

Research Note 84-74

DEVELOPMENT OF A GENERAL MODEL OF THE CAR DRIVERS' EYE MOVEMENT SEQUENCES
AND EFFECTS OF SUBJECT AND ENVIRONMENTAL VARIABLES

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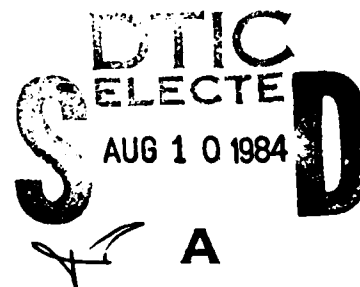
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→ The conducted experiments empirically support the validity of the pre-suppositions. The results also yield that a driver's visual search depended on his long-term variables. The observed eye movement behavior represented a visual adaptation to the environmental conditions. The degree of adaptation depended, however, on the individual's capabilities. ←

The further data evaluation pointed out that a sequence of fixations can be attributed to a semi-causal relationship between the successive movement of the eye. Whenever the driver's internal representation deviates from its objective characteristics, then the next fixation is devoted for reducing this discrepancy. When this discrepancy is rather small and still tolerable, then the next fixation of the eye depends stochastically on the previous one. A control model is suggested which describes this process.



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PREFACE

The macro-movements and fixations of the eye have already been identified as accurate criteria of the highly selective process of accurate information input. The observable peripheral ocular activity is the closest measurable dynamic variable of the flow of the intake of information, its' processing and the search for subsequent input.

The essential regularities of eye movement behavior, already known, can be summarized into three main groups of variables. First, visually guided behavior requires the input of task-oriented information located within the surroundings. Therefore, the environment determines which information is at all available, as well as the relative importance of each target. Secondly, the subject is comparable to an information processor and output generator. He is always seeking that particular information which facilitates the advancement of his activity, such as locomotion, visual search, operating an apparatus or a vehicle, etc. Thirdly, the information which the subject has already picked up remains stored for a while. Therefore, the information the subject is seeking depends also on his prior input, that is, on his short-time memory. Correspondingly, the subjective value of the information available, defined as a not yet known aspect, is a function of previous input.

These three interacting variables, environment, subject (i.e., in relation to the self-determined goal of activity) and prior input, are supposedly the main variables which govern the subject's eye movement behavior.

The general goal of the present study was to describe the car drivers' eye movement behavior, i.e., the program governing the movements of the eye, in terms of dynamic process models which are based on system theoretical approach. The method used facilitated the consideration of these three variables simultaneously, that is, to analyze their roles as well as their interdependence upon one another.

The present study is a direct continuation of a previous project carried out on the "Feed forward programming of car drivers' eye movement behavior: A system theoretical approach".

The authors appreciate very much the fruitful discussions with Prof. Dr. Hardi Fischer and the important suggestions and comments of Dr. Peter Driscoll. The cooperation of the subjects, who voluntarily participated in the experiments, permitted the achievement of the experimental goals. The cooperation of Prof. Michael Kaplan, Prof. William H. Helme and last not least, Prof. Arthur J. Drucker from the European Research Office of the U.S. Army in London is greatly appreciated.

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Section 1: Aimed movement production and goal oriented eye movements

1. GOAL ORIENTED ACTIVITY

Human behavior is characterized by purposeful activities. Each movement is produced, in general, as an integrated part of a continuous chain of activities, carried out in order to approximate the goal desired at that moment.

Approximating a desired goal means also to act within a given environment. In order to perform efficiently, each movement must be well adapted to the circumstances. Therefore, efficient goal achievement does not necessarily suggest reaching the intended goal by choosing the shortest way possible, but rather to select the optimum manner of handling; that is, to sidestep each obstacle while keeping the way as short as possible. Performance efficiency means, in other words, to investigate the minimum effort (time, etc.) necessary for goal achievement. This relationship can be denoted as a simple

S → R → G

relationship, whereby S indicates all the stimuli currently available and R represents the most adequate reaction leading to goal achievement (G). The desired goal releases the motor performance, in a manner adapted to the environmental conditions, whereas its achievement terminates movement production.

The simple S-R-relationship described above considers human performance from a rather static point of view and includes two central presuppositions. It implies, first, that nothing happens in the environment, except to the movement of the person concerned. Secondly, it must also be presupposed that the program underlying the movement production was perfectly set up and carried out quite exactly. These two presuppositions are usually the exception and not the rule. Therefore, the S-R model is far too simple for explaining human behavior.

Behavioral adaptation to the environmental conditions, in dynamic terms, extends the former description to the environmental alterations occurring during the course of time. There exist, in general, three main kinds of alterations. First, the person changes his own spatial position. Meanwhile the environmental conditions are thus altered, at least from an egocentric point of view. If the stimuli has been altered, then the optimum reaction is currently different than it was just a moment ago. Secondly, the goal-target might also si-

multaneously move. Therefore, the location of the goal achievement, which was right just a moment ago, might be currently wrong. Thirdly, further non-goal-objects might change their position in the environment. As a result, some objects which previously represented obstacles might lose, in the meantime, their goal-oriented relevance. Several other objects, on the other hand, which were non-relevant just a moment ago, may currently impede the desired goal achievement. In short, the dynamic alterations of the external environmental conditions determine whether the activities planned ahead still remain efficient. If not, then the subject has to react promptly, that is to readapt his behavior to the current circumstances. Such a behavioral readaptation is not necessarily required just once, but can happen repeatedly, while the subject continues to approach his goal.

Efficient goal achievement requires, under dynamic circumstances, much more than just the spatial consideration of all currently relevant objects. The subject has to continue picking up the relevant information during the execution of his performance, in order to readapt his behavior to any alteration. The underlying relationship between information input and motor output can better be approximated by extending the simple S - R - G interdependence described above. It can now be represented as a chain of S - R linkages, occurring in the

course of time, for example:

$$S_1 \rightarrow R_1 \rightarrow S_2 \rightarrow R_2 \rightarrow S_3 \rightarrow R_3 \cdots S_n \rightarrow R_n \rightarrow G$$

S represents again the total stimulation present at a certain moment, which is indicated by the index number, ranging from time interval 1 to n. R represents the most adequate reaction at that specific moment, as represented by the index number. The environmental constellation, that is, the stimulation, might alter in each next time interval, e.g. S_1 changed to S_2 . Consequently, the optimum goal oriented behavior R_2 is different from that which was previously the best way, e.g., R_1 .

The desired goal is approximated by the succession of the process described, until it is finally reached in the last time interval n. In other words, the subject has continuously to pick up feed-back information as well as to control his output while transforming the respective consequences into motor behavior.

1.1. Anticipation

Even though spatial relationships are considered in the extended model of S - R - linkages in successive time intervals, it cannot yet facilitate the most efficient behavior possible. The model's disadvantage is, that it always considers the current environmental constellation and fails to take into account the circumstances to occur in the near future, for example, at the moment of goal achievement. Furthermore, the crucial variable in determining the efficiency of motor performance is the concurrence of events.

The spatio-temporal movement relationships, i.e., the course of alterations of each relevant object, is an essential dimension of behavioral preadaptation to the environmental conditions. The subject must be aware of the invariable movement pattern, prior to the initiation of his own activities, if he wants to perform efficiently. For example, if a person wants to catch a ball, he must stretch his hands in advance toward the estimated trajectory, at the right time to the right place.

How can the subject know the future spatio-temporal relationships or the coincidence of events in advance? In order to answer this question, we must clearly distinguish between

three kinds of information. First, the information available at each current moment provides the perception of the present objects. The subject perceives what is where. The input occurs, of course, repeatedly in the successive time intervals and remains stored for a while. According to the processed information, the subject identifies, secondly, whether the objects moved and also recognizes the pattern of their movements, that is which object is moving, in what direction and how fast. If the objects' invariable pattern of locomotion is known, then the subject can, thirdly, estimate their location in each next time interval. This is the information given beyond the available input. It is facilitated due to the underlying process of mental interpolation from the information, picked up in the past time intervals. This future-oriented information processing is termed anticipation. It includes also the timing of events versus their estimated coincidence.

The advantage of the anticipatory process, as CHRISTINA (1967) stresses, is that "it allows the subject to prepare his motor responses in advance of stimulus occurrences so that they can be made in the 'right' place at the 'right' time in relation to these occurrences" (p. 188). As the subject expects certain occurrences in advance, i.e., timing of events, he can consider them already when setting up the motor programs. While performing, on the other hand, the fore-

seen events are calculated beforehand. After the subject has started to execute the programmed movement, he has to continue picking up relevant information. It is needed, first, to control movement production and, secondly, for perceiving each environmental alteration occurring at the meantime.

The disadvantage of anticipatory processes is, however, that the foreseen stimulus occurrences are based upon cognitive assumptions derived from prior input and past experience, in contrast to certainty. Anticipated events may or may not occur. The reason is that there is no necessity that the past pattern of alteration remains invariable in the future. This is one of the main reasons why anticipatory behavior has to be accompanied by uninterrupted information input, i.e., in order to compensate any unexpected deviation between the anticipated circumstances and the actual occurrences, provided that such a discrepancy actually occurs.

To illustrate this notion, suppose that you are driving a car along a straight road. You perceive a pedestrian in the middle of your lane, that is, on a momentaneous collision course. When considering this constellation in static terms, as a simple S - R relationship, then the only proper reaction is to stop the car at once. However, if the same constellation is considered from a more dynamic point of view, which

actually better suits human behavior, then the situation is perceived in a completely different manner. First, the integration of the information already processed is sufficient for recognizing that the pedestrian is not just standing in the middle of the lane, but that he is crossing the road. Secondly, the driver perceives also in which direction the pedestrian is walking and how fast he is going. On the other hand, the motorist also knows his own speed of travelling and the spare driving time (or distance) still left to effect a junction, that is a coincidence of events which should be avoided. When the driver assumes that the pedestrian will already leave his lane at the right time - including a sufficient spare distance as a safety factor - then he can continue driving on with an unchanged velocity. Nevertheless, the driver has to maintain picking up relevant information, as unexpected events might occur. For example, the pedestrian might stumble. In this case, he has either to slow down or stop the car at once. This is just one example which clearly indicates that anticipatory programs, set up in advance, have to be readapted if required. In summary, efficient motor behavior is planned according to past information input, while its execution is accompanied by an uninterrupted input of further information.

The subject's ability to anticipate future spatio-temporal constellations is highly influenced by cognitive processes, as

well as by previous senso-motor learning. KELSO and STELMACH (1976) have suggested that the mode of motor control shifts, as a function of learning, from a predominantly feed-back mode to a predominantly feed-forward mechanism. This statement implies that the role of feed-back decreases with increased learning, whereas that of anticipatory behavior becomes greater. The reason is, first, that learning is associated with the development of a system of categorial codes (BRUNER, 1964) which facilitate integration of the input into the schema with increased efficiency (e.g., NEISSER, 1976). Secondly, the subject possesses, at higher hierarchical levels in the CNS, an integrated store of programs which he can recode in order to initiate a required motor performance (e.g., MARTENIUK, 1976), and to adapt it to the current circumstances.

1.2. Requirement for studies carried out under field conditions

Motor behavior, as a goal oriented activity, is associated with a quite complex mechanism of movement production, in its interdependence with the environmental conditions, the information processed, the subject's capabilities, etc. This mechanism includes highly cognitive processes, like those associated with processing the input or setting up the appropriate

motor program. On the other hand, while performing, execution of the movement must be controlled, and readapted, whenever necessary. Even though motor behavior depends, under daily circumstances, on a diversity of variables, like dynamic alterations in the environment, uninterrupted input, anticipation, etc., present knowledge is primarily based upon results obtained from quite simple laboratory designs (e.g., reviews are given in STELMACH, 1976 or CRATTY, 1973). NEISSER (1976) summarized the current state of research by stating that investigators are "focusing inward on the analysis of specific experimental situations rather than outward toward the world beyond the laboratory".

The reason for this current investigational approach is the hardly manageable complexity of the environmental conditions as well as that of the motor behavior itself, which has to be analyzed. When using an experimental design in the laboratory, on the other hand, there is no certainty whether the results obtained are valid for reality, i.e., because of the influence of interfering variables which are neglected in the laboratory design.

The general investigational goal, according to WOODWORTH (1948) is "to make scientific study of the activities of the individual, considered as a unit, as he is dealing with other

individuals and with the world". If so, then field experiments should be preferred to simple laboratory designs (e.g., NEISSER, 1976). However, the mechanisms underlying movement production and its execution are so complex, that they are difficult to analyze even under the simplest design possible. The structural complexity of motor behavior, connected with the environmental complexity in field conditions raises the question as to whether motor behavior can be studied under these circumstances at all.

An attempt to investigate the program underlying motor behavior - under field conditions - can be undertaken if the complexity of the underlying processes could be reduced. One possibility is to study the most simple kind of movements. Such a movement has to be initiated by a motor program, generated according to the information available prior to its execution. While performing, on the other hand, any modification of the initiated movement should be excluded, in order to reduce the complexity of the mechanisms underlying movement production. The movement analyzed should not be readaptable during its execution, i.e., any input of feed-back information has to remain useless until a next movement is initiated. When these requirements are fulfilled, then the complexity is reduced and the program underlying the movement production can be studied.

The requirement above is fulfilled, if the movement considered is characterized by its ballistic course. That means a very fast acceleration when starting to move, followed by a quite sharp deceleration just before the movement is completed. After a ballistic movement has been initiated, there is no possibility at all to change its course. If the movement is inaccurate, for example because of an improper program set up in advance, then deviation from the desired goal has to be compensated with a further discrete, subsequent movement.

A typical ballistic movement is that of the eye, meaning the saccadic eye movements. Consequently, after the eye has started, saccadically, to move, there is no possibility to change its execution. Therefore, the saccade's course reflects its underlying motor program without any interfering modification, i.e., readaptation, which could have occurred due to the intake of feed-back information. When the investigational goal is the study of the program underlying movement initiation, in contrast to its modification during its execution, then the study of eye movements seems to be a quite suitable field of research.

It must be stressed, however, that there are two essential differences between the saccadic eye movements and other kinds of movements. First, the ecological purpose of each saccadic

eye movement is to successively fixate the eye upon relevant targets, in order to facilitate the most efficient input possible. The goal of other kinds of movements, on the other hand, is efficient motor performance, either by changing their own position or together with that of any object in the environment. Secondly, the course of saccadic eye movement, as mentioned above, cannot be altered due to feed-back information, in contrast to non-balistic movements.

On the other hand, all kinds of movements have some common characteristics. They do not occur at random, but are initiated according to a motor program priorly set up. This program is based upon information processing and executed as a purposeful activity. However, there are some peculiarities of the saccadic movements of the eye which has to be discussed in the followings.

2. SACCADIC EYE MOVEMENTS AS PURPOSEFUL ACTIVITY

At this point the question arises as to what are the reasons for moving the eye from one to another target, i.e., the alternating sequence of saccades and subsequent fixations. The main reason for moving the eye is to successively fixate

different targets. This process is related to the physiological structure of the retina, as its different zones facilitate unequal visual acuities.

The specific retinal spot which corresponds to the maximal visual acuity possible, as well as the fastest and most detailed input, is called the fovea centralis. Therefore, in order to see a target (under photopic conditions) most accurately, the object must be brought into projection on the fovea centralis through the movement of the eye. This corresponds with changing the direction of sight, i.e., with altering the fixation point in connection with further oculomotoric processes.

2.1. Eye movement behavior

The visual system is the most active modality which facilitates the perception of colors, forms, spatial extensions, etc. from rather great distances. The other sense organs are, on the contrary, limited to information input from the near surroundings, like hearing, or from the immediate proximity, like touch.

The dynamics of the eye in the process of gathering visual information is mainly manifested by its rapid saccadic move-

ments, which guide the eye toward a successive scanning of different targets in the environment. Thereby, the eye is moved from one to another environmental element with a frequency of about 10'000 times per hour.

The temporal course of the visual search strategy can be divided into two essential phases or states of the eye. The first of them is the rapid ballistic movement of the eye from one target to another. This rapid movement will subsequently be referred to as saccadic eye movement or, equally, as saccade. The magnitude of the saccadic eye movement, which is expressed in arc degree, is denoted as the eye movement's amplitude. The second phase of the eye corresponds with that temporal extension during which no saccadic eye movement occurs, meaning that the eye is in a relatively stable state in relation to an unmoved environmental target. This state is called eye fixation or, equally, fixation. The duration of the eye's fixated state is denoted as fixation time, which varies from 0.25s to a maximum of 0.50s on the average, or vice versa. The saccade's mean frequency is approximately 2 to 4 movements per second. The specific target which is focused upon during the eye's fixated state is termed the fixation point.

The temporal course of the oculomotor activity consists,

therefore, of a succession of changes between the saccadically moved and the fixated states of the eye. These two phases of the eye and their temporal course in relation to the environment describe the essential variables manifested during the visual search strategy, and will be subsequently referred to as eye movement behavior.

When using the term "eye movements" in relation to visual perception, one does not only mean the saccadic movement of the eye but, importantly, its goal, i.e., the eye's fixations, during which the information is picked up. The movement of the eye itself is, consequently, just the means for facilitating the efficient input of relevant information.

The present dichotomic distinction between saccades and fixations represent a simplification of the actually occurring oculomotor activity. For understanding the considerations at hand, however, no further differentiation is required. It should be nevertheless mentioned that detailed reviews of oculomotoric activity and its underlying neural mechanisms have appeared, e.g., by DITCHBURN (1973) or by CARPENTER (1977).

2.2. Processes governing the saccadic movements of the eye

The points of fixation are not distributed across a viewed picture or, in general, across the optical array at random. On the contrary, they are directed toward targets characterized by certain aspects. On the other hand, during the saccadic movement, a peripheral as well as a central inhibition of visual information input occurs (VOLKMAN et al, 1978), so that it is hardly possible to assume that a fixation point is determined while the eye moves. Furthermore, the saccadic movement is of a ballistic nature, as mentioned above. This is a further fact which does not support the idea that a subsequent target of fixation could have been selected during the saccade or that any feed-back information would modulate the saccade's course after the movement has been initiated. This reasoning, i.e., that a specific target is fixated which is not selected during the saccade, must lead to the conclusion that each subsequent fixation point, that is, the program of each saccade, is determined before the eye begins to move. How does the mechanism function which guarantees an accurate program governing the movements of the eye?

As to the visual component underlying the process governing the movements of the eye, it can be stated that visual information input occurs out of the whole visual field, i.e.,

through the whole retina. The efficiency of the information processed depends, however, on the corresponding visual acuity (e.g., MACKWORTH, 1976). High resolution favors the input and the subsequent processing, whereas low visual acuity impedes these interrelated processes.

During every fixation, i.e., while picking up information from the fixated target, other objects or events can be simultaneously detected due to peripheral vision, even when they are not necessarily associated with conscious perception. They provide, however, an undetailed detection of available targets. In this way, after each fixation, there are several targets within the visual field which are potential objects of the subsequent fixation. The non-detailed information, provided by peripheral vision about possible targets of fixations, entails two aspects. The observer must first know what the potential targets of a next fixation are and secondly, where they are located. Then he can select the most important target, at that moment, as the goal of the subsequent fixation. In summary, it can be stated that the eye function as a two-channel processor. Detailed and rapid task-oriented information input is facilitated through the first channel, that is through the fovea. The second channel, which is associated with peripheral vision, explores the environment. This non-detailed input, through the parafoveal field of vision, facilitates the de-

termination of the target to be subsequently fixated.

Analysis of saccadic movement has shown that before the eye begins to move, it is already known in which direction and at what distance the intended, subsequent fixation point lies. The saccadic movement guides the eye toward that target and stops quite exactly, if the amplitude is rather moderate or small. When carrying out saccades with great amplitudes, the intended target is not always fixated exactly (e.g., PRABLANC, MASSE and ECHALLIER, 1978). In that case, the intended, exact fixation point is subsequently reached due to a further small saccadic movement of the eye which is called the corrective saccadic eye movement. These two movements are different, not only in their amplitudes, but also in regard to their latencies. The saccade's latency is approximately 200ms while that of the corrective saccadic eye movement amounts to about 50ms. It can be assumed that the underlying processes of these two kinds of movements are different, at least in part. POEPPPEL (1974) suggested that, for programming the saccade, the movement's direction as well as the distance must be precalculated. For programming the corrective saccadic eye movement, on the other hand, only the angular deviation from the goal (i.e., the intended target of fixation), but not the direction, must be computed. This suggestion is supported by empirical observations showing that if the subject is presented

with periodical alterations of a limited number of required points of fixation, i.e., if he becomes acquainted with the amplitude and direction of the prescribed saccades - or, equally, with the targets' localization - then the latency of the saccade becomes shorter, even if the subject does not know in advance when the saccade should be initiated.

This all suggests that the subsequent target of fixation is known before the eye begins to move, and that the required information could have been picked up solely due to input through peripheral vision. The mechanism guiding the movements of the eye can therefore be characterized as a sensomotoric feed-forward program. It is based upon information picked up in advance, in contrast to any feed-back information. Consequently, the programmed saccade is carried out without any further modulation.

Therefore, the system governing the movements of the eye can not function according to the characteristics of the optical array only, but is also dependent upon the observer's cognition, as well as his processing capacity. The process of controlling the movements of the eye should be understood as a process consisting of four essential components in its simplified form (see Fig. 1). This program starts to function after a retinal projection (1) has occurred. Then, predeter-

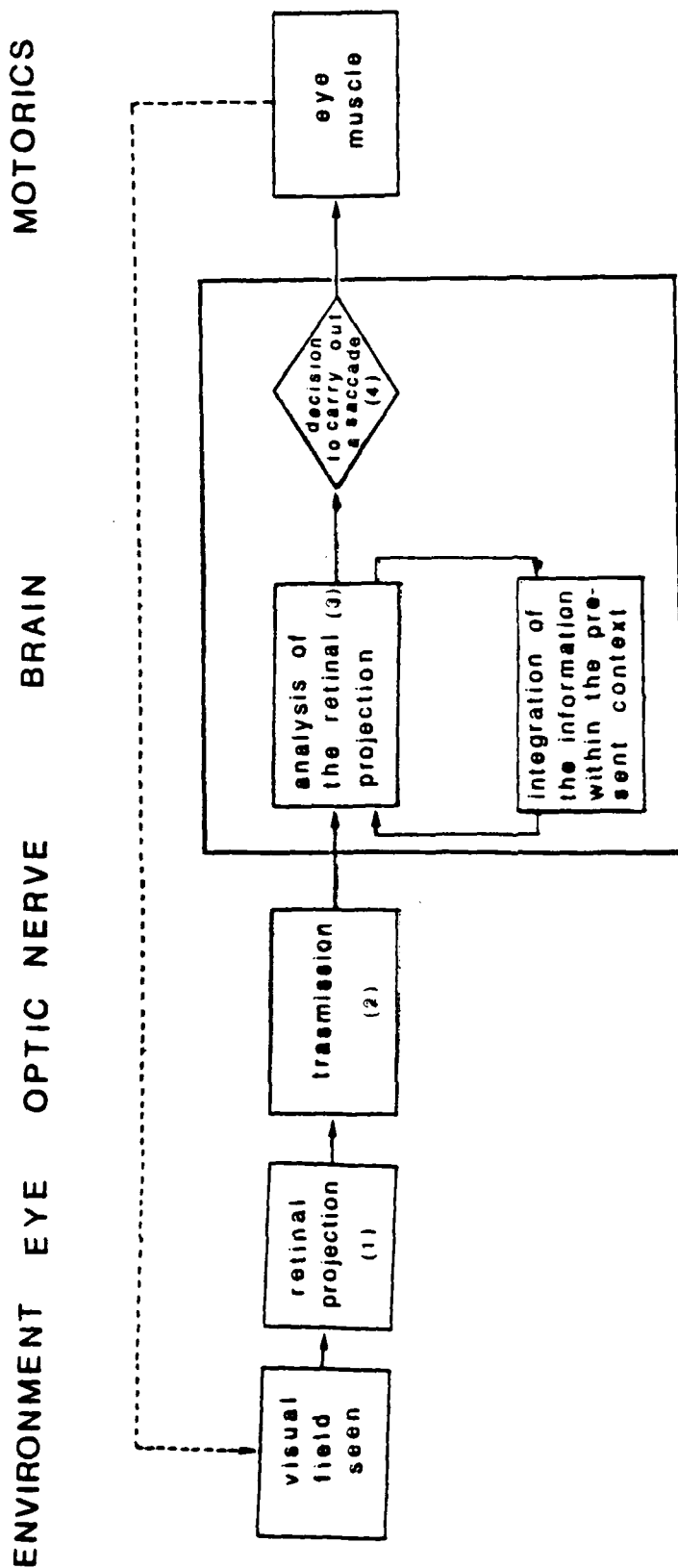


Figure 1: Schematic diagram showing the essential components of the program governing the movements of the eye.

mined nerve fibres facilitate the neural input's transmission (2) from the retinal photoreceptors to the brain. This transmitted information correlates to the original retinal projection (e.g., COWEY, 1979) but is different in its dimension, as the electromagnetic waves are now nerve pulses. Also, an abstraction of the available information already occurs at the retinal level, as LASHLEY (1941) has pointed out. Furthermore, as a consequence of the greater number of photoreceptors compared to the number of optic nerve fibres, only a reduced part of the information available at the retinal level is transmitted to the visual cortex. GREGORY (1966) has characterized the retina rather accurately as the brain's first stage.

The analysis of the retinal projection (3) occurs in the visual cortex during the ongoing fixation. This analysis, of course, does not occur for its own sake, but in relation to information already picked up as well as that being sought, i.e., in dependence upon the observational goal (YARBUS, 1967) and the subject's present cognitive schema (e.g., MACKWORTH and BRUNER, 1970). The present information input then both modifies and is integrated within the cognitive schema. At this stage, after the information input has been processed, the subject can determine which information he is seeking in order to gradually complete the goal of observation, i.e., what target should be next fixated. Afterwards,

the neural signal can be directed to the oculomotoric system, in order to carry out a new, aim oriented saccadic movement (4), in order to bring the next most important target, within the shortest time possible, to projection on the fovea. As soon as the subsequent retinal projection is available the described process starts over again.

The rapid sequence of discrete fixations allows the perception of the visual world as a continuity, despite the discrepancy between introspection and the objective course of information input. The inputted information and its processing and integration within the existing semantic context facilitates the perception of the environment, gradually adding to the knowledge about it.

There are, notwithstanding, also fixations which are not associated with visual information input, but with starring (e.g., PURKINJE, 1825). They are, however, the exception to the rule in visually guided behavior. It can be quite certainly assumed that detailed information is picked up through foveal vision, while parafoveal vision is devoted simultaneously to exploration of further targets of interest in the environment in order to determine the next fixation point prior to beginning the eye movement.

3. REQUIREMENTS FOR MEANINGFUL EYE MOVEMENT ANALYSIS

The analysis of eye movement behavior can only then be valid, when the subject is uninterruptedly engaged in a visual or visuo motor task, i.e., he has continuously to pick up relevant information. For example, in the case of a visual task like reading, the subject has always to forward his input of relevant information. When observing pictures, as a further example of a visual task, the subject certainly picks up information in the first phase of viewing. After a while, however, he might refixate the same targets repeatedly (e.g., ANTES, 1974). Refixations, as an indicator of intake redundancy rather than new information, might be related, instead to different processes than goal oriented visual activity. Therefore, the eye movements observed during prolonged picture viewing (for example, YARBUS, 1967, presented pictures for 30 minutes) might inadequately refer to the process of information input as a goal oriented activity. Consequently, presenting the subject with a static array over an extended period of time has to be excluded from studies on eye movement behavior conducted to investigate aimed behavior.

Uninterrupted information input is required when the subject is engaged in visually guided motor performance. The information input occurs then, not for its own sake or in order

to fulfill any instructions given, but rather to establish an internal representation of the external environment and its ongoing alterations. The intake of information is then a necessary precondition for setting up appropriate motor programs for efficient goal oriented activity. Perception is, in this sense, an intervening mechanism which facilitates the adaptation of the organism to external conditions. The active search for information is manifested in the alternating sequences of saccadic movements and fixations of the eye.

The goal of the saccadic eye movement is, as stated above, to bring the eye rapidly from one target of fixation to another, in order to pick up the information required for a perfect internal representation of the external conditions. The intensity of visual search has to increase when the rate of environmental alterations becomes greater, i.e., under conditions of rather great work-load, in order to keep the internal representation up to date. Under these circumstances, the subject has little opportunity, if any, to pick up non-relevant information without neglecting his task.

A reasonable analysis of eye movement behavior, when considered as a purposeful activity, is facilitated only when the three following conditions are simultaneously fulfilled: First, the subject has to perform under conditions of rather great

visual (or visuo-motor) work-load. He has then little opportunity to input non-relevant information. Secondly, the role of peripheral vision in the process of gathering relevant information should be quite limited because the input considered in the data analysis is associated with foveal, in contrast to peripheral, vision. However, parafoveal vision has still to guarantee the input of undetailed information in order to determine each subsequent target of fixation. This is a requirement for setting up the proper motor program of the next saccade, prior to initiating the eye movement. The third precondition for reasonable analysis of eye movement behavior is related to the correspondence between the occurring process of information input and its analysis. The objects considered as targets of fixation in the data analysis must correspond with moderate spatial extension. If they are too great, then the inputted information is insufficiently differentiated. If the targets of considered fixations are too small, then the accuracy of eye movement registration might be insufficient (e.g., ROCKWELL and ZWAHLEN, 1977; COHEN, 1980).

These three preconditions for a reasonable analysis of eye movement behavior can completely be fulfilled when the subject has to operate a vehicle under rather complicated environmental conditions. The subject has then uninterruptedly to pick up relevant information in order to adjust the vehicle's move-

ment parameters to the altering circumstances. Furthermore, the perceptual system function under field conditions of car driving not just in order to fulfill any experimental instructions given, but rather in its original sense, that is, to provide spatial orientation and survival.

The aim of saccadic eye movements is, therefore, to bring a target of special current relevance into foveal projection. A study on eye movements can be conducted through an analysis of the targets fixated, in relation to available information. If the subject fixates each time a target of the greatest momentaneous importance for driving, then the goal of each saccadic eye movement has been perfectly fulfilled. It is rather improbable that the subject would fixate these targets just by chance. On the other hand, if the subject fixates targets having, rather, little or no goal-oriented relevance, then it can be assumed that the underlying motor program was imperfectly set up. In other words, the analysis of the targets of fixations, in relation to the task-oriented importance of the available information, provides an estimation of the accuracy of the motor program that has initiated the saccadic eye movement.

4. RELATIONSHIP BETWEEN SUCCESSIVE FIXATIONS

Previous studies on modelling the drivers' eye movement behavior have shown a close relationship between the successive eye fixations (COHEN and HIRSIG, 1980). Each successive fixation depended upon the information which the motorist has already picked up. That, in turn, modified his internal representation of the environment, i.e., his cognitive schema. The next fixation of the eye also depended on the information available from the environment. The drivers' cognitive schema and the characteristics of the environment are the two interdependent variables which together influence visual search strategy. The crucial purpose of information seeking is to facilitate a behavioral adaptation to the existing circumstances. It is a necessary precondition that has to be fulfilled prior to any adequate motor output, e.g., altering the vehicle's parameters of movement.

