VISUAL FACTORS IN DRIVING

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1. THE ROLE OF VISION IN DRIVING

Vision is one of the major senses with which we perceive the surrounding world. At the same time, it usually appears to make no sense to question about the processes behind vision, since "it works" without effort and the world looks just fine.

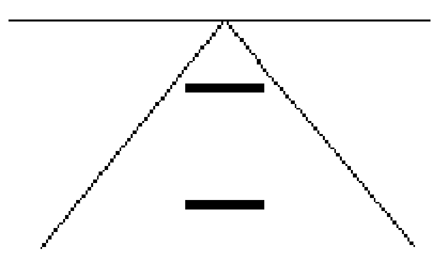

Figure 1. An outline sketch of a straight road.

However, one only has to consider the drawing in Figure 1 to admit that there is more to vision than just meets the eye. The reader may easily agree that the two lines converging onto the upper horizontal line can be perceived as the edge lines on a road receding into the distant horizon. Moreover, if you consider the two thick horizontal lines, the upper one looks wider than the lower one, although they are objectively the same size. From this simple observation, we can conclude:

- that our perception is not a copy of the retinal image,
- that we have a tendency to interpret the visual input in three dimensional terms (whether this is an innate or learned ability is beyond the scope of this chapter, and the interested reader is advised to refer to textbooks on perception);
- that our perception can be erroneous. In the present case, it seems that the tendency to perceive the upper line as longer might be linked to our 3D interpretation of the drawing. The line would appear to be farther away on the road. Thus, if its retinal image is the same size as the lower (closer) one, it must be larger (due to the inverse size/distance relationship).

Such preliminary remarks are meant to alert the reader to the fact that vision, which is obviously involved in driving, relies on external inputs, sensory encoding and mental processes. For that reason, visual information processing has to be taken into account in road engineering design. In that domain, the main (complex) question is how to obtain a safe correspondence between the driver's visual needs and/or abilities and the visual road environment.

Accepting that the information input to the typical driver is mainly visual (Hills, 1980), the problem remains to determine which visual cues are involved, depending on the actual sub-task of the overall driving process (i.e. highway cruising vs. intersection crossing), and on the internal state of the driver (i.e. his/her age, experience in driving, level of awareness, and other human factors). One way to tackle this problem has been to look for correlations between the driver's visual performance and accident rate, involving large-scale investigations. We will review some of this research, which is related to the scientific and social problems of refining and extending the visual standards for driving.

1.1. Background

In 1968, Burg reported the results of a large-scale study, involving visual measurements in Californian drivers. To provide driver-licensing administrators with here-to-fore unavailable information on which to establish effective vision-screening procedures for driver license applicants, a number of visual performance, personal, and driving habit characteristics of some 17,500 volunteer California driver license applicants were compared with their 3-year driving records (accidents and convictions). Of all the visual tests, *dynamic visual acuity* was most closely and consistently correlated with driving record, followed by *static acuity, field of vision, and glare recovery*. All relationships were in the "expected" direction, i.e., poor vision was associated with poor driving records. As expected, among all variables studied, age, sex, and average annual mileage played the largest role in influencing driving record. Accident and conviction frequencies increased with increasing mileage, were lower for females than for males, and were highest for the young age groups.

In a subsequent report, data from the 1968 California driver vision study were reanalyzed. For the main analysis, the sample was divided into four age groupings: under 25, 25-39, 40-54, and over 54. The most consistent result throughout the study was the failure to find a direct relationship between poor visual performance and high accident rates for young and middle-aged drivers. For the *over 54* age group, dynamic and static visual acuity showed the most consistent relationship with accident rates. Considering that visual capacities normally decrease with age, this suggested a causal relationship between visual performance and the risk of accident while driving.

To elucidate the possible traffic safety risks induced by visual field defects, various methods have been developed, using either driving simulators or real driving situations. For instance, in a simulator study, the capacity to detect stimuli of different sizes appearing in different positions of the screen in front of the driver was measured. Two groups of normal subjects and a number of subjects with different visual field defects were studied. In the groups of normal subjects, the median reaction times were homogeneous. There was a slight difference between central and peripheral stimuli, which was somewhat larger for the older subjects. Among the subjects with field defects, individual variations were very dominant. However, the most interesting finding was the quasi-inability of most subjects to compensate for visual field defects under the test conditions. The authors concluded that the use of test methods that come close to duplicating real world driving tasks may reveal functional capabilities differing from what would be assumed based on clinical (or laboratory) tests. Another study tried to determine the effect on driving of restricting vision. This was undertaken by comparing the driving performance of young, normal subjects under conditions of simulated visual impairment with a baseline condition. Visual impairment was simulated using goggles designed to replicate the effects of cataracts, binocular visual field restriction, and monocular vision. Driving performance was assessed on a closed-road circuit for a series of driving tasks including peripheral awareness, maneuvering, reversing, reaction time, speed estimation, road position, and time to complete the course. Simulated cataract resulted in the greatest decrement in driving performance, followed by binocular visual field restriction. Thus, it appears that visual deficits exhibit positive correlations with driving performance and potential exposure to road accidents. One parameter, which seems to be related to this aspect of the problem, is the driver's age.

