.	77.	3.	-90.	-33.	202.	-49.
126.	-189.	11.	-195.	47.	-2.	82.	0.	-87.	-36.	206.	-52.
143.	-110.	19.	17.	79.	8.	78.	3.	-91.	-32.	203.	-50.
15.	-67.	29.	-128.	43.	10.	56.	-1.	-99.	-36.	196.	-42.
92.	-68.	21.	77.	-1.	-8.	75.	5.	123.	-12.	-122.	-11.
190.	-148.	13.	98.	-80.	-8.	85.	-4.	-136.	-35.	233.	-67.
149.	-84.	24.	-41.	64.	11.	90.	7.	149.	-20.	-185.	-25.
-22.	85.	55.	-171.	169.	31.	67.	52.	-371.	42.	1413.	-290.
-18.	-84.	30.	4.	-169.	-25.	149.	0.	-111.	-29.	197.	-28.
9.	-120.	22.	27.	-36.	-8.	182.	-11.	-126.	-52.	271.	-40.
378.	-228.	20.	369.	-108.	-2.	194.	-13.	-66.	-38.	414.	-52.
64.	-91.	29.	-314.	137.	9.	228.	-16.	-17.	-30.	10.	-2.
279.	-157.	16.	215.	-66.	-13.	162.	-8.	262.	-15.	-24.	-38.
42.	-65.	31.	-237.	92.	15.	163.	2.	263.	-10.	-23.	-33.
147.	-107.	16.	105.	-42.	-15.	214.	-6.	327.	-22.	-47.	-58.
17.	-87.	19.	-130.	20.	3.	215.	-2.	327.	-16.	-46.	-58.
-20.	-70.	39.	-37.	17.	20.	97.	18.	283.	7.	-135.	-79.
-1.	-46.	13.	19.	24.	-26.	150.	5.	396.	0.	-265.	-136.
151.	-50.	8.	152.	-4.	-5.	224.	14.	519.	-8.	-78.	-79.
-9.	-62.	17.	-160.	-12.	9.	349.	2.	-70.	-52.	0.	0.
-42.	-72.	23.	-33.	-10.	6.	-58.	-6.	465.	-16.	-143.	-84.
75.	-61.	28.	117.	11.	5.	217.	8.	-96.	-96.	0.	0.
2.	-15.	28.	-73.	46.	0.	183.	46.	394.	4.	-117.	-79.
15.	-32.	32.	13.	-17.	4.	68.	25.	593.	20.	-102.	-82.
207.	-58.	10.	192.	-26.	-22.	147.	19.	636.	-15.	-120.	-85.

Table 18: The values of the six state variables $X_{31},\ldots,X_{36}$ as well as those of the environmental variables $W_{31},\ldots,W_{36}$ for the first set of data (observed on Subject No 3).

ject No. 3. The respective individual values of the weighting factors A, B and G were, respectively, 1.00, 0.50 and 0.80. These data were used for establishing the individual time discrete process model. A second set of independent data, which is given in Table 19, was similarily computed and used for the model validation. Analogous tables were prepared for each subject.

Table 20 represents the coordinates of the observed (X_1 and X_2) as well as the predicted point of fixation ($\hat{X}_1$ and $\hat{X}_2$) for the dependent set of data of Subject No. 3. The correct predictions are marked by an arrow-head. Table 21 shows the results obtained according to the independent set of data, i.e., the predicted fixation points.

A time discrete process model was developed in an analogous manner for each driver individually, which has, nevertheless, the same mathematical structure in common. The individual models vary, however, in regard to the values of factors A_i, B_i and G_i. Different values of these factors were optimal for each individual subject. Nevertheless, their optimal values were intra-individually constant, that is, they did not vary between the two sets of data considered.