These variables were sufficient to establish time discrete process models, which described the drivers' sequence of fixations in a sequential manner. The models established had a common mathematical structure for all motorists whose visual search strategy was analyzed. An inter-individual variability was observed which was not related to the model's mathematical structure, but rather to the subjects' characteristics.

The rate of correct predictions of the sequence of fixations was well above the level of chance. A problem remaining in continuing this investigation is thus, to find out whether the drivers' sequence of fixations could be described in terms of a general model which reflects the structure of the motor program of saccadic eye movements.

4.1. Preconditions for establishing a process model

The essential three conditions facilitating the establishment of an accurate process model are the following:

- 1) The set of functions f can be called a process model of the observed eye movement behavior only if it accurately predicts each movement vs each fixation of the eye, i.e., if the predicted and the observed state vectors deviate in all observational intervals only within a priori defined limits 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 le-

vel of tolerance, then it means either:

- a) that not all relevant variables have been considered, or
- b) that the essential suppositions of a time invariable,
and a steady mathematical relationship between the input
and output variables, had not been fulfilled.

4.2. Essential suppositions

Any time discrete process model can only be accurate when all of the essential presuppositions underlying its functions are fulfilled. These presuppositions include two crucial hypotheses which have not yet been sufficiently investigated. First, in the contemporary studies on drivers' eye movement behavior the question arises as to whether the visual search strategy is a stable process, i.e., as to whether it does not change when driving under comparable environmental conditions, or repeatedly on the same route. If the drivers' eye movement behavior would not be stable, then there is little sense to analyze the program governing the saccadic movements of the eye. Because the stability of eye movement behavior, i.e., its dependence upon the driver's characteristics and the environmental conditions, is an essential precondition for the present issue, it was necessary to investigate the validity of

this presupposition. However, the empirical findings regarding this issue are conflicting (e.g., MOURANT and ROCKWELL, 1970, in contrast to BLAAUW and RIEMERSMA, 1975). Therefore, this issue had to be investigated. The present results obtained, as reported in Appendix I, suggest that the driver's eye movement behavior remains stable when repeatedly driving on the same route. The motorist's visual search is, in other words, a task oriented and rather stable activity.

Secondly, while considering the available information in the data analysis it was supposed that the relative importance of the present targets were always accurately scored by experts engaged with this task. Scoring the traffic oriented relevance of the available targets is of crucial importance, because it determines each subsequent target of fixation or, equally, each saccadic eye movement to be carried out in picking up the most important information in each time interval. Consequently, the data analysis can only then be accurate, if the expert has identified the relative importance of each target available, and scored every element precisely. This presupposition has been empirically tested and reported in Appendix II. The results showed that different experts scored the available information equally, even though they used different frames of reference.

Three other important issues must be mentioned here, even though they must remain within this frame-work as non-validated presuppositions. First, the hypothesis underlying the establishment of any model requires that the observed behavior corresponds with a deterministic process. Secondly, a deterministic relationship between past and future information input implies that the subject is capable of immediately recognizing, or at least recognizing within a rather short period of time, any new important target within his forward field of vision. Thirdly, the assumed deterministic relationship in the process of information input implicitly suggests that the driver picks up task-oriented information only, and that he completely neglects non-relevant input. This third assumption may eventually be governed by the motorist's current workload (e.g., COHEN, 1980, p. 98). Indirect evidence suggesting the validity of these presuppositions may be derived, at least in part, from previous findings (COHEN and HIRSIG, 1980).

Inter-individual variation is a common finding in different studies. The question then arises as to whether the motorist's individual personality, as well as perceptual variables, influence his eye movement behavior. The process of information input can be understood as a self-regulating system that adapts itself to the environmental conditions in relation to

the individuals' capabilities. The question to be investigated was, therefore, whether these variables influence the level of the acquired visual adaptation to the traffic circumstances. As the driver's internal capabilities might be overlapped by external, i.e. environmental, conditions, it was also necessary to study the role of individual variables on visual search in different situations. The respective study is reported in Appendix III.

4.3. The environment and its internal representation

A good correspondance between the environment's objective characteristics and its internal representation may be constructed by the driver through relevant information input. The validity of any internal representation is, however, limited to a short period of time. Because the driver moves within the environment, the relevant surroundings alter as a function of time, as does the relevant input. Therefore, the driver has to continuously input essential information in order to update his internal representation. If this hypothesis is valid, and the tolerable discrepancy between the environment's internal representation and its objective characteristics is rather small, then the precondition for establishing an accurate model is fulfilled.

5. SUMMARY

Human behavior is characterized by purposeful activities. Initiated motor performance must, therefore, be efficient. The underlying motor program, set up prior to goal oriented movement production, is based upon prior information input, anticipation of certain occurrences etc. While in motion, feedback information facilitates the control of the course of movement production, as well as the recognition of any environmental alteration occurring in the meantime, the consequence of which would be to readapt the ongoing behavior if necessary.

The scientific study of the program underlying movement production is quite complex. It is the result of, first, the complicated variables involved, like cognitive processes, the subject's current schema or his past experience. Secondly, external variables like ongoing stimulation and its dynamic alterations during movement production are extremely difficult to operationalize in suitable terms of human information processing (e.g., BERLYNE, 1958). Furthermore, the program set up to initiate motor performance is not necessarily manifested in the course of the movement actually produced. The process of readaptation, carried out either because of an inaccurate motor program originally set up or because of external altera-

tions which have occurred in the meantime, might cause the executed movement to be different from that which was previously programmed. The huge complexity associated with motor behavior impedes the study at present, of the structure of the motor program set up prior to movement initiation, especially under field conditions.

A reduction of the complexities involved in motor behavior is the only possibility for studying the programs underlying movement initiation. This requirement can be fulfilled when the movement analyzed lacks readaptability. The movement's execution would reflect, in that case, the underlying program quite accurately. For example, after a saccadic eye movement has been initiated, the trajectory remains the result of the passive properties of the orbital mechanical factors involved (e.g., DICHGANS, NAUCK, WOLPERT, 1973).

The saccade's goal is to fixate the eye upon a target characterized by its greatest current goal-oriented relevance. Therefore, the analysis of the fixations, instead of the movement itself, in relation to available information and prior input, could facilitate an estimation of the program's accuracy which has initiated the preceding saccade. For example, if the subject successively fixates targets which are of greatest relevance at the moment, then it can be concluded that the

underlying program was always accurate.

In order to analyze the goal-oriented activity of the saccadic eye movements, it is required that the subject will be engaged with a visual or visually guided task which is associated with a rather great work-load, i.e., an uninterrupted input of relevant information. The subject's visual capacity is devoted then to absorbing relevant, rather than interfering, information.

Even though the study of non-readaptable movements, like the ballistic trajectory of the saccade (as indicated by the fixation points), makes the investigation of the motor program underlying movement production more simple, the whole process still remains quite complex. The goal of the present study is to investigate the structure of the motor program governing the saccadic movements of the eye while driving a car. This issue will be treated in the subsequent section.

A review on the driver's scanning behavior should be limited to the specific investigational goals directly concerned. Such a review has been given elsewhere (COHEN, 1980).

Section 2: The eye movement behavior's basic characteristics considered as a semi - stochastic process

SUMMARY

The goal of the subsequent experiment was to study whether the basic characteristics of the driver's eye movement behavior could be described by means of a deterministic quasi-continuous control model. The criterion for evaluating the driver's eye movement behavior was the lateral angle of the fixation's direction in relation to the road's vanishing point. The environment was simultaneously considered in terms of the available essential information at the same moment.

The eye fixations of eight subjects were registered while driving twice on the same road, one time in each direction. The experimental route was characterized by rather great information density which was caused by frequent alternations (curves) and relatively short forward view distances.

The results obtained suggest that the drivers' eye movement behavior can be characterized as a part of a control model which stresses a good correspondence between the internal re-

presentation of the environment and its objective characteristics. Any non-tolerable discrepancy between the two variables is reduced due to a postulated error signal.

Each observed sequence of fixations could be attributed to a deterministic, quasi time-continuous control model. It is suggested that the eye movement behavior partly consists of a deterministic process which is active whenever the magnitude of the postulated error signal is rather great. The visual search includes, on the other hand, a stochastic component which operates when the discrepancy between the environment's internal representation and its objective characteristics is small and still tolerable. The error signal is then not sufficiently efficient for governing the subsequent movement of the eye. It is suggested, consequently, that a sequence of eye fixations represents a semi-deterministic process. As a result, it is supposed that an upper limit of the causal relationship between the successive fixations of the eye might exist.

1. INTRODUCTION

Previous research on modelling the drivers' eye movement behavior has led to the description of the motorists' sequence of fixations as time discrete process models. The models accuracy for succesively predicting the drivers' future fixations reached a level of 50% to 60% correct predictions on the average (COHEN and HIRSIG, 1980). Even though this rate is well above a level of chance (because one target of fixation was predicted out of some possibilities) it is, nevertheless, of importance to study further whether a more accurate model could be established. This is the first investigational goal of the present experiment. A further goal is to investigate whether the eye movement behavior's basic characteristics could better be described by means of a deterministic quasi-continuous control-model, while assuming a semi-stochastic process governing the sequence of fixations.

2. EXPERIMENT

2.1. Driving route

The requirement for facilitating a reasonable data evaluation determined the selection of the experimental route. The environment had to be characterized by relatively great in-

formation density in contrast to redundant elements. Furthermore, the path had to be rather narrow and the maximum forward view distance short in order to increase the drivers' motor as well as visual work-load. These conditions were fulfilled by an experimental route already used in a previous experiment (see COHEN and HIRSIG, 1980).

The experimental route is shown in Figure 2. Each driver drove his car twice along this urban road, that is, once in each possible direction. This alternation introduced a rather great environmental change between the two runs (i.e. due to the dependence of the curve's direction on the driving direction).

2.2. Data registration

The drivers' eye movement behavior was registered with a NAC-IV Eye - Marc - Recorder in connection with an AKAI videorecorder. The environment was additionally photographed with a Nikon motor drive F2S camera while using a frequency of two shots per second. The respective photos were subsequently used for estimating the relevance of the available information at each moment. (A technical defect prohibited to photograph the second run of subject No. 5. As no environmental data were available for scoring

Figure 2: The experimental route.

the information, there was no possibility to evaluate this run.)

2.3. Subjects

Eight subjects whose ages ranged between 23 and 42 years, participated in this experiment. They had between 1 and 23 years car driving experience. None of them knew the exact experimental goal.

3. HYPOTHESES AND METHODOLOGICAL APPROACH

3.1. The visual field

The methodological approach to be described simplifies the process of information input in regard to the drivers' subtasks of guidance and lateral control. The description of the subjects' eye movement behavior neglected the fixation distances and considered their lateral distribution around the road's vanishing point only.

The drivers' visual field was arbitrarily divided into 13 sectors. Each sector's origin was the drivers' current position. The origin direction of view, i.e., 0° , was the line connecting the motorists' current egocentric position with the road's vanishing point. Figure 3 schematically illustrates the definition of the egocentric direction of fixation as angle x° .

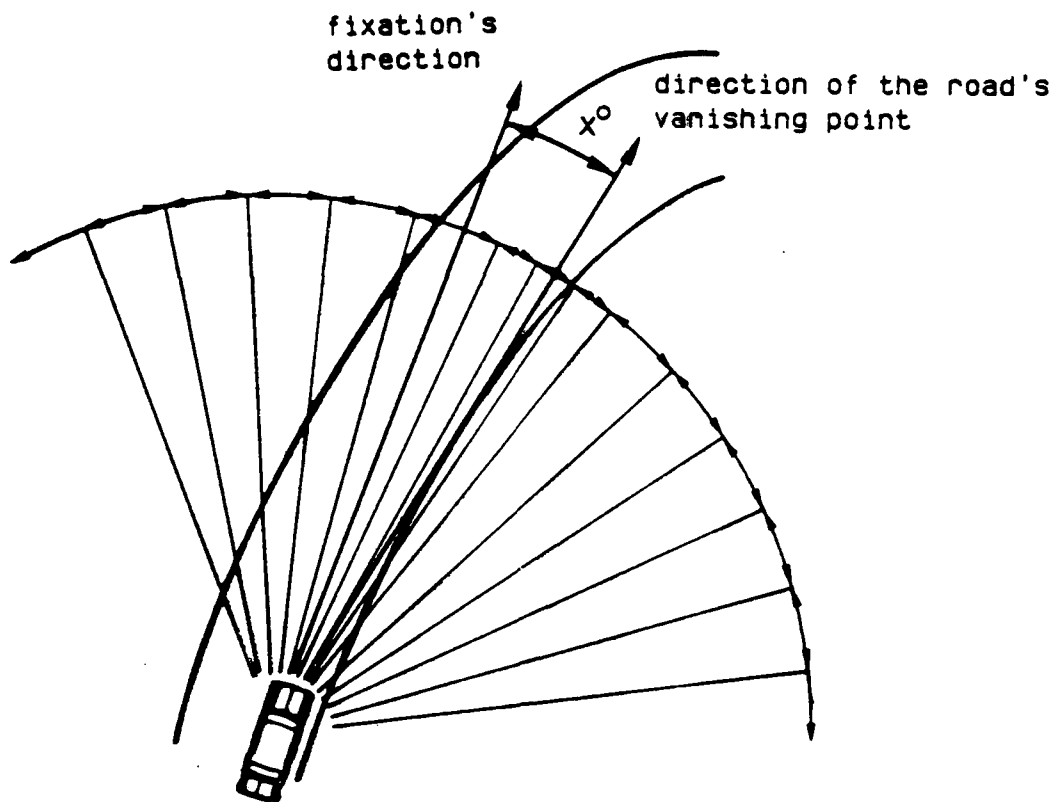


Figure 3: Definition of the fixations lateral angle X° in relation to the road's vanishing point, and the visual field's partition into 13 sectors.

3.2. Control mechanism

Figure 4 represents the suggested mechanism controlling the eye movement behavior, as a block diagram. The essential assumption of this model is that the environment's objective characteristics are closely related to its subjective representation. In KOFFKA's (1935) terms, it can be stated that the distal stimuli corresponds with the proximal one.

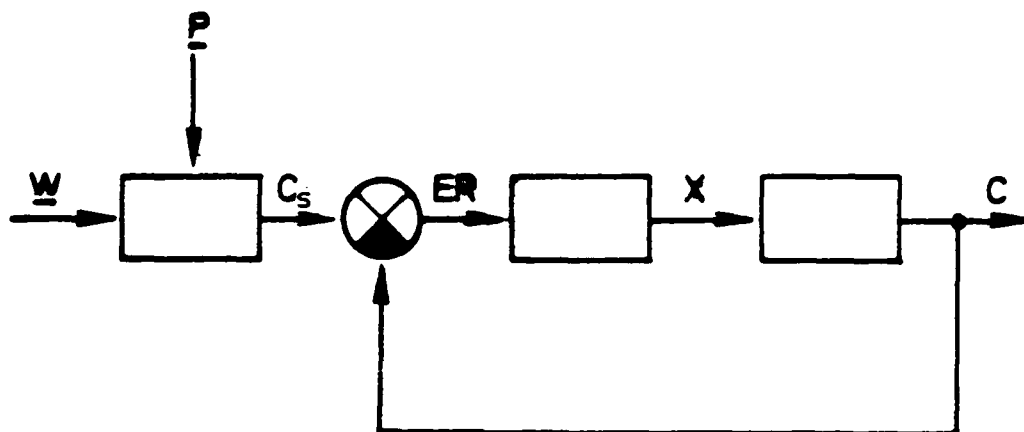


Figure 4: Block diagram showing the postulated structure of the deterministic part of the system governing the movements of the eye.

The vehicle's locomotion is associated with the driver's positional change within the environment. Correspondingly alters also the relevant environmental extension wherefrom the subject can input task-oriented information. Consequently, the environmental representation which the driver had just a moment ago, is, therefore, not valid for the current conditions. The subjective representation must, however, be dynamically adapted to any current alternation. Therefore, the driver has continuously pick up new relevant information, as represented in his eye movement behavior. Due to this dynamic process he approximates the proximal to the distal stimuli while maintaining a minimum discrepancy between them.

The proximal stimuli will be subsequently referred to as the "driver's concept" (C) and the distal stimuli as the "concept the driver should have" (C_s). Any discrepancy between the subjective and the objective concepts should be an essential variable in the program governing the movements of the eye toward the next relevant target of fixation. The essential variables involved in this process are shown in Figure 4.

3.3. Description of the available distal stimuli: Environmental vector $\underline{W}$

The environment was registered as a sequence of photos taken with a frequency of two shots per second. Every photo corresponded with the driver's forward field of vision in a defined moment. These photos were used for estimating the available information. This method enabled also an inference to be drawn on the environmental alternations occurring within time intervals of 0.5s each.

The photographic representation of the environment was divided into 13 sections as shown in Figure 5. The center of sector NO. 7 was always identical with the road's current vanishing point. The traffic-relevant information contained within each sector represented the corresponding environmental variable W_i . The numerical value of W_i amounted to 1 if sector i

contained relevant information, and to 0 if it did not. The derived 13 environmental variables W_i were summarized in a 13-dimensional vector $\underline{W}$ which described the lateral distribution of essential targets in the field of vision.

The durations of the eye fixations were evaluated with an accuracy of 20ms. The respective changes occurring within two successive photos were lineary interpolated while using discrete steps of 20 ms each. In this way it was possible to consider the distribution of the relevant information which was present during each fixation.

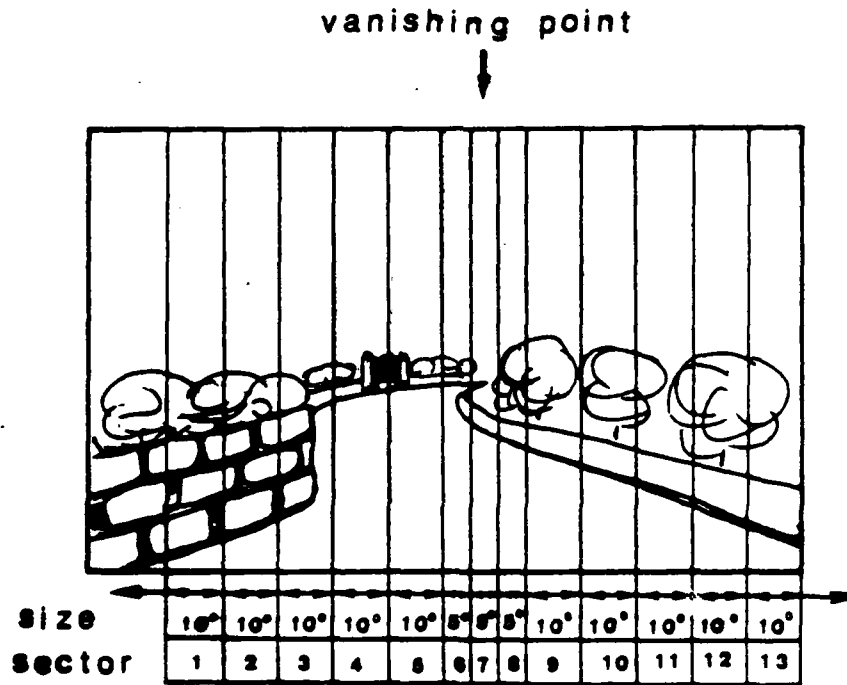


Figure 5: The 13 sectors defined in the visual field.

3.4. The driver's individual coding factors P_i

The environmental variables located in the driver's field of vision are assumed to be coded, i.e., cognitively weighted, according to their lateral distribution. For example, if a subject desires to pick up guidance information he has to fixate his eyes approximately straight ahead, in contrast to information input required for the car's lateral control. These two subtasks are unequally considered by different subjects, as previous experiments pointed out. Inter-individual variation occurs, for example, as a function of driving experience, which is related to very long process of perceptual learning. Therefore, it is assumed that different subjects will inter-individually vary in regard to their individual coding factors P_i .

The concrete values of the driver's individual coding factors P_i have to be estimated for each of the 13 sectors, whereby each value ranges between 0 and 1. The individual coding factors are, therefore, described as a 13-dimensional vector $\underline{P}$. For illustrating this notion, hypothetical values of P_i are given here:
 $\underline{P} = (0.7, 0.6, 0.5, 0.4, 0.4, 0.2, 0.2, 0.3, 0.3, 0.5, 0.6, 0.8, 0.8)$.
These values suggest that the driver increasingly considers the information located in the environmental sectors at the sides of his visual field.

3.5. The distal stimuli: The concept the driver should have C_s

The simultaneous consideration of the environment $\underline{W}$ and the driver's stable coding factors $\underline{P}$ allows the definition of a hypothetical variable C_s for representing the concept the driver should have, that is the adequate internal representation of the environmental conditions. This concept is brought into operation by the lateral angle C_s indicating the center of the weighted distribution of the available information. The sum of all weighting factors is defined as follows:

$$DS = \sum_{I=1}^{13} W_I * P_I$$

The concept the driver should have is defined as follows:

$$C_s = \sum_{I=1}^{13} (W_I * D_I * \alpha_I) / DS$$

whereby α_I represents each sector's center.

The environmental vector $\underline{W}$ can be computed in discrete time intervals of 20 ms each. Corresponding to these intervals it is possible to compute the values of each C_s for the same intervals.

3.6. The proximal stimuli: The driver's concept of the environment C

The driver's information input, facilitating him to construct his representation of the environment, is indicated by the

sequence of his fixations. However, the driver's concept depends on his memory limits. The information still stored can be related to the input he shortly picked up, that is approximately during the last second. (This time interval of 1s is suggested by estimations on the duration of iconic, or working memory; for example see AVERBACH and SPERLING, 1961.)

The driver's concept C was computed as a function of the lateral angle X^0 which were observed during the last second. The value of C was computed as an average the fixations' lateral angles X in intervals of 20 ms each.

3.7. Error signal ER

At any N 'th observation interval the subject has a concept of the environment $C(N)$, while the actual characteristics of the relevant surroundings corresponded to $C_s(N)$. The discrepancy between the proximal and the distal stimuli, computed as the difference between $C_s(N)$ and $C(N)$, is denoted as error signal $ER(N)$.

3.8. Control system

The driver's goal is always to perceive the environment as completely as possible, and to do this rapidly and accurately,

through fixations upon relevant targets. The motorist's fixations can be understood in this line of reasoning as a part of a control system which endeavors to approximate the driver's concept C to the environment's objective characteristics, i.e., to concept C_s . The required approximation between the proximal and the distal stimuli is not supposed to be perfect. It allows instead some limits of tolerance whose range is not yet known. In other words, it is supposed that the environment's subjective representation should fluctuate, in a dynamic but stable manner, around the surrounding's objective characteristics. When the environment's representation deviates from its objective characteristics beyond the hypothetical limits of tolerance, the driver has to correct this error by inputting the relevant information. The error signal ER , therefore, represents a measure for the necessity to reduce the discrepancy between C and C_s .

The internal characteristics of the control system, with $ER(N)$ and $X(N+1)$ as its crucial variables is shown in Figure 4. The value of these variables can be computed. Nevertheless, instead of formulating any further hypothesis, it is preferable to identify the control law governing the movements of the eye. The following procedure is used:

- a) The variables $\underline{W}$ and X are directly observable and they are measured in discrete time intervals amounting to 20 ms each.

- b) A stable coding factor $\underline{P}$ is postulated which depends upon the subject's characteristics.
- c) C_s is computed as described above in intervals of 20 ms each.
- d) The subject's concept is a function of his previous eye fixations which occurred during the last second. The respective information is supposedly still stored in his iconic memory. C is computed in intervals of 20 ms each.
- e) The comparison between C and C_s in the N 'th interval defines the error signal $ER(N)$ for the interval N .
- f) The respective value of $ER(N)$ in the N 'th interval and the change $DX(N+1)$ of the fixation angle in the next interval ($N+1$), describes the relationship between $DX(N+1)$ and $ER(N)$. In the same way, the relationship between $DX(N+1)$ and the derived properties of ER (i.e., the sum $SER(N)$ of all error signals $ER(N)$ and its deviations $DER(N)$ in successive intervals) can be considered as follows:

$$SER(N) = \sum_{n=1}^N ER(n)$$

$$DER(N) = ER(N) - ER(N+1).$$

The general hypothesis to be tested is that the subjective representation of the environment closely approximates reality. Any change in the environment is adapted by the subject. It is

associated with his coding factor P_i in relation to the information available. The underlying control laws are not expected to be of a completely deterministic nature as the requirement is that the proximal stimuli should approximate the distal stimuli. They must not be identical. Therefore, it is not expected that the fixations observed could completely be explained due to the error signal ER and the derived variables SER and DER.

4. DATA ANALYSIS AND RESULTS

Two sets of data were prepared per subject for data evaluation. They were derived from the first and respectively from the second experimental run. Each set of data included the time sequence of the environmental vector $\underline{W}$ and that of the fixation angle $X(N)$. Each variable was computed in intervals of 20 ms each.

The individual coding factors P_i were individually determined for each subject and run separately while using a trial and error search method. The time sequences of $\underline{W}(N)$, as well as the error signal $ER(N)$ and the derived sequences of DER and SER were observed vs computed.

The obtained results are presented graphically in Figure 6 to Figure 13 for each subject. They represent the plots of the three pairs of variables DER and SER, ER and SER as well as

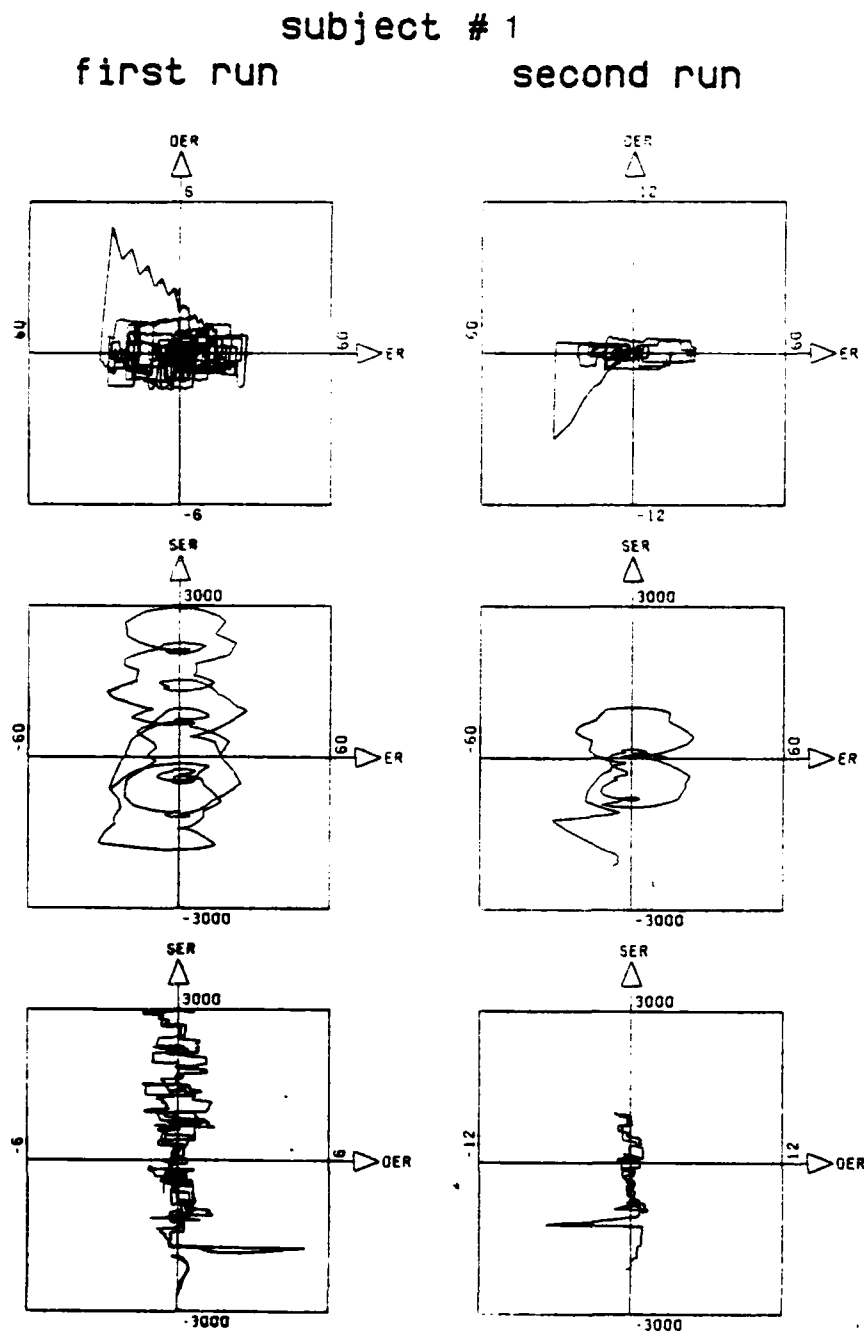


Figure 6: The control space's two dimensional projections and the corresponding trajectories observed on subject No. 1 in the first and the second run.