<u>Aging.</u> Older adults rely on the automobile to maintain their mobility and independence, in spite of the fact that age-related behavioral and biomedical changes may make driving more difficult. Indeed, accident and fatality rates begin to rise after age 55. One research goal, therefore, is to identify functional measures that differentiate older adults who drive safely from those who do not (Ball and Owsley, 1991). In particular, one can examine the elderly drivers' perception of their driving abilities, compared to their clinically tested functional skills in the area of visual perception, and their actual in-car driving performance. The specific skills assessed include ***peripheral visual field, depth perception, color sensitivity, static visual acuity, dynamic visual acuity, and figure-ground discrimination***. Results indicate that clinically tested visual perception skills (notably peripheral vision and color sensitivity) and actual in-car driving performance could be related. Many studies also indicate that people generally tend to over-estimate their driving abilities.

For example, subjects, ranging in age from 30 to 83, participated in a closed-course driving test and in laboratory tests of visual perception. Driving tests included responding to traffic signals, route selection, avoidance of moving hazards, and judgment at stationary gaps. Lab tests included measures of perceptual style, selective attention, reaction time, ***visual acuity***, perceptual speed and risk-taking propensity. Analyses were conducted to determine how well lab measures predicted driving performance. Results revealed different patterns of correlations for different age groups. For younger drivers (30-41), lab measures generally showed no association with measures of driving performance. For older drivers (74-83), measures of information processing were associated with overall rated driving performance, while measures of reaction time showed strong correlations with objective driving measures. These results suggest that different mechanisms are utilized by drivers of different ages, and that the slowing of reaction time associated with aging has certain effects on driving skills related to vehicle control.

Efforts to assess visual deterioration with increasing age, coupled with new mechanisms proposed to limit the exposure of visually impaired drivers to driving risks, have emerged in response to the increase in older drivers. Visual functions discussed in this context include ***static acuity*** (photopic, mesopic, and in the presence of glare), ***dynamic visual acuity, visual field, contrast sensitivity, and motion perception*** (see definitions in next section). More recent surveys point out that, whereas static acuity and color deficiencies are only weakly correlated with crash involvement, peripheral vision appears to play a more critical role.

<u>Drugs and alcohol consumption</u>. The behaviours involved in driving a motor vehicle are also impaired by alcohol to varying degrees. Certain skills important for driving, in particular the brain's ability to observe, interpret, and process information from the eyes and other senses are impaired even at the lowest levels of alcohol concentration in the blood that can be measured reliably (Moskowitz and Burns, 1990). It seems reasonable to assume that a driver cannot operate a vehicle safely if information processing is slowed, visual perception is degraded and/or the ability to allocate attention to multiple sources of information limited.

It is important to understand that crashes are not limited to drivers with high levels of alcohol. Rather, there is a significant risk that extends to low and moderate levels. Drivers need to know that they are impaired and are at increased risk of crash when they have consumed even small amounts of alcohol. The safety-minded consumer will restrict alcohol use to times and places that do not include driving.

To identify the impairment effects of alcohol on driving performance and to determine whether providing enhanced visual information concerning roadway alignment would improve the performance of subjects when sober and/or alcohol-dosed, simulations of continuous roadway treatments (i.e., standard and wide edge lines) were evaluated experimentally (Ranney and Gawron, 1986). Twelve subjects drove a simulator at three levels of blood alcohol concentration. The effects of alcohol included increases in the number of times the speed limit was exceeded, the number of obstacles that were struck, and the magnitude of tracking errors that were made in the approach and negotiation of curves. Edge line presence was associated with faster curve entry speeds and reduced amount of road used in curve negotiation. Increased speed entering curves could be one aspect of driving behavior in nighttime and low-visibility conditions, when ambient cues are not degraded, leading drivers to drive too fast for degraded focal visual abilities. One implication of this finding is that given clear edge lines in conditions of poor visibility and related degraded focal ability (as in fog), drivers may opt for too high a speed, especially under the influence of alcohol.