The score used to describe individual model accuracy

G= 0.80   A= 1.00   B= 0.50

X1	X2	X3	X4	X5	X6	W1	W2	W3	W4	W5	W6
18.	-29.	17.	0.	0.	0.	311.	28.	-22.	-8.	0.	0.
21.	26.	11.	3.	55.	-6.	313.	35.	-19.	-4.	0.	0.
48.	-39.	12.	27.	-65.	1.	42.	12.	311.	-36.	0.	0.
18.	-20.	26.	-30.	19.	14.	40.	10.	311.	-37.	0.	0.
28.	-63.	22.	10.	-43.	-4.	85.	-12.	353.	-65.	-61.	-59.
-86.	-113.	35.	-114.	-50.	13.	-163.	-11.	82.	-16.	-189.	-83.
-150.	-36.	11.	-64.	77.	-24.	-162.	6.	79.	-25.	-294.	-34.
128.	130.	55.	278.	166.	44.	362.	93.	-5.	89.	1465.	-478.
-91.	-94.	17.	-219.	-224.	-38.	-145.	-3.	90.	-32.	-396.	-59.
-171.	-34.	8.	-80.	60.	-9.	-145.	-4.	93.	-28.	-398.	-60.
-37.	-62.	15.	134.	-28.	7.	-144.	0.	90.	-33.	-398.	-55.
-61.	-25.	14.	-24.	37.	-1.	-160.	24.	-53.	-46.	-508.	-52.
-11.	93.	16.	50.	118.	2.	-195.	8.	-80.	-49.	-609.	-76.
-207.	-148.	14.	-196.	-241.	-2.	-394.	-19.	-233.	-82.	-6.	-8.
-396.	-131.	14.	-189.	17.	0.	-482.	-5.	-276.	-90.	0.	0.
-212.	-110.	51.	184.	21.	37.	-55.	27.	-627.	-2.	-290.	-90.
-42.	-71.	17.	170.	39.	-34.	-87.	29.	-200.	-94.	0.	0.
-81.	-90.	31.	-39.	-19.	14.	-300.	-35.	-295.	-135.	0.	0.
53.	-80.	14.	134.	10.	-17.	-344.	-35.	-171.	-133.	0.	0.
198.	-44.	22.	145.	36.	8.	-347.	-48.	-54.	-165.	0.	0.
10.	-91.	36.	-188.	-47.	14.	-413.	-52.	75.	-150.	0.	-8.
1.	-130.	29.	-9.	-39.	-7.	-67.	-21.	8.	-44.	0.	0.
9.	-37.	54.	8.	93.	25.	-44.	1.	-84.	-23.	105.	-66.
26.	-53.	23.	17.	-16.	-31.	-76.	-28.	-145.	-65.	254.	-63.
129.	-120.	18.	103.	-67.	-5.	-106.	-44.	156.	-47.	-237.	-128.

Table 19: The values of the six state variables $X_{31}, \ldots, X_{36}$ as well as those of the six environmental variables $W_{31}, \ldots, W_{36}$ for the second set of data (observed on Subject No 3).

X1	$\hat{X}1$	X2	$\hat{X}2$	
15.	141.	-67.	-125.	
92.	65.	-68.	-97.	◄
190.	53.	-148.	-70.	
149.	53.	-84.	-72.	◄
-22.	141.	85.	-57.	
-18.	98.	-84.	-58.	
9.	38.	-120.	-84.	◄
378.	2.	-228.	-18.	
64.	72.	-91.	-99.	◄
279.	123.	-157.	-69.	
42.	190.	-65.	-137.	
147.	119.	-107.	-57.	◄
17.	137.	-87.	-100.	
-20.	49.	-70.	-50.	◄
-1.	45.	-46.	-70.	◄
151.	19.	-50.	-48.	
-9.	47.	-62.	-43.	◄
-42.	28.	-72.	-42.	◄
75.	38.	-61.	-44.	◄
2.	5.	-15.	-37.	◄
15.	15.	-32.	-32.	◄

Table 20: Comparison between the observed fixations (on Subject No 3) and the model's respective predictions for the first set of data (correct predictions are indicated by arrow-heads).