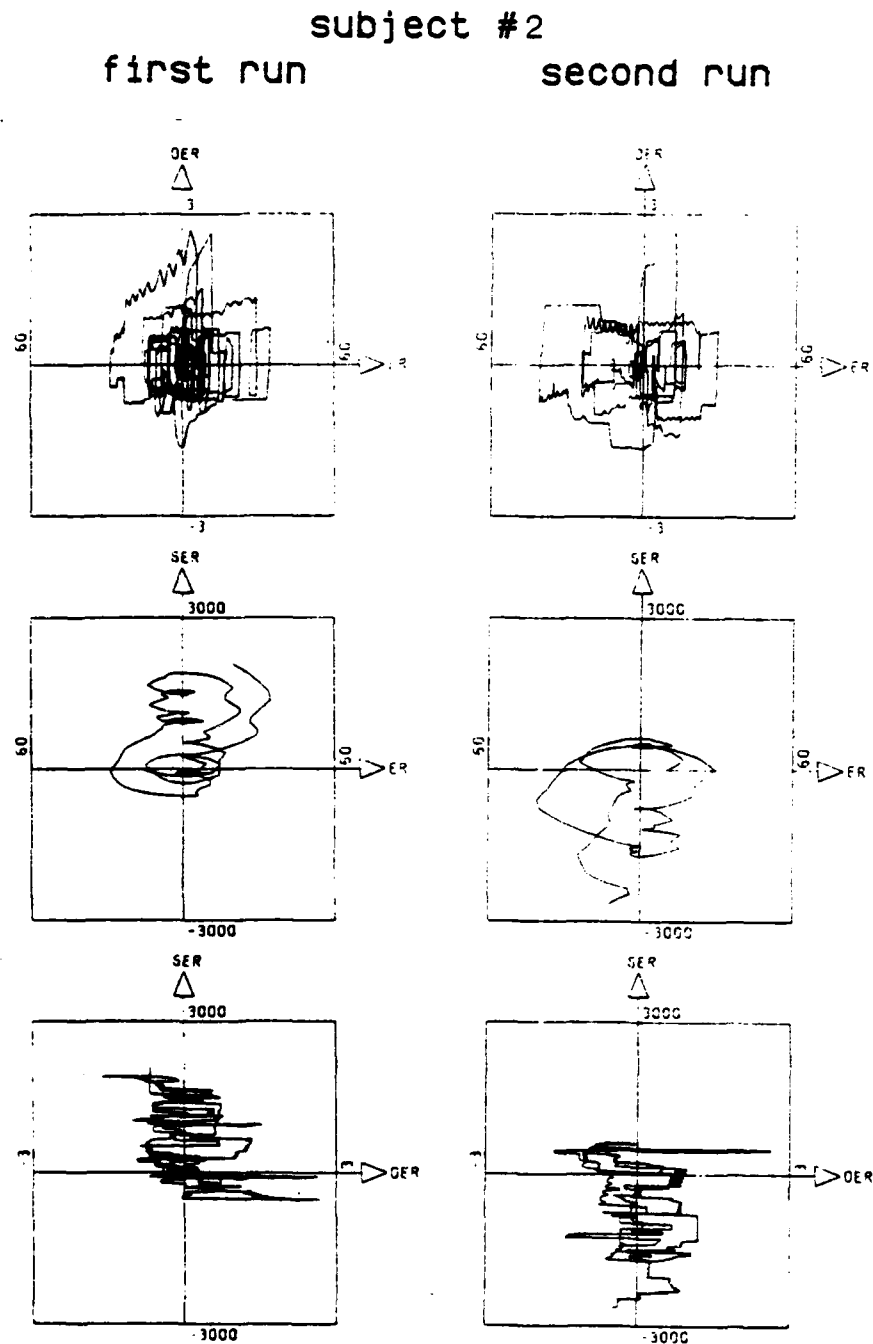


Figure 7: The control space's two dimensional projections and the corresponding trajectories observed on subject No. 2 in the first and the second run.

subject # 3
first run second run

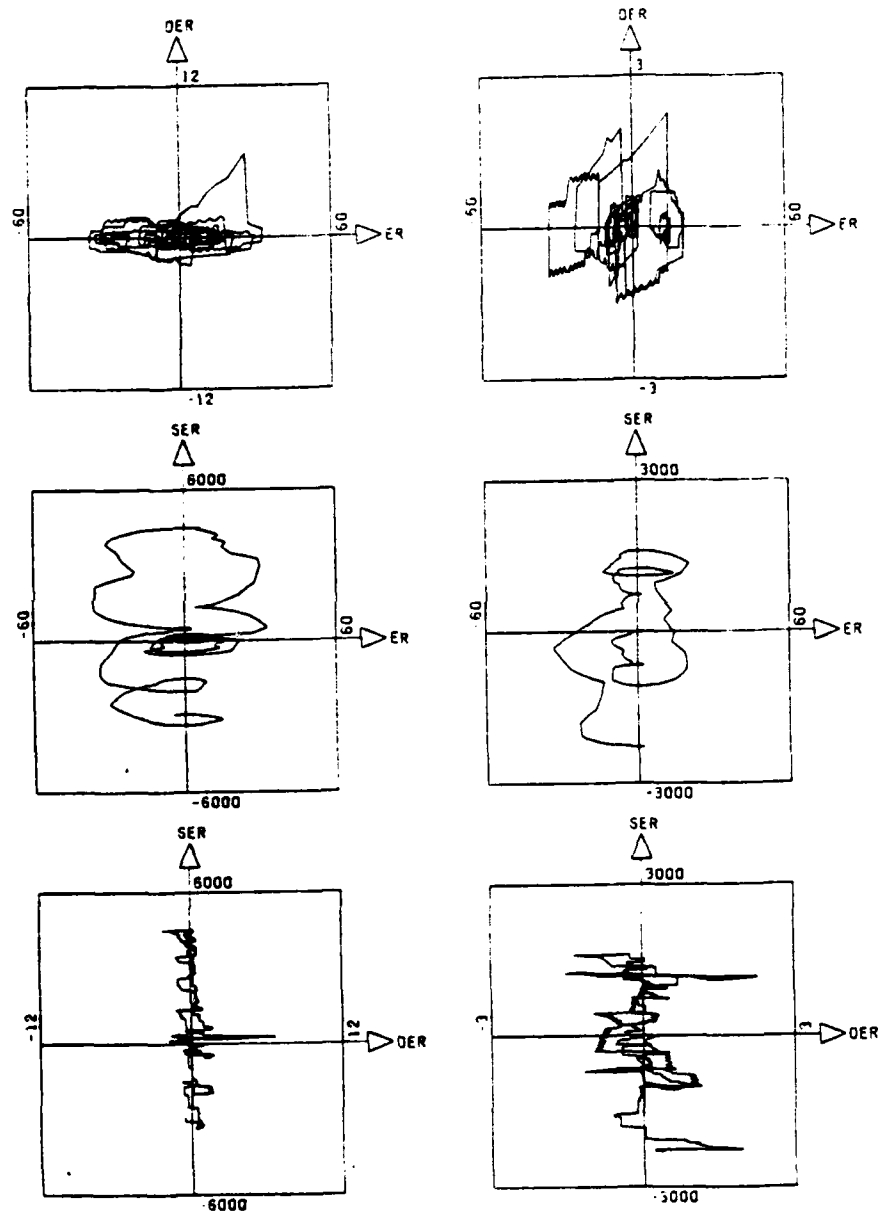


Figure 8: The control space's two dimensional projections and the corresponding trajectories observed on subject No. 3 in the first and the second run.

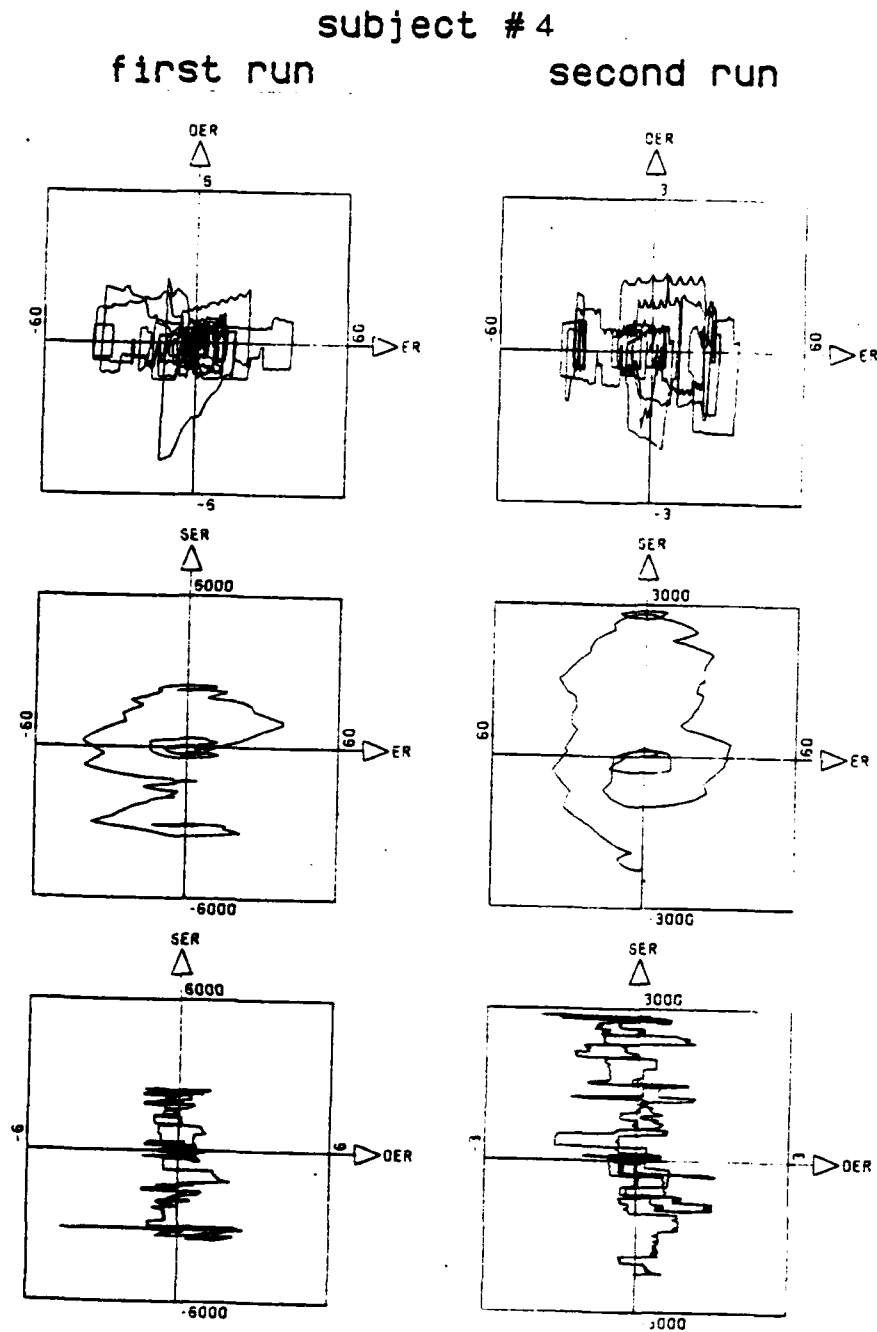


Figure 9: The control space's two dimensional projections and the corresponding trajectories observed on subject No. 4 in the first and the second run.

subject # 5

first run

second run

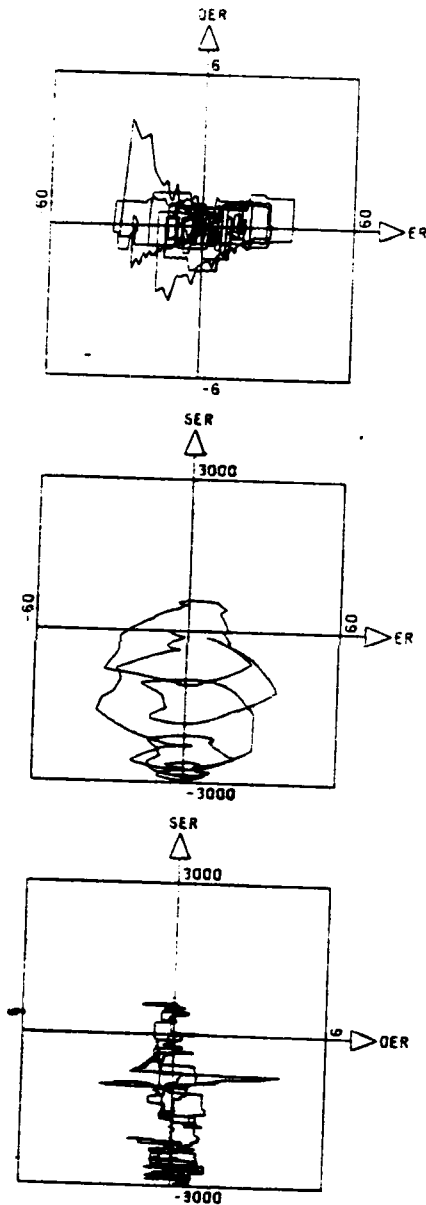


Figure 10 :

The control space's two dimensional projections and the corresponding trajectories observed on subject No. 5 in the first run (no environmental data were available for the second run).

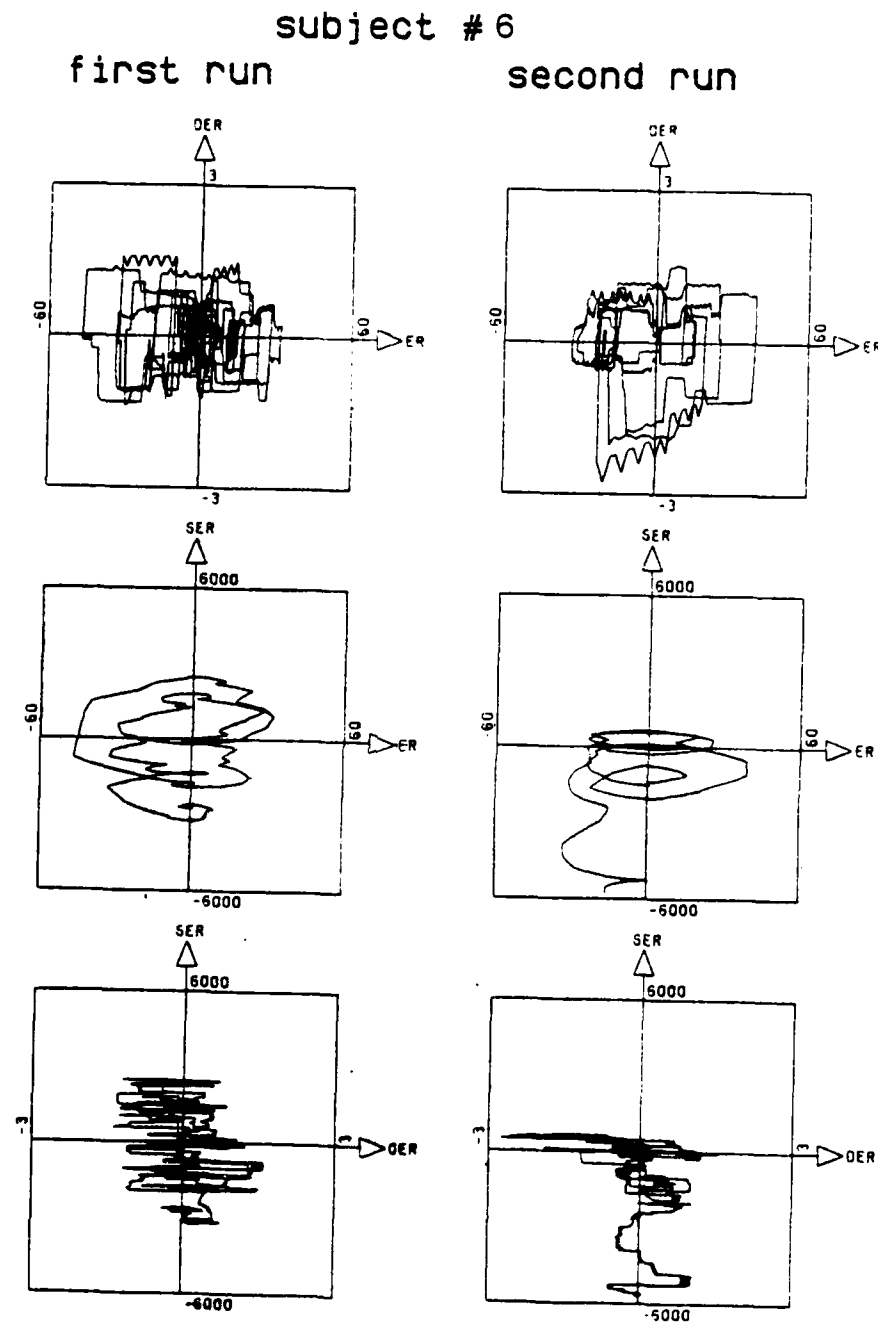


Figure 11: The control space's two dimensional projections and the corresponding trajectories observed on subject No. 6 in the first and the second run.

subject #7
first run second run

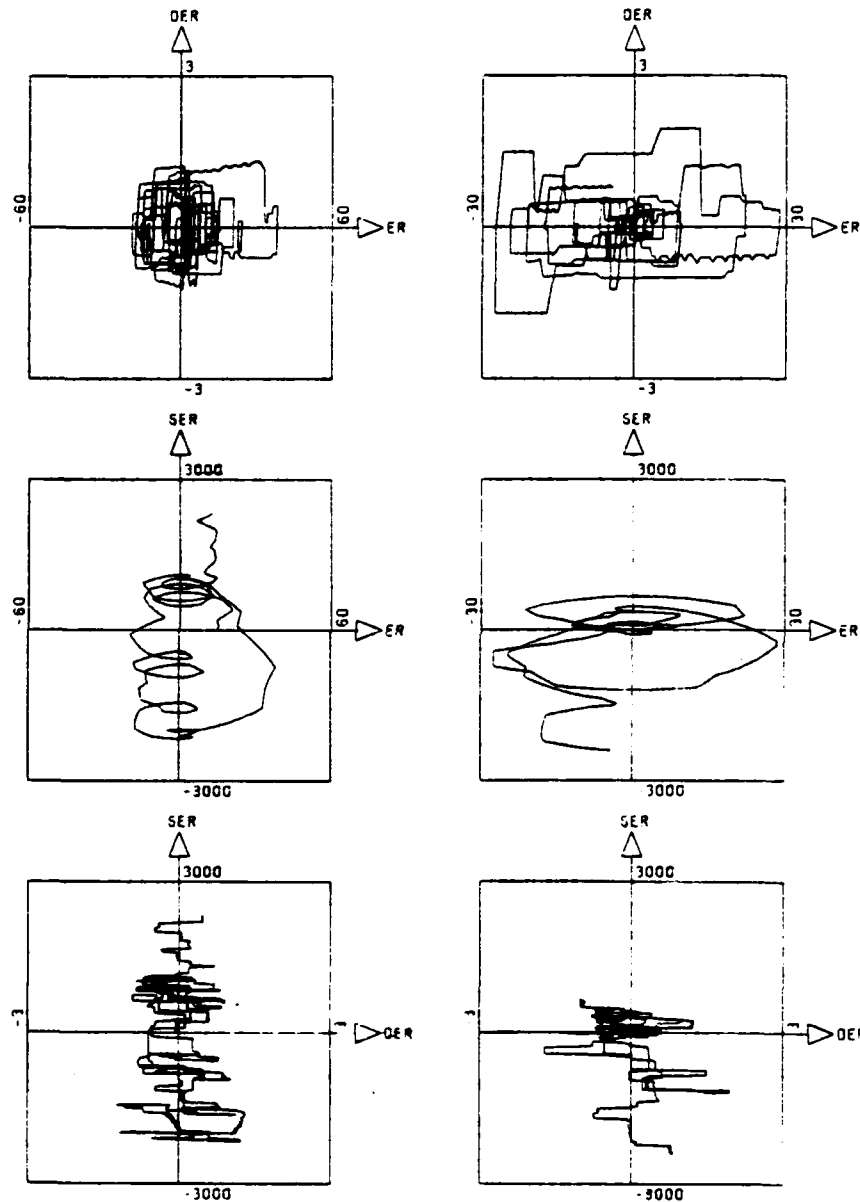


Figure 12: The control space's two dimensional projections and the corresponding trajectories observed on subject No. 7 in the first and the second run.

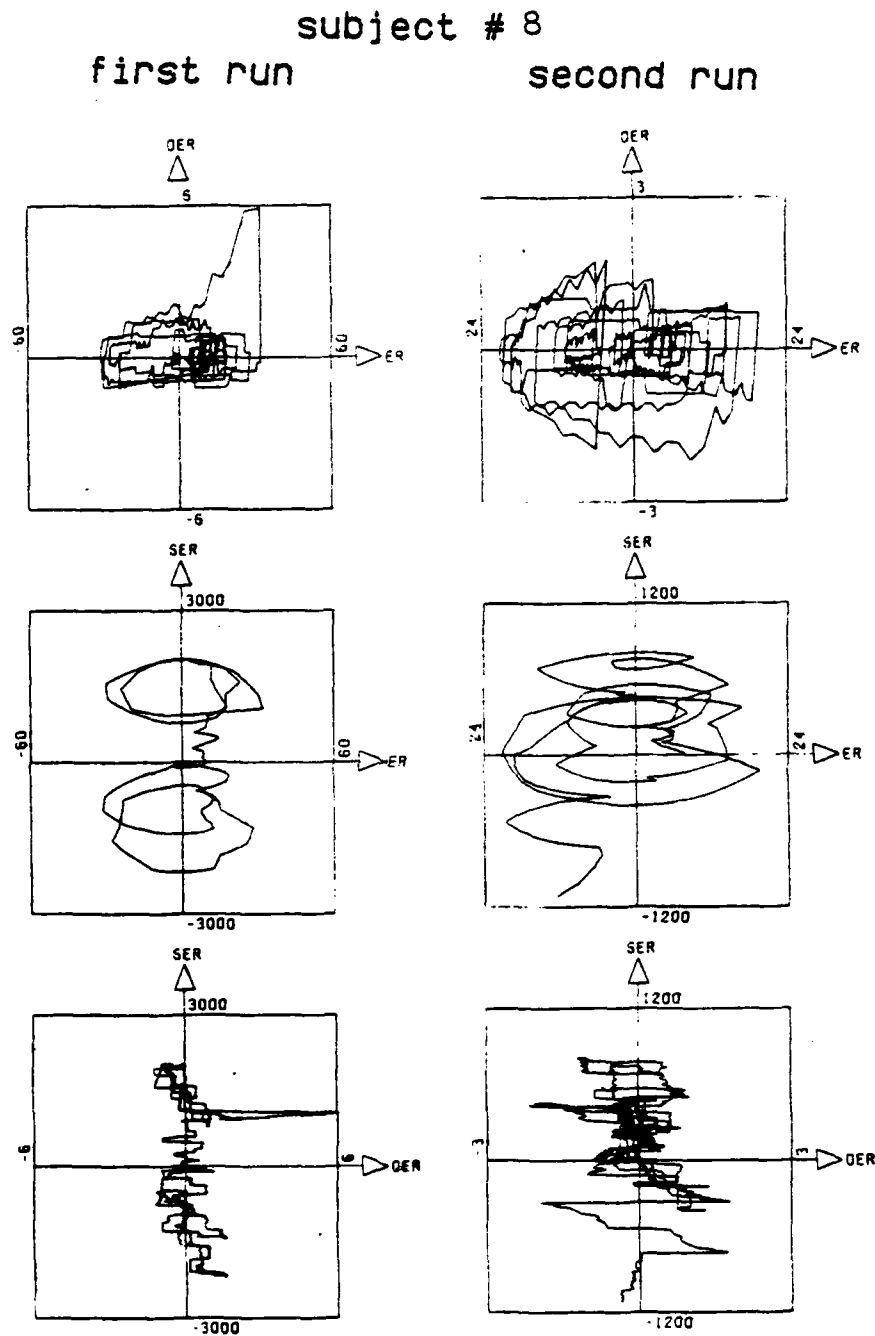


Figure 13: The control space's two dimensional projections and the corresponding trajectories observed on subject No. 8 in the first and the second run.

ER and DER. Each pair of variables represents a two dimensional projection of the control space, respectively. A specific point could be defined within each two-dimensional projection of the control space which represented the system's state in each corresponding time interval N . Conducting this procedure over the cumulated time sequence provided a trajectorized description of the dynamic behavior of ER and the two deviated variables SER and DER. This procedure was conducted for each subject and each run separately.

The results yield that each of the three trajectories oscillated, as hypothesized, around each control space's origin. This was a common finding for all subjects, as observed in each run. It suggests that the driver's eye movement behavior represents a part of a dynamically stable process. Any deviation between the environment's internal representation and its objective characteristics were corrected due to new relevant input as modulated by the error signal and the two derived variables SER and DER. As a result, the observed deviations varied within limited ranges and the trajectories were dynamically stable in regard to the control space's origin.

An essential precondition for finding out the dynamically stable equilibrium was the proper estimation of the values of the individual coding factors P_i . They were arbitrarily chosen, separately for each driver and each run. They were then altered

by means of trial and error, until the trajectories showed that the process was dynamically stable. The individual factors P_i are graphically presented in Figure 14. The stability achieved was highly sensitive to any change of P_i vs of $\underline{P}$.

The comparison between the two runs suggests that the inter-individual differences, obtained in regard to the distribution of the coding factors P_i across the 13 sectors, were much greater than the intra-individual fluctuations. An exceptional case was subject No. 4. Nevertheless, if considering that the experimental run determined the direction of the curves driving around (which massively influenced a driver's visual search strategy), then the intra-individual fluctuations observed seems to be unexpectedly small.

Further data analysis considered well defined points of the trajectories, that is, those where the driver changed his input due to an altered target of fixation. The respective alternations were considered for every subject and each run separately. They were then always related to the three projections of the control space, that is to the dimensions SER/DER, SER/ER and DER/ER, as shown in Figure 15 to Figure 22. A circle was used to indicate a positive change (that is, an eye movement toward the right) and a triangle a negative change (to the left). The size of the symbols used indicates the respective alternation of the motorist's input. The graphically presented results indicate,

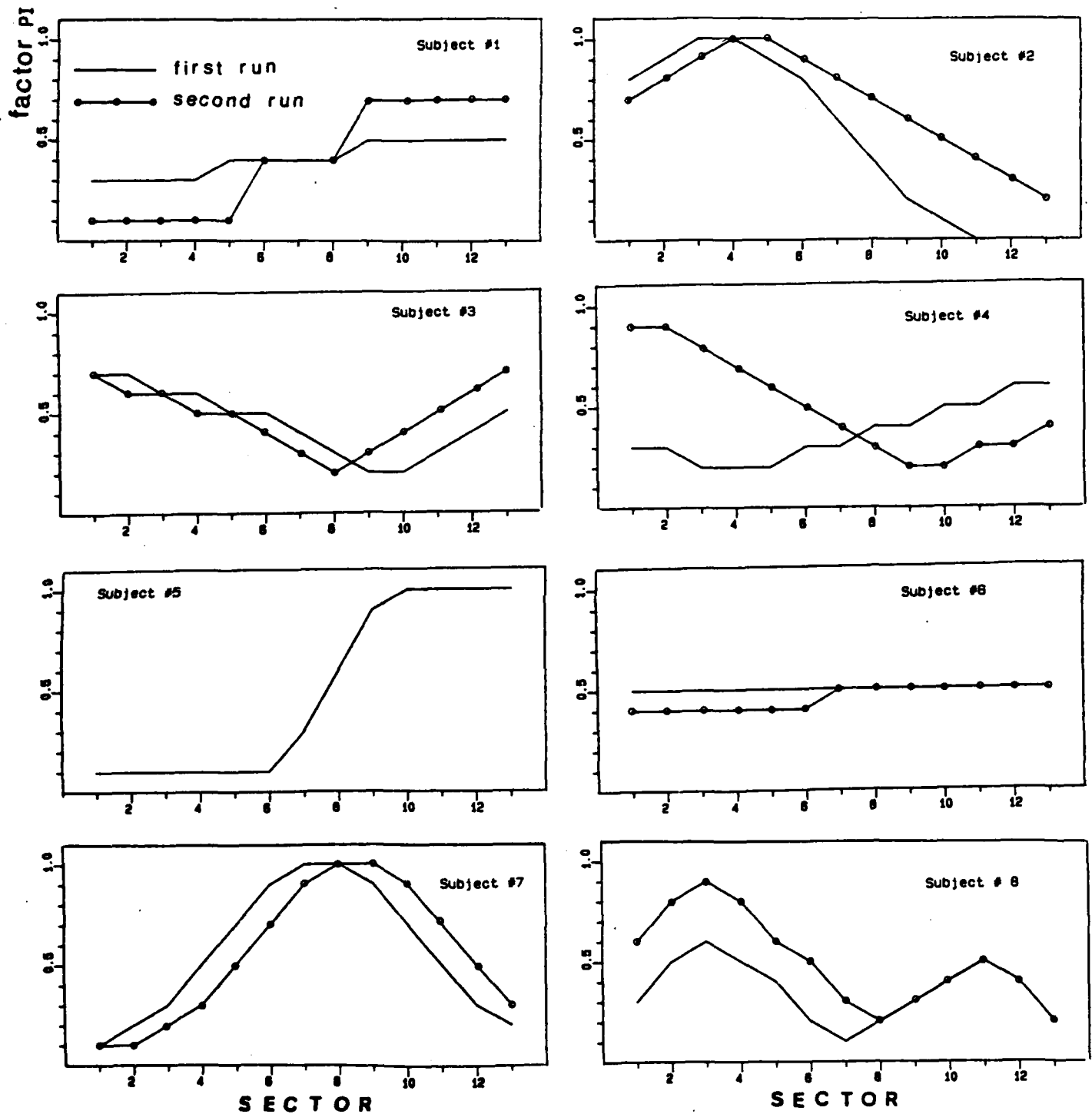


Figure 14: The individual weighting factors P_i plotted for every subject and each run.

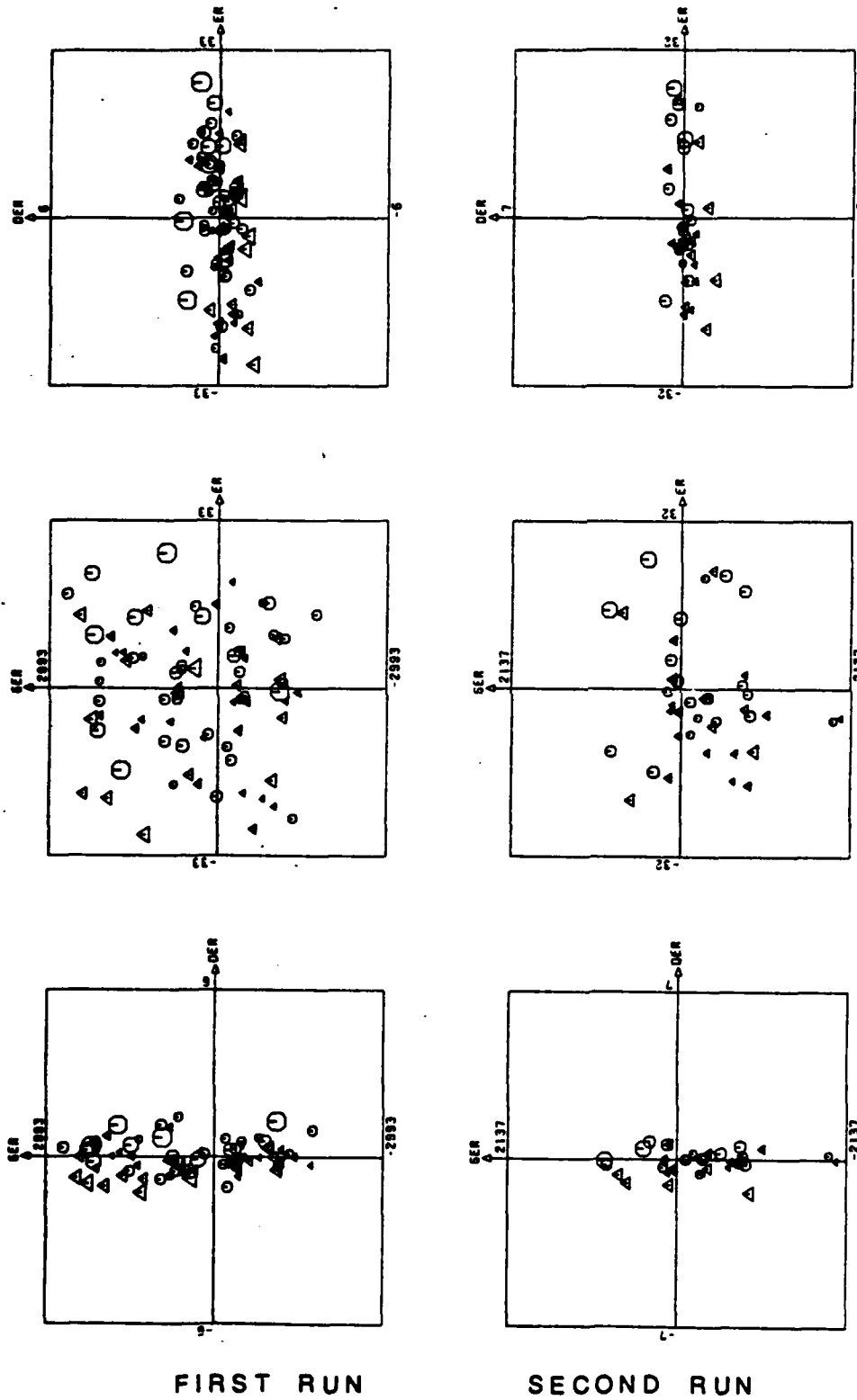


Figure 15: Selected points of the trajectories indicating a change of the lateral fixation angle. The symbols O and Δ indicate a positive versus a negative change. Observed on subject No. 1.