More generally, it has now become an important issue to understand whether psychotropic drugs, which are being increasingly used, can affect driving performance. It is in particular a matter of debate whether psychoactive drugs, such as benzodiazepine, will affect the overall nervous system, resulting in sleepiness for instance, or whether more specific effects on perceptual abilities can be evidenced. For instance, recent reports suggest that benzodiazepine use increase significantly the risk of motor vehicle accidents. It is proposed that, even if no direct relation between drug administration and driving performance can be evidenced, caution has to be exercised, because of induced sleepiness. Recent studies suggest that visual dynamic sensitivity might be sensitive to GABAergic drugs. Recently, we found in our laboratory a significant effect of midazolam on visual segmentation processes (figure-ground discrimination), suggesting that these drugs, via visual deficits, might affect driving performance.

1.2. Selected Visual Determinants

Throughout this short review, we saw that, beyond classical evaluations of static visual acuity (the minimum visual angle that our optic system can resolve), a number of visual tests were proposed, that might predict driving performance more efficiently. We will now present some of the most promising ones in more detail.

<u>Useful terms.</u> We need first to define some terms, related to basic concepts in visual perception and its measurement.

- ***Illumination*** is the amount of light falling onto a surface. It refers to the lighting conditions in the environment and to how the objects are struck by photons, directly from light sources or indirectly from reflections by other objects.
- ***Reflectance*** refers to the fraction of incident light that is reflected by a surface.
- ***Luminance*** is a measure of the amount or intensity of visible light energy emitted or reflected from a given source or surface.
- ***Contrast*** between two adjacent regions is their relative luminance levels.
- ***Lightness*** is the perception of a surface's reflectance. ***Lightness constancy*** refers to the ability to perceive the constant reflectance properties of surfaces, despite changing conditions of illumination.
- ***Fovea*** is a small region in the center of the retina, about 2 degrees in diameter that contains exclusively cone-shaped photoreceptors (***cones***), and is responsible for highest spatial acuity. Rod-shaped photoreceptors (***rods***) are located everywhere in the retina, except in fovea. They are used for vision at low levels of illumination.
- ***Photopic*** conditions of vision are viewing conditions under high level of illumination (e.g. normal daylight), in which the cones in our retina are active and color is perceived.
- ***Scotopic*** conditions of vision refer to vision under low levels of illumination when rod activity dominates vision, particularly at night (***night vision***).

- ***Myopia*** (or nearsightedness) is a condition in which people can see well at short distances, but cannot focus properly on distant objects. ***Night myopia*** is a similar effect observed in conditions of night vision.
- ***Accommodation*** is the process by which the image is focused on the retina. In degraded conditions of vision (night, fog), a special case of accommodation error arises from the fact that the eye tends to slip into a relaxed state of ***"dark focus accommodation".***
- ***Psychophysics*** is a branch of psychology. It includes behavioural studies of quantitative relations between people's perceptual experience and physical properties of a stimulus. Psychophysical methods were developed to find the ***sensory threshold*** for a given sensory dimension, which corresponds to the weakest stimulus value that can just barely be perceived.
- ***Contrast sensitivity*** is a measure of the limits of visibility for low contrast patterns (how faded can an image become, before it is invisible). Everyone who has been driving in fog can intuitively see its potential relevance to road safety. The image in Figure 2 was proposed by Campbell and Robson (1969) to illustrate the form of the contrast sensitivity function. Their results suggested the existence within the nervous system of linearly operating independent mechanisms selectively sensitive to limited ranges of spatial frequencies.

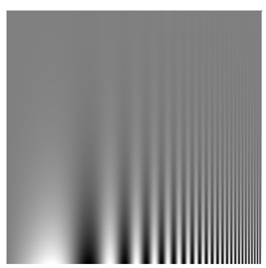

Figure 2. ***Test your own*** *contrast sensitivity function. In this image, the luminance of pixels is modulated in the horizontal dimension, with the modulation (spatial) frequency increasing logarithmically from left to right. The contrast of the modulation increases from top to bottom. Note that the bars appear taller in the middle of the picture. The inverted U-shaped curve of visibility that you can draw on the figure is your contrast sensitivity function.*

Present visual standards are generally based on the observer's ability to see small high contrast black and white letters or symbols. Current research shows that such vision tests are not adequate to evaluate an individual's target detection and recognition capability over ranges of target size and contrast used in real situations. New vision tests are being developed that use the observer's report of the visibility of sine-wave gratings (that look like fuzzy bars) to assess visual capability with much more sensitivity than that of standard tests.

In a simulator study, for instance, it was found that contrast sensitivity was better than visual acuity for predicting a pilot's ability to detect a small, semi-isolated, air-to-ground target. This type of results provides a piece of evidence for the predictive validity of contrast sensitivity.