X1	$\hat{X}1$	X2	$\hat{X}2$	
18.	21.	-20.	-26.	◄
28.	21.	-63.	-4.	◄
-86.	-22.	-113.	-43.	◄
-150.	-53.	-36.	-39.	◄
128.	36.	130.	-40.	
-91.	-111.	-94.	-29.	◄
-171.	-102.	-34.	-81.	◄
-37.	-99.	-62.	15.	◄
-61.	-152.	-25.	-55.	◄
-11.	-154.	93.	-26.	
-207.	-106.	-148.	-10.	
-396.	-168.	-131.	-71.	
-212.	-213.	-110.	3.	
-42.	-265.	-71.	-90.	
-81.	-267.	-90.	-87.	
53.	-163.	-80.	-84.	
198.	-95.	-44.	-72.	
10.	-29.	-91.	-64.	◄
1.	40.	-130.	-64.	◄
9.	35.	-37.	-55.	◄
26.	-23.	-53.	-58.	◄

Table 21: Comparison between the observed fixations (on Subject No 3) and the model's respective predictions for the second set of data (correct predictions are indicated by arrow-heads).

was the percentage of the correct predictions. These are summarized in Table 22 for every driver individually and for each set of data. This table also includes the individual values of A_i, B_i and G_i. As Table 22 indicates, model accuracy amounted approximately to 50 % on the average. Although this is not a high figure, it is surprising that model accuracy for describing a sequence of fixation (i.e., dependent set of data) as well as that for predicting a sequence of fixations (i.e., independent set of data) are approximately equal. This finding suggests that the individual models established are equally valid for different sections of the experimental route. This suggestion is further supported by the finding that individual factors A_i, B_i and G_i do not vary between the two different sections, even though they vary across the subjects.

	value of the factors			accuracy score	
Subject No.	A	B	G	first set of data	second set of data
1	1.0	0.5	1.0	39	58
2	1.0	0.7	1.2	69	50
3	1.0	0.5	0.8	57	57
4	0.8	1.0	1.1	55	60
5	0.1	1.0	1.0	66	50
6	0.4	1.0	0.8	42	29
7	0.01	10.0	1.0	50	40
8	0.9	1.0	0.8	38	50
			$\bar{X}$	52.0	49.3

Table 22: The individual values of factors A_i, B_i and G_i as well as the model's accuracy (in percentage) for the first as well as for the second set of data.

4. DISCUSSION

The conventional data analysis presented above pointed out a close relationship between the driver's visual search strategy and the characteristics of the road for driving on (i.e., curves). Furthermore, for driving along straight sections, the motorist's eye movement behavior can be related to the properties of the road structure negotiated (i.e., curve or intersection). This relationship suggests that the driver's visual search strategy reflects an adaptive behavior, which is related to feed-forward (i.e., anticipation, guidance), as well as feedback mechanisms (i.e., control). The suggested adaptive behavior depends on environmental conditions but also on the driver's individual capabilities. This suggestion is supported by the observed inter-individual differences and is as well a function of the driver's experience. These outlined relationships are the central issues of the present discussion, based on conventional data treatment.

The relationship between environmental conditions and visual input was clearly demonstrated for driving around the same curve in different directions. The saccade amplitudes were greater when driving around a left as compared to a right handed curve. This difference, which is supported by other findings (e.g., COHEN and STUDACH, 1977), reflects a dissimilar spatial distribution of the information required to input for safe driving. The control information is located in closer distances than that required for guidance. The spatial directional difference between the targets providing control as compared to guidance information is, however, greater in left handed as compared to right handed curves. In order to pick up the information continuously required for safe driving, the motorist has to move his eyes with greater amplitudes in left than in right handed curves. This suggestion is in accordance with previous considerations (COHEN, 1980). Additional variables considered in the present experiment was to demonstrate differentiation between curves as a function of their handedness.

The maximal preview distance does not depend on the curve's handedness at all. A right turned curve can be treated just as a mirror image of the left turned one. The motorist's fixation distances (as indicated by their mean vertical coordinate) depend, nevertheless, on the curve's handedness (see Fig. 21). The fixation distances are shorter in a right than in a left turned curve. This difference is significant in each of the two considered curves, so that this result can not be attributed to a specific curve's characteristics only, e.g., such as the wall at the first curve's north side. The question arising here regards the reason for this difference, as well as the consequences of the eye movement behavior obtained.