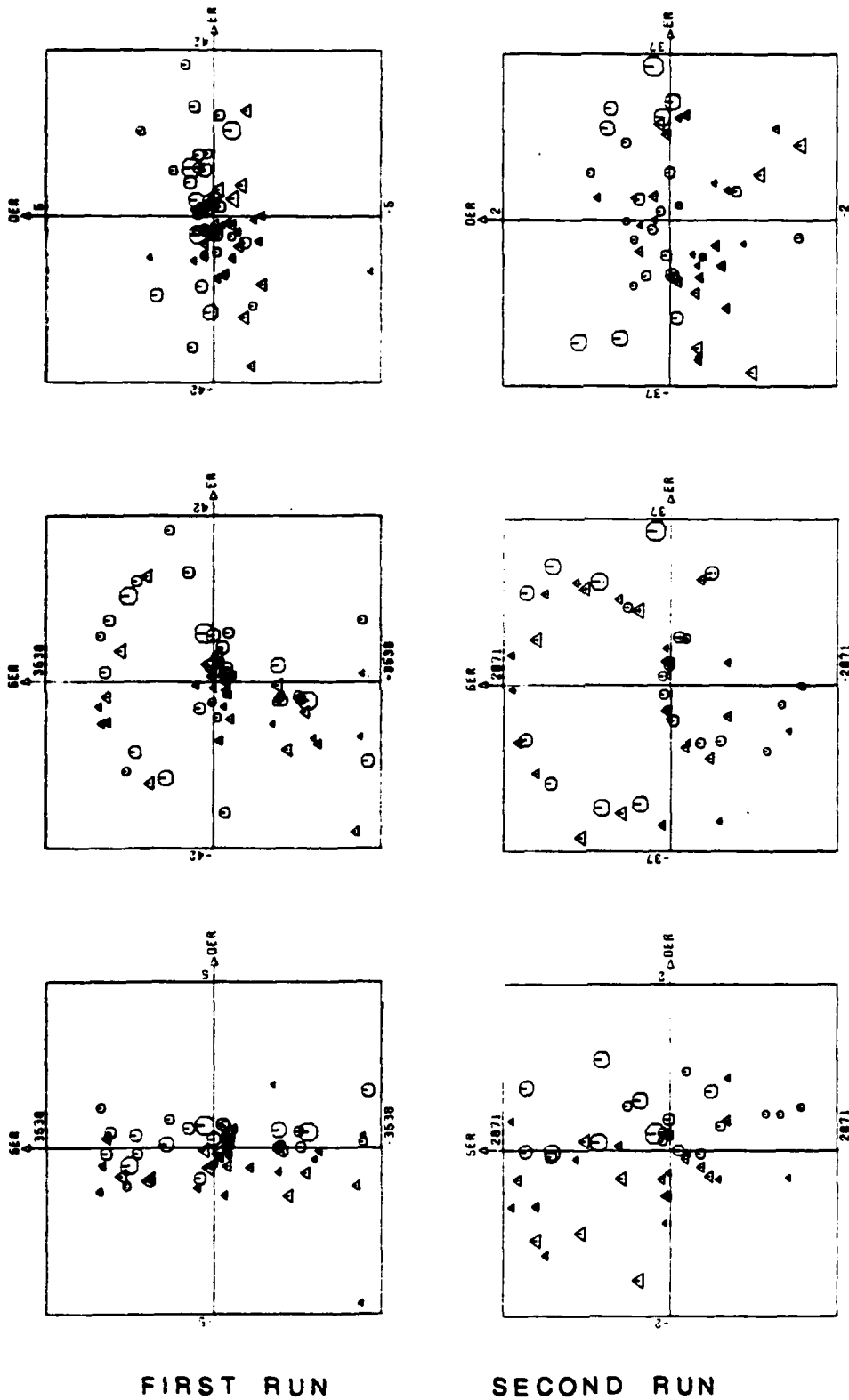


Figure 18: Selected points of the trajectories indicating a change of the lateral fixation angle. The symbols O and Δ indicate a positive versus a negative change. Observed on subject No. 4.

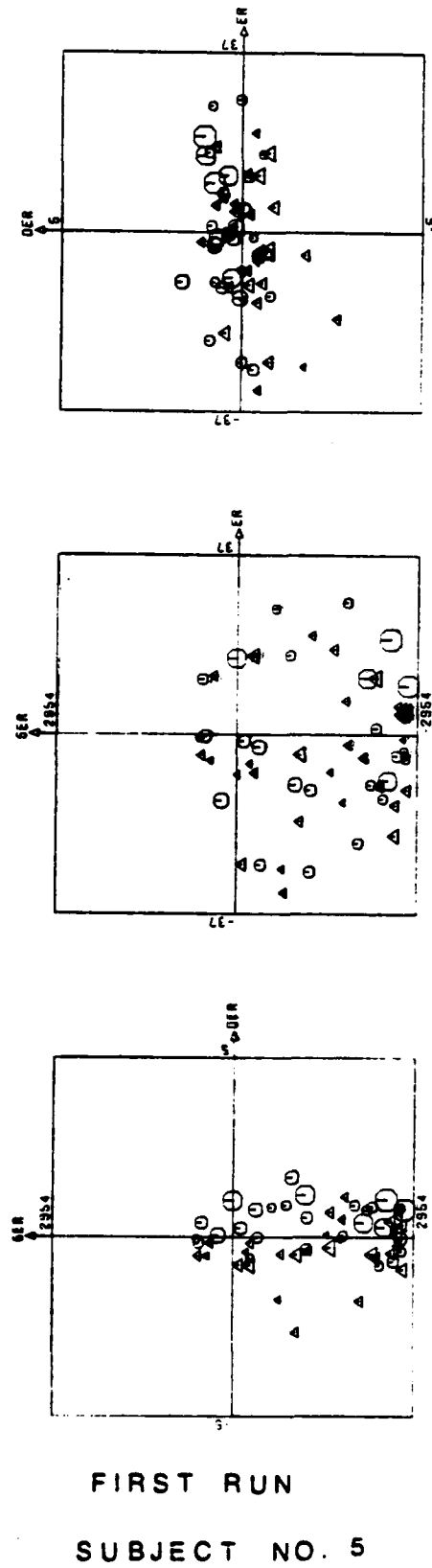


Figure 19: Selected points of the trajectories indicating a change of the lateral fixation angle. The symbols O and Δ indicate a positive versus a negative change. Observed on subject No. 5 (no environmental data available for the second run).

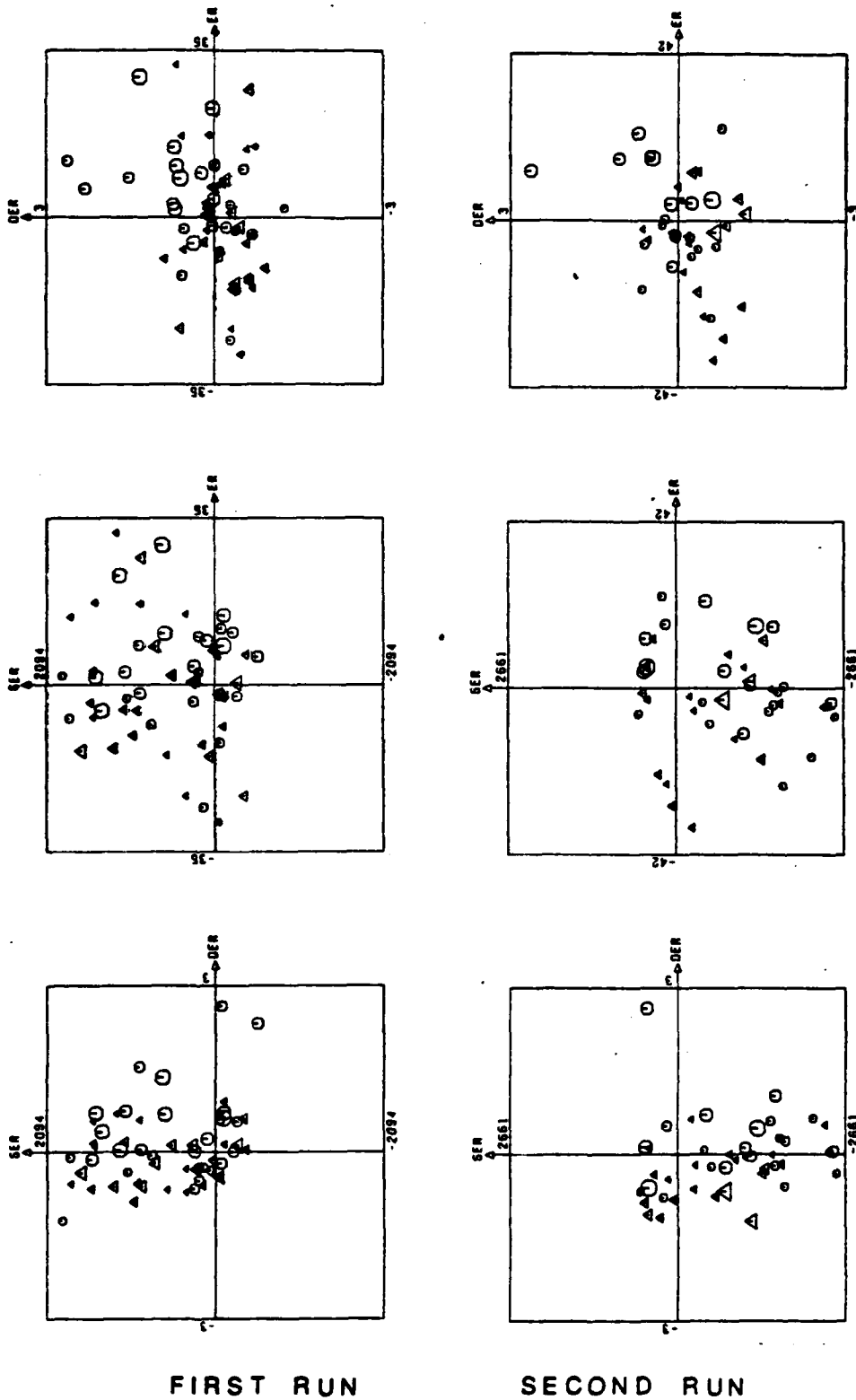


Figure 16: Selected points of the trajectories indicating a change of the lateral fixation angle. The symbols O and Δ indicate a positive versus a negative change. Observed on subject No. 2.

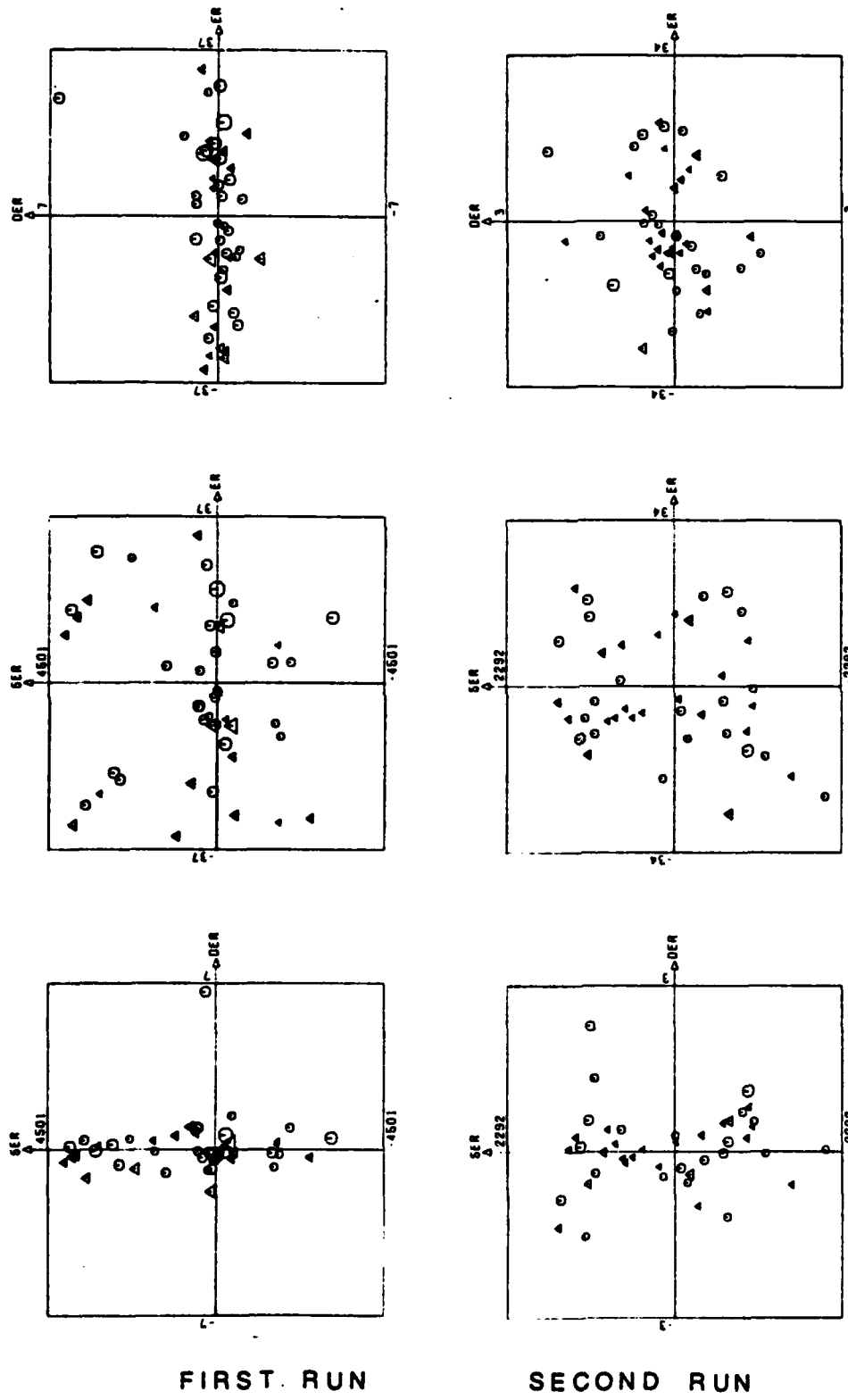


Figure 17: Selected points of the trajectories indicating a change of the lateral fixation angle. The symbols O and Δ indicate a positive versus a negative change. Observed on subject No. 3.

in general, that the alternations' magnitude tended to increase when the deviations between C and C_s were also great. The alternations were, on the other hand, smaller, when the discrepancy between the internal representation and the environment's characteristics were rather small, and presumably tolerable.

The dynamical stability of the process governing the driver's eye movement behavior was provided due to the motorist's reaction on the deviations between C_s and C , that is due to the error signal ER , its cumulation SER and the deviations between successive time intervals DER . The role of these three variables in maintaining a dynamically stable correspondence between the proximal and the distal stimuli was unequal among the subjects. Subject No. 1 was, for example, less considered with the cumulation of the error signal SER or the present deviations between C and C_s , i.e., ER , but rather with the deviations occurring between successive intervals. Subject No. 8 responded, on the other hand, rather to the present deviations between C and C_s . This consideration suggests that different subjects responded unequally to the same variable. However, the observed sequence of fixations cannot be explained due to the influence of a single variable solely but rather due to their cumulation and the respective interactions. The role of each variable is descriptively, nevertheless, shown in Table 1 which suggests the relative contribution of every single variable. This table indicates that the contribution of

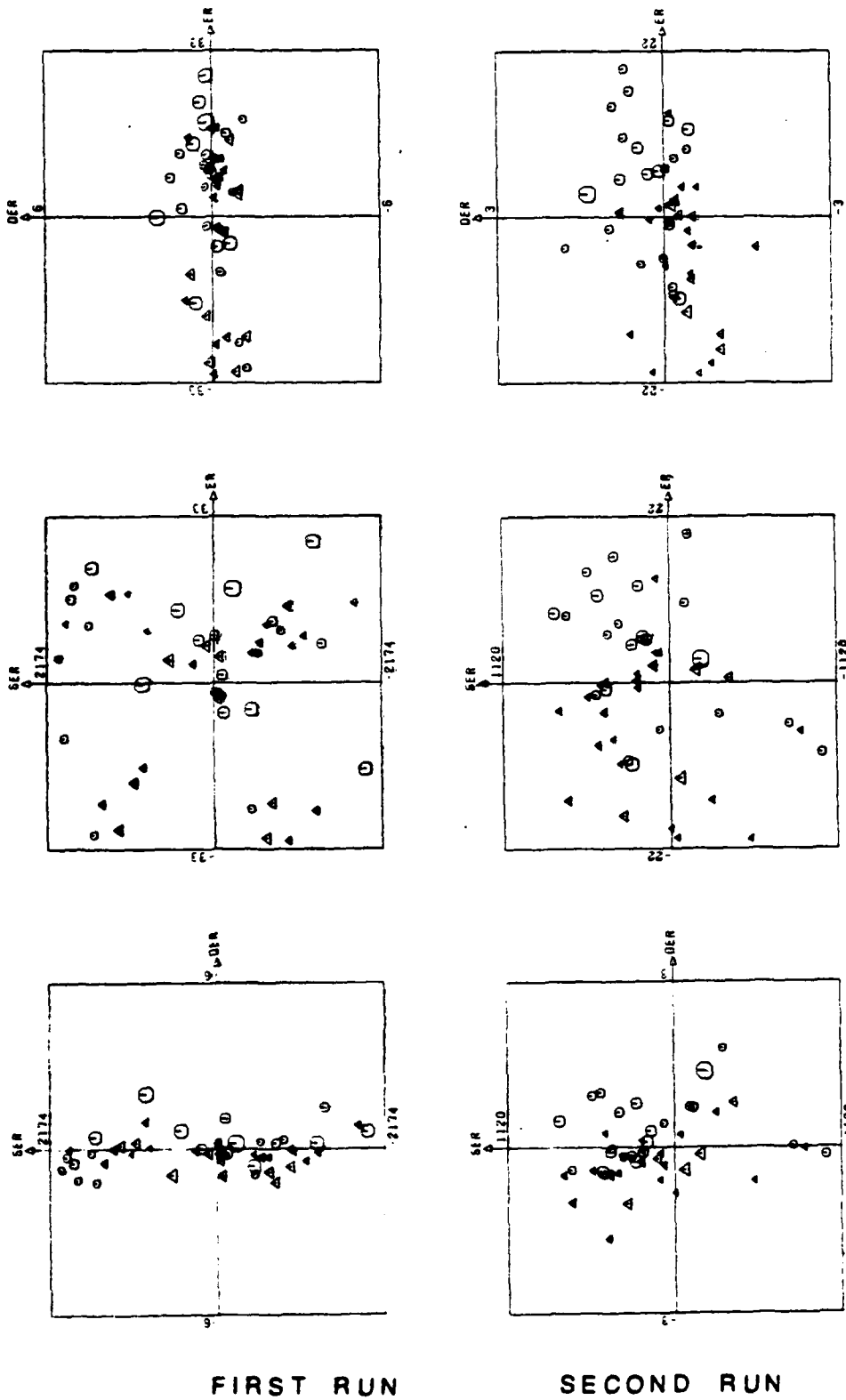


Figure 22: Selected points of the trajectories indicating a change of the lateral fixation angle. The symbols O and Δ indicate a positive versus a negative change. Observed on subject No. 8.

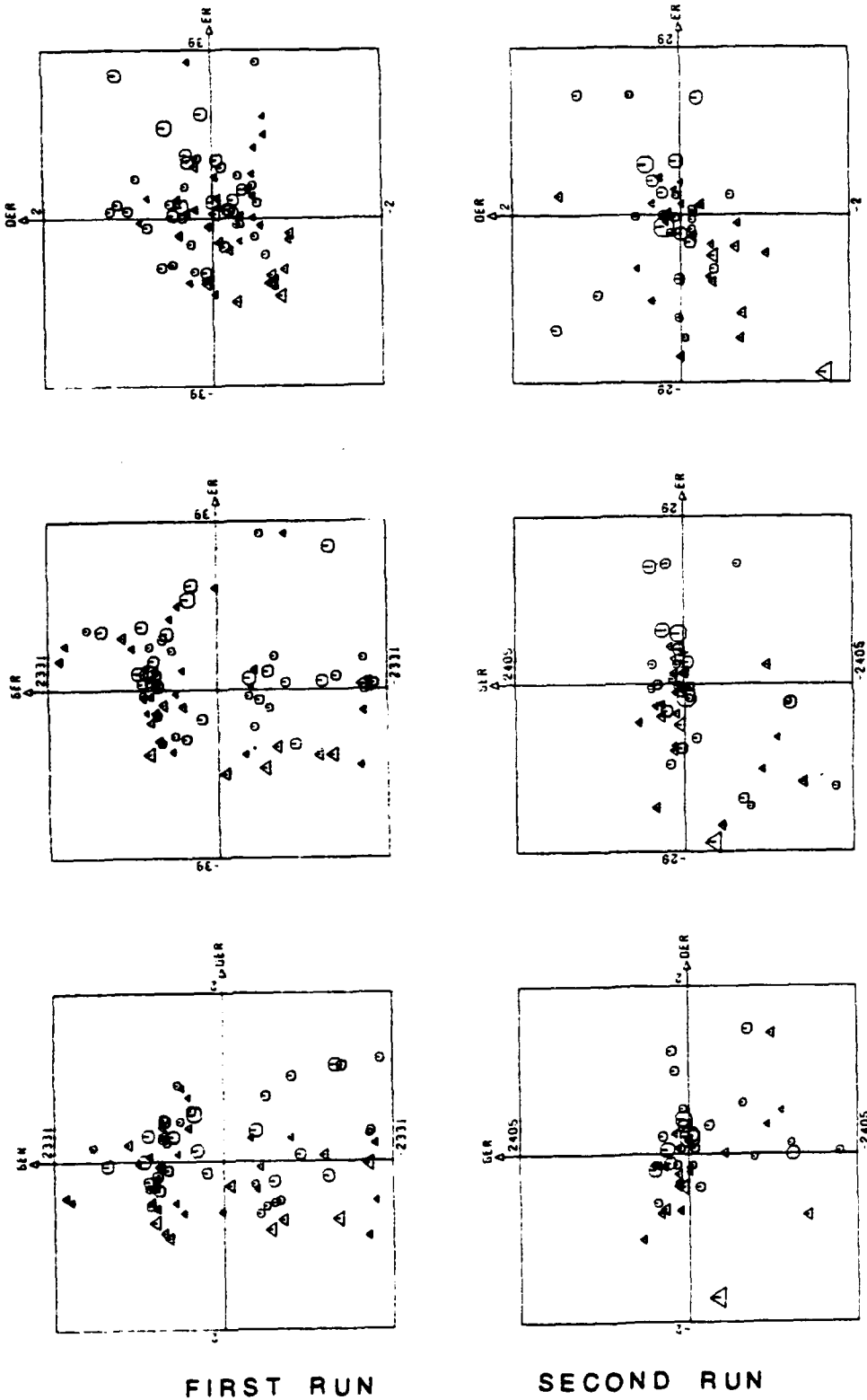


Figure 21: Selected points of the trajectories indicating a change of the lateral fixation angle. The symbols O and Δ indicate a positive versus a negative change. Observed on subject No. 7.

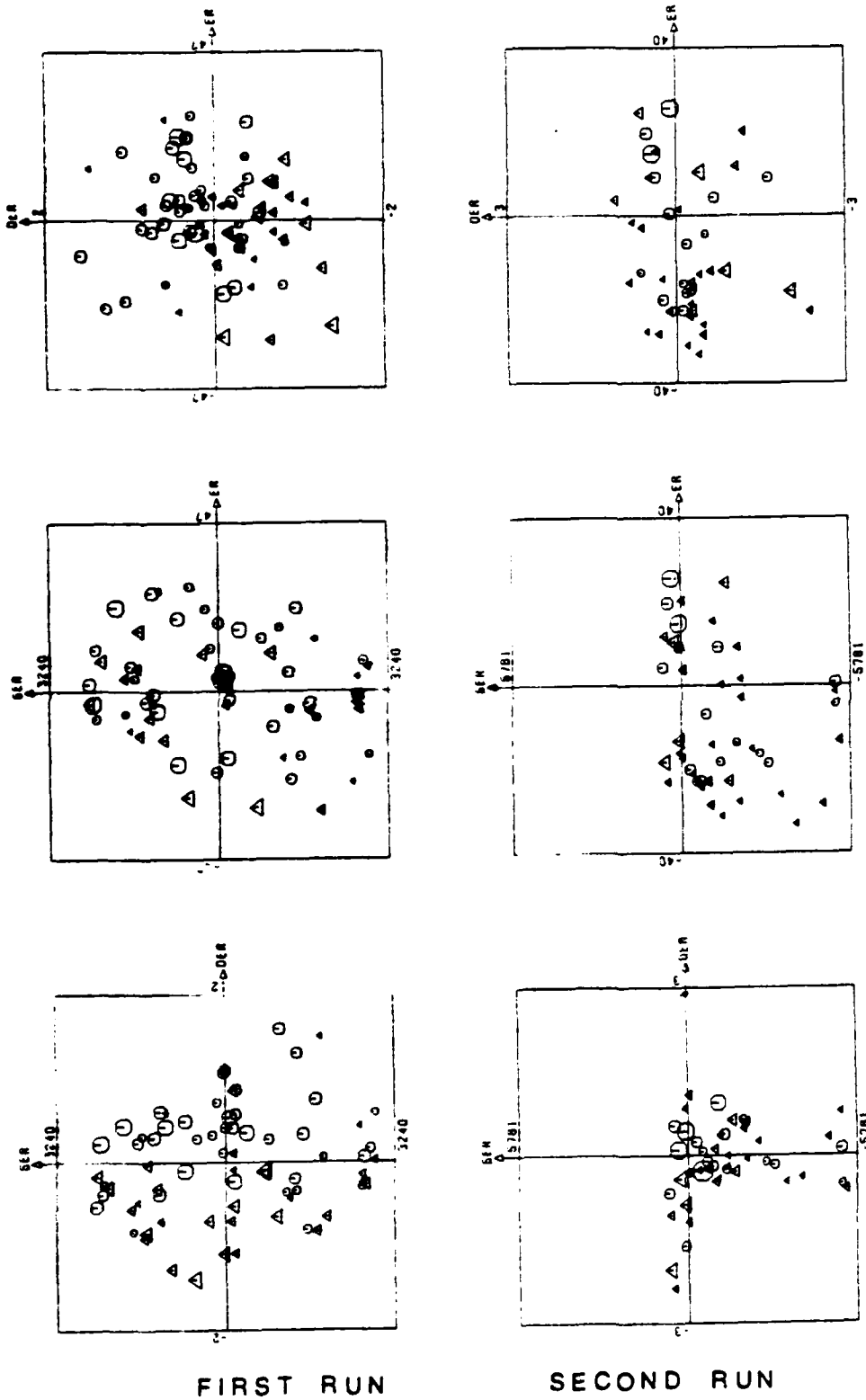


Figure 20: Selected points of the trajectories indicating a change of the lateral fixation angle. The symbols O and Δ indicate a positive versus a negative change. Observed on subject No. 6.

each variable is intra-individually rather stable.

run error signal	1			2		
	ER	DER	SER	ER	DER	SER
subject No. 1	0 ¹⁾	+	-	0	+	-
2	0	+	0	0	+	0
3	-	-	-	-	-	-
4	-	+	0	-	+	0
5	0	+	-	0	+	-
6	0	+	0	0	+	0
7	-	+	-	-	+	-
8	-	+	0	-	+	0

1) + relatively great influence; 0 moderate influence;
- little influence

Table 1: Qualitative description of the relative influence of the error signals ER, DER and SER in maintaining a dynamic stability between C and C_s for each run and every subject. Note that there is a good intra-individual correspondence between the two runs.

5. DISCUSSION

The results yield to support the general hypothesis postulating a close relationship between the proximal and the distal stimuli. As the distal stimuli are continuously altering, as a function of the car's locomotion, the motorist has to reduce the resulting discrepancy between C and C_s due to uninterrupted information input. This process supposedly does not stress to achieve an identity between proximal and distal stimuli but rather a good approximation between the two variables. An identity could not and theoretically can also never be achieved. The reason is not only the driver's capacity limits to process the available information but also a problem of time. While the driver attempts to approximate his C to C_s , the environmental conditions are already changed once again. This means that the driver's internal representation can never completely be up-dated, as a lag of time necessarily causes a discrepancy between C and C_s . While $ER(N)$ ideally approximates zero, $ER(N+1)$ is already different than zero and so on.

A closer inspection of the Figures 15 to 22 suggests also that there is a close relationship between the error signal (i.e., ER , DER and SER) and the course of the subsequently altered information input. To illustrate this notion Figure 23 represents the data of subject No. 1, derived from her first run, in an enlarged form. It represents the projection of the control space's

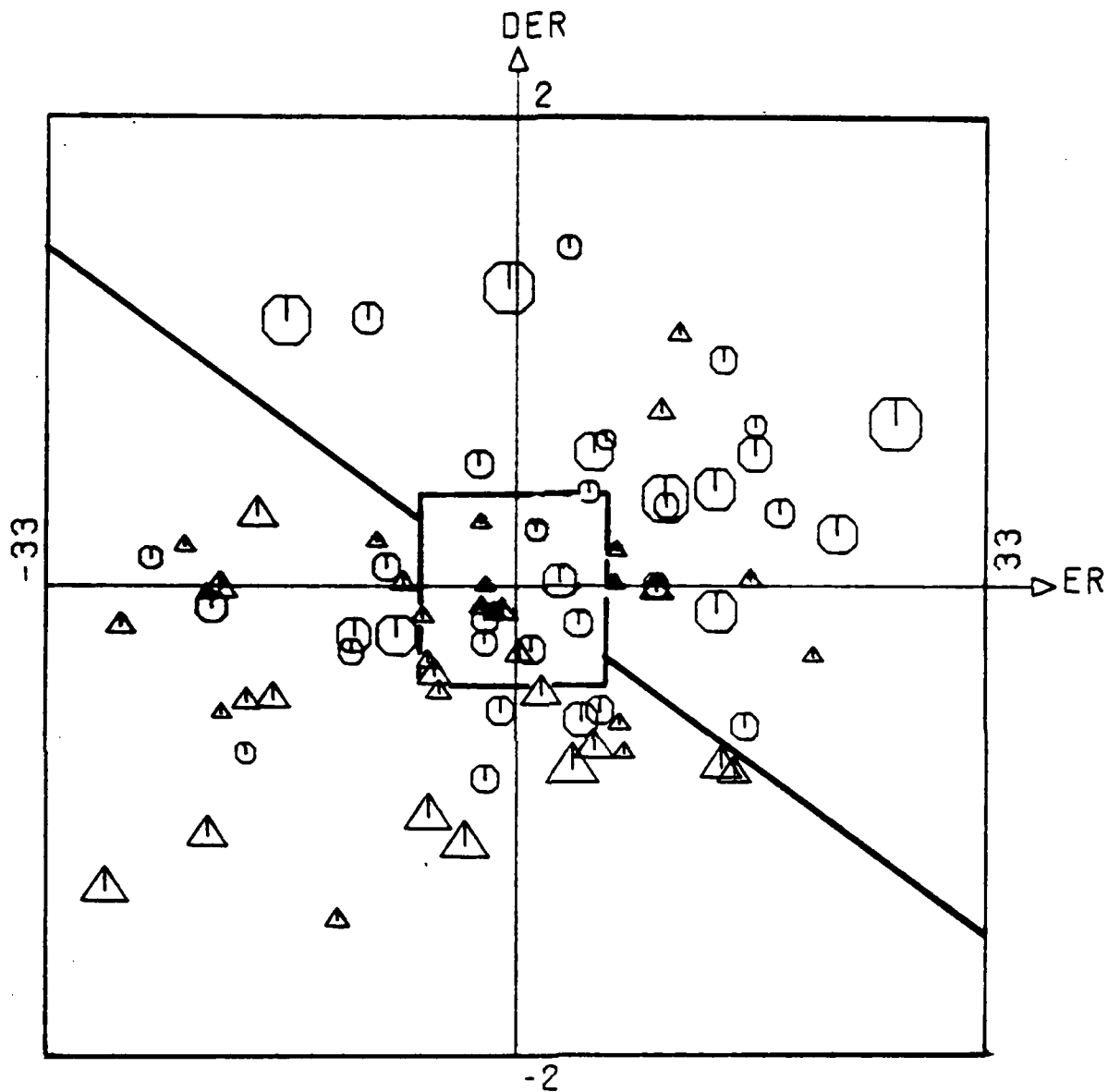


Figure 23 : Selected points of the trajectories indicating a change of the lateral fixation angle as observed on subject No. 1 during the first run. A closer inspection of this figure indicates that the control spaces' dimensions DER and ER distinguished between the positive changes (circles) and the negative ones (triangles). Above the slant line there is a concentration of circles whereas down a concentration of triangles. This distinction is, however, not perfect. The inner square suggests a random fluctuation near the control space's origin.

dimensions ER and DER together with the changes of the eye fixation's lateral angle.

