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TECHNICAL REPORT

FUNDAMENTALS OF THE VISUAL TASK
OF NIGHT DRIVING

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FOREWORD

The following members of TC 4-09, Fundamentals of the Visual Task of Night Driving, took part in the preparation of this Technical Report. The Committee comes under CIE Division 4, Lighting and Signalling for Transport.

W. Adrian	Canada
H. R. Blackwell	United States
T. L. Flodina	USSR
G. Helmers (until 1991)	Sweden
M. Keck	United States
P. Padmos	The Netherlands
D. A. Schreuder	The Netherlands
R. N. Schwab (Chairman)	United States
B. W. Tansley	Canada
H. L. Woltman	United States
Y. Yoshimura	Japan

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FUNDAMENTALS OF THE VISUAL TASK OF NIGHT DRIVING

SUMMARY

This report presents the principal fundamental information known about the visual task of driving at night and provides insights as to how these principals may be used to make roadways safer and improve traffic flow at night. The first chapter describes the visual task of driving and establishes the elements in the perceptual process. It then discusses how night driving differs from daylight operations. Chapter two identifies and critically evaluates how the night driver acquires information from the roadway scene and discusses what are the important cues needed for vehicular operation. The third chapter discusses the required sight distances for carrying out the three major subtasks in driving. Chapter four discusses visibility models and their potential uses. The final chapter suggests methods for improving road design for nighttime conditions. Design elements discussed include public and vehicular lighting, the use of retroreflective materials and the use of self-luminous signals.

DONNEES DE BASE DE LA TACHE VISUELLE DANS LA CONDUITE DE NUIT

RÉSUMÉ

Ce rapport présente les principales données de base concernant la tâche visuelle dans la conduite de nuit; il fournit aussi un aperçu des applications possibles de ces données pour rendre la route plus sûre et améliorer la circulation de nuit. Le premier chapitre décrit la tâche visuelle de conduite et les éléments du processus de perception. Il analyse ensuite les différences entre conduite de jour et conduite de nuit. Le chapitre 2 identifie et évalue de façon critique comment l'usager, de nuit, prélève l'information dans la scène routière et quels sont les objets importants, nécessaires pour la conduite du véhicule. Le troisième chapitre analyse les distances de visibilité nécessaires pour mener à bien les trois principales sous-tâches de la conduite. Le dernier chapitre propose des méthodes pour améliorer la route et ses équipements pour la circulation de nuit. Les éléments étudiés concernent l'éclairage, tant l'éclairage public que celui des véhicules, ainsi que l'emploi des matériaux rétro réfléchissants et des signaux lumineux.

GRUNDLAGEN DER SEHAUFGABE BEI NACHTFAHRTEN

ZUSAMMENFASSUNG

Dieser Bericht stellt die Grundlagen und Prinzipien dar, die uns über die Sehaufgabe bei Nachtfahrten bekannt sind. Er gibt Aufschluß, wie diese Prinzipien anzuwenden sind, um die Straßen sicherer zu machen und um den Verkehrsfluß bei Nacht zu verbessern. Das erste Kapitel beschreibt die Sehaufgabe beim Fahren und erläutert die wesentlichen Einzelheiten des Wahrnehmungsprozesses. Es wird dann untersucht, worin sich Fahrten bei Nacht von solchen bei Tage unterscheiden. Im zweiten Kapitel wird kritisch untersucht, wie der Fahrer bei Nacht die Information über das Straßenbild erfaßt und was die wichtigsten Punkte für das praktische Fahren sind. Das dritte Kapitel untersucht die Sehweiten, die erforderlich sind, um die wichtigsten drei Unteraufgaben beim Fahren ausführen zu können. Das vierte Kapitel untersucht die Sehmodelle und ihre Anwendungsmöglichkeiten. Das letzte Kapitel regt Methoden zur Verbesserung des Straßenbildes für Nachtzeitbedingungen an. Die Hinweise umfassen sowohl die Beleuchtung durch ortsfeste Anlagen als auch durch Fahrzeuge, sowie die Anwendung retroreflektierender Materialien und selbstleuchtender Zeichen.

1. Analysis of the Night Driving Task

"In areas where the primary function of the lighting installation is to provide illumination for the quick, accurate performance of visual tasks, the task itself is the starting point in the lighting design."

- IESNA Lighting Handbook, 1972, p. 10-10

1.1 Introduction

Driving involves the complex interaction of perceptual, cognitive and psychomotor processes and is affected by and dependent upon our capacities for learning, remembering, decision-making and selectively attending. The role of visual perception in driving must be considered in the context of these interrelated processes.

We obtain information from the environment pertinent to driving through all of our senses: with our visual sense by looking at the roadway environment, other vehicles, and our vehicle's instrumentation; with our auditory sense by listening to sounds generated from within the vehicle and from the environment outside; and with our proprioceptive senses by feeling the changes in forces acting upon our body in motion, obtained from kinesthetic and vestibular mechanisms.

Nevertheless, visual feedback is the most important source of control information for human locomotion. The visual sense is the source of the most important information required in the performance of the driving task. The basic visual task of locomotion is to obtain sufficient information to navigate through the environment. During the act of driving the driver has to dynamically control the velocity, acceleration and direction of vehicular movement by observing the roadway, the boundaries marked on it, other vehicles upon it and the environment nearby and by adhering to both general and specific traffic rules recalled from memory. The dynamic aspect of control of a moving vehicle involves the visual perception of the driver's own movement relative to the roadway and its surroundings plus that of other road users relative to his/her vehicle. In addition, the driver must "think and look ahead" in order to better prepare for the various eventualities associated with changes in the roadway alignment and oncoming traffic. This requires bidirectional mental adjustment in space and time and the mental processes necessary to achieve this must be carried out while the immediate control processes of driving operate in "real time." The driver must not only adjust lane position in accordance with the vehicle directly ahead but must also anticipate the position of the pedestrian a half block away approaching the crosswalk that is coming up. In spite of the complexity of the driving task, viewed in this way, millions of individuals perform it safely every day, and with very little thought of the complexity of the information processing involved.