A decrease of fixation distance usually occurs under unfavorable conditions such as fatigue (KALUGER and SMITH, 1970), consumption of alcohol (MORTIMER and JORGESON, 1974), reduced visibility circumstances for instance, night-time driving (GRAF and KREBS, 1976). Reduced fixation distances are usually associated with degraded visual search activity. In applying this term on the data observed while driving in curves, it can be suggested that motorist visual search activity is less retarded while driving around a left handed curve as compared to a right handed one. This also means that the motorist increasingly devotes his visual attention in right handed curves to picking up control information. Thereby the amount of guidance information input is decreased. Why does he need more control information in a right than in a left handed curve? At the present state of research,it is rather difficult to answer this question completely. However, it might be speculated that the increased need for control information in right handed curves could be related of the relationship between the momentary changing of the car's direction of traveling and the future path's lateral extention. While driving around a right handed curve, the motorist has to steer the car toward the direction which corresponds with the contemporary shoulders of the road. On the other hand, while traveling around a left handed curve he steers toward the momentary direction of the oncoming traffic's lane. This comparison indicate that the potential danger of driving off the road, i.e., as a consequence of inadequate information input, is greater in a right handed curve. In order to avoid this potential danger, the driver has to increase his lateral information input. The simultaneous decrease of guidance information input is an accompanying phenomenon. In a left handed curve, on the other hand, the driver scanned more extensively, maybe because he has to attend more carefully any potential oncoming traffic while taking care to avoid cutting the curve.

The comparison between right and left handed curves pointed out a difference in regard to the total spatial area the driver considers. This difference is manifested by the fixations' mean location in a vertical, as well as in a horizontal direction. These findings and the smaller spatial variability of the fixations' locations indicate a relative perceptual narrowing while driving around a right as compared to a left handed curve. Furthermore, the perceptual narrowing is greater in inexperienced than inexperienced drivers.

As the poorer, i.e., narrowed visual search strategy is associated with decreased view distance, there is less spare time to react after an essential target has been recognized. Because driving safety is of crucial importance under all conditions equally, the motorist has to increase his vigilance when the efficiency of his eye movement behavior is decreased, that is to compensate for the degraded visual search strategy. If this suggestion is valid, then the inexperienced driver is handicapped not only because of his poorer visual search in curves, but also because of his less under-developed skills in operating the car.

Three of the four subjects termed here as inexperienced drivers had operated a car for some years. Therefore they should not be confused with novice drivers. Significant differences observed between the two sugbroups according to their driving experience (which can not be attributed to the data of one novice driver) indicate that driving skills, i.e., perceptual learning, are acquired over a long period of time. The importance of driving experience for adequate visual information input seems to depend on environmental con-conditions. The general impression is that driving experience is of crucial importance when the complexity of the traffic conditions increases and less so when environmental conditions are rather simple. This suggestion is supported by differences observed between the two subgroups of subjects - more pronounced while they drove around curves than when they travelled along straight road sections. This means that the inexperienced driver has to increase his vigilance even more than does the experienced driver when he already has to operate under a great load of information and has rather little spare capacity.

The comparison between curves and straight sections did not yield any significant difference with regard to the fixation times, their vertical or the horizontal locations in relation to the road's focus of expansion. The only significant difference is that the saccade amplitudes is greater for driving along straight sections (4.90°) than for traveling around curves (4.41°). This result might be interpreted as a relatively narrowed field of visual search in curves as compared to straight roads. This suggestion is congruent to that made above in regard to the curve's handedness.

The relatively small variability between curves and straight road sections, which are less pronounced, as one could expect, might be the result of the road's structure ahead. Each straight section could always be characterized as the approaching zone of either a curve or that of an intersection. Because the driver's visual search strategy reflects anticipatory behavior, his workload was already increased while steering the car on the straight road. This notion is supported by SHINAR,McDOWELL and ROCKWELL (1977),who pointed out that the driver's visual activity increases when approaching a curve.

All the three straight sections possessed similar characteristics. Therefore the differences observed between them can only be attributed to the changing road geometry at their ends.

In summary, it can be stated that visual information input is clearly related to environmental conditions, as well as to the future motor activity required. The role of driving experience for selecting adequate targets of future fixations increases, supposedly, when the motorist's workload is great. Perceptual learning in particular, and driving experience in general is therefore of essential importance in complicated traffic or environmental conditions and less so when driving, for example, along a highway. This suggestion is supported by **GRIMM** (1978) who emphasizes that the driver's task requirement are additive. Presumably they are even hyper-additive.