The data near the control space's origin are excluded from further discussion, as they can be associated with tolerable random fluctuation. The remaining area of this two-dimensional projection of the control space can be divided into two discrete zones, as shown in Figure 23 by a straight line. This slant line divides between positive and negative alternations which were observed. However, there were also fixations which altered in the non-expected direction. Nevertheless, it should be reminded that the control space's dimension SER remained in this example unconsidered. Furthermore, the model is based on binary distinction between essential input (1) in contrast to non-essential input (0). Consequently, a non-expected course of information input does not yet mean that the driver did not pick up relevant information. It does suggest, on the other hand, that the subject did not pick up the most relevant information available at that moment.

The model established could not explain the complete sequence of the fixations observed with perfect accuracy, that is, without any deviation between the trajectories and the control space's origin. The supposed reasons, beyond the mentioned lag of time required to input new relevant information, are, first,

the driver might input also interfering, non-task-oriented information. This input cannot be then related to the control law governing the task oriented regulation. Secondly, the system is not correcting tolerable discrepancies between the proximal and the distal stimuli. The error signal must, supposedly, reach a certain threshold prior to inputting further relevant information. Therefore, it is suggested that fixations located near the control space's origin are characterized by rather high proportions of stochastic alternations. This suggestion is supported by the present findings. The fact that a plausible clustering of the data could be found, as obtained in the projections of the control space, indicate that the deterministic part of the control law is associated with a PID - control law which is common in the classical control theory. A further, third, reason for limiting the correspondence between C and C_s is related to the motorist's limited capabilities to recognize a new relevant object. If a target is projected on the periphery of his retina, beyond the limits of the useful field of view, then there is no possibility to recognize the presence of that target (MACKWORTH, 1976). If the eye is incidentally moved toward that target's direction, so that it is now projected within the useful field of view, then a subsequent movement of the eye might be initiated for fixating upon that target. The eye's physiological limits for identifying relevant targets might cause, at least, some delay

in reducing the discrepancy between the proximal and the distal stimuli. The rule is, however, that an error signal cannot be efficient, if a relevant target is projected upon the periphery of the retina which is beyond the limit of the useful field of view.

In summary, the presented results suggest that the driver aims to maintain any discrepancy between the proximal and the distal stimuli within a hypothetical level of tolerance. However, its magnitude is neither known nor can accurately be estimated at present. The suggested level of tolerance might depend on the road characteristics, the traffic constellation as well as on the motorist's individual variables. This suggestion is also supported by the preliminary results reported in detail in Appendix III. Consequently, it might be further assumed that the successive fixations of the eye are causally interrelated whenever the discrepancy between C and C_s is rather great, that is, it is no more tolerable for safe driving. On the other hand, when the discrepancy is rather small, then the error signal ER and its deviates DER and SER are not sufficiently efficient to initiate a further approximation of the distal stimuli toward the proximal one. In this case it is assumed that the next fixation of the eye does not causally depend on the driver's previous input but rather stochastically. Provided that this interpretation is correct, it

can be suggested that the succession of the eye fixation can adequately be attributed to a semi-deterministic process.

The conclusion is that the stochastic component of the eye movement behavior in driving might be the essential factor which limits the accuracy of describing an observed sequence of fixations by means of a time discrete process model. Nevertheless, it is assumed that a more differentiated data treatment can increase the rate of correct prediction. The contribution of a very precise data treatment could be an increased accuracy of the description of an observed sequence of fixations and using the established models for predicting the future fixations of the eye. This means a quantitative improvement. However, the stochastic component of the eye movement behavior is supposed to set some other, presumably higher upper limit for the accurate description of the process governing the visual input.

The findings presented and discussed above are based on car drivers' eye movements, investigated as an example of aimed motor behavior. Each motor output is carried out in order to approximate a desired goal in an optimum manner. May be that optimum behavior is not reached by means of perfectly accurate out, as its programming requires too great efforts. It is possible that the organism functionates better when a movement is

initiated with imperfect accuracy and corrected after a while. In the case of eye movements a deviation from the desired goal of fixation is reduced due to the corrective saccadic movements. When performing a non-balistic movement, like hand movement, then the deviation can be corrected during the movement itself, i.e., due to the input of feed-back information and reprogramming the hand's trajectory. The question of optimum behavior, in terms of most efficient output, while performing in different tasks remains an important goal for future investigations. The findings derived from the drivers' eye movements suggest that the motor output initiated has to be programmed with quite great, but not necessarily perfect accuracy.

Section 3: General discussion and outlook

The present study was carried out in order to investigate the processes governing the movements of the eye, considered in the context of purposeful motor behavior. The goal of each saccadic movement is the facilitation of efficient visual input. The efficiency of goal achievement can be estimated, therefore, in terms of the intake of available, relevant information. On the other hand, if efficient input is observable, i.e., by analyzing the targets of fixation, then it can be concluded that the preceding saccadic eye movement has been accurately programmed in advance. This reasoning led to the experimental method used, which was an analysis of the sequence of fixations in terms of input efficiency, as an indication of the accuracy of the underlying motor program of discrete saccadic eye movements.

Analysis of the visual input, in relation to the available information, suggests that the saccadic movements were quite accurately programmed. Each subject attempted to coordinate his internal representation of the environment to reality, by means of an ongoing input of relevant information. This general statement is compounded by an inter-individual variability,

however. First, different subjects achieved dissimilar levels of approximation between the proximal and the distal stimulation. Secondly, they used also unequal strategies for updating their internal representation and, thirdly, they considered their subtasks (lateral control as opposed to the vehicle's guidance) in a dissimilar manner, as also manifested in their individual coding factors P_i . In addition, the three error signals ER, DER and SER contributed, for the approximation of the internal representation of the environment (C), to its objective characteristics (C_s) in dependence upon the subject's individual characteristics (see Appendix III for a related issue).

Even though each subject attempted to achieve a good correspondence between the proximal (C) and the distal stimulation (C_s), none of them achieved this goal with perfect accuracy, as manifested in the observed magnitude of the error signals (see Figure 6 to Figure 13). Nonetheless, the observed deviations between the proximal and the distal stimulation oscillated in a dynamically stable manner within a limited range around the control space's origin. This finding is supposedly of crucial importance for understanding the driver's visual input. It should be understood as a dynamic process of searching for task-oriented information governed by the principle of optimum, in contrast to complete, input of the avail-

able information.

The statement above is based upon the findings indicating that the subject seldom achieved a perfect internal representation of the external circumstances. The discrepancy obtained was presumably small enough - at least from the motorist's own point of view - for maintaining efficient driving. When the discrepancy between the proximal and the distal stimulation increased, then the probability of up-dating internal representation increased also. As a consequence, the internal representation always fluctuated around the environment's objective characteristics in a dynamically stable manner. The question arising here is related to the reasons for the imperfect correspondance between the proximal and distal stimulations.

1. Lag of time

A first reason is the lag of time between the occurrence of events and their perception. While the subject is consuming relevant information some events might happen simultaneously. He can perceive these alterations only after a delay, i.e., after the present input (from the currently fixated target) has been completed and the new relevant events have been fixated in succession. Therefore, the environment's internal representation

cannot be perfectly up-dated.

2. Role of the useful field of vision

A second reason is associated with the size of the useful field of vision which MACKWORTH (1976) defines as the area around the point of fixation from which information is being processed in the sense of being stored during a given visual task. Consequently, if a target is projected upon the retina beyond the limits of the useful field of vision, then the driver cannot recognize it. He has then no opportunity to program a goal oriented saccade in order to fixate that object and to input subsequently detailed information.

On the other hand, the size of the useful field of vision is greater than that of the point of fixation (which size corresponds to a visual angle of approximately 2°). Therefore, it cannot be excluded that the drivers could pick up some information via peripheral vision. It was assumed, that the contribution of parafoveal vision in the process of gathering relevant information was quite limited, because the drivers had to operate their car precisely under conditions of great work-load. Under these conditions a narrowing of the useful field of vision can be assumed (e.g., MACKWORTH, 1976; COHEN,

1983) and the requirement of a detailed and rapid input is guaranteed by foveal vision only. Nevertheless, if some relevant input occurred via peripheral vision, then it can be assumed that the driver's internal representation of the environment corresponded even better to its objective characteristics as indicated by the established model.

The contribution of parafoveal vision in the process of gathering relevant information has to remain, within this frame-work, as an unsolved problem. There is no possibility at present to control any input occurring via peripheral vision. The researcher has only the opportunity to limit its role by modulating the driver's work-load through perceptual narrowing, and by emphasizing the importance of detailed input (due to the task requirements). In any case, in the present experiment it was supposed that the role of peripheral vision was rather limited for programming the subsequent saccadic eye movement and for integrating successive inputs. The exact contribution of peripheral vision remains, however, unknown. The role of peripheral vision and its interaction with foveal vision remains an important issue for future investigations.

3. Pressure of time

A third reason for explaining the observed discrepancy between the proximal and the distal stimulation might be related to the driver's work-load, as he had to operate his car under the pressure of time. Even if the driver recognizes several important targets within the peripheral field of vision simultaneously he is able to fixate just a limited number of them (approximately three different targets per second). Because the motorist continues driving, the targets are not available after a while and the information remains unprocessed.

Because of these peripheral capacity limits, the density of the available information determines the proportion of essential information input. A process of selecting the available targets of fixation is an inherent part of the visual system. Selection of available information also means a neglecting of its residual part. In other words, no driver is able to perceive the environment completely, but rather just approximates the proximal to distal stimulation.

4. Central capacity limits

It is well known that the amount of the available information excessively extends the subject's processing capacity. As a consequence, the subject has to select the most relevant part of the information for input. The limits of the subject's processing capacity force him to pick up only a limited part of the available information or, vice versa, to neglect some information. This fact might be a crucial reason for the imperfect internal representation of the external conditions. Nevertheless, the occurring fractional input has to be sufficient for adequate performance. How can the subject perform efficiently, if he did not perceived the environment completely? It can be speculated that the information received combined with information already stored in the sense of the clue theory (e.g., KOLERS, 1968), as well as some interactions between feed-back and feed-forward mechanisms facilitate to set up a quite good representation of the environment.

5. Cognition

The present findings reveal that different subjects established an unequally accurate internal representation of the external conditions. Furthermore, they also absorbed a dissimilar amount of information required for the vehicle's lateral

control, as compared to its longitudinal guidance. The inter-individual variability is consequently related not only to the amount of the total input, but also to the kind of the information picked up. Some subjects strove to achieve a better correspondance between the proximal and the distal stimulation in regard to the vehicle's lateral control then in regard to its guidance, whereas some other subjects preferred to consider their future path of driving. This finding suggest that different subjects managed the same task while using different strategies. It reflects presumably an interaction between the environmental conditions and the subjects cognitive processes, as the subject is always searching for information, depending upon his schema (e.g., YARBUS, 1967; NEISSER, 1976).

6. Conclusions

The present study pointed out that the subjects attempted to achieve a close relationship between the proximal and the distal stimulation. A perfect correspondance was not achieved but the discrepancy obtained oscillated around the control space's origin, i.e., the observed visual input represented a dynamically stable process. Furthermore, the correspondence between the environment's internal representation and its objective characteristics varied among the subjects in general,

and in regard to their subtasks in particular. The reasons for the observed discrepancy were discussed.

The presumed role of the individual level of tolerance (in terms of maximum discrepancy between the proximal and the distal stimulation), the individual weighting of the subtasks' importance, the role of the drivers' cognition, etc. remain important issues to be analyzed in future investigations. These are crucial variables which determine a person's qualification to fulfill the requirements of a given task.

The present study pointed out that the subjects evidently performed according to fractional information input, but they nevertheless fulfilled their task of driving, carried out under conditions of a rather great work-load. They could manage their task, presumably, due to the interaction between current information input and stored information. From the human factor point of view it is worth while to investigate the underlying mechanisms in order to better understand the variables involved in their interactions. The applicability of this knowledge is rather obvious, even if its realization is quite difficult.

The necessary precondition for efficient performance is adequate input, occurring in advance. If so, then the question to be solved is how to transmit to the performing person the

task-oriented information in order to facilitate an optimum input. This problem is related to the spatial distribution of the (artificial) information, presentation rate, etc.

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Appendix I: Stability of car drivers' eye movements

SUMMARY

A common presupposition of studies dealing with drivers' eye movement behavior is that the process of relevant information input is determined by the interaction between the environmental conditions and the motorist's capabilities. It is, as a result, assumed that the information input should not change when the same motorist drives repeatedly on the same route for a limited number of times (i.e., when excluding a process of route acquisition). This assumption is a central precondition, as it suggests that the reliability of numerous replications have been provided, even though the results were obtained while the subjects completed just one experimental route, one time.

Despite the importance of this presupposition, no systematic efforts have been made to test this issue. The present experiment was conducted to study whether the driver's eye movements remain stable while driving repeatedly on the same route. In order to reduce the influence of the subject's individual capabilities, or of the road's specific characteristics, it was decided to study this issue on two different routes while using two different groups of subjects. The results obtained suggest that the driver's eye movement behavior remains stable, and that results obtained due to a single run are reliable.

1. INTRODUCTION

The car driver orients himself in the environment mainly through visual search activity as manifested by the succession of his saccadic eye movements, each followed by a subsequent fixation. The saccade's purpose is to bring a target of greatest momentary relevance, within the shortest time possible, into projection on the fovea. The reason for fixating a target of relevance is related to the properties of central vision which facilitate the most accurate and most rapid information input. These two essential properties facilitate the driver in carrying out efficient motor operation for adapting the vehicle's movement parameters to the environmental conditions. The underlying assumption is that accurate perception of the road and its surroundings, as well as that of the traffic constellation, is a necessary precondition for steering the car accurately. Furthermore, the driver operates under pressure of time, especially when the available information's density is high. He consequently has to select the most important targets of fixation quickly, and to extract the relevant information rapidly, in order to maintain an adequate representation of the continuously alternating environmental conditions.

The targets which the driver successively fixates essentially correspond to the sequence of inputted "packages of infor-

mation" (GAARDER, 1975). If the motorist does not fixate an object, on the other hand, he cannot perceive it in detail. Therefore, the analysis of the subject's eye movement behavior is an appropriate method for investigating not only the available information but also for relating it to the information the driver actually picks up. These reasons and the close relationship between peripheral and central processes (e.g., YARBUS, 1967) have inspired investigations of the driver's input while steering a car under daily conditions through the technique of recording eye fixations. The contemporary results and the respective implications following the development of that technique have been reviewed by ROCKWELL (1971), HOEFNER and HOSKOVEC (1973), FISCHER (1974) and COHEN (1980).

The experimental method frequently used in contemporary investigations has been to drive under field conditions along a preselected route and to relate the driver's visual search activity either to the environmental conditions (e.g., road geometry) or to his characteristics (e.g., driving experience) or to his current state (e.g., fatigue). However, in the most part of the experiments reported, the motorist had to drive his car along a defined route once only. Thereby, an essential precondition regarding the reliability of the obtained results was rather neglected. For example, it is not yet sufficiently known whether the driver would manifest a comparable

eye movement behavior while driving on the same route repeatedly. It has been consistently presupposed that the driver would maintain an approximately equal visual search strategy in the next runs. The sparse data available on this issue are contradictory, however.

MOURANT and ROCKWELL (1970) analyzed the motorist's eye movement behavior while repeatedly driving on rather simple routes (straight sections of an expressway). Their goal was to estimate the role of the route's familiarization. Their subjects were instructed in the first run to consider each sign as if they were searching for information required to orient themselves locally. The subject had to consider in the next run only signs which they believed to be of importance, and in the final run to drive as if they were completely accustomed to the route. MOURANT and ROCKWELL obtained a different visual search strategy among these three runs. The locus of fixations was closer in the final run, as compared to the first one, and the lateral distribution of the fixations narrowed. MOURANT and ROCKWELL suggest in accordance with their findings that the route's familiarization plays a determining role in a driver's visual search strategy.

BLAAUW and RIEMERSMA (1975) observed, on the other hand, that the motorist's eye movement behavior remained un-

changed while repeatedly approaching a highway during driving on curved sections. They did not instruct their subjects, in contrast to MOURANT and ROCKWELL, in any specific manner.

These contradictory results might be either a direct result of the experimental conditions, i.e., the dissimilar instructions given and/or that of the different environmental conditions. It can also be speculated that the route's familiarization occurs more rapidly under conditions of low work-load in contrast to moderate work-load (i.e., while negotiating curves).

The investigational goal of the present study was to clarify whether route familiarization could be the result of a process occurring during a short period of time. If the required period of time is very short, then an altered eye movement behavior might be expected even between two different sections of the same road (which possess comparable characteristics), as the motorist can better anticipate his future path of driving. If the route's familiarization is a matter of actually knowing the route, in contrast to anticipation, then a difference can be expected between two successive runs. However, if no difference could be obtained either between the two sections or between two runs, then it must be concluded that route familiarization does not occur during a rather limited period of time.

The relevance of this issue concerns, in general, the reliability of previous findings obtained on the driver's visual search strategy. If the motorist's eye movement behavior already alters as a function of repeated driving, then the validity of previous findings is rather limited.

2. METHOD

Two experiments were conducted in order to study any alteration in the driver's visual search strategy under conditions of low versus moderate work-load. As data evaluation is associated with an enormous time expenditure, only a limited number of subjects could participate in each experiment. In order to compensate for inter-individual variability it was decided to use two different groups of subjects who also were heterogenous in regard to their driving experience. Each subject drove his own car.

The driver's eye fixations were registered with an NAC Eye-Marc-Recorder connected to a portable video-recorder. The records were evaluated by means of a GRUNDIG-Slow-Motion Apparatus facilitating single frame analysis with a capacity of 50 frames per second.

2.1. Experiment 1: Open straight road condition

2.1.1. Experimental design

The first experiment was conducted to investigate the quantitative criteria of eye movement behavior. The criteria considered were fixation times, the saccade amplitudes including their components in horizontal and vertical directions, the duration of non-evaluative fixations (regardless of whether they were due to eye-blinks or due to fixation located beyond the range of registration) and their rates as well. Further criteria were the rate of head movements occurring during the fixation (i.e., compensatory movements), as well as the vertical and the horizontal directions of the saccadic eye movements.

2.1.1.1. Subjects

Six subjects participated in the first experiment. They were 27 years of age, on the average, varying between 23 and 38 years. Their driving experience ranged from 5 to 19 years. Three of the subjects were females and three were males. None of them received any special instructions during the experiment and they were unaware of the purpose of the experiment.

2.1.1.2. Experimental route

Each subject negotiated the experimental route for the first time after having driven his car for approximately 15 to 20 minutes. The route was an infrequently used straight urban road, selected in order to avoid influencing the driver's visual search (e.g., oncoming traffic or lead-car, see MOURANT and ROCKWELL, 1970). The experimental route was divided into two sections which had similar characteristics. The reason was that if the driver could rapidly familiarize himself with road's characteristics and consequently alter his eye movement behavior after a rather short time (a few minutes), then a difference might be expected even during the same run, i.e., between the two sections. A second comparison could then be carried out between the two runs. The second run began approximately 20 minutes after the subject has completed his first run.

2.1.2. Results

The results are summarized in Table I.1. The statistical data analysis did not yield any significant differences either between the two sections or the two runs in regard to fixation

variable		section		run		total
		first	second	first	second	
mean fixation	$\bar{X}$	0.41	0.43	0.44	0.42	0.43
time in s	s	0.21	0.30	0.29	0.24	0.26
mean amplitude	$\bar{X}$	5.7	5.9	5.7	6.0	5.8
in arc degree	s	5.3	4.6	5.3	4.6	5.0
amplitudes' mean	$\bar{X}$	5.3	5.8	5.4	5.7	5.5
horiz. component	s	4.1	4.7	4.1	4.7	5.0
amplitudes' mean	$\bar{X}$	0.2	0.3	0.3	0.2	0.3
vert. component	s	0.4	0.6	0.6	0.2	0.5
saccades' horiz. none	¹⁾	4.4	7.5	6.9	5.0	5.9
direction in left		52.1	47.0	50.4	48.6	49.5
percent right		43.5	45.0	42.7	46.4	44.5
saccades' vert. none	¹⁾	32.9	29.1	33.3	28.7	31.0
direction in up		39.4	39.5	39.4	39.5	39.4
percent down		27.7	31.3	27.3	31.8	29.6
rate of compensatory head movements (percent)		37.9	33.9	38.1	33.7	35.9
rate of non-evaluable fixations in percent		3.4	4.6	3.3	4.6	4.0

Table I.1. Quantitative parameters of the drivers' eye movement behavior while driving either along each section or in each run as well as in total.

¹⁾ If less than 1°.

times ($F_{1,948} = 1.82$; $p > 0.05$ and $F_{1,918} = 3.44$; $p > 0.05$), saccade amplitudes ($F_{1,946} < 1$ vs $F_{1,946} = 2.19$; $p > 0.05$) or its lateral ($F_{1,892} > 1$ vs $F_{1,892} > 1$) or its vertical components ($F_{1,650} > 1$ vs $F_{1,650} > 1$). Furthermore, the components of the saccades directions also did not differ between the experimental conditions ($\chi^2 = 5.30$; $df = 2$, $p > 0.05$ vs $\chi^2 = 2.31$; $df = 2$; $p > 0.05$). Similarly, no difference was found in regard to the rate of head movements occurring during the fixations, i.e., compensatory head-eye movements ($\chi^2 = 1.55$; $df = 1$; $p > 0.05$ vs $\chi^2 = 1.87$; $df = 1$; $p > 0.05$) or in regard to the rate of non-evaluable fixations ($\chi^2 = 1.52$; $df = 1$; $p < 0.05$ vs $\chi^2 = 2.17$; $df = 1$; $p < 0.05$) or their respective durations ($F_{1,86} < 1$ vs $F_{1,86} < 1$). The only significant differences obtained were among the subjects, which will not be further considered here. In summarizing these results, it can be stated that the quantitative parameters of the motorists' visual search strategy did not alter either between the two sections nor between the two experimental runs.

2.2. Experiment 2: Negotiating a T-formed intersection

Experiment 2 was designed for retesting the results obtained in Experiment 1, under different environmental conditions. Be-

cause an inter-individual variability was expected and observed in Experiment 1, it was decided to use a second group of subjects in order to decrease the influence of the subject's characteristics on the findings obtained.

2.2.1. Experimental design

This experiment was designed for analyzing the driver's eye movement behavior while operating a car under conditions of moderate work-load, inherent within the environment conditions. The criteria used this time for data evaluation were the fixation times, the saccade amplitudes, and the targets of fixations categorized according to the spatial relationships. The respective categories were (1) the road's vanishing point, (2) left of that path, (3) the path of driving, (4) right of that path and (5) elsewhere, e.g., fixation upon the rear-mirror, toward the sky etc. A fixation upon the road's vanishing point was defined as the location within the spatial area amounting to 1° around it. Otherwise, the fixation was ordered to the remaining four categories.

2.2.1.1. Experimental route

The subjects negotiated the experimental route for the first time after having driven their car for a period of approximately 20 to 25 minutes and for the second time after approximately 10 minutes after the first run was completed. The experimental route was a left turn curve's approaching zone and the curve itself, at the termination of which was a T-formed intersection. No other car was present during the experimental runs.

2.2.1.2. Subjects

Seven subjects whose ages ranged between 24 and 35 years participated in this experiment. They had between 3 and 17 years car driving experience. Each subject drove his own car during the experiment, and did not know the purpose of the experiment.

2.2.2. Results

The results did not indicate any significant difference

between the two runs. The fixation times amounted to 0.35s on the average and varied between the two runs at random ($F_{1,317} > 1$). The individual mean fixation times varied significantly between the subjects and ranged from 0.30s to 0.39s ($F_{6,317} = 4.26$; $p < 0.001$). Also, a significant interaction was observed between the subjects and the runs ($F_{1,317} = 3.01$; $p < 0.01$) indicating an intra-individual fluctuation between the two runs. The fixation times, on the other hand, did not depend on the target fixated upon.

The saccade amplitude varied between the first run (3.28°) and the second run (3.58°) at random ($F_{1,317} < 1$). A significant difference existed, on the other hand, among the subjects and the ranged between 2.2° to 4.3° ($F_{6,317} = 3.57$; $p < 0.01$). They depended also on the target subsequently fixating upon, and amounted to 4.83° , 3.87° , 3.37° , 3.00° and 2.75° on the average when fixating, respectively, upon the road's right side, its left side, upon the path of driving, "elsewhere" and upon the road's focus of expansion. This result reflected solely the spatial relationships between the targets and the driver's frequent direction of fixations, which was closer, on the average, to the road's focus of expansion than to any other categorized target. The qualitative data inspection indicated that the drivers intensively considered the road's right shoulders and fixated upon those quite close to the road's vanishing point.

The fixation's greatest rate was devoted to the individual's path of driving followed by fixation on the left of the road's focus of expansion and on the right of the road. The subjects fixated upon other targets, termed "elsewhere", only seldom. The fixations' distribution was not influenced by the sequence of the experimental runs, as Figure I.1. clearly indicates.

3. DISCUSSION

The results obviously pointed out that the drivers' eye movement behavior was not changed while driving on the same road for a second time, as compared to the first run. These results were observed in two different groups of subjects while they steered their own cars on two different types of roads. The findings do not suggest, of course, that each driver fixated exactly the same targets in each run. The eye movement behavior's basic characteristics were nevertheless stable, i.e., in regard to the fixation rates, their distribution upon categorized elements of the road or in regard to other investigated quantitative parameters. The present findings conclusively support that assumed presupposition regarding the stability of eye movement behavior. The present findings do not suggest that road familiarization has no influence on the driver's visual

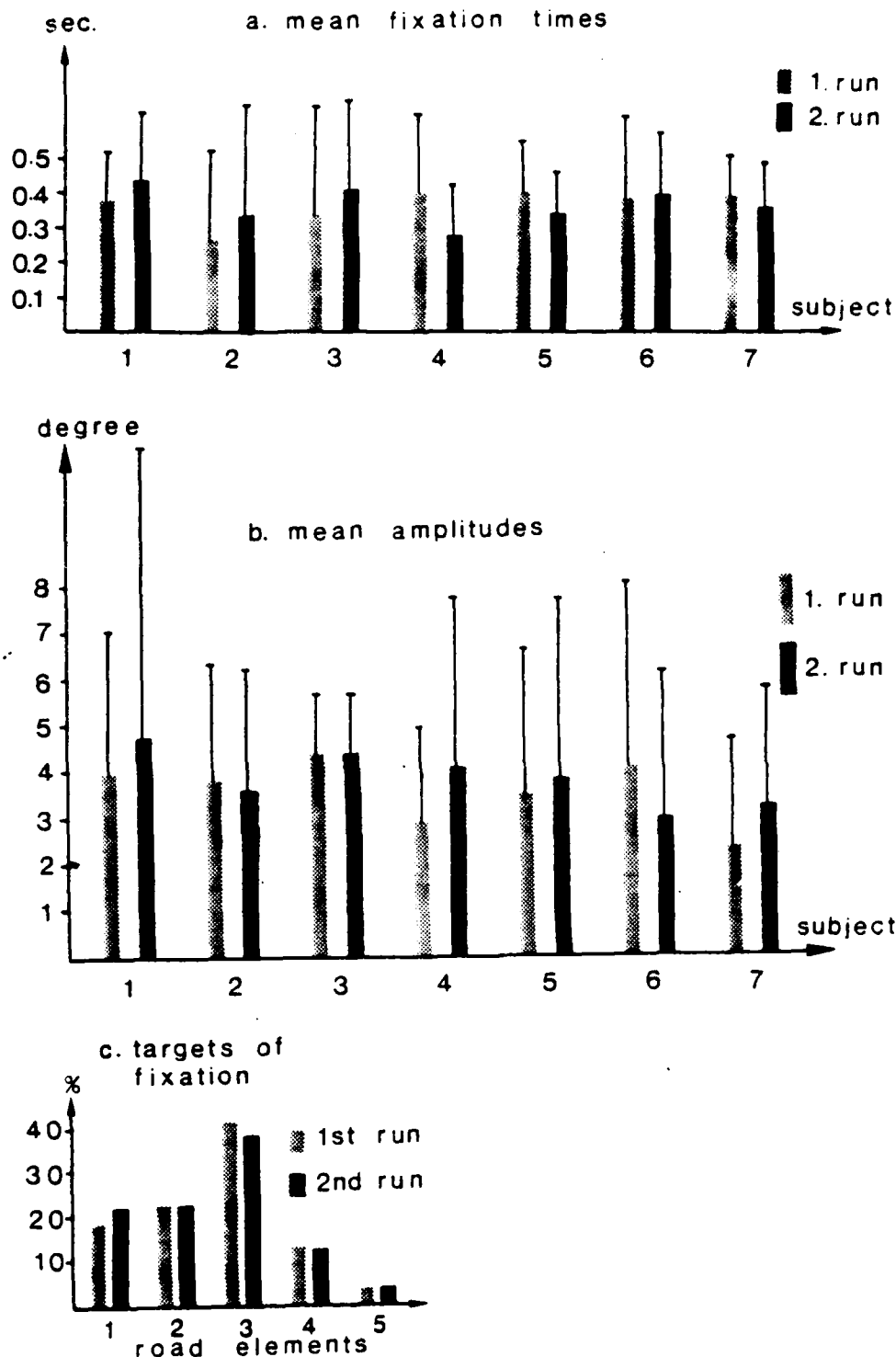


Figure I.1.: Each drivers' (a) mean fixation times and (b) mean amplitudes and the corresponding standard deviation observed in the first and in the second run. The targets of fixations (c) are given for each run.

search strategy but they clearly indicate that it did not occur within as short a period of time as required to complete two runs.