Human vision evolved to provide information for control of the moving human body, which is capable of speeds no greater than about 15 km/h (except for the well trained runner and then, only for exceptional circumstances and/or reasonably brief periods of time). During driving, however, it is used to provide feedback for control of a vehicle capable of speeds ten times greater, often sustained for hours at a time. Because human control responses take time to organize and execute, these greater speeds require that adaptive motor responses be made at distances much greater than are needed when walking. From perception vision is able to provide information about distant objects and events. Consequently, there is a relative greater dependence upon visual information than on information from the other senses during driving.

Locomotor and visual functions evolved together and are, consequently, matched to one another with respect to their operational characteristics. We experience a sense of motion at very low speeds through a more or less constant, stable and complete environment in spite of the fact that the light level maybe very low and the sensory information obtained from the environment variable, unstable and incomplete. Our perception of the external world is unified: we hear things from the same location that we see them; we touch objects in the same location that we hear and see them, etc., and we sense that our own movements are relative to those of other objects within the environment. This is why one can find ones way about a darkened bedroom at night without running into objects.

In a sense, driving is not a "natural" human behaviour because of the speed involved. It is one for which we are ill-equipped in terms of perceptual-motor skills. The visually-mediated control of a vehicle is both qualitatively and quantitatively different from walking, and driving at night is a very different visual-motor task from walking by either day or night. Walking in the dark, the natural environment at night without lighting is considerably slower paced than its daylight counterpart because visual functions do not provide sufficient information for rapid, adaptive locomotor control.

Descriptions of human visual performance must vary with both the lighting level and the visual task being considered. When considered simply as a light detector, the human visual system has an enormous dynamic range - about 12 orders of magnitude. However, the dynamic range of the visual system over which more specific visual abilities are possible, such as the perception of fine detail, is considerably smaller.

The human visual system's wide dynamic range depends in large part upon the duplex nature of the photosensitive retina of the eye. The duplex retina consists of two functionally distinct, though not anatomically separate, retinæ - one subserving vision during extremely low light levels, seldom found during night driving, and one mediating vision under higher light levels conditions. A number of differences between these two interwoven retinæ reflect the nature of their contributions to visual function.

In low light levels condition ($< 1 \text{ cd/m}^2$) the retina becomes increasingly specialized for the detection of weak light signals. The scotopic, or low light level, retina receives inputs from photoreceptors called rods. The responses from a number of rods are summed by second-order neurons before transmission to higher visual centres. Because the responses of many rods are summed or pooled, the increased detection sensitivity offered by scotopic vision comes at the expense of poorer visual acuity. At light levels above approximately 3 cd/m^2 , vision is essentially or exclusively mediated by the photopic retina's photoreceptors, called cones. Cones are less efficient at detection of weak light images, having a dynamic range covering retinal illumination above those encountered at scotopic levels. Most night driving (between 0.01 to 2.0 cd/m^2) is done at the transition region between these two retinal systems where the systems overlap. This region is known as the mesopic region.

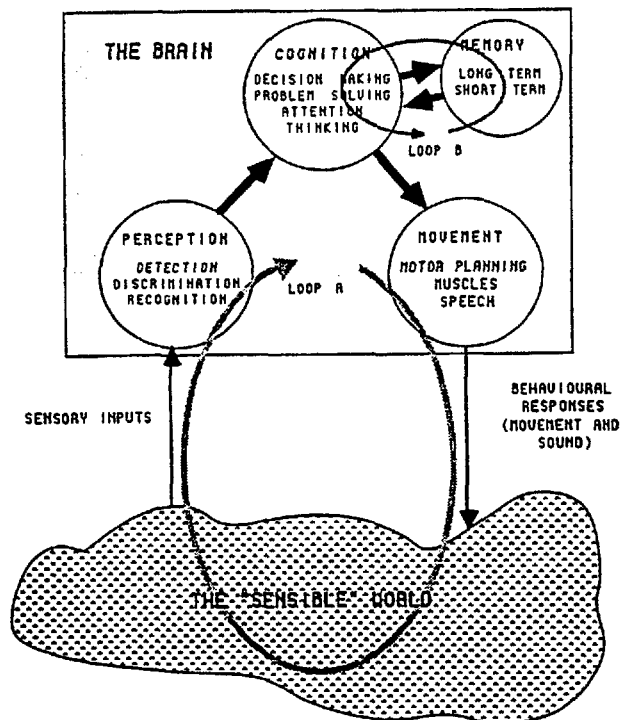
The photopic retina is adapted for the task of providing information regarding finer spatial detail. In the central fovea, where visual acuity is best, one-to-one connection of cones to higher-order retinal neurons is typical. There are virtually no rods in the central fovea and, as a consequence, one can not see small objects in the centre of the visual field whose absolute luminance level is below the threshold of cone vision.

For night driving, most objects seen in the headlamp beam; such as, retroreflective signs and markings, and objects in areas with adequate public lighting, are above the cone threshold. However, for non-retroreflective objects beyond the reach of the headlamps, the retinal illuminance of an object subtending less than about 2 degrees of visual angle is low, and the object cannot be seen by looking directly at it. It will only become visible when its luminance is increased by coming into the path of one's own headlights or those of another vehicle.

In any single glance, it is not possible to "see" clearly all of the visual field. Yet, except in a few special instances, our visual experience is not one of a world that degrades with respect to visual quality as the angle from the point of fixation increases. In most circumstances we perceive the visual scene as one that is homogeneous in its detail. Our everyday visual experience is a synthesis of many single glances about our environment. Because of the capacity for visual memory, these glances need not be successive. Indeed, these glances could be weeks, or possibly years apart. The individual visual samples, each incomplete in its detail, serve as interacting parts to the "whole" that is perceived. Visual experience might properly be regarded as an "end product" of a number of brain functions - only part of which is derived directly from the visual system itself. Thus, visual perception and visual information processing are but one aspect of the complex set of information processing tasks required in driving. As such, visual perception represents only a portion of the total information processing load placed upon a driver. It is best considered in the context of a more comprehensive model of human performance. Such a model should incorporate other sensory processes as well as learning, memory, attention, arousal, and motor control processes.