The system theoretical data analysis pointed out that the models established are equally accurate for the dependent, as well as for the independent set of data. The models' accuracy, however, amount approximately to 50 %, i.e., for describing the driver's sequence of fixations, as well as for predicting his future fixations. This similar rate suggests that the model established is equally valid for different sets of data observed on the same subject. The general level of accuracy is, nevertheless, moderate. However, the individual models established in this experiment are based on a hypothetical program suggesting a mechanism of information processing. The models established, which have the same mathematical structure for each subject in common, show that the essential parameters governing the movements of the eye were considered.

The inter-individual differences between the models obtained are not related to their mathematical structure but to the weighting parameters A_i, B_i and G_i. The parameters A_i and B_i are related respectively to the information for control and for guidance. These inter-individual differences suggest that different drivers consider control and guidance information in a dissimilar manner. This might be associated with subject variability as no intra-individual variation was obtained between the two sets of data analyzed. The parameter G_i is associated with the driver's ability to integrate any new information within his schema, that is, to minimize any discrepancy between S_{ic} and S_{ie}. This parameter varies among the motorists, but not intra-individually.

The individual models established do not predict the driver's future fixations perfectly. They, nevertheless, represent a step forward in research on the driver's eye movement behavior. The prinicpal methodological achievement is the fact that this was the first attempt to *predict the point (i.e., corrdinates) of the next fixation of the eye*. The prediction of the next fixation was associated with the target, i.e., its spatial location, and not only with a category of road elements, which is progress of a qualitative nature.

Chapter 7

OUTLOOK

1. CONCLUDING REMARKS

The essential preconditions for reasonable analysis of eye movement behavior in driving are (1) the relative great importance of the foveal, as compared to peripheral,vision, (2) the driver's relative great work load and (3) the moderate size of the road elements to be considered. When these preconditions are fulfilled, then the drivers' fixation points correspond with the underlying information input.

The conditions required for reasonable analysis of the driver's visual search strategy contradict the crucial requirement to increase traffic safety. The road engineer makes efforts to decrease to driver's work load by reducing the environmental complexity. He attempts, furthermore, to increase the driver's preview distance. Under these conditions, as BHISE and ROCKWELL (1971) pointed out, the driver must not necessarily use his central vision in order to pick up the required information. His peripheral vision is sufficient for facilitating correct driving and the analysis of the drivers' points of fixations can not adequately refer to the associated information input occurring at the same moment. Therefore the ideal road, from the point of view of traffic safety, is not suitable for investigating eye movement behavior.

In order to find out the regularities of information input, or processing, each fixation of the eye must be related to a particular input which can be associated with central and not with peripheral vision. This ideal experimental design can never be completely achieved but can be approximated only in field conditions because of difficulty in proper selection of the experimental route used.

A central issue of an ideal experimental design to be used in studies on the motorist's eye movement behavior is to reduce the possible input of non-relevant information. This can be better achieved under laboratory conditions than for driving in daily traffic conditions. A further essential advantage of laboratory experiments is the better controllability of independent variables, including the manipulation of the driver's work load. A laboratory design, however, does not seem to reflect the driver's visual search strategy adequately, as the first experiment showed. Even though the experimental paradigm used was rather simple, the observed differences between the field and the laboratory were, nevertheless, quite great. This result does not justify study of drivers' eye movement behavior in the laboratory.

Experiments carried out under field conditions are less sophisticated than those which can be achieved in the laboratory. They have the advantage, on the other hand, that respective findings can be directly related to reality. Field experiments are, however, associated with a decreased controllability of the crucial variables.

Relevant information input is accompanied in field conditions with "noise", i.e., fixations on non-relevant targets, when used to reflect the driver's visual search strategy. There is essentially no opportunity to "overload" the driver's capacity because he operates as a "compensator". If the information's density increases, the driver can reduce his speed of traveling, which causes a reduction of the information to be processed within a certain time interval (e.g., LIEDEMIT, 1977). This difficulty was one central issue of the experiment reported in the third chapter.