The fact that the driver's eye movement behavior did not significantly differ either between the two sections (in Experiment 1) or the two runs also suggests that a further essential precondition for reasonable analysis of the drivers eye movement behavior was fulfilled. It regards the question of whether the drivers participating in an investigation on eye movement behavior would willingly influence their visual search, e.g., in order to be subsequently characterized as a skillfull driver. Even though the present experiment did not provide data to solve this problem conclusively, the findings nevertheless suggest that the drivers did not make any attempt to modify their visual search. Otherwise, it would be rather improbable that the drivers participating in the first Experiment could intentionally manipulate their input in a consistent manner during approximately one hour, as they did not know where the experimental route was. The subjects participating in the second Experiment, on the other hand, might have identified the experimental route, as the experimentator photographed the road simultaneously to video-recording. Nevertheless, even under this condition no difference was observed between the two runs.

The present findings coincide with those of BLAAUW and RIE-MERSMA (1975), but are not in accordance with MOURANT and ROCKWELL's (1972) results. This discrepancy should either be attributed to the instructions given by MOURANT and ROCKWELL or to a different process of route's familiarization, perhaps caused by unequal environmental conditions or some other factors.

It might be assumed that the subjects participating in MOURANT and ROCKWELL's experiment willingly modified their eye movement behavior. They could supposedly fulfill the instructions given, as they still possessed a rather great spare capacity during the experimental runs. Consequently, their results might rather reflect an intentional modification of eye movement behavior than an actual process of route's familiarization. The suggested re-interpretation of MOURANT and ROCKWELL's data is supported by YARBUS (1967) who pointed out that his subjects variously viewed the pictures with which they were presented depending upon the observational goal, that is, as defined by the verbal instructions given beforehand.

The central issue of this study was to investigate whether data observed during a single experimental run reflect the driver's eye movement behavior with sufficient accuracy. The

present findings suggest that results obtained due to a single run did reflect the driver's visual input in a reliable manner. Furthermore, the results also supported the presupposition underlying each experiment, namely, that the driver does not intentionally manipulate his eye movement behavior but rather manifests a consistent visual search strategy. The route's familiarization did not occur, on the other hand, during two or three experimental runs (e.g., BLAAUW and RIEMERSMA, 1975). Familiarization supposedly does influence the information the drivers are seeking, but it might be rather the result of a quiet long-termed sensomotor learning. This issue is worth being investigated in the future, as a route's familiarization could be associated with positive effects, like the decrease of work-load and, on the other hand, be accompanied by negative phenomena like neglecting to input unexpected objects. Finally, the discrepancy observed between MOURANT and ROCKWELL's study and that of BLAAUW and RIEMERSMA (1975), or the present results, might rather be attributed to different instructions given to the subjects than to rapid familiarization with the route.

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Appendix II: Estimation of the traffic-oriented relevance of defined road elements

SUMMARY

The central assumption of the system theoretically-oriented method, used for modelling the driver's successive fixations, was the postulated relationship between his past input and the relevance of the target located in his forward field of vision. It was suggested that the driver's sequence of fixations represents a goal-oriented activity required to set up an internal representation of the external environment. Consequently, his future eye fixation depends upon his past input, as well as on the relevant information ahead.

There exist no acceptable methods to describe the environment in terms of an adequate matrix of information. In order to approximate this requirement it was decided to score the available targets' traffic-oriented relevance by experts. However, it was not empirically tested whether their scores reflected the objective circumstances on the road.

The goal to the present experiment was to verify whether the

presupposition of adequate scoring was fulfilled. Ten mature professional drivers had to score the traffic-oriented relevance of each target across a sequence of photos taken from a car while negotiating a curve. The results showed that the subjects scored the road elements' relative importance, in each single photo, equally. The inter-individual variation was related rather to the score's absolute value than to its relative relevance for driving. This finding suggests that the subjects scored the available targets adequately. Consequently, the presupposition of correctly considering the available information in modelling the drivers' eye movement behavior was fulfilled.

Beyond this result, which was correct for each discrete time interval, it was also found that the subjects were hardly able to consider the importance of dynamical alternations. They scored a target's relative importance, i.e., that of the road's vanishing point, equally, across the complete sequence of photos. However, the importance of the road's focus of expansion does depend on the maximum forward view distance. Even though the maximum forward distance differed across the sequence of photos presented, the subjects could not distinguish this adequately.

1. INTRODUCTION

Driving behavior can be described as a closed-loop circuit consisting of three main components: vehicle - driver - environment. Whenever it is intended to treat this circuit as a model for influencing road safety or efficiency, it is not sufficient to consider this closed-loop circuit from a qualitative point of view only. Experience has shown, in general, that the utilization of any preventive measure increases proportionally with the underlying model's accuracy, as determined in advance, in terms of quantitative parameters.

The precondition for treating the closed-loop circuit vehicle - driver - environment as a system, is to analyze the functioning of each component separately, afterwards integrating the components into the system as a whole. The most precisely determined variable of this circuit is the vehicle. Its output causally depends on its input, occurring after a calculable lag of time. The driver, as the system's second component, has frequently been the central issue of several investigations. His behavior, as a regulator, depends on his internal capabilities in relation to several external variables, such as information intake. The driver's behavior, as output, stochastically depends on his input. The road, as the closed-loop's third component, cannot be treated in terms of

an input-output mechanism, except that it is dynamically changed from the motorist's egocentric point of view. The driver's motor output, which is transformed to the vehicle's movement, systematically changes the environment's relevance. The environment, as a layout of information which the driver has to input adequately in order to manage his task safely and efficiently, is difficult to define. The problem is that the road and its near surroundings cannot yet be described in an objective manner, i.e., in terms of an information matrix. However, even if this goal could be achieved, it might also be affected by processing mechanisms like chunking (e.g., MILLER, 1956) or filtering (BROADBENT, 1958).

In order to understand better the driver's output, it is necessary to define his visual input in a more accurate manner, which is the main issue of the present study. The goal is limited here to the question as to whether the traffic-oriented relevance of defined elements of the road can adequately be estimated. Adequacy means that different persons score the elements' relevance in a comparable manner. An object's relevance depends on its static characteristics and also on its instantaneous location within a complex picture, in relation to the car's position and its movement. Consequently, each road element's relevance should continuously change in a dynamic manner while the car moves. A broader frame of

reference in the present investigation is to understand better the characteristics of the available information as potential input. This line of inquiry also has the purpose of checking the method already used for describing the spatial distribution of the information on the road, and at its near surroundings, for determining the driver's sequence of fixations. If the available targets would not have been treated correctly, then there would be no possibility of determining the driver's future fixations in an accurate manner, as his input was inaccurately treated.

2. METHOD

2.1. Classification of the environment

As there exists no possibility of comprehending the environmental layout experimentally in relation to the vehicle's movement parameters under field conditions, it was decided to photograph the road while driving along a defined section. This was done by means of a Nikon motor camera with a frequency of 2 shots per second. A total of 28 photos were considered. They represented the negotiation and driving around a left turned sharp curve. As each photo was taken from a sequentially

changed position, the vehicle's movement was also indirectly represented in terms of altered environment.

Each picture was subdivided into all reasonable targets available, such as the road's surface, fence, gate, parked cars, etc. All other objects located in the distance, such as houses, or those having little if any importance for driving, such as trees, were collected into the category "elsewhere". The road's vanishing point was used, finally, as an abstract category which was defined as the location of the maximum forward view distance. Figure II.1. illustrates, as an example, the road elements' categorization used in photo No. 2. The number and kind of elements categorized varied between successive pictures, according to the environmental circumstances. For example, a parked car was considered from when it became visible, and it remained categorized until it disappeared from the forward field of view. In the meantime, a new object, or more, may have appeared which were similarly treated. This classification was also preferred because a comparable method used in studying static pictures has been pointed out as a rather effective approach (ANTES, 1974).

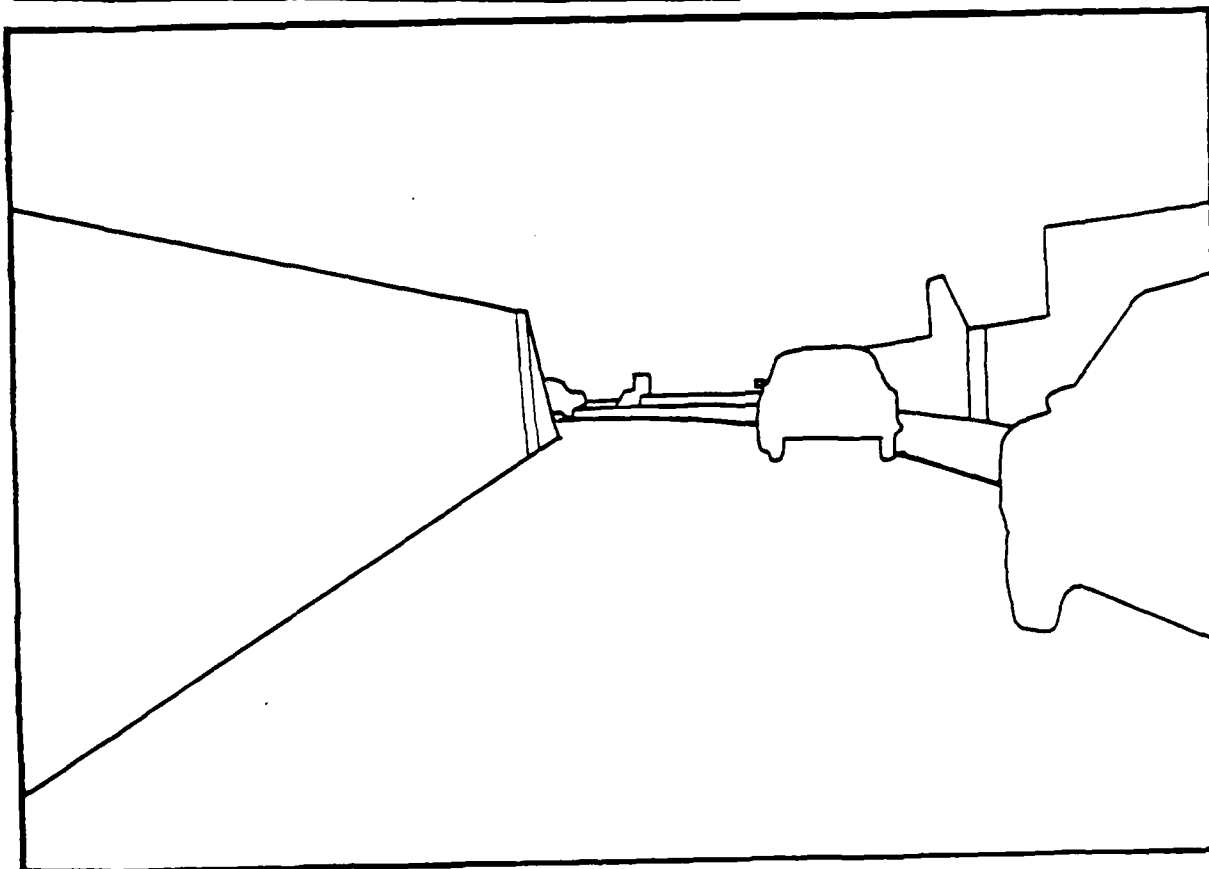
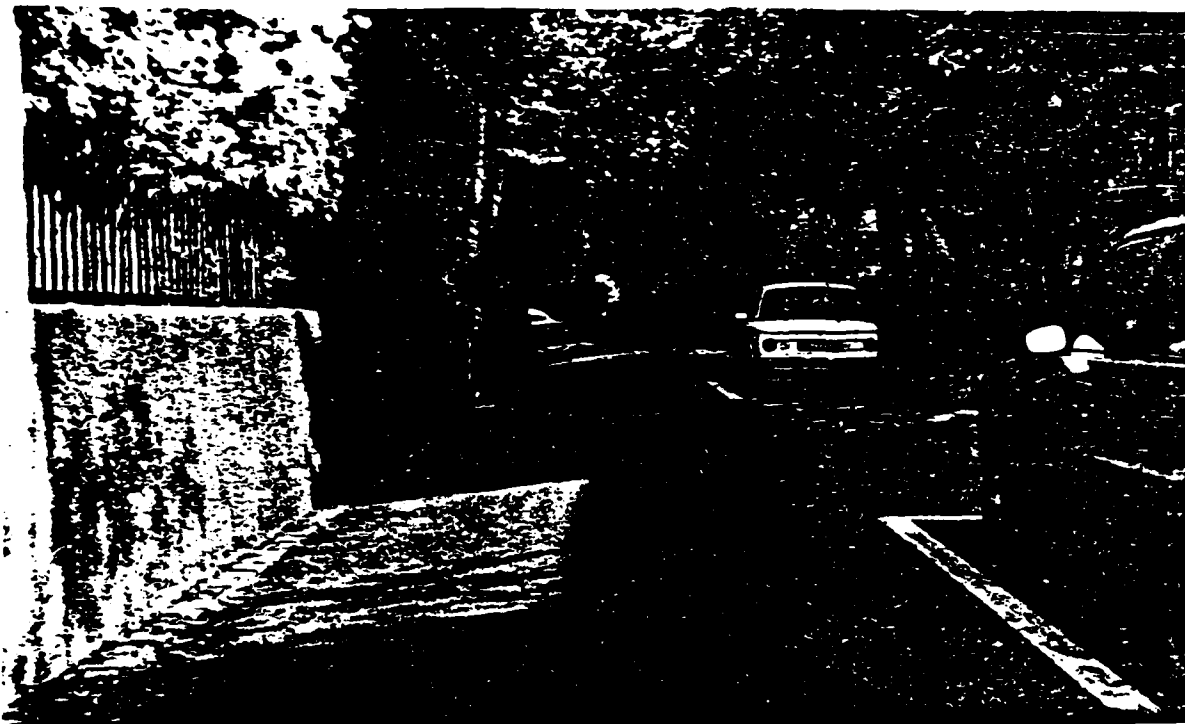


Figure II.1.: A photo from the sequence of 28 pictures, showing the categorization of the road elements used (down) and the schematical representation of the categorized targets.

2.2. Scoring method

The sequence of the 28 prepared photos were presented in their logical order to each subject individually who were, in turn, instructed to estimate each element's traffic oriented relevance according to an estimation scale in which values ranged between the scores "1" and "7". The value "1" represented the highest possible relevance of an element; that is, its perception was a necessary precondition for continuing to drive safely and efficiently. The value "7", on the other hand, was to be associated with a completely unimportant element. Its consideration was just an attentional diversion causing one to neglect more important targets at the same time. The other values represented intermediate levels between these two extreme scores. Each subject had to score every element in each picture separately. The 31 elements taken into account required 302 separate estimations, in total, over the 28 photos considered. Each individual experiment lasted approximately 2 to 3 hours, including a training period to become accustomed to the method used.

2.3. Subjects

The main criterion for selecting the subjects was extensive

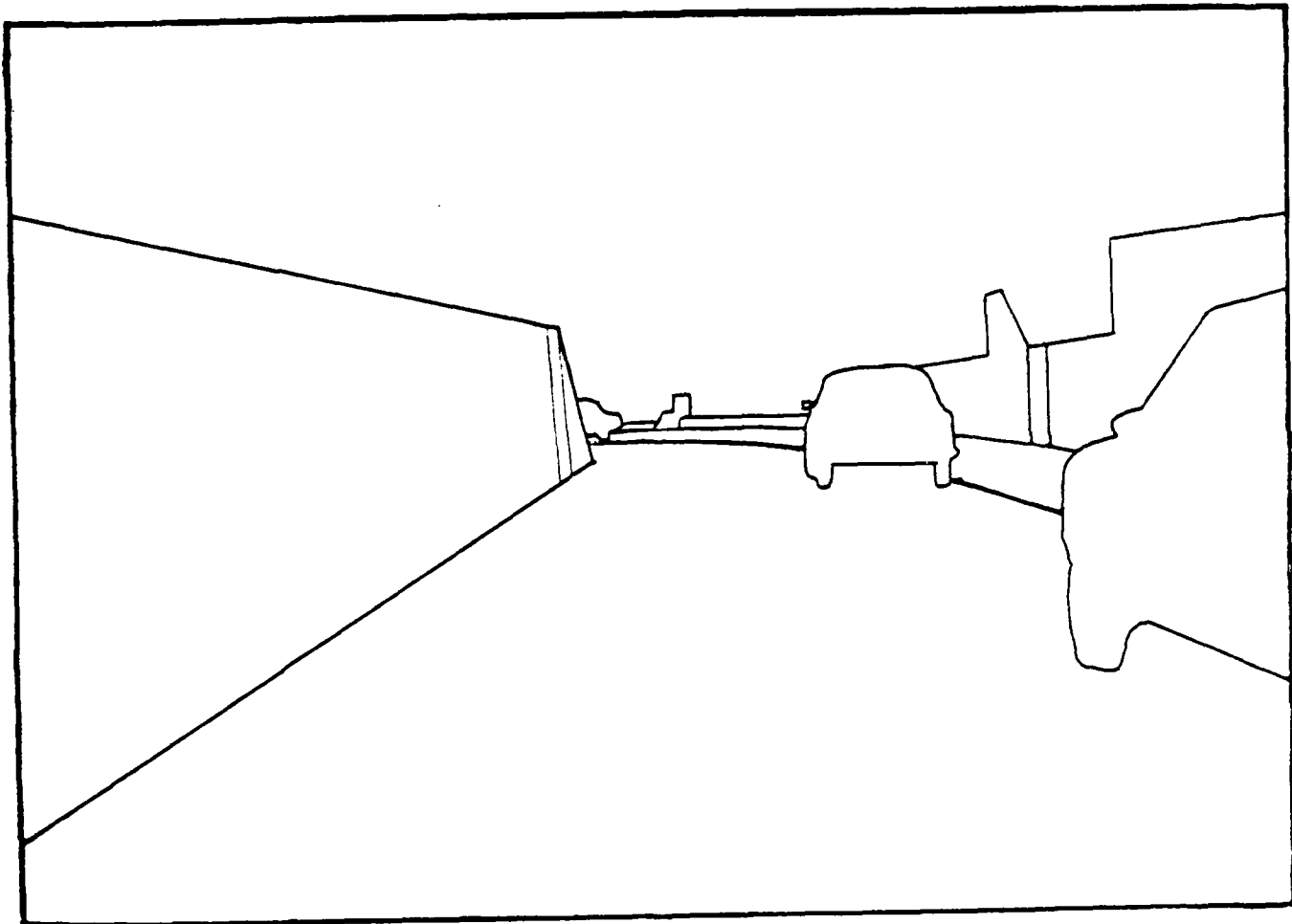


Figure II.1.: A photo from the sequence of 28 pictures, showing the categorization of the road elements used (down) and the schematical representation of the categorized targets.

contact with traffic. Professional truck drivers¹⁾ were preferred as they could be expected to score the elements' relevance according to their extensive experience.

Ten male subjects participated in this experiment. Their essential characteristics are summarized in Table II.1. Each motorist was instructed to score each road element's relevance according to the dual meaning mentioned above. An example, showing another road section, was used for training. Each subject was further told that "they should rely on their experience only, as there exists no satisfactory theory which would facilitate the construction of accurate scoring rules". This instruction was given in order to create a cooperative and relaxed experimental atmosphere. Furthermore, it encouraged each subject actually to rely on his long driving experience, without considering any expert's subsequent criticism.

1)
The authors thank Mr. Max Gun and the Company KIBAG, Zurich, as well as the drivers participating in this experiment, for their cooperation. Acknowledgement is directed also to Mr. Thomas Meierhofer who collected the data and prepared them for statistical evaluation.

		experience					
		in years		in total driven km		observed score	
subject's run No.	age	car	truck	car	truck in km. 10 ³	mean	mode
1	41	20	18	300	700	2.2	2.1
2	48	30	17	320	900	3.6	3.8
3	24	6	5	140	160	3.3	3.2
4	51	25	21	100	1050	3.4	3.0
5	50	32	30	300	1920	3.0	3.1
6	33	13	9	150	90	4.5	4.8
7	52	18	18	700	200	4.9	6.6
8	54	30	18	300	390	3.5	3.7
9	48	30	30	600	1950	4.1	3.9
10	56	35	34	800	1750	2.1	2.2

Table II.1.: The essential characteristics of the subjects and their scores.

3. RESULTS

Nonparametric statistical methods were used for data evaluation, as the estimation scale used represented a rank ordering

and not an interval scale. It was found that a significant inter-individual difference existed between the subjects in regard to the frequency of the scores they used ($\chi^2 = 4302.7$, $df = 54$; $p < 0.01$). The average score amounted to 3.5, which varied among the subjects within a rather great range, as shown in Fig. II.2. This finding raised the question as to whether the obtained inter-individual difference reflected (1) unequal scoring of the same elements or (2) an inter-individual shift of the scores used by different subjects. If the last possibility is correct, that is, if the subjects used different scoring techniques, then it should indicate that some subjects frequently used high scores and seldom low scores, and other subjects vice-versa. In that case, despite the differences observed in terms of absolute values, the relation between their scores might still remain comparable. For example, the relationship between the scores of an element A and an element B should be approximately equal for all targets. If this supposition is correct, then a high correlation among the subjects must exist in regard to the individual scores given to the 31 elements considered.

For testing the two alternative hypotheses mentioned, a closer data analysis had to be performed. The first step was a comparison between those two elements over the complete sequence of photos which received the highest and the lowest

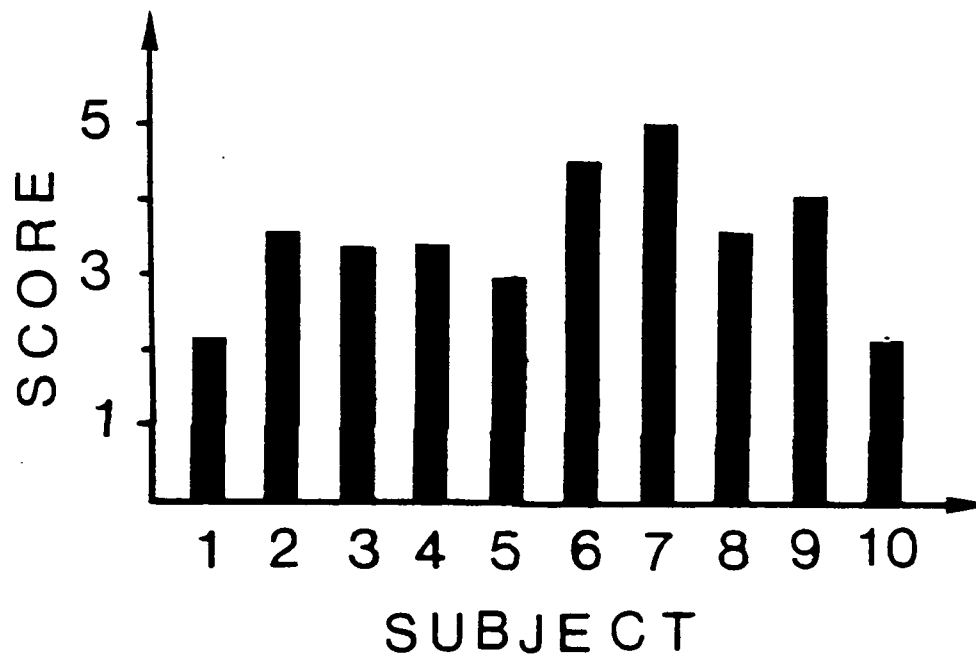


Figure II.2.: Each subject's mean score over all elements and pictures.

sub- ject	2	3	4	5	6	7	8	9	10
1	.49**	.54**	.43**	.54**	.46**	.62**	.64**	.53**	.49**
2		.35**	.23~	.68**	.56**	.47**	.60**	.78**	.46**
3			.21 ^{ns}	.52**	.67**	.33*	.44**	.46**	.49**
4				.26~	.18 ^{ns}	.27~	.43**	.17 ^{ns}	.48**
5					.75**	.61**	.66**	.89**	.44**
6	**	p<0.01				.45**	.41*	.74**	.42**
7	*	p<0.05					.46**	.53**	.19 ^{ns}
8	~	0.05<p<0.10						.59**	.58**
9	ns	not significant							.46**

Table II.2.: Correlation coefficient between each possible combination of two subjects, conducted over their scores on 31 elements of the road. Six coefficients at a level of $p > 0.05$ are related to the scores of subject No. 7.

scores. These were the road's vanishing point (having a mean score amounting to 1.7) and the category described as "elsewhere" (the average score amounted to 4.8). The comparison between these two elements pointed out that the subjects who scored one element with relatively high values also applied relatively high values to the other one, and vice-

versa ($r_s = 0.62$, $N = 28$, $p < 0.001$). Similar results were obtained in all further comparisons. This finding meant that the inter-individual differences obtained were caused by unequal frames of reference the subjects used to mark the definition of importance. The numerical values used, even though they were unequal, nevertheless represented an approximately equal relative importance for the same road element across all subjects. This suggestion is supported by the cross-correlation conducted on all possible combinations of each pair of two subjects. Out of the 45 computed Spearman rank correlation coefficients there were 35 coefficients significant at the level $p < 0.01$, and 3 other coefficients were significant at the level of $p < 0.05$ (see Table II.2.).

The comparison among the 31 defined elements of the road pointed out that their scores were significantly different $\chi^2 = 1791.2$; $df = 180$; $p < 0.01$). This finding is almost trivial and was expected, as their relative importance was unequal for fulfilling the driving task. The mean scores, as shown in Figure II.3., for each element separately did not reached extreme values, but ranged between 1.7 (vanishing point) and 4.8 ("elsewhere"). This finding suggests that the subjects did properly differentiate between the targets available. However, they did not use the full range of the given scale. This fact is not surprising, as it is a common re-

sult of experiments where an estimation scale has been used.

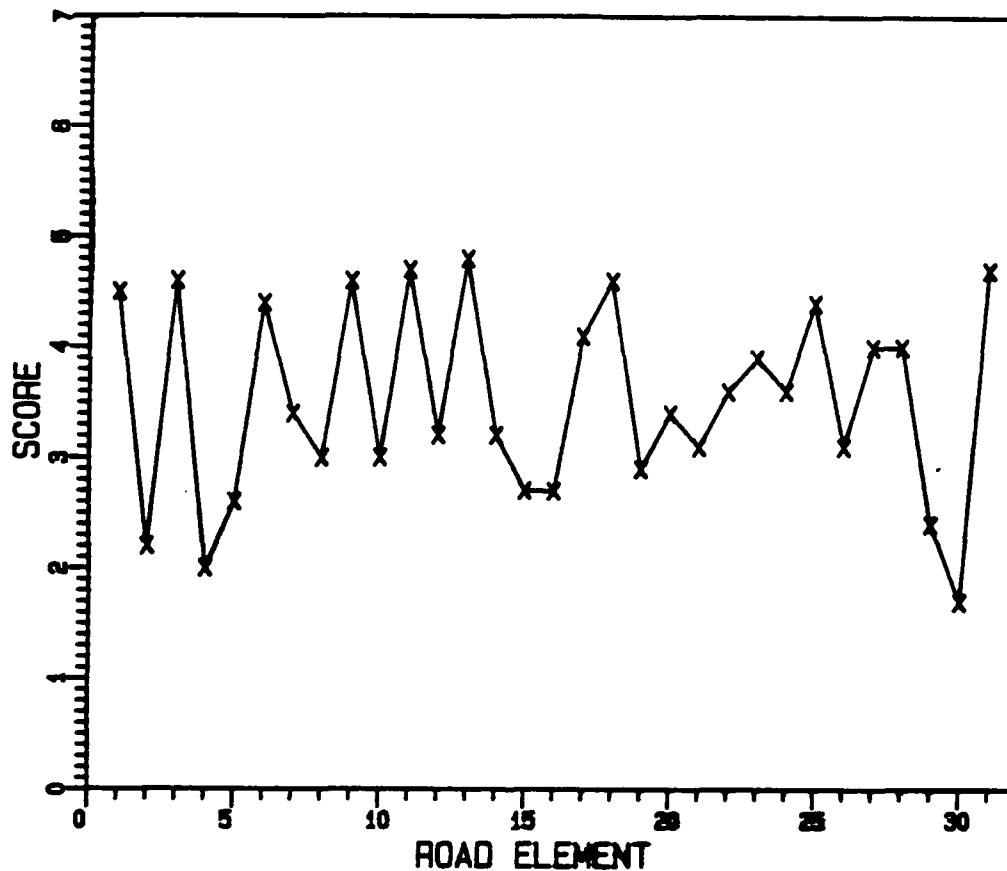


Figure II.3.: The mean score of each element of the road in each photo of the sequence.

When comparing the average score of each picture, over all elements contained therein, then a relatively small and random variation could be obtained. It ranged from 3.2 to 3.6 only. This result could not be expected, as the importance of each road element should also depend on the dynamics of the circumstances, such as the motorist's egocentric distance and the

car's movement parameters. However, the targets available were quite similarly scored in every picture ($\chi^2 = 128.1$; $df = 162$; $p = 0.98$). Fig.II.4.represents the average scores of the elements "elsewhere", "road's surface" and "focus of expansion". It clearly indicates that the subjects did not consider the situation's dynamics, as the scores were always approximately equal. The scores of any element did not depend on whether the subjects negotiated the curve or traveled around it, even though the maximum forward distance obviously varied.

4. DISCUSSION

In the present study, the subjects scored the traffic-oriented relevance of the available road elements with unequal numerical scores. This finding was not surprising, as it is known that, for example, different teachers do not use equal marks at school for the evaluation of an identical examination (e.g., INGENKAMP, 1968). Different subjects, or teachers, use estimation scales unequally. This suggestion is supported in the present experiment by the finding in-

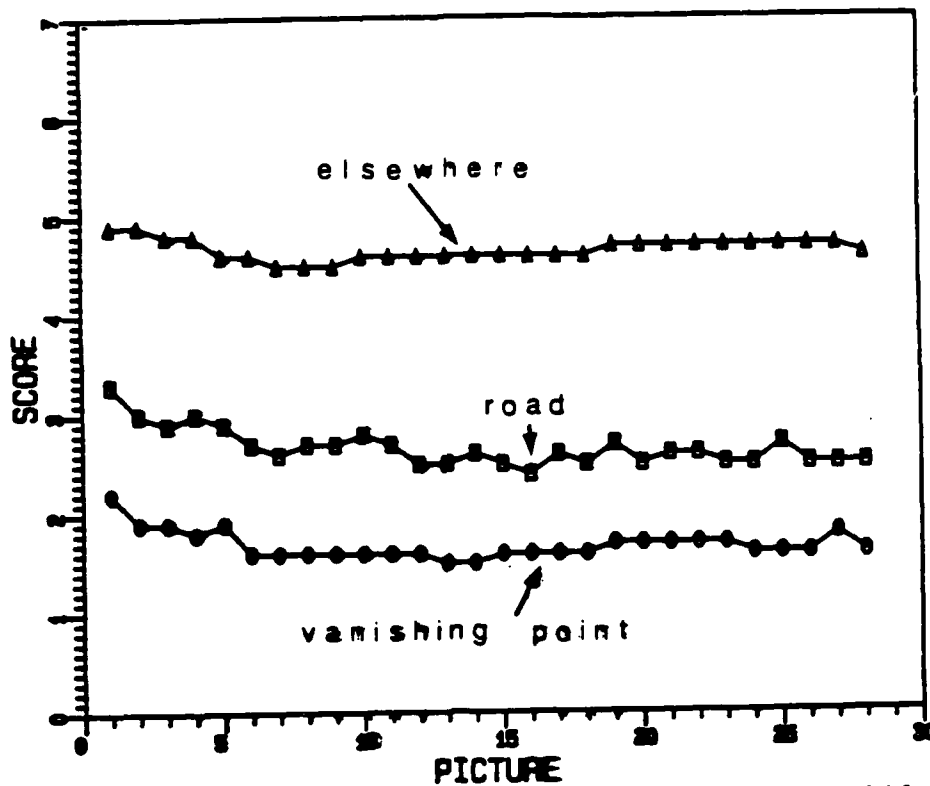


Figure II.4.: The average scores of the road elements elsewhere, road's surface and focus of expansion. An element's mean score obviously does not depend on any specific photo within the sequence considered.