Figure 1.1 shows a cyclical information processing model of human performance. A neural model of the environment represented within the central nervous system contains all of the information from which behaviours are initiated. This includes all those processes that mediate skilled motor acts, such as driving. The fidelity of the model, or the degree to which it

accurately reflects the status of the real world, has important survival implications for the individual. The neural model also includes information used to control the individual's sensorimotor interactions with the environment. During any sensorimotor act, such as the act of driving, where interactions used in controlling a motor vehicle must be continuously performed, information must continuously cycle through the model. Cycling of information results in a change in the neural model; the basis of learning.



What's 'inside' and what's 'outside' the CNS

Figure 1.1: Schematic model of human information processing.

many cycles and, judging from the amount of time required to learn certain motor skills, exceedingly large numbers of cycles may be involved in learning complex psychomotor tasks such as driving.

This model has some important implications for the learning and performance of skilled behaviours. Every cycle through the model may be thought of as a limited form of "practice." Another important implication of the model is that information is processed at least partially in a serial fashion; each of the model's subcomponents passing its output to another component within each cycle. Thus, as each processing element takes a finite amount of time to determine its output, there will be a minimum amount of time necessary for the execution of any motor control action.

Learning to drive may be a progressive refinement in the number of behavioural alternatives from which to choose. In this context, good roadway design is evident where the most obvious choice among a driver's response choices at any given instant results in the greatest safety on that section of roadway. Designs that acknowledge the drivers' expectancy and limitations on human visual performance offer the greatest promise of improved roadway safety.

An important aspect of this model is that it is automatic. Performance of any motor act will be treated in the same way, regardless of intent. Thus, as long as sensorimotor interactions occur, learning will occur. Every cycle through the model may be thought of as practice; not only those produced by individuals intentionally trying to refine their performance.

Motor responses, because they involve the use of muscles that, themselves, act upon the external world, become part of the "sensible environment" - rendering them as information that can be fed back to the brain. In this way skills develop by successively detecting and reducing the errors introduced by the motor control mechanisms.

Starting from the cognitive process, the model requires that the performance of even the simplest voluntary motor act requires at least one complete information processing cycle through the model. It is likely that any learning of a voluntary motor act requires

1.2 Scope of Report

The objective of this report is to review the fundamental principles of the visual task of night driving and to show how these principles can be applied to improve road design for nighttime operations. In the following section of this chapter we will consider the perceptual processes involved in the three major visual subtasks of driving and implications for the visual task of night driving in particular. The next chapter identifies various sources of visual information and critically evaluates the importance of each as they are involved in nighttime vehicular operation. The third chapter will discuss the required seeing distance for carrying out the subtasks of driving at night while the fourth chapter discusses the problem of predicting visibility for use in roadway design work. The final chapter suggests methods for improving road design for nighttime operations. Design elements included are vehicular and public lighting systems, delineation, signing, and signalling.

1.3 Driving as a Complex of Behavioural Subtasks

The overall driving task may be regarded as consisting of three behavioural subtasks, each with its own set of visual information processing requirements. These three subtasks are concerned with the positional, situational and navigational aspects of driving. Table 1.1 shows the types of control functions associated with each of the three subtasks. In the search to identify relevant stimuli in driving, all visual performance requirements within each subtask must be considered.

TABLE 1.1. Levels of driver performance and related control functions

Performance Level		
Positional	Situational	Navigational
A) maintenance of lateral position	C) avoidance of objects/hazards	G) route selection
B) maintenance of correct heading with respect to the roadway immediately ahead	D) execution of guidance manoeuvres/course changes	H) route following
	E) gap maintenance	
	F) maintenance and adjustments to vehicle speed	

1.3.1 Positional Information Requirements

There are essentially two major positional subtasks - maintaining the desired lateral position and correct heading with respect to the road surface ahead. Speed maintenance is also sometimes considered to be a positional subtask; however, the relative position of other vehicles on or near the travel lane are also of prime input to speed control. Therefore, speed control will be considered at the situational level.

Most positional information is obtained from the detection and recognition of the visual changes in features of the roadway, such as lane lines, curbs, shoulders, edgelines, etc., that occur during vehicle motion [1.1]. In good driving conditions the driver usually obtains much of this information through peripheral vision. A variety of visual information is obtained from the periphery of the visual field, including stimulus parameters that provide information regarding relative movement of the environment and objects within it. This ability to perceive relative motion is also important for lane position maintenance.

The same information sources are used by the driver to control speed. Of particular importance are the dashed lane and centreline markings and other sources of information that flow by the driver at a regular rate.

During night driving insufficient illumination limits the use of peripheral vision to obtain positional information beyond the area illuminated by the headlamps so that foveal vision must be used to a larger extent. Because of the limited extent of the foveal visual field, night driving must necessarily involve a greater number of foveal fixations. This is supported by the work of Rockwell, Ernst and Rulon [1.2] who found that, under nighttime conditions, drivers visual fixations tended more towards the right hand side of the roadway in the region less than 25 metres in front of the vehicle.*

1.3.2 Situational Information Requirements

The situational subtask requires information sources that indicate a need to change speed, direction of travel or lateral position on the roadway due to changes in the geometric, traffic, and/or environmental situation. Visual information needed at this level concerns the relative position and relative velocity associated with the driver's and other vehicles, traffic control devices, pedestrians, hazards, and changes in roadway alignment, etc. Modifiers to vehicle response characteristics, such as the effect of wet pavements on the braking response time, must be accounted for at this level and are dependent both upon visual and sensorimotor inputs.