The motorist steers his car according to his skills and the environmental conditions, that is, he is aware he must not deal with a greater amount of information than he can process. Therefore under daily conditions he might possess a spare capacity for picking up information having no or limited relevance for driving. However, when analyzing the driver's sequence of fixation, there are no adequate means for distinguishing between fixations devoted to the input of adequate versus non-relevant information (e.g., noise). Because the noise's source is not known, there is no suitable method for its filtering.

In order to reduce the rate of irrelevant information input and to increase the adequacy of the experimental design used in field conditions, it is necessary to investigate the driver's eye movement behavior under rather great workload conditions. In those circumstances he has no spare capacity or only reduced spare capacity for picking up non-relevant information. Due to this design, as approximated in the field experiments reported above, the role of noise could be reduced but, supposedly, not completely excluded.

A further important precondition for a reasonable study of eye movement behavior was the central issue regarding the stability of the driver's visual search strategy. When he is repeatedly driving on the same road, his eye movement behavior does not alter significantly but rather fluctuates at random. This was an important finding reported in the fourth chapter.

Each of the experimental carried out yield a significant relationship between environmental conditions and the driver's eye movement behavior. The reported findings suggest that visual search strategy reflects an anticipatory behavior, that is to pick up relevant information in advance, permitting the setting up of feed forward motor programs for adequate future activity. The sequence of the eye fixations corresponds thereby to a continuous modification of the driver's schema, which is an important controller for the selection of the required action or reaction.

The suggested relationship between successive eye fixations is supported by findings based on the system theoretical approach applied. A next fixation of the eye is causally determined by the available information, by that which the driver has already picked up (i.e., his schema) and also by the driver's capacity to process the information input. This statement is a direct implication from the time discrete process models which were determined for each motorist individually. The approach used clearly pointed out that it is possible to describe the driver's sequence of fixations by means of mathematical models.

The time discrete process models established facilitate a sequential prediction of the driver's future fixations of his eye. Although that prediction accuracy is moderate, one must consider the accompanying conditions. These are essentially related first to the field condition discussed above and second, to the imperfect possibility of determining the informativeness of a complex visual array, such as the driver's forward view.

At the present stand of research there is no suitable method for operationalizing the information available in an adequate manner, as pointed out in this report's first volume. The attempts made to deal with information represent its attributes more than its complete definition. The operationalism used seems to be adequate but not yet completely satisfactory. (The operationalism of complex environmental layout must remain an important topic for future investigations.) Therefore the description of the information available as used in the reported experiments is not perfect, but represent, nevertheless, a suitable approach.

The progress accomplished with regard to the system theoretical data treatments also has implications for qualitative points of view. In the first attempt to describe the drivers' sequence of eye movement behavior, a method was used which required the successive fixations be divided into constant time intervals, regardless of their actual duration. In the subsequent experiments the constant time intervals required were replaced with discrete, but variable, time intervals whose durations always corresponded with those of the respective eye fixations.

Furthermore, in the last experiment reported, a hypothetical model was suggested which has a rather simple structure based on intrinsic feedback loops. This model accounted for the role of essential variables governing the movement of the eye in driving.

Inter-individual variability was observed in each experiment reported above. HOSEMANN (in preparation) stresses that eye movement behavior is highly related to the driver as an individual. The individual visual search strategy is, furthermore, influenced by long-term variables (i.e., fatigue). For future research therefore it seems to be of importance to consider as a variable the individuality of the motorist when analyzing his eye movement behavior.

In summarizing the results obtained it can be stated that the system theoretical approach used seems to be a powerful tool to describe the driver's eye movement behavior, as well as for predicting his future fixations. The models established consider simultaneously the driver's peculiarities, the information he already has picked up, as well as that which is available. The causality between these variables suggests that the manipulation of one of the variables mentioned causes a variation in the others. For example, the modification of the environmental layout will alter the driver's sequence of fixations. In this way, the driver's eye could be "voluntarily" guided toward targets characterized by their importance for correct driving. This goal remains a central issue of future investigations.

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SUPPLEMENTAR INFORMATION

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