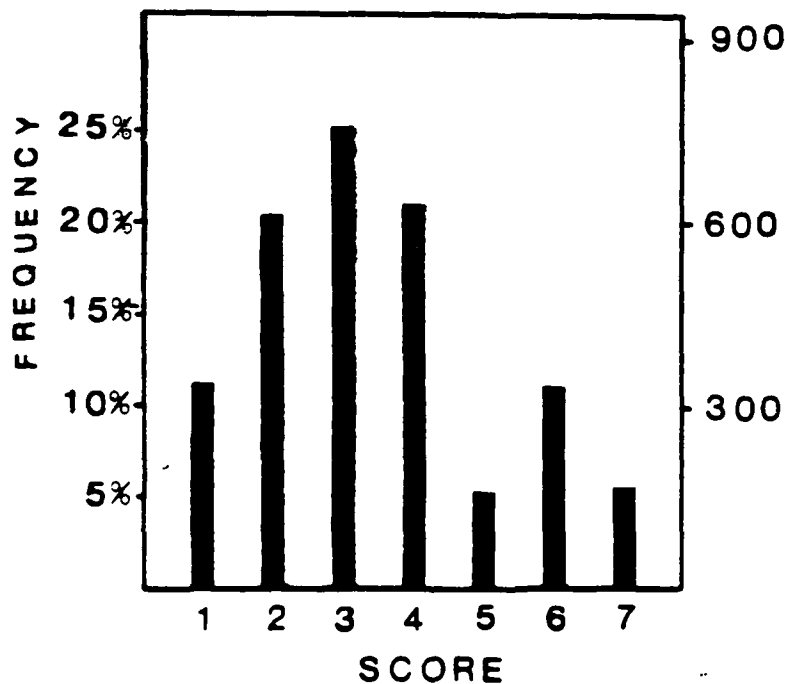


Figure II.5.:

The frequency of the seven scores used to estimate the road elements' relative importance.

dicating that the subjects used the seven levels of the estimation scale with different frequencies (see Fig. II.5.).

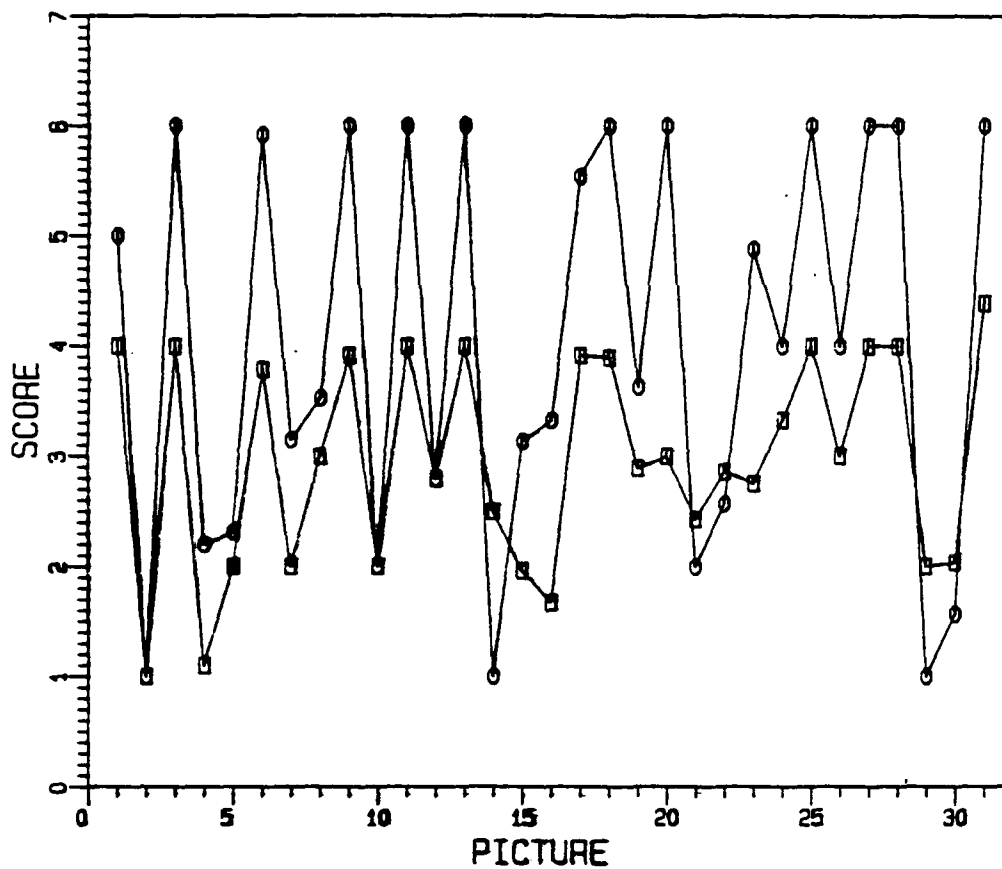


Figure II.6.: The mean scores of each element of the road as scored by subject No. 5 and No. 9. A good correspondence exists between the two curves when considered in relative terms.

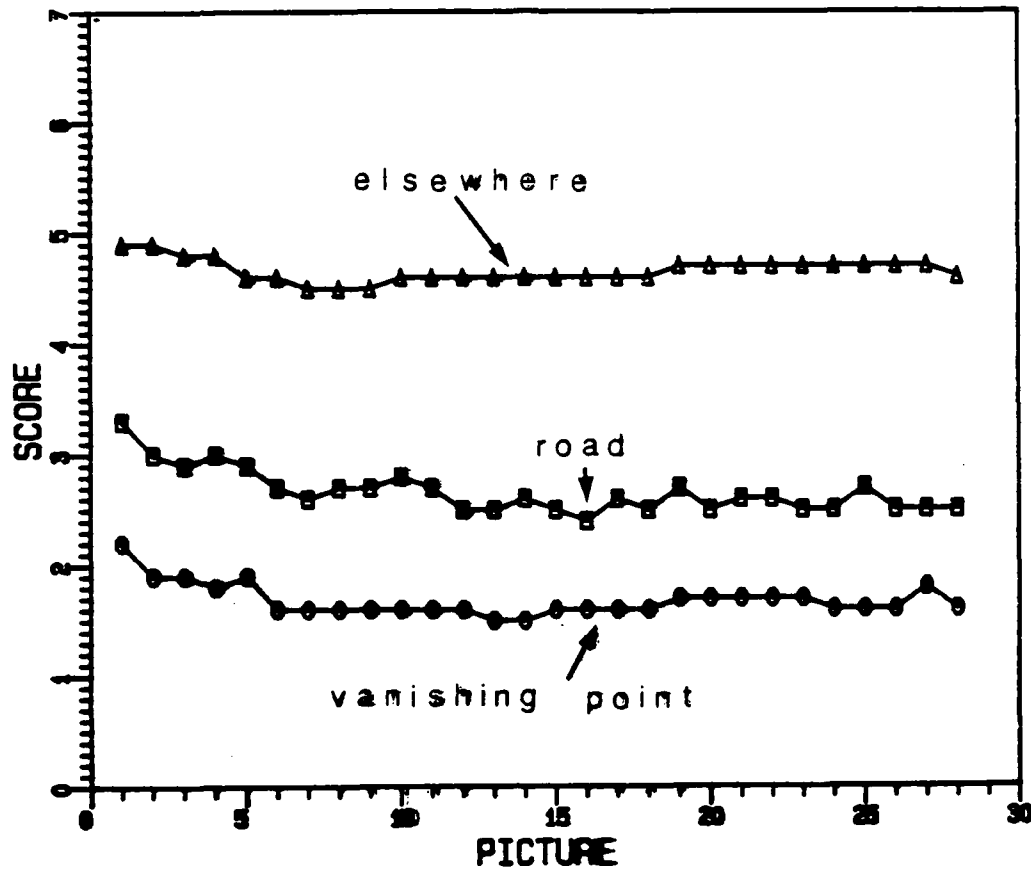


Figure II.4.: The average scores of the road elements elsewhere, road's surface and focus of expansion. An element's mean score obviously does not depend on any specific photo within the sequence considered.

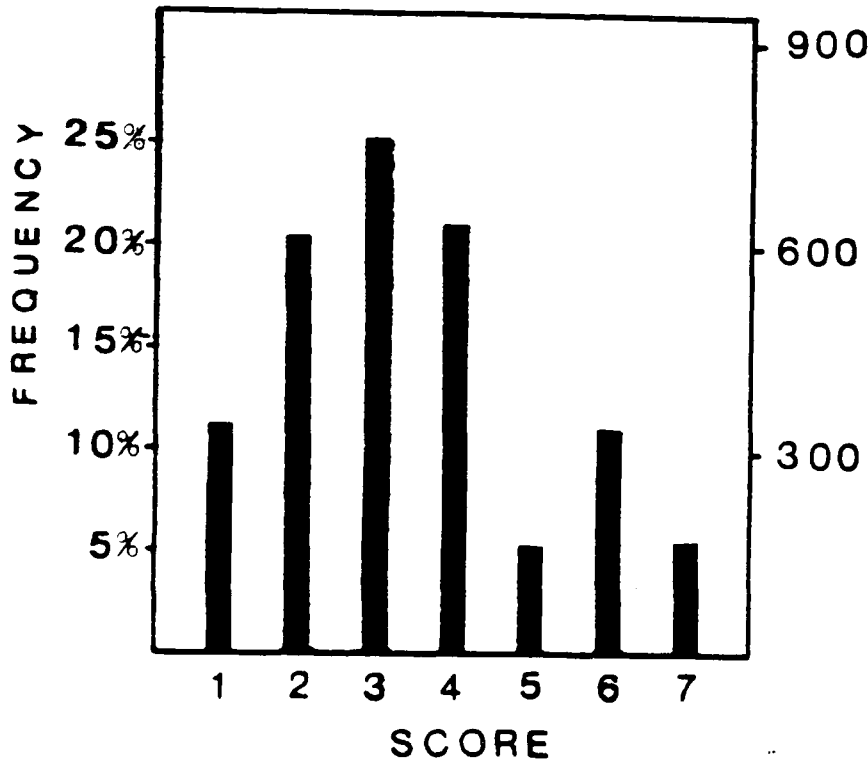


Figure II.5.: The frequency of the seven scores used to estimate the road elements' relative importance.

The experimental goal was to study whether the road elements' relative importance could be properly estimated while using a pictorial representation. Therefore, the absolute values of the scores are less important than their relative values. The results indicated that different subjects used unequal numerical values but they suggested, nevertheless, that the motorists still judged the target's relative importance in a comparable manner. This finding was supported by the correlations between each pair of two subjects. As the rank order was quite similar, it can be stated that the subjects scored the targets' relative importance similarly (see Fig. II.6.).

A further issue was to investigate whether the subjects considered the dynamic changes occurring during the vehicle's movement. The 28 pictures, taken as a sequence, represented the car's altered position within the environment, in discrete time intervals. The comparison across the sequence of photos did not point out any systematic alternation of the scores of any element of the road. For example, neither the scores of the road's vanishing point changed nor the path's surface (see Fig. II.4.) or that of parked cars, e.g., as a function of their egocentric distance. The subjects supposedly did not, or could not, consider the dynamic alternation occurring over the sequence of photos. Their scores were

given rather according to a judgment of what the object was without regarding where it was located.

On the other hand, the subjects, who were mature motorists, actually always considered in reality, that is, while driving on the road, not only what the object was but also its egocentric distance, in order to set up an adequate motor program. It necessarily also included the timing for the executions of motor output.

Even though egocentric distance in relation to the vehicle's movement parameters is a crucial variable of the motor program for facilitating safe and efficient driving, the subjects' responses in the present experiment did not reflect the role of spatio-temporal relationships while scoring the sequence of pictures. The reason for the assumed discrepancy between reality and the data obtained in the laboratory could be a result of unequal perceptual processes occurring in a real environment in comparison to its pictorial representation (e.g., COHEN, 1981). Furthermore, it is also obvious that motorists must never explain their driving behavior under normal circumstances. They were required in the present study, however, to analyze the importance of each statically presented element in relation to the others in an analytic way of thinking.

In summary, the results obtained suggest that drivers are able to estimate the road element's relative importance at any discrete moment. They are, on the other hand, unable to consider the dynamic alternations occurring due to the vehicle's movement, i.e., as represented in the photos within the sequence. The uniformity of the drivers' judgments suggests that their scores, in relative terms, are objective. There seems to be also a high probability that their judgments reflect reality at each discrete moment. On the other hand, the situation's dynamics are not considered, that is, the changes occurring between successive time intervals are neglected.

This experiment was primarily conducted in order to test whether experts were able to identify a target's relative importance. This expectation was fulfilled and it can be stated that the method used for scoring the available objects' importance in pictorial representation, as previously used (COHEN and HIRSIG, 1980), is adequate to relate the available information to the motorist's eye movement behavior.

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Appendix III: Inter - individual variability of the
drivers' eye movement behavior:
The role of personality and perceptual
variables

SUMMARY

Inter-individual variability of drivers' eye movement behavior is a common finding of different studies. This means that the motorist's visual search is not definitively influenced by the traffic constellation. The question arising here is whether the subject's individual characteristics partly determine the adequacy of his visual search, as a complementary factor to the environmental conditions. The problem is then to identify these relevant individual factors. This problem is important, as accident involvement does correlate with the driver's individual characteristics.

The drivers eye movement behavior as observed under three environmental conditions, i.e., open road, negotiating curves and driving around them, were related to his individual characteristics. The results pointed out that a relationship exists between selected parameters of the driver's eye movement behavior and his perceptual and personality characteristics. This

dependence is rather pronounced while operating the car under a great sensomotor work-load (i.e., in curves), as compared to simple environmental conditions (i.e., while driving along a straight road). Furthermore, the role of the individual variables is overlapped by driving experience. It is therefore suggested that an inexperienced driver, who might steer his car on straight roads as good as a mature motorist does, should not attempt to drive his car in complicated situations in a similar manner to that of experienced drivers.

1. PERCEPTION AND ACTION

Perceptual processes influence a person's capability to fulfill any goal oriented sensomotor task, because continuous information input is required to program and to guide the adequate movement production. This principle is generally accepted. To validate this statement experimentally is, nevertheless, a rather great challenge. The main problems in identification the close relationship between perception and action include the information processing, motor behavior and the coordination between the two. However, the dependence of action on perception may imply that any alternation of the information input results, even if not necessarily, in a modification of the subsequent motor output and influences, therefore, the subject's performance.

The information a subject inputs in order to set up a motor program or to control movement production represents a selection out of the available information in the environment. This kind of information filtering is observable at the peripheral level by the eye movement behavior, specifically the discrete sequence of targets fixated upon. Consequently, the subject's visual search strategy represents the particular aspect of the information he is seeking. This information is used to set up appropriate motor programs in advance and also to pick up feedback in-

formation during the execution of the movement. Goal-oriented motor behavior is, therefore, principally based upon the information which a subject currently selects or he has already stored in advance.

The current sequence of targets fixated on indicates the flow of information input. This correlate, however, does not conclusively define the modulation of each discrete input during its processing. The perception based on present input should be understood as a function of integrating the information picked up within the current cognitive schema. The schema's great role in modulating the information is obvious when observing ambiguous drawings. For example, BUGELSKI and ALAMPY (1961) pointed out that subjects perceive an ambivalent figure either as a man's head or as a mouse. What a subject sees, depends on the subject's prior task, i.e., the information input is processed in dependence on the current cognitive schema. If different subjects possess different schemas but are exposed to equal information, they may perceive the same optical array equal even under conditions differently, e.g., either as a man's head or as a mouse.

The cognitive schema influences the information processing under daily conditions less drastically than under laboratory conditions because, under daily conditions, 1) the objects are

not ambiguous and 2) a great number of redundant cues are present. However, it can never completely be excluded that different subjects might perceive an equal target in a slightly different manner, even if they picked up, the equal information. Furthermore, any inter-individual variability is not limited to the perception itself, but includes also the judgment about the perception, for example, a recognized object's task oriented relevance.

Although that information input is closely related to motor behavior, it is still a challenge to identify the causal relation between the two. The main problems in identifying the causal coordination between information input and motor behavior in driving are discussed. Inter-individual variability and its relation to road safety, is also considered.

1.1. Role of individual long-term variables on motor behavior

Perception must be understood as the combination of information input and selection, cognitive processes, perceptual learning, and further interfering variables (like motivation, physical condition, willingly initiated actions etc.). For example, HAGEN (1975) observed (on driving simulator) some essential dif-

ferences between females and males in regard to their executing operations while performing an identical task. Males produced (in contrast to females) more accelerations and more braking. The males also drove their simulated car faster and closer to the centerline as compared to the female subjects. HAGEN (1975) suggested that females and males differ in their psychomotor skills, for example, their readiness to take risk.

1.2. Fluctuating delay between information input and reaction

A second problem in identifying the immediate influence of information input on motor output is the delay between perception and action. The information picked up must be processed before any motor program can be set up, that is, prior to any possible movement production. The duration of this lag is, under daily conditions, unknown. Only the minimum time needed to react can be measured. A person who is, for example, driving a car usually must not react immediately as in experiments on reaction time. In contrast, he can and should store the information he has picked up in order to plan his accurate actions ahead. The execution of any motor program already set up is then delayed. Consequently, there is necessarily a minimum delay between information input and any possible reaction but no definite known ma-

ximum interval of time between perception and action. This interval has, of course, no constant duration but a variable lag. Further, not each input is of goal-oriented relevance and the driver can even forget non-significant input and it will then never be manifested in his behavior.

The researcher, who neither knows which particular input is subsequently translated to a motor program, nor when its realization occurs, can not accurately relate a particular input to a specific reaction. This relationship is nevertheless clearly identifiable only when the information input is of great and immediate importance. While driving a car, however, reaction to hazards should be the exception and not the rule.

1.3. Capacity limits and selection of the inputed information

The third problem in identifying the causal relation between information input and behavior is based on the operator's limitations. The capacity of inputing information is greater than that of processing, which is even still greater than that of movement production. Therefore, it is highly improbable that each particular input could be manifested in a person's motor behavior. The motor program consists of a limited part of the

information picked up, that is of the selected part of prior input. However, it is hardly possible to determine which particular input causally initiated to execute a specific motor operation. On the other hand, under some circumstances even a fractional input of information, i.e., a cue can initiate a chain of actions like braking the car when seeing a ball rolling on the pathway and anticipating a child running behind.

The attempt of better understanding the process of information input as a part of sensomotorics is essential for future considerations of more complex relationships between perception and motor behavior. Therefore, the problem of perceiving and handling will, in this work, be limited to studying the driver's visual search strategy. The purpose of the subsequent considerations is to relate the motorist's eye movement behavior to his personal long-term variables. The considerations above do suggest that inter-individual variability should be the result of cognitive components involved in the processes of selecting and processing information. This suggestion is in accordance, e.g., with YARBUS (1967) who states that there is a close relationship between seeing and thinking.

2. PERCEPTUAL CAPABILITIES AND ACCIDENT INVOLVEMENT

High visual performance in particular and proper perceptual capabilities in general are essential preconditions for safe and efficient driving. The relationship between perceptual performance and accident frequency can serve as an indicator for supporting the suggested dependence of road safety on the drivers perceptual variables. An essential cause of being involved in an accident results from non-adequate perception of the traffic circumstances ahead, at the right moment and from the right distance, meaning that the driver needs spare time to plan his adequate re-actions.

This suggestion is obviously valid for the driver who is primarily causing a mishap. Nevertheless, another "passively" involved driver at that crash, who will not be blamed from a juridical point of view, also did not properly anticipate all possible alternations in advance. Otherwise he would certainly prefer to yield right-of-way in favour of avoiding an accident. Therefore, accident involvement almost always reflects an improper recognition and anticipation of the traffic circumstances regardless of the question if a driver caused it or was just "involved".

Accident frequency can be treated from two different points of view. First, one can consider the localities where a high rate of accidents occur and, second, the motorists' individual mishaps frequency in relation to his characteristics.

2.1. Influence of environmental conditions and work-load

The accidents' frequency within the roads' network is not distributed at random. On contrary, there are localities where a high rate of accidents occur in contrast to other places. For example, the probability of being involved in a mishap within a curve or crossing is greater than on a straight road.

In regard to the relationship between the accidents' locality and the driver's visual search the findings of SHINAR, McDOWELL and ROCKWELL (1977) are of importance. They pointed out that the drivers' mean fixation time was prolonged when driving around accident-prone curves as compared to accident-free curves even when the two curves possess comparable physical characteristics.

The reason for the obtained relationship between the accident frequency and the drivers' mean fixation time is not completely

clear. However, increased mean fixation time corresponds, as GAARDER (1975) suggests, with a decreased rate of information input which is picked up in discrete "packages of information". When the number of fixations per time interval decreases the total amount of the information input decreases also. The question arising here is whether the prolonged mean fixation time in accident-prone curves was caused by the environmental conditions or that the a priori prolonged fixation times were the reason for the subsequent increased rate of mishaps.

Some experimental findings support the idea that environmental conditions, i.e., information density, might influence the driver's mean fixation time. HOSEMANN (1979) suggests that the fixation time depends on the target one is fixating. It increases when the target's information content increases also. This finding is in accordance with studies on picture viewing. For example, LOFTUS and MACKWORTH (1978) pointed out that a target with more information content is fixated longer and that the mean fixation time durates longer. Furthermore, when an optical array's information density increases the fixation times increases also (MACKWORTH, 1967). In analogy to visual search tasks in the laboratory it can be assumed that increased information density at the road and its near surrounding could cause prolonged fixation times in an analogous manner.

Under conditions of great sensory work-load the driver must, presumably, make greater efforts to find the relevant information required. As a result of the impaired information extraction he must prolong the fixation time and therefore can fixate on a reduced total number of targets per time interval. Correspondingly he picks up a decreased amount of information in total. As the number of fixations per given time interval decreases, there is an increased probability of overlooking essential targets.

Hand in hand with the decreased number of fixations per time interval under conditions of great sensory work-load the size of the effective field of vision decreases also (e.g., MACKWORTH, 1976). This phenomenon means that the information picked up by peripheral vision decreases also. Therefore, the driver is handicaped not only by the reduced visual search activity but also by more limited information input due to peripheral vision. Narrowed field of vision, on the other hand, limits the accuracy of programming the subsequent eye movement and impairs the efficiency of visual search.

Although the dependency of information input on sensory work-load is supported by studies carried out in the laboratory (e.g., while performing a visual search task), it is not yet directly validated by studies of the driver's visual search

behavior. In such studies, indirect evidence suggested that a motorist, who has shorter mean fixation time on average, preferred to drive his car faster while passing a quite complicated building site in contrast to other subjects, who had longer mean fixation time. All subjects, on the other hand, completed the same route with approximately equal number of fixations. This finding suggest that all subjects picked up approximately the same amount of information in total. They needed, however, different time intervals for inputing similar information (COHEN and HIRSIG, 1980). When the driver is overwhelmed with relevant information, as occurred in the above mentioned experiment, he compensates voluntarily his limited processing capacity by reducing his speed of traveling. He has then more time to extract the relevant information, i.e., to increase his fixation times. Without this self-regulation the driver's processing-system could break down (e.g., LIEDEMIT, 1977).

Usually, as ROCKWELL (1971) suggested, the driver's processing system is only moderately loaded, e.g., when traveling on rural roads or highways, he still possess a spare capacity. This spare capacity is required to manage unexpected traffic constellations.

2.2. Perception and accident involvement

The driver's perceptual capabilities are directly related to road safety. In this sense, MIHAL and BARLETT (1976) pointed out that professional driver's accident rate depends on his field dependency, on complex (but not simple or choice) reaction times and on the subject's capability to attend selectively. This result is in accordance with previous findings of KAHNEMAN, BEN-ISHAI and LOTAN (1973). The subjects participating in their selective attention test were also professional drivers. They were simultaneously presented with two different verbal messages. By means of dichotic hearing each car was presented at the same time with a different message. A signal indicates subsequently which message was the relevant one, meaning that one which the subject had to reproduce in part (i.e., the message's first part). After the subject has responded, a further delayed random signal indicated once again the relevant car for a second time. Now, the subject had to reproduce the corresponding message's second part. The results yield that accident-free drivers performed better than accident-prone drivers. This difference between the group of drivers with unequal accident rate was even more pronounced for reproducing the message's second part as compared to its first part.

The common variable between the selective attention-test and driving, as KAHNEMAN et al (1973) suggest, is the subject's capability to reorient himself selectively but rapidly and accurately to the currently relevant information. This capability might be of crucial importance not only for driving a car but also in performing different sensomotor tasks, especially under conditions of great work-load. For example, GOPHER and KAHNEMAN (1971, cit. in KAHNEMAN et al, 1973) observed on Israel Air Force cadets a significant relationship between subjects' performance on selective attention-test and their achievement in pilot training. Furthermore, pilots flying high-performance crafts achieved higher scores than another group of pilots, who were preselected to fly slower propeller aircrafts or helicopters only.

The above reported findings suggest that the driver's performance, as indicated by his individual rate of accident involvement, depends on his own individual long-term characteristics in general. The question is whether long-term variables influence his eye movement behavior in particular. The underlying idea is that less adequate visual searching might be associated with increased accident involvement. This relationship is discussed in the subsequent sections.

3. INTER-INDIVIDUAL VARIATION OF EYE MOVEMENT BEHAVIOR

Inter-individual variability of car drivers' eye movement behavior is a common finding of different investigations on visual search strategy. The driver's individual search strategy presumably reflects a process of optimalization of the input of relevant information. There is some evidence that the motorist adapts his eye movement behavior to the environmental conditions in accordance with his own capabilities. In other words, each driver extracts that part of the available information which he has identified as important and useful to forward his purposive activity. The motorist is actively seeking only that particular part of the environmental information available which is currently useful in facilitating his goal oriented behavior and at the same time neglecting other available targets.

The selected input evidently depends on the motorist's long, as well as on his short term variables. As the drivers' variables are dissimilar, the pragmatics of equal information input might be of unequal task oriented relevance for different drivers even when the objective circumstances are comparable or identical.

The inter-individual variability of the motorists' visual search strategy is related to the quality, as well as to the

quantity, of the actual information input. The qualitative differences are obvious when considering the targets being fixated. For example, novice drivers tend to fixate increasingly on targets located at moderate or at short distances, even when they travel on straight roads. Mature drivers, on the other hand, are rather more concerned with targets located at greater distances, e.g., at the focus of expansion of the road. This differences indicates that inexperienced drivers are increasingly involved with input of control information. Mature motorists are, on the other hand, rather engaged with their subtask guidance. The different involvement with the two subtasks (control vs guidance) reflects a qualitative influence of driving experience on the motorist's eye movement behavior even though fixation distance is a quantitative variable.

Further quantitative inter-individual differences are obvious when considering the frequency of the road elements being fixated. There are drivers who increasingly tend to fixate on the road's smooth surface in contrast to other subjects who preferentially fixate on the road's shoulders. Contours, such as the road's shoulders contain more information than the path's surface. The amount of information picked up in each individual fixation depends on the target of fixation. For example, the road's shoulder facilitates the extraction of the relevant information about the pathway's limitations or inferences concern-

ing any future change in of the more readily road's direction than its surface.

The amount of information picked up may intra-individually vary from fixation to fixation. Furthermore, the amount of information the motorists cumulatively have picked up during a given period of time may also differ inter-individually. An inter-individual difference regarding the total information input could reflect the driver's capacity limits for input or to process the relevant information available.

In summary, the inter-individual variability of the drivers' eye movement behavior depends upon quality and the quantity of the information picked up. Some of the possible primary reasons for such inter-individual differences either due to direct influence and due to mutual interactions are listed below.

3.1. Role of sensomotor learning and sensory work-load on the visual search strategy

A crucial variable influencing the driver's movement behavior is sensomotor learning. Different experiments have noted that novice drivers use a different visual search strategy than ma-

ture drivers (e.g., MOURANT and ROCKWELL, 1971; COHEN and STUDACH, 1977). Essentially, the inexperienced driver fixates his eyes on targets at relatively close distances which also contain less relevant information in comparison to experienced drivers. The different fixation distances indicate further that inexperienced drivers are rather more concerned with input of information required for control, whereas the experienced motorists pick up information necessary for fulfilling the guidance subtask.

The processes underlying the modification of eye movement behavior as a function of driving experience have not yet been completely identified. They are, nevertheless, related to sensory, as well as, to motor components. According to the central limit theorem, each driver possesses a limited processing capacity. The individual capacity must, however, be sufficient to govern all required subtasks including motor, as well as, sensory processes. When the driver learns to organize the input information in a more efficient manner (e.g., by chunking), he then has more spare capacity for motor behavior. On the other hand, when he has learned to operate the car's steering elements, he might then have more spare capacity to deal with sensory information.

When learning to drive, the novice driver is confronted with a considerable motor, as well as sensory work-load. With increased driving experience, however, the steering operations become increasingly an "automatized" activity, which can, presumably, be carried out in parallel to sensory processing.

Perceptual learning, or the modification of eye movement behavior as the result of driving experience is relatively permanent, to enduring several years. It remains, nevertheless, very sensitive to the current information load. When mature driver's eye movement behavior, as observed while driving around curves, is compared to that of less experienced motorists (who have already driven a car for some years or approximately 50'000 km in total), then no differences can be observed, provided that the information load is moderate. On the other hand, when the information load is increased, e.g., by preventing the driver from seeing the curve's termination when the vehicle enters the curve and thereby increasing the amount of uncertainty (i.e., information), then clear differences are observed between these groups of subjects (COHEN and HIRSIG, 1980). This finding suggests, first, that motor behavior is learned earlier than an elaborated visual search strategy or, at least, that it does not influence the visual search when the visual processing capacity is not completely loaded. Secondly, a less experienced

driver is somewhat handicapped in his eye movement behavior under a greater visual work-load and less so under moderate or low information density. The sensitivity of eye movement behavior to sensory work-load seems to decrease when the process of perceptual learning has been completed. This means that the experienced driver maintains his adequate eye movement behavior more easily than the inexperienced motorist, when the information density increases. Therefore, the probability that great sensory work-load prevents the recognition of essential targets (e.g., because of the changed visual search priorities such as the increased involvement with input of control information and decreased attention to guidance information) is greater in novice than in mature drivers.

3.2. The driver's current condition

The elaborated visual search strategy does not depend on only the long-term perceptual learning or sensory work-load but also on short-term variables such as the driver's current condition. When he is influenced by blood-alcohol concentration (BELT, 1969) or when he is fatigued (KALUGER and SMITH, 1970), his eye movement behavior is retarded and is much more comparable to that of a novice driver. The intra-individual variability, as a

function of the motorist's current state, suggests that a general inhibition of the driver's processing system is reflected in his visual search strategy. The driver's reduced capability to process the relevant information available is manifested in the selected targets of fixation. They are located at lesser distances and indicate that the motorist is mainly engaged with the subtask of vehicle control.