The types of visual tasks performance required at the situational level are dependent on the driver's perception of the current situation; his/her anticipation or prediction of what is likely to occur in the near future; and the ability to make an appropriate response. Typical driving subtasks at this level are related to hazard avoidance, changes in velocity or lateral position due to traffic control devices, changing roadway geometry, vehicle following, overtaking and passing, and yielding to other road users, especially at intersections. The driver must recognize the distinctive features of the visual scene, based largely on prior experience and knowledge, and be able to draw on that knowledge to determine what control actions are necessary.

At the situational level (and, to a certain extent, at the navigational level) rapid comprehension of visual information is an important factor. Driving behaviour is thought to depend upon a number of decision making processes and visual input may be viewed as contributing information to those processes. If the driver is unable to associate meaning with a specific stimulus, that stimulus is of no assistance in the generation of an adaptive driving response. Indeed, such a stimulus may be harmful in a given situation as it might distract the driver from the processing of other, more useful information. For example, a driver may see an object as a warning sign with a symbol on it, but if he/she does not understand the meaning of the symbol no communication has occurred; yet, the process took up information processing effort and attention. Even though visual information was available, the warning message was not successfully transmitted and the driver may have been temporarily distracted during a critical moment of driving. Of course, the visual input must be there or no process is started at all.

* This is in contrast to daytime conditions, where the driver's eye fixations tend to be located at the apex of the driving scene (central and greater than 80 metres from the vehicle).

1.3.3 Navigational Information Requirements

The navigational subtask takes into account more general trip planning information processing requirements. It includes a trip planning component and a route following component. Generally the trip planning portion occurs prior to starting the actual driving and is beyond the scope of this report. However, if the pretrip planning is adequate, it should provide the driver with some basis to anticipate when and where he/she is likely to need and find information on which to base the course changes.

The information used to accomplish this subtask is usually of two forms: direct and indirect. Direct information is information obtained from the road environment. Examples of direct information sources include guide signing systems such as street, place name or roadway route number signs. Indirect information is obtained from attending information sources extrinsic to the roadway environment and provides the driver with information regarding what to attend to in the roadway environment. Indirect information sources include maps, written lists of instructions, and verbal communications. The major difference between direct and indirect information relates to the amount of time available for adaptive responses. The direct information sources typically should be placed at or near the point of decision and motor response, whereas indirect information sources typically provide the driver with a perceptual set of information that prepares the driver for when and where direct information will be found on the roadway.

1.4 Types of Visual Stimuli in the Driving Environment

The successful performance of visual tasks associated with each performance level, discussed above, requires visual scanning of the environment. While good roadway designers make ample provision for conspicuous visual stimuli to inform the driver of roadway changes, there are many other visual cues, outside the control of the highway designer, that also provide information regarding changes in the roadway that are of importance to the driver. Pertinent visual stimuli for the driving task can be classified into four categories:

a Permanent elements of the roadway as built

Elements of the roadway that are more or less permanent, such as roadway geometry, road surface treatment, shoulders, curbs, road markings, curvature, signing, traffic signals, and permanent hazard markings including barricades.

b Temporary elements of (or on) the roadway

Elements of the roadway that are not permanent, such as other motor vehicles, cyclists and pedestrians; construction or maintenance signing, markings, or signals; stationary or uncontrolled moving objects on the road surface such as animals, mufflers, stones, or boxes; and hazards in the road surface such as potholes.

c Permanent elements of the surrounding environment

Buildings, advertising signs, bushes, trees, hills, horizons, and utility structures, etc., are not a part of the roadway, but a permanent part of the visual environment surrounding it. Included in this category are the various weather conditions that are more or less predictable from knowledge of the climate of the locale. Also included in this category are the permanent visual characteristics of the motor vehicle windscreen and interior.

d Temporary elements in the surrounding environment

Visual stimuli within the driver's field of vision that bear no systematic relationship to the roadway, including accidental or unpredictable events, objects, weather, and/or people. Included in this category are various unpredictable weather conditions and temporary changes that may occur to the visibility from within the vehicle such as a dirty windscreen.

This classification gives insight into the types of visual tasks needed during driving and the implications for driving performance under conditions where the availability of the various types of visual information is reduced, distorted or eliminated.

1.5 The Visual Tasks of Driving

As summarized below in Table 1.2, visual performance in the driving task may be compartmentalized into three "direct" and two "indirect" general information processing functions: visual attention, visual detection, visual stimulus recognition, decision making based upon visual information and visually guided response execution. In this section we consider some of the functional subcomponents of the visual system that are necessary for the optimum performance of each of these functions. The reader is encouraged to refer to several excellent reviews for further details [1.3 - 1.8].

1.5.1 Visual Attention

Driving is often thought of as an overlearned skill to which drivers in normal situations are generally able to devote considerably less than their "complete" attention. However, the skill of driving requires the new, inexperienced driver to coordinate the execution of a number of behaviours which they often find difficult to manage. Aside from the motor coordination requirements, there are also visual information processing tasks necessary to successfully operate a vehicle. Visual information must be periodically obtained from the environment and evaluated to determine its relevance to the immediate task being performed.

Drivers need to pay attention to incoming information which provides for the improvement in their perception of the state of the environment through which they are navigating. However, the inexperienced driver is less capable of rapidly deciding the relative importance of incoming stimuli.

TABLE 1.2. The visual subtasks of driving

DIRECT FUNCTIONS: (directly related to visual perception)		
1. VISUAL ATTENTION affected by perceptual set, degraded by increasing task load and mental status	2. VISUAL DETECTION dependent upon conspicuity, degraded by environmental conditions and mental status	3. VISUAL RECOGNITION dependent upon visual information content, degraded by environment and driver's mental status
INDIRECT FUNCTIONS: (dependent upon visual information)		
4. DECISION MAKING affected by total task load; a function of speed, traffic congestion and mental status	5. VISUALLY GUIDED RESPONSES affected by total task load, speed and by mental status; possible responses limited by previous responses and by the future consequences	

This places a greater information processing burden upon him/her as attentional mechanisms cannot assist in reducing the information processing load by filtering out irrelevant information. In addition, visual perception changes under increased task loads. It has been found that the effective visual field over which the observer can attend to incoming information becomes more heavily weighted to the fovea [1.9, 1.10].

Attention is the capacity to selectively "tune in" to certain stimuli and to "filter out" certain others and to be able to voluntarily switch the attended stimulus. As humans have both limited attention and limited visual information processing capacity, a driver is incapable of continuously attending to all potentially relevant features in the visual scene. The way in which this limit is overcome is by regular sampling from the wide variety of locations where potentially relevant visual stimuli might occur, by storing these visual samples in memory and by periodically "upgrading" them.

There are several types of information that have to be attended to - the most important of which is that which is unexpected. Of all of the information available to attend to, we somehow choose to attend to specific information and to selectively ignore the rest. How this is accomplished and what happens to this capacity when we become fatigued is of interest and concern to those studying the performance of skilled behaviours such as driving. We consider, below, the role that higher attentional mechanisms may play in providing information to cognitive processes which presumably mediate the performance of these skilled acts.

"Visual attention" has three basic functions: the directing of peripheral visual mechanisms based upon previous information input, the modulation of central attentive variables associated with the processing of information from a number of sensory modalities, and the encoding and storage of information obtained through the visual channel.

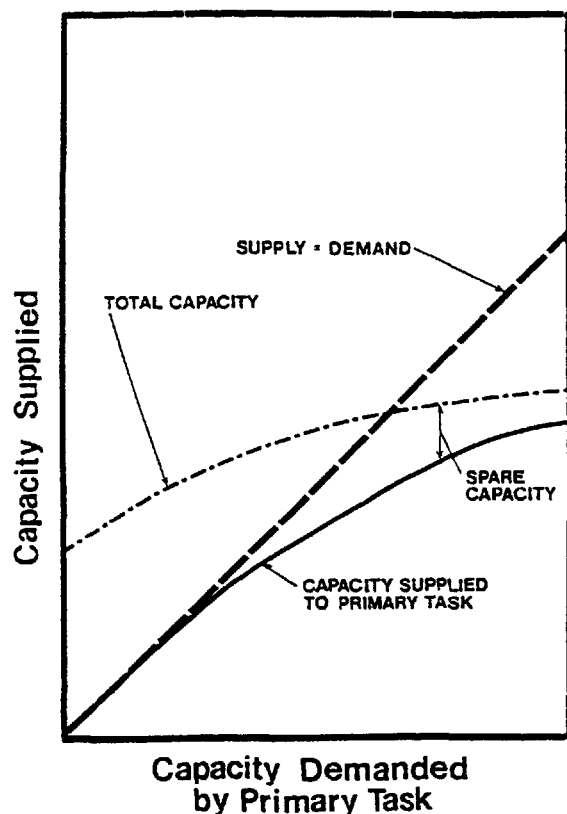


Figure 1.2: Supply of effort as a negatively accelerating function of demand.

Kahneman [1.11] presented a limited-capacity model of attention based upon the notion that the supply of effort in central information processing mechanisms is a negatively accelerating function of demand. Figure 1.2 (adapted from Kahneman [1.11]) shows the relation between supply of effort and demand of effort as a function of the capacity demanded by a given task. If the requirements for the given task on attentional processes are minimal relative to the total capacity of the system, a considerable amount of space or reserve capacity remains that enables the subject to perform other tasks more or less simultaneously. However, as the capacity demanded by the first task increases, the relative proportion of reserve capacity decreases.

Kahneman argues that the quantity of capacity or attention available at any given moment is a non-monotonic function of the arousal level of the individual; a concept known as the Yerkes-Dodson law [1.12]. The Yerkes-Dodson law is schematized in Figure 1.3, where the relation between arousal level and quality of performance is indicated for two levels of task complexity. This figure suggests that there is an optimum level of arousal for each task under consideration and that modulation above or below the optimum level of arousal for a specific task will result in a decrement in the performance of that task.

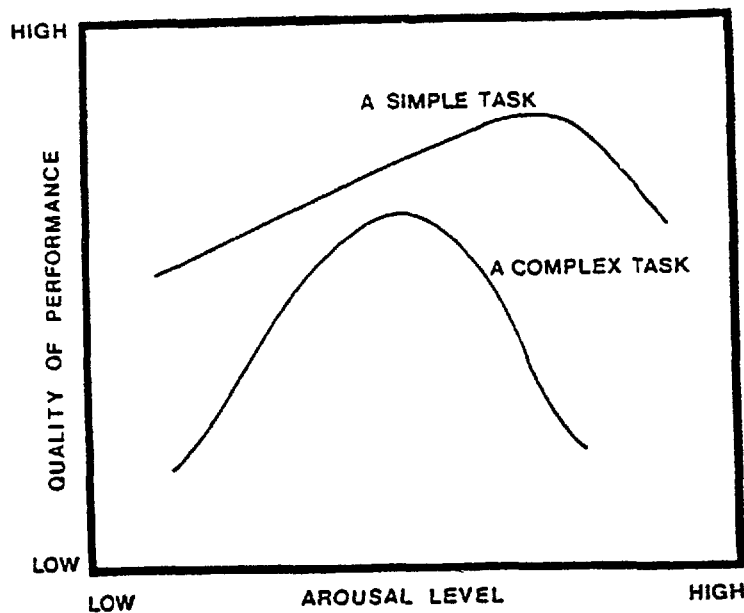


Figure 1.3: Schematic of the Yerkes-Dodson Law.