4. THE DRIVER'S INDIVIDUAL CHARACTERISTICS AND HIS EYE MOVEMENT BEHAVIOR

The role of sensomotor learning and that of the driver's current condition can not entirely explain the consistent inter-individual variability. Differences exist among subjects having comparable driving experience even when they are driving under comparable psychophysical and environmental conditions. Therefore, it is necessary to consider the motorist's individual characteristics in relation to his visual performance.

4.1. Field-dependence

The perceptual capability termed as field-dependence is re-

lated to accident involvement. Field-dependent persons, as pointed out by MIHAL and BARLETT (1976) are more frequently involved in crashes than field-independent drivers. Further evidence is reported by GOODENOUGH (1974).

The term field-dependency, which is a relatively stable individual capability (e.g., WITKIN and GOODENOUGH, 1970) refers to the person's capability to extract relevant information from a confusing context. Field-dependent in contrast to field-independent subjects must make relatively greater efforts in order to disembed (i.e., to detect) a relevant target, that is to distinguish between figure and surroundings.

The common factor shared by field-dependency and safe driving is the capability to recognize the relevant targets regardless of their surroundings. Field-dependent drivers probably need more time than field-independent subjects to detect the relevant targets while steering a car and they do this, presumably, even less accurately. The limited capability of field-dependent persons to extract the relevant information might be a major reason for their higher accident rate.

SHINAR, McDOWELL, RACKOFF and ROCKWELL (1978) investigated the influence of field-dependence on the motorist eye movement

behavior. Their essential finding was that the more field-dependent the subject was, the smaller was the observed change on his eye movement behavior when they drove along straight sections as compared to curves. This finding suggests that a field-dependent driver also possesses a reduced capability to adapt his visual search strategy to the environmental conditions.

SHINAR et al (1977) argued that optimal eye movement behavior depends on the road geometry (i.e., on the task requirement). The adequate visual search strategy when traveling along straight roads is different from that suitable to driving around curves. An essential difference is that the density of control information increases in curves as compared to straight roads, because there are more alternations at small distances. The driver must increasingly fixate on proximate targets in order to rapidly pick up accurate control information. This means that optimal eye movement behavior in curves requires more frequent alteration of fixation distances than on straight roads. This requirement, as SHINAR et al pointed out, was more easily accomplished by field-independent in contrast to field-dependent motorists.

Further, field-dependent drivers moved their eyes with smaller amplitudes on the average and they also concentrated

their visual attention within a more limited region of the total field of view ahead in comparison to the field-independent drivers. SHINAR et al even concluded that field-depended drivers developed a mild form of tunnel vision.

The drivers' fixation times were not reported by SHINAR et al (1978). They investigated, nevertheless, the minimum time required to pick up the minimum information which is necessary for safe driving. Their subjects were instructed to maintain the eyes closed as long and as frequently as they could. The results demonstrated that the field-independed motorists (aged 20 to 25 years) had a mean eye-open time amounting to 0.7 s, whereas the field-dependent drivers (aged 63 to 70 years) had a mean eye-open time amounting to 1.5 s. This finding supports the hypothesis that field-dependent subjects require a longer minimum time than field-independent persons to aquire the information required for maintaining efficient and safe driving. However, the two groups of participating subjects differed not only in regard to field dependence, but also in regard to their age.

4.2. The driver's age

The great age difference between the two experimental groups used by SHINAR et al (1978) in addition to their field-dependence might influence the observed results. HOSEMANN (1979), who did not consider the role of field-dependency, but that of the drivers' age on the visual search, pointed out that older subjects were less capable in adapting their eye movement behavior to the task requirements as compared to their younger counterparts. When subsequently completing different tasks, such as driving around a curve followed by a straight section, approaching a traffic light etc., the older drivers tended to maintain their prior visual search strategy longer. The older drivers did not change their eye movement behavior at the same time as the task requirements changed but only after some delay. Thus, they used an improper visual search strategy at the beginning of each new situation in contrast to the younger driver's, who adapted their eye movement behavior to the environmental conditions rather quickly.

The influence of the driver's age on his eye movement behavior might be caused by the development of increased field-dependency. It increases with increased age, e.g., after about 50 years old as WITKIN and BERRY suggest (1975). However, the

drivers' age might influence their visual search due to various other indirect variables. For example, a dissimilar level of aspiration regarding the subjective attitude toward traffic safety could exert an influence on the observed eye-open time (in the SHINAR et al study) in addition to the motorist's individual capability to extract the relevant information. The notion that attitudinal change toward traffic safety is affected by the driver's age is supported by SOLIDAY (1974). He pointed out that young drivers consider mainly non-moving objects, whereas older motorists pay more attention to moving targets. This shift might be caused by either a different weighting of the available targets' importance or reflect the cognitive components guiding fixation. Elder drivers, who fixate more frequently on moving targets like cars or pedestrians, probably estimate the potential danger stemming from moving objects as greater than do younger motorists. The older driver pays more attention other cars and can better perceive any inadequate reaction of other motorists. The older driver is, thus, also better able to compensate for another motorist's failure as compared to the young subject. The young driver, who considers mainly non-moving objects, seems to be involved more with planning his own path of driving and in a limited manner with current traffic conditions. This comparison suggests that the motorist's increased age corresponds with a more defensive

approach to driving. However, increased age also corresponds with increased driving experience which could underlie the above reported relationship.

The considerations above have pointed out that the inter-individual variability of the driver's eye movement behavior depends on his individual capabilities. The subsequent experiment was designed in order to extend the findings reported above and to explore the possible influence of the following variables.

Three kinds of related variables should be considered. These are (1) the driver's characteristics like his age or his driving experience, (2) the driver's personality and perceptual variables, such as extroversion or his capability to deal with contradictory information, and (3) the quantitative parameters of the motorist's eye movement behavior, such as fixation times or the saccade amplitudes.

5. EXPERIMENT

5.1. Experimental route

The experimental route was a narrow street in Zurich. It consisted of three straight sections which were connected by two rather sharp curves. Each curve had a central radius of 30 m. The short forward viewing distances (limiting the spare time between any target detection and the required subsequent reaction), the road's narrowness (requiring precise steering operations) and the great number of potential events (e.g., sudden entering of the path at a close distance) forced the motorist to drive carefully and continuously search for new information. These environmental conditions were suitable to facilitate a reasonable analysis of the driver's eye movement behavior.

Each driver travelled on this route twice, i.e., once in each direction. A more detailed description of this route has been given in Figure 2.

5.2. The investigated variables

The purpose of this study was to examine whether the driver's

eye movement behavior depended on some individual variables. The parameters which were considered are as follows, divided into the three main kinds of variables mentioned above.

* The driver's characteristics and the environment

- A The subjects' running number (used for notation only),
- B The motorists chronological age,
- C Driving experience in years,
- D Driving experience in total driven km, and
- E if the route driven was either the complete run,
 straight sections only or curved sections only (used for
 notation only).

Further individual variables like the motorist's visual acuity, the rate of involvement in accidents, driving habits etc. were similar among the tested subjects.

* Long-term personality and perceptual variables

Each subject participated on several tests which were designed for determining his personality, as well as his perceptual variables. These were the followings:

- F Field dependency (absolute values): measured by means of the Rod and Frame-Test (OLTMAN, 1968). The rod's observed deviation from the objective vertical direction in arc degree was scored in absolute values.
- G Field dependency (relative values): obtained as F but the relative values were considered. That is, a positive value was scored when the deviation from the vertical was clockwise and a negative value was scored if otherwise.
- H Psychoneuroticism: obtained by the Maudsley Personality Inventar (M.P.I.; EYSENCK, 1959). It could be hypothesized that the more psychoneurotic the driver is, the more he is considered to pick up information from the near surroundings.
- I Extroversion: also obtained by the M.P.I. It can be hypothesized that extroversion is associated with a more intensive consideration of the environment which should be indicated by a greater visual search activity as manifested by the saccade amplitude.
- J Attention load (capacity): obtained by the d2-Test (BRICKENKAMP, 1962). The score used was the number of items which the subject could consider within a defined period of time. It can be assumed that a driver who achieves higher scores in this test possesses an increased capability to extract the relevant information available.
- K Attention load (accuracy): also obtained by means of the d2-Test. The score used was the number of critical items

which the subject did not recognize. (The third score, that is the number of non-critical items confused with the critical ones - false alarm - was not used, because this failure occurred very rarely.)

- L Spatial imaginary: obtained by the Cube-Subtest (form A) taken from the Intelligence-Structure-Test (AMTHAUER, 1955). This test measures the subjects capability to identify one cube among five others which exactly match the patterned surfaces of the critical one, i.e., after rotating it mentally. Each cube was patterned on the three surfaces seen. The number of correctly solved problems was used as a score for the subjects spatial imaginary. The common variable between this test and driving is the motorist's capability to infer from a cue to entirety.
- M Spontaneity: measured by the Color-Naming-Test (taken from the HSOA-Battery: CATTELL, 1968). The total number of correct answers was scored. Spontaneity and eye movement behavior might have in common that the greater the driver's spontaneity the more likely he is to shift his attention from fixating a present target to another new object (even if he did not yet completely picked up the available information from the current target of fixation).
- N Figure-Field-Test was constructed to measure the subject's

- X The vertical deviations' variability
- Y The eyes' mean distance travelled in arc degree per second.
- Z Percentage of the fixations upon the focus of expansion of the road.
- ZZ Percentage of the fixations upon targets at a close distance and, finally,
- NF The total number of fixations observed during the two complete runs.

5.3. Subjects

There was no possibility to test the personality and the perceptual variables of a large number of drivers and afterwards to select those motorists showing divergence in their capabilities. Therefore, the seven subjects who participated in this experiment could not be divided into two different experimental groups. However, the selected subjects were heterogeneous in regard to their age, driving experience, occupation etc. Their personality and perceptual variables were tested individually. Their respective scores are given in Table III.1.

5.4. Statistical treatment of the data

From the statistical point of view, a rather small number of subjects participated in the present experiment. Although much data was obtained on the motorist's eye movement behavior, there were only a limited number of scores on their personality and on the perceptual variables. Because of the limited data on the subjects' characteristics, the normal-distribution could not be approximated. This resulted in a preference for non-parametric statistical methods for the data evaluation.

Non-parametric correlations were chosen to test the relationship between a driver's characteristics and the parameters of his eye movement behavior. As the data inspection yield, there were ties in some scores used and, therefore, the Kendall correlation was preferred to the Spearman rank correlation.

5.5. Registration of the eye movement behavior

The eye movement behavior and the environment were registered with a NAC IV Eye Marc Recorder. This method has been described in more detail elsewhere (COHEN and HIRSIG, 1980). The parameters evaluated have been already mentioned above.

6. RESULTS

The drivers' characteristics are summarized in Table III.1. This table indicates, the scores considered varied among the subjects within a rather great range. The parameters of eye movement behavior evaluated are summarized in Table III.2. for each driver individually. The scores are given for the complete route but they are also differentiated to the condition when driving either on straight sections or around curves.

The Kendall correlation coefficients matrix (indicated in the following by "T") for 12 parameters of eye movement behavior by the driver's age and his experience are given in Table III.3. This table refers to the complete route and, on the other hand, to straight and to curved sections.

The driver's fixation time was neither related to his age nor to his driving experience. The variability of the fixations' durations was also not significant ($0.05 < p < 0.10$) in regard to the motorists' age either when traveling along straight or curved sections. The saccade amplitudes, on the other hand, correlated negatively with the drivers age. Older motorists made smaller saccades than their younger counterparts. This relationship was significant only in curves.

Variable	Subject						
	1	2	3	4	5	6	7
B age	28	42	32	24	23	28	27
C driving experience (years)	4	23	12	5	5	8	1
D driving experience (10^3 km)	20	400	80	50	5	220	1
F Field dependency (absolute values)	5	34	13	24	38	3	5
G Field dependency relative values	22	-34	-13	11	-18	2	4
H Psychoneuroticism	21	18	15	20	30	12	28
I Extraversion	23	24	23	38	32	20	21
J d2-Test performed items	390	647	501	518	510	620	555
K d2-Test unrecognized items	31	7	4	12	4	5	26
L Cube-Test (I.S.T.)	9	13	17	8	11	10	15
M Color-naming	55	67	58	90	64	59	62
N Figure-Field	133	154	99	114	82	89	101
O Stroop-Test	61	55	63	60	60	50	71
Sex	f	m	m	f	f	m	m

Table III.1.: Each subject's personality and perceptual scores

		Subject								
Parameter			1	2	3	4	5	6	7	
mean fixation time in seconds and standard deviation	complete route	$\bar{X}$	0.38	0.36	0.38	0.37	0.35	0.36	0.37	
		s	0.17	0.15	0.24	0.16	0.15	0.22	0.16	
	in curves	$\bar{X}$	0.37	0.40	0.34	0.42	0.34	0.36	0.37	
		s	0.16	0.17	0.13	0.18	0.17	0.15	0.18	
	on straight sections	$\bar{X}$	0.38	0.33	0.43	0.31	0.37	0.36	0.37	
		s	0.17	0.14	0.28	0.15	0.14	0.25	0.16	
mean amplitude in degree and standard deviation	complete route	$\bar{X}$	5.48	5.12	5.73	5.68	8.08	6.28	8.20	
		s	3.78	3.90	3.85	2.97	6.36	4.22	6.26	
	in curves	$\bar{X}$	6.65	3.45	5.33	5.54	7.67	6.39	9.58	
		s	5.33	4.78	2.03	2.96	3.28	6.29	4.85	
	on straight sections	$\bar{X}$	5.39	5.95	5.94	5.70	3.25	6.23	7.46	
		s	3.15	4.40	4.25	2.82	6.42	3.90	4.98	
the fixation points' mean horizontal deviation from the road's focus of expansion and in coordinate units and standard deviation	complete route	$\bar{X}$	2.13	0.37	-0.05	0.73	3.31	1.97	1.47	
		s	5.60	3.95	3.62	4.60	7.18	5.17	5.58	
	in curves	$\bar{X}$	2.06	-0.57	-0.95	0.76	4.76	1.87	2.05	
		s	5.92	2.40	2.79	5.09	7.45	5.75	6.15	
	on straight sections	$\bar{X}$	2.17	0.87	0.91	-0.02	2.36	2.03	1.01	
		s	5.47	4.52	3.93	4.35	6.88	5.22	5.24	
the fixation points' mean vertical distance from the road's focus of expansion and in coordinate units and standard deviation	complete route	$\bar{X}$	-0.06	-0.14	-1.84	-1.38	-0.06	1.61	-0.88	
		s	1.19	1.75	2.32	1.49	2.04	1.92	2.15	
	in curves	$\bar{X}$	0.00	0.47	-1.29	-1.38	-0.11	1.58	-0.94	
		s	0.96	1.85	1.42	1.07	1.62	1.80	2.18	
	on straight sections	$\bar{X}$	-0.10	-0.32	-2.14	-1.39	0.18	1.63	-0.86	
		s	1.30	1.61	2.64	1.65	2.26	1.98	2.15	
the eye's mean travel distance in arc degree per second	complete route	$\bar{X}$	14.42	14.22	15.07	15.35	23.08	17.44	22.16	
	in curves	$\bar{X}$	15.27	8.63	15.68	13.43	22.56	17.75	25.89	
	on straight sections	$\bar{X}$	14.18	18.03	13.81	18.39	24.56	17.31	20.16	
percentage of the fixations upon the road's focus of expansion	complete route	$\bar{X}$	16.7	23.7	9.6	5.3	9.3	24.3	18.5	
	in curves	$\bar{X}$	13.6	36.7	16.3	10.3	5.6	35.8	17.2	
	on straight sections	$\bar{X}$	18.3	16.7	6.1	2.5	11.7	19.0	19.2	
percentage of the fixations in close distance	complete route	$\bar{X}$	4.7	5.0	13.6	9.0	7.7	4.7	7.6	
	in curves	$\bar{X}$	7.6	0.0	0.0	8.6	11.1	0.0	6.3	
	on straight sections	$\bar{X}$	3.1	7.7	20.7	9.1	5.4	6.9	8.3	
total number of eye fixations	complete route	$\bar{X}$	195	139	125	179	183	169	184	

Table III.2.: Each subject's quantitative parameters of his eye movement behavior.

variable	complete route				straight section				curved section			
	age	driving experience in years	driving experience in driven km		age	driving experience in years	driving experience in driven km		age	driving experience in years	driving experience in driven km	
P fixation time	(B) 0.26	(C) -0.16	(D) -0.10		(B) 0.15	(C) -0.15	(D) -0.20		(B) 0.00	(C) -0.10	(D) 0.15	
Q s of fixation time	0.15	-0.25	-0.20		0.45*	-0.05	-0.10		0.41*	-0.41*	0.35	
R Amplitude	-0.49*	-0.39	-0.42*		-0.49*	-0.20	-0.23		-0.59*	-0.68*	-0.71*	
S s of amplitudes	-0.20	-0.10	-0.14		0.00	-0.10	-0.14		0.10	-0.19	-0.05	
T horizontal deviation	-0.39	-0.39	-0.42*		-0.29	-0.29	-0.33		-0.49*	-0.49*	-0.52*	
V s of horizontal deviation	-0.49*	-0.49*	-0.52*		-0.39	-0.39	-0.43*		-0.68*	-0.68*	-0.71*	
W vertical deviation	-0.10	-0.20	0.14		-0.10	0.00	-0.05		0.29	0.20	0.33	
X s of vertical deviation	0.00	-0.10	-0.14		-0.20	0.10	-0.14		0.10	0.20	0.14	
Y travel distance per sec	-0.68*	-0.39	-0.42*		-0.49*	-0.20	-0.24		-0.39	-0.49*	-0.52*	
Z fixations on focus of expansion (%)	0.45*	0.15	0.29		0.05	-0.25	-0.10		0.68*	0.29	0.52*	
ZZ fixations at close distance (%)	0.27	0.00	-0.15		0.29	0.68*	0.52*		-0.79**	-0.37	-0.51*	
NF total number of fixations	-0.39	-0.78**	-0.62*		-0.29	-0.78**	-0.52*		-0.52*	-0.58*	-0.62*	

* $p < 0.05$ ** $p < 0.01$ " $0.05 < p < 0.10$

Table III.3.: Correlation matrix.

On straight sections, however, the obtained correlations did not reach a level of significance. Also, the saccade amplitudes were smaller in older than in younger motorists. This relationship was once again significant only while driving around curves. When driving along straight sections it reached a level of tendency only. The visual search activity is also indicated in terms of the eye's travel distance per time unit. A negative dependency was found between driving experience (in terms of total driven km) and the eye's travel distance per second in curves only.

The more experienced drivers manifested a smaller search activity in comparison to the less experienced motorists. Also, the older drivers tended toward a more reduced search activity than the younger ones. When comparing the two variables, saccade amplitude and the eyes average distance travelled, it can be stated that the two variables depend in a similar manner on the subject's age, as well as on his driving experience. The variability of the saccade amplitudes was neither influenced by the driver age nor by his experience.

The fixation points average closeness to the roads vanishing point is indicated by the horizontal, as well as the vertical deviations. The respective variabilities depended neither on

the driver's age nor on his experience. The horizontal deviations, however, were related to the drivers age, as well as to his experience, but only when driving around curves. The older and the more experienced drivers tended to fixate rather to the road's left side and the younger motorist, or those possessing less experiences, fixated more frequently to the road's right side. Further, the variability of the horizontal deviations from the road's focus of expansion was smaller in the older and the more experienced driver, but only while driving around curves, as compared to younger and less experienced drivers.

The driver's involvement with his subtasks guidance versus control is indicated by the number vs the relative number of fixations upon the road's focus of expansion as compared to fixations in close distances. The older and more experienced drivers were more frequently involved with the input of guidance information in curves. On straight sections, on the other hand, the subject's fixations rate at the road's focus of expansion neither depended on his age nor on his experience. However, when driving along straight sections, the rate of fixations at close distances depended upon the motorist's experience. The more experienced driver fixated on straight sections more frequently in close distances. These findings

suggest that under conditions of increased work-load (curves) the experienced driver was concerned rather with input of guidance information and when the information load was reduced he was also engaged with the input of control information.

Finally, the driver's total number of fixations depended on his driving experience. When driving around curves then, the driver's age was also associated with the total number of fixations. The more experienced the driver was, the less fixations he needed to complete the route. This relationship can, presumably, be explained due to the different speed of traveling which the subjects preferred. Although the car's velocity was not recorded, the experimentator observed, however, that inexperienced drivers tended to drive slower than the experienced motorists.

The motorist's personality and perceptual variables were related to the parameters of his eye movement behavior. The general impression is that individual variables corresponded with the selected quantitative scores of eye movement behavior, but none of them influenced all the parameters consistently.

Field-dependency (as measured in absolute values) was associated with the variability of the fixation times ($T = -0.65$, $N = 7$; $p < 0.05$). The more field-dependent the subject was,

the smaller was the variability of his fixation times. The expectation that the field-dependent motorist would make longer fixation times bordered on significance ($T = 0.51$; $N = 7$; $p = 0.053$).

Psychoneuroticism was associated with the fixation points' horizontal deviation from the road's focus of expansion ($T = 0.52$; $N = 7$; $p < 0.05$) as well as with the deviation's variability ($T = 0.62$; $N = 7$; $p < 0.05$). Also, the higher the subject's score on the psychoneuroticism scale, the greater was his tendency to increase the number of his fixations ($T = 0.49$; $N = 7$; $p = 0.62$).

Extroversion, like field-dependency, was related to the fixation time's variability ($T = -0.55$; $N = 7$; $p < 0.05$) as well as to the rate of fixation upon the road's focus of expansion ($T = -0.65$; $N = 7$; $p < 0.05$). The greater the subjects score on the extroversion scale was, the smaller was the variability of his fixation times and the less frequently he directed his fixations at the focus of expansion.

Attention load: the number of the considered times was almost associated with the motorist's mean fixation time ($T = -0.51$; $N = 7$; $p = 0.053$). If a subject was able to deal

with more items, then he tended to make shorter fixation times. On the other hand, if the motorist failed to recognize critical items in the d2-Test, then he also tended to manifest longer fixation times ($T = 0.47$; $N = 7$; $p = 0.068$). Furthermore, with an increased number of the unrecognized items, the greater was the tendency to fixate upon targets in close distances ($T = -0.46$; $N = 7$; $p = 0.075$) and the greater was the horizontal variability of the fixation points' deviation from the road's focus of expansion ($T = -0.59$; $N = 7$; $p < 0.05$).

Spatial imaginary was associated with the horizontal variability of the fixation points from the road's focus of expansion ($T = 0.71$; $N = 7$; $p < 0.05$). A motorist who had a rather high score on spatial imaginary considered the sides of the road more intensively. He tended, however, to do that with a smaller number of fixations ($T = -0.48$; $N = 7$; $p = 0.62$) and, thereby, he also considered the near surroundings more frequently ($T = 0.52$; $N = 7$; $p < 0.05$).

Color naming, i.e., the motorist's spontaneity was slightly associated with his fixation times. A subject who had high scores on the Color naming Test tended to manifest short fixation times ($T = -0.42$; $N = 7$; $0.05 < p < 0.10$).

The Figure-Field-Test was designed to test the subject capability to reorient himself. It was found that subjects who needed a long time to complete this test, moved their eyes with smaller amplitudes ($T = -0.71$; $N = 7$; $p < 0.05$) and the eye's mean travel distance per second was also shorter ($T = -0.71$; $N = 7$; $p < 0.05$). Furthermore, the saccade amplitudes' variability and that of the fixation points' distribution around the road's vanishing point in a horizontal direction tended to be greater in those subjects who needed less time to complete the Figure-Field-Test in the two cases ($T = -0.43$; $N = 7$; $p = 0.089$).

The Stroop-Test was used to score the motorist's capability to deal with contradictory information, i.e., to extract the relevant information. A motorist who needed more time to complete this test, also tended to manifest longer fixation times ($T = 0.48$; $N = 7$; $p = 0.068$). Furthermore, he also used greater amplitudes ($T = 0.55$; $N = 7$; $p < 0.05$) and fixated his eyes, on the average, on closer distances ($T = -0.68$; $N = 7$; $p < 0.05$).

7. DISCUSSION

The results presented above pointed out that a driver's eye movement behavior depended on personal characteristics. In particular, personality and perceptual variables were associated with specific parameters of the visual search strategy. Furthermore, perceptual learning, as well as environmental conditions play an essential role in modifying the eye movement behavior of the motorist. It can be assumed that the development of an adequate visual search, i.e., which is adapted to the environmental conditions, might be either favored or impeded by long-term individual variables.

As the results demonstrate, the driver's long-term variables influenced his search strategy even after a long period of perceptual learning. Nevertheless, driving experience modified essentially the visual search strategy. Its influence was greater when driving was done under conditions of a great workload (i.e., around curves) and less so when driving along straight sections. This finding supports a previous hypothesis that the importance of driving experience for maintaining adequate flow of information input increases as the work-load increases (COHEN and HIRSIG, 1980). Presumably, with increased driving experience, the motorists learned to deal with more

information efficiently and to identify more easily the location of essential traffic-relevant targets. For example, the more experienced a driver was the more frequently he fixated the road's focus of expansion while traveling around curves. Meanwhile, he reduced the total search activity, as well as the rate of fixations upon targets in close distances. This finding indicates that the experienced driver, in contrast to the inexperienced motorist, increased his fixation distance in curves in order to increase his forward view time. This suggestion is also supported by the finding that an experienced driver fixated less frequently upon targets at close distances as compared to a less experienced driver.

On straight sections, on the other hand, the more experienced the driver was the more frequently he fixated upon targets at close distances. These comparisons suggest that the experienced driver was relatively more engaged with the input of control information than the inexperienced driver on straight sections of road. However, all drivers were approximately equally able to pick up guidance information. This difference suggests that the experienced driver picked as much control information as possible prior to any curve entrance. Presumably, he needed this information to store it. Then, when he entered the curve, he was better able than the less experienced motorist to direct his attention toward the subtask guidance. This comparison sug-

gests that the more experienced the driver was, the better he could anticipate the future requirement of environmental information. On the other hand, the less experienced driver's eye movement was only moderately influenced by the environmental conditions.

This suggestion is further supported by the analysis of the visual search activity as measured by the saccade amplitudes or by the eye's mean travel distance. Increased perceptual learning is associated with smaller amplitudes while driving around curves. Nevertheless, the more experienced a driver was the more he increased his total visual search activity, as indicated by the eye's travel distance per second. That is, the more experienced driver scanned the environment more intensively when the information load increased. On the other hand, when driving along straight sections, i.e., under condition of moderate work-load, driving experience influenced neither the saccade amplitude nor the eye's total travel distance per second. These considerations also suggest that the role of perceptual learning is of importance under complicated traffic conditions.

The driver's age has a similar influence on the visual search strategy as the motorist's driving experience. However,

with increased age the subjects also had driven a car for longer time ($T = 0.55$; $N = 7$; $p < 0.05$). Therefore, it cannot be decided at this point whether the more adequate visual search strategy of the older motorists results solely from driving experience or whether it results from other kind of perceptual learning.

The driver's personality and perceptual variables were related to selected parameters of his eye movement behavior. Field-dependency influenced the motorist's visual search strategy less than would be expected on the basis of the SHINAR et al (1978) study. In accordance with SHINAR et al, a significant relationship was found between field-dependency (scored in absolute values) and the variability of fixation times. The more field-dependent the driver was the smaller was the variability of his fixation times. This finding suggests that the fixation times of the field-dependent person were only slightly influenced by the target being fixated, in contrast to the field-independent motorist. Furthermore, the field-dependent driver, as expected, tended to fixate for a longer time on the average and tended to fixate the road's focus of expansion less frequently as compared to the field-independent driver. This finding, which is based on a non-significant tendency (i.e., $0.05 < p < 0.10$), should only be treated tentative evidence. However, it suggests that the

field-dependent driver did not do the maximum use of the environmental information available concerning his future route as soon as possible.

The increased difficulty of the field-dependent driver to extract the relevant information, as indicated by his tendency to prolong the fixation times, is in accordance with further perceptual variables. Even though that the variables attention-load, spontaneity and the capability to deal with contradictory information, i.e., the Stroop-Test, did not reach a level of statistical significance, they nevertheless, indicate the same relationship. The greater the number of items was which the subject correctly cancelled (in the d2-Test) or the fewer the errors he made or the faster he performed in the Stroop-Test, the more likely was his tendency to decrease his fixation times. Insofar these tests measure the capability to deal accurately with a great amount of information, it is reasonable to assume that the shorter fixation time (on average) can be attributed to the individual's greater capability to extract the relevant information.

Psychoneuroticism influenced the eye movement behavior with regard to the lateral distribution of the fixation points, as well as the variability of the fixation distances. The higher a motorist scored on the psychoneuroticism scale the more

frequently, even though the average fixation distance was not related to psychoneuroticism. Also, the higher a motorist's psychoneuroticism score was the greater was his tendency to increase the number of his fixations while completing the experimental runs. As the subjects did not significantly differ in their fixation times, the tendency to increase the number of the fixations means that the higher a subjects score on the psychoneuroticism scale the slower he drove his car. The obtained relationships suggest that the higher a motorist's score on the psychoneuroticism was the more time and attention he paid to acquiring the information concerning his path of driving while neglecting to scan available or potential information from the road's left side (i.e., opposite path). This increased search within a reduced spatial area might reflect anxiety about overlooking essential targets. The "price" which a psychoneurotic driver might pay for this strategy, is the reduced input of information related to possible oncoming traffic. This tentative hypothesis should, however, be treated carefully and it requires further experimental support.

Extroversion influenced the visual search strategy in regard to the variability of fixation times and the rate of fixations on the road's focus of expansion. With an increased

score on the extraversion scale, the variability of the fixation time decreased. In this respect, the role of extraversion is similar to that of field-dependency. However, extraversion correlated significantly with field-dependency ($T = 0.75$; $N = 7$; $p < 0.01$). Therefore, it is not particularly meaningful to further discuss the isolated role of extraversion on the eye movement behavior.

The role of attention load on the fixation time was mentioned above. The subject's capability to recognize all critical items in the d2-Test inversely related to the horizontal deviation of the fixation points from the road's focus of expansion and more tenuously was related to the rate of fixations in near distance. In other words, it can be stated that the motorists who overlooked a small number of items on this test did not scan the road (in horizontal direction) in a uniform manner and also overemphasized their attention on near surroundings. As these results corresponded with that observed on the motorist's spatial imagery it might be assumed that greater attentional performance associated with good spatial imagery helps the driver pick up the relevant information in a selective manner. These results are supported by the results on the Figure-Field-Test. A subject who completed this test quickly manifested an increased visual search activity when

driving. This was seen in both the greater magnitude of his saccades, as well as by the eye's total travel distance per second.

In summary, it can be stated that driving experience plays a major role in modifying the driver's search strategy. It is most clearly manifested under conditions of great work-load and less so when the work-load is minimal. At the same time, the driver's personality and perceptual variables also influence specific parameters of the visual search strategy, but in a less consistent manner. Their role, however, might be greater in young novice drivers. This topic, however, must remain an important issue for further consideration and attempts to integrate the drivers task specific and task non-specific capabilities within a coherent theoretical framework. The results reported above clearly indicate that the inter-individual variability of eye movement behavior results in relationship to the motorist's personality and perceptual variables, as well as a function of perceptual learning.

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