This model suggests that, in the early phases of information processing, part of the total system capacity is automatically marshalled toward the acquisition of information from the environment while in later stages more of the capacity is allocated through voluntary control. This model has important implications for driving performance in that it offers insight into the role of learning and experience in modulating visual attention. Attention mechanisms can be thought of as representing an intermediate step between the initial encoding processes of the sensory mechanisms and cognitive processes associated with perception, learning and memory; a means of automatically allocating limited information processing resources where most needed - to incoming stimuli carrying high information content. Learning is a means of reducing the information processing requirements necessary to evaluate incoming sensory input.

As the efficiency of information processing increases (i.e., as more and more environmental events can be predicted from less and less incoming information) the probability of adaptive behaviour in any given situation increases and the allocation of limited visual information processing capacity may be made to other information sources.

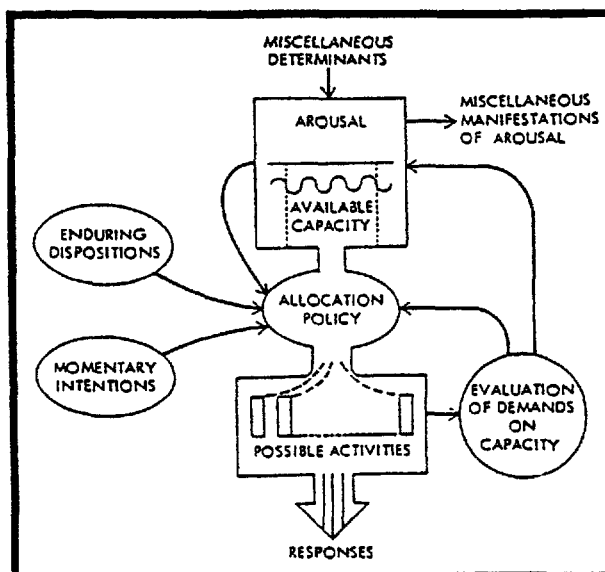


Figure 1.4: The Kahneman limited information processing capacity model.

The limited-capacity model of Kahneman is shown in Figure 1.4. He argues that, at any given moment in time, the organism is involved in the completion of a number of tasks and that the proportion of total capacity or attention that is devoted to each of these tasks is allocated by a number of factors including momentary intentions of the subject, arousal level and an ongoing evaluation of the demands of performance of the various tasks upon the available capacity. The so-called allocation policy is modified by various inputs depending upon the nature of the inputs and their relation to ongoing activities of the organism.

The time required to accumulate sufficient information to make the necessary decision is dependent upon the nature of the decision. Based upon the immediacy of the behavioural response required, the highest priority would be given to the positional tasks, followed by situational tasks and finally the navigational requirements. Information sources for each task are sampled periodically rather than continuously to see if the threshold for decision and reaction has been reached. Therefore, driving may be thought of as including a supervisory process which evaluates the needs for information based upon the hierarchy. Once information needs at the positional level are temporarily met, the information for situational needs are attended to, with navigational tasks having the lowest priority. If the needs of the lower levels are too demanding the navigational task is omitted. For example, in heavy fog drivers will concentrate almost exclusively on tracking the lane lines to keep their vehicles on the road. It is not uncommon in such situations for a driver to fail to detect the destination guide sign and to continue driving past the desired turn.

As a general rule, the optimum level of arousal for complex tasks is higher than that for simple ones. This notion was accommodated into the Yerkes-Dodson relation by Easterbrook [1.9] who proposed that an increase in the arousal level results in a restriction in the domain of inputs that the central nervous system will utilize for determination of further behaviour.

A driver's motivation may also influence whether a stimulus will be seen. For example, in attending to the navigational task, the driver is actively searching for relevant information required for successfully reaching his/her destination. This involves the driver's expectation for where and when such information might appear. Expectations about the targets' appearance are defined in terms of detectable stimulus physical parameters; such as size, shape and colour. When the driver is searching for a particular highway designation sign, the perceptual set is to detect a sign within a certain size range, rectangular in shape, of a specific colour (perhaps, green for the route in question), of specific message length, and mounted in specific locations relative to the roadway. There is an increase in the attentional value for all stimuli that conform with these specifications. The driver attends to those stimuli that meet his/her expectations and to ignore those that do not conform. Therefore, to reveal an unexpected hazard requires that the perceptual set of the driver be changed.

1.5.2 Visual Detection

The driver's visual experience of the roadway environment is characterized by a perceptual continuum from sensory detection that something is there to recognition of specific objects. While the detection process is characterized by progressive differentiation of the visual field, the precise nature of the dynamic process is unknown. The detection threshold of a target or object is generally taken as the minimum luminance contrast of the target against its surround necessary for the driver to become aware that something is present in the visual field. For small objects at a distance, the detection threshold is usually at a lower contrast than is required to correctly recognize it. Part way between these two extremes are found successive levels of identification/recognition, where various perceptual qualities about the object become apparent, such as its specific location in space, its general shape and colour, etc. While attention is important at all levels in the detection/recognition continuum, it is toward the recognition end that selective attention factors play their most important role.

The likelihood of detection of a foveal stimulus is dependent on four factors:

- 1) the luminance of the object,
- 2) the object's luminance contrast with its immediate surround,
- 3) the object's size, colour and shape, and
- 4) the viewing or observation time.

Each of these factors can be varied so as to reduce the visibility of an object to a threshold level on the detection/recognition continuum - a level that is measured with reference to the physical parameters of the test stimulus used. As indicated above, most studies in the transportation field have generally utilized the contrast variable because of the relative ease of its manipulation. (See Chapter 4 for a discussion of detection threshold models and where they may be useful in the design of transportation facilities.)

Most sensory detection studies have been done in situations where the surroundings of the target were relatively uniform. The conspicuity of a stimulus relates to the ease with which the presence of a visual stimulus is capable of attracting the observer's attention when that background is non-uniform. A conspicuous stimulus is one that by definition stands out from

its visual surroundings and, therefore, has a high probability of being detected. The conspicuity of an object is dependent on physical parameters associated with both the stimulus and its surround. The conspicuity of a stimulus is a function of the same physical stimulus values that influence the detectability of a target in uniform space, including its luminance, luminance contrast, colour, shape, size, and time for viewing. In addition, the number, size, similarity, proximity and spatiotemporal characteristics of other nearby visual elements in the surround are important.

The location of a stimulus within the driving environment will also influence its probability of detection (i.e. how conspicuous it is). In general, a target is more detectable the closer it is to the visual axis and the closer its actual location is to its expected location; however, there are important situations where this is not true. Night driving is one such situation, wherein the dim objects, beyond the headlighted area, may be more readily detected in the peripheral retina. However, in this case, visual recognition would still require the viewer to look at the object to extract enough detail for recognition.

When driving in busy urban environments, it is advantageous to be able to filter out large amounts of irrelevant visual information. The schematic model shown in Figure 1.1 illustrates the way in which it is believed that this is done. The extraction of pertinent features about the visual scene is likely to be carried out at a number of different levels in the visual pathway, with the visual detection process providing information to more cognitive mechanisms, which include those concerned with pattern recognition. It is at the cognitive level that attention value of a stimulus serves to highlight information of relevance to the driving task and to actively suppress information about irrelevant objects.

The extent to which a given stimulus is attended, once it has been detected, is partially related to the information content of the stimulus. As content in a stimulus increases, so does the probability of the driver's attending to it. However, this relationship only holds over a limited range. Extremely improbable or unfamiliar stimuli, which carry more information than more probable ones, are often of little use to drivers unless they are detected sufficiently far away in both space and time from where the adaptive responses will be required. The ability to "make sense" out of an incoming visual stimulus is partially a function of the observer's familiarity (i.e. prior experience) with it. When the observer is capable of remembering relevant previous experiences and associating them with incoming sensory inputs, it is possible to make comparisons between the incoming information and stored information that permits the organization of adaptive behaviours in advance of the instant in which they are needed.

1.5.3 Visual Recognition

Visual recognition is the ability to comprehend more of the perceptual details in a stimulus than simply, "where" and "when" it occurred. While it is not always easy to clearly specify the differences between detection and recognition, the following example may help: imagine driving in heavy fog conditions and being able to see "something" in front of you - but not being able to determine what it is. In this case, the stimulus is above your detection threshold but below your recognition threshold. Recognition is said to occur when you can tell that the object is a sign or the rearend of a car ahead of you. The recognition of a visual stimulus is believed to require more cognitive activity than does its detection because memory plays a more important role in the recognition of an object.

One model of early visual information processing postulates that the detection and recognition of events and objects is an iterative process involving a comparison in the central nervous system of stored memories and incoming visual signals. The process attempts to match specific visual features of the unknown stimuli with information stored during prior experience. Applied to the driving situation, a search through memory is initiated for items with similar features as discreet elements (e.g. line segments, shapes, texture, colour, etc.) are assembled into sets of features. In the event no association is made, a loop is established that contains the earlier attention and detection stages with the result of obtaining more visual input for comparing to prior experience. Of course, additional sensory input may lead to a revised set of features which can alter the memory search, forcing this comparison process to undergo several successive iterations. As the object is approached, the number of visual stimulus characteristics that are detectable increases and a greater number of its features become available to this process.

The point in time at which recognition occurs may not be the earliest point at which such recognition is possible after detection. The difference or latency between stimulus detection (or availability) and the point of recognition may be dependent upon the perceptual load of the driver, the general task requirements of driving at that moment, and the driver's concentration on the immediate driving task. In general, as each of these increases this latency increases, and as a result, the specific point of stimulus recognition can only be predicted under idealized conditions which are always greater than that obtained in real world driving situations.

Legibility of alpha-numeric information is a special case of recognition that has been much studied in the transportation field. It has an obvious relevance to the effectiveness of highway signs. A word message sign, such as that needed to guide a driver to a specific destination, must be read and comprehended if the message is to be communicated. It should be noted here that not all elements of a stimulus will become recognizable at the same distance (time) away from the sign. For example, the shape and colour of a sign are usually seen much further away than one can read its legend or word message. This is the reason for colour and shape coding of highway signs. The letter style, spacing, and contrast of the legend to the sign background are all important in determining legibility of specific sign designs. For further information on this topic see reference 1.13.

1.5.4 Decision Making

Two general types of decision making processes are involved in driving: namely, monitoring of position within the travelled way and route finding/route following. Both require visual input. The monitoring task is defined as such because the behavioural appearance of the driver is that no activity occurs until a preconceived path boundary is exceeded by some predetermined amount. Typical of this process is speed control and lateral lane position maintenance. In this instance, the visual task of the road user consists of perceiving the lane boundaries and lane path over some finite distance ahead. The driver proceeds along his/her path and no corrective steering or change in accelerator position is undertaken unless the vehicle's position exceeds some preconceived limits.

The decision processes for determining action in position monitoring depend upon visual perception of the roadway and the vehicle itself. At night, the lane boundaries are typically delineated by retroreflective materials. Naturally occurring contrast between the road edge and its shoulder, raised curbs or other roadside development may also be used in the case of the road margin. The driver must be able to observe the relative motion and position of his/her vehicle against the "background" of the road markings.

The second decision task involves route finding/route following; i.e. to determine and follow a course safely to a predetermined destination. Route following involves making discreet decisions concerning the changes in path to take in order to reach the intended destination. The visual information required by the driver involves inputs from highway signs, as well as from other road users and objects located on or near the roadway. Route finding/following involves the comparison of expected course changes with the visual information obtained from observing the road environment while driving. The locations of expected course changes are anticipated based on prior knowledge obtained from maps, pretrip planning, or having taken the route before. The ongoing visual perception of the roadway also provides additional information useful for safe driving behaviours, such as the avoidance of other traffic (both vehicular and pedestrian), random obstacles, fixed obstacles, and/or changes made in the roadway since a prior trip (construction and maintenance).

Position monitoring and route following are subtasks that are often carried out in the presence of one another. In such a situation the limits to human information processing may result in the degradation of either or both subtasks. While route following involves decision making with long term implications, the driver may be engaged in deciding what route to follow at a time when the immediate decision of position monitoring must also be attended to. It is common to observe the results of the degradation of driving behaviour when both subtasks are required of the driver in a given instant. While rational driving would demand that the subtask with the more immediate consequences for safety (i.e. route following) be attended to, evidence from traffic behaviour often shows the contrary. The navigational task is let slide and the driver becomes lost.

Four general responses are usually observed when positional monitoring demands conflict with route following demands. The driver can: 1) change the direction of motion, 2) alter speed, 3) do both or 4) do nothing. No overt response does not mean that the driver has

failed to see and react to some stimulus in his/her field of view. It may mean that the driver's decision (possibly the safest decision, under the circumstance) was to remain on the same course. In a given situation any of these four alternatives may be the safest alternative.

1.5.5 Visually Guided Responses

The final aspect of driving performance upon which visual information has impact is upon the selection of driving responses. Response selection may be viewed as a subset of decision making in that the driver is charged with the task of selecting an appropriate motor response from a behavioural repertoire. In many instances this is constrained by the implicit and explicit "rules of the road," such as the driver's knowledge of good driving practice, local traffic laws, traffic and route control information and physical barriers. While each of these "rules" is capable of modifying and restricting human behaviour behind the wheel of a vehicle, the degree of explicitness of a given "rule" generally reflects its relative importance in the context of the driving environment.

Visual information from the roadway is important in assisting the driver in making choices among response alternatives. When rapid, adaptive responses are required, the availability of visual information that provide for recognizable alternatives is often critical to road safety. For example, the regular and consistent design and positioning of highway signage makes it possible for drivers to learn to quickly attend to certain roadway features in order to have more time to choose and execute the appropriate response.

1.6 How Specific Visual Tasks Change During Night Driving

It has been said above that driving requires the execution of specific visual tasks. While the visual information requirements of driving at night are similar for both daytime and nighttime driving, the function characteristics of the visual apparatus used during night driving can be quite different from those used during daytime driving. During daytime driving it is possible to see a wide variety of details in the surrounding environment because of the high daytime ambient or background illumination levels. These high daytime illumination levels provide a rich field of information for guiding the driver. At nighttime illumination levels, however, many if not most, of the same details in the surrounding area beyond the direct illumination of the headlamps cannot be seen at all. The availability of guidance information is greatly restricted and the useful visual field is narrowed to that revealed by the headlamps. Table 1.3 summarizes the differences between day and night vision during driving.

When driving in situations where vehicular headlamps are the only source of illumination, the sensitivity of the visual field becomes sharply divided near the edge of the headlight illumination pattern represented in the retinal image. The visual sensitivity of the rods in the illuminated field and very nearby will be lowered by light adaptation due to the presence of the headlight pattern, and recovery of that sensitivity will be relatively slow. During the act of night driving the adaptation level of the visual system will be in a constant state of change - especially at or near the limit of the headlight beam pattern. This means that the visual detection of objects near the edges of the headlight beam distribution will be different (usually worse) than either those areas well inside the headlighted area or those well outside it. As foveal vision contains only cones, one can never see the detail of an object beyond the area illuminated by the headlamps.

Public lighting installations are designed to provide increased visibility of both the permanent elements and any temporary conditions that might be encountered on the roadway and its immediate surroundings. This enhanced visibility is provided not just for vehicular drivers, but in many (particularly urban) situations is provided as much for pedestrians and other road users. Installations of public lighting should be designed to provide the driver's visual system with adequate spatial resolution abilities to see over a longer and wider area than with headlamps alone. The driver's visual field, however, will still be restricted to a significantly lesser number of guidance cues than are available in daylight.

Even with both roadway and vehicular lighting systems, the area where foveal fixations can occur is limited to a relatively short distance in front of the vehicle. In general, the rest of the details of the nighttime environment will be difficult to resolve unless there is additional illumination available. For example, many off-roadway details of the environment, which are often used as landmarks in route following, are invisible at night. However, most building lights,

commercial advertising, and illuminated or retroreflectorized signs are sufficiently intense to provide for adequate visibility. These can usually be seen no matter how low the ambient illumination level.

TABLE 1.3. Differences between day and night driving visual functions

VISUAL FUNCTION	DAYTIME	NIGHTTIME
Adaption Level	Constant, except tunnels	Variable, especially near edge of headlight pattern
Depth of Field (dependent on pupil size)	Constant	Variable with illumination level
Susceptibility to Disability Glare	Low	High
Susceptibility to Discomfort Glare	Moderate	High
Accommodation	Good	Requires photopic illumination, affected by reduced contrast and dark field
Fixation Control	Good	Requires photopic illumination
Spatial Vision (fine)	Good	Good only when image is on fovea and light level is adequate In highlight beam: usually sufficient light Outside beam: usually insufficient illumination
Spatial Vision (coarse)	Good	Road mediated vision is spatially coarse
Visual Component of Reaction Time	Good	Slower
Movement Perception	Good	Slower, poor under intermittent illumination
Colour Vision	Good	Requires photopic illumination
Binocular Vision, Stereopsis	Good	Poor outside illuminated area

Colour vision is mediated almost entirely by cone mechanisms. This means that any signal or sign that uses colour as part of its message must be either illuminated or retroreflective if it is to be recognized as coloured at night.

1.6.1 Reading During Driving

Reading of signs effectively adds a second perceptual/cognitive task during driving. The reading material is usually perpendicular to the line of sight, but not always (for example, lane control messages placed on the lane surface). Reading involves both peripheral and central components of the nervous system, including memory, language, and cognition. The visual component of reading is mainly carried out with the high resolution spatial mechanisms necessitating the positioning of the retinae such that the image from a single location in space (the sign) falls upon the foveas of both eyes. Driving requires that the driver pay attention to