Owsley, Sekuler and Siemsen (1983) measured the contrast sensitivity function on a large sample of adults, ranging in age from 19 to 87. The sensitivity for stationary gratings of low spatial frequency remained the same throughout adulthood. At higher spatial frequencies, sensitivity decreased with age, beginning around 40 to 50 years, and corresponding to the expected reduction in visual acuity with age. When a low spatial frequency grating was made to move, young adults' sensitivity improved by a factor of 4-5 over sensitivity to a static grating; this motion enhancement was markedly diminished in adults over 60 years, implying an impairment of temporal processing in the elderly. The reduced retinal illuminance characteristic of the aged eye (caused by the progressive yellowing of the lens) could account for a large part of older adults deficit in spatial vision, but appeared to play little role in their deficit in motion vision. It is argued that the reduction in motion sensitivity may affect routine activities, such as visually guided locomotion, which depends on low spatial frequencies.

<u>Night vision</u>. In a study by Fejer and Girgis (1992), a total of 380 randomly selected patients aged 16 to 80 years, who did not have eye disease, underwent testing for night myopia (changes in refraction of the eyes under low-illumination conditions). Overall, 17% of the subjects were found to have night myopia. The results indicate that driving in the dark could create visual difficulties for certain younger patients that a night myopic correction would eliminate. In another study, it was found that, at luminance levels equal to those recommended for road lightning at night, acuity was about two-third of its normal value in daylight. Night myopia was only present for very low luminance, well below normal night-driving conditions. It was concluded that neural mechanisms, rather than optical ones, are responsible for the acuity loss experienced by drivers at night.

In another study conducted by Owens and Leibowitz (1976), the relationship between night myopia under simulated night driving conditions and the dark focus of accommodation (see above) was examined. Over a range of luminance and contrast conditions typical of the night driving situation, college-aged subjects accommodated to about one-half the difference between a distant simulated road sign and their individual dark focus. Subsequent laboratory and field experiments demonstrated that: (1) a negative correction equal to one-half the value of the dark focus significantly improved night visual performance as compared with their normal or full dark-focus correction, and (2) greater improvements in performance were obtained for subjects who exhibited a relatively near dark focus.

Recent studies explored the possibility that drivers' ability to steer a vehicle under challenging conditions may decline with advancing age. Older drivers are frequently reluctant or unwilling to drive at night, apparently because they lack confidence in their visual capabilities. They used a simple night driving simulator, designed to evaluate the effects of reduced luminance on steering performance of younger and older subjects. The results showed that the resistance of steering performance to degradation in low light declines with age.

A last interesting aspect, related to night vision and driving, concerns glare from the headlights of oncoming vehicles. Disability glare affects elderly drivers, but we all know young people around us who refrain from driving at night, explaining that they have difficulties recovering from glare.

Concerning general adverse visual conditions, Owens and Sivak (1993) investigated the contribution of reduced visibility to fatal accidents. They evaluated accidents that occurred during morning and evening time-periods, called Twilight Zones, during which natural illumination varied systematically in conjunction with the annual solar cycle. Fatal accidents were found to be over-represented during darker portions of the Twilight Zones. The contribution or reduced visibility was also indicated by higher overrepresentation of fatal accidents in low illumination under adverse atmospheric conditions and with pedestrians and cyclists as opposed to all other accidents. Reduced visibility was more important than drivers' drinking as a contributor to fatal pedestrian and bicycle accidents, while the reverse pattern was found for all other fatal traffic accidents.

Still another example concerns driving in fog. Snowden, Stimpson and Ruddle (1998) report a simulation experiment, in which it was shown that observers tend to underestimate their own velocity in foggy weather. This result seems to be related to an apparent reduced perception of speed under conditions of reduced contrast. It is also the case that under such degraded conditions, when monocular cues to distance may be greatly reduced, drivers tend to overestimate the distance to objects. The interesting point here is that accidents in fog, due to exaggerated speed in foggy weather and distortions of distance perception, might be due to a deficit in visual perception (of which drivers are not conscious), rather than to their irresponsibility. This line of argument might also be applied to night driving, and to driving under the influence of drugs. Roadway engineers might want to consider these facts.

<u>Useful field of view</u>. The useful field of view is defined as the visual area in which information can be acquired within one eye fixation. A number of reports argue for a reduction in the size of the useful visual field as a function of age. This loss, however, can be recovered partially with practice. Standard acuity and perimetric tests of visual field, although efficient diagnostic of disease, underestimate the degree of difficulty experienced by visually healthy older adults in everyday activities requiring the use of peripheral vision. To aid in predicting such performance, a model incorporating the effects of distractors and secondary task demands was developed (Ball et al., 1988). Subjects responded to dual tasks, one central, one peripheral (10 to 30 deg in eccentricity). The most interesting finding was a practice effect, where performance improved on peripheral tasks after practice, and improvement persisted six months post-training. If confirmed and extended to performance on clearly driving-related tasks, this could have implications for testing and licensing.

Experimental results suggest that the size of the useful field of vision may not be influenced by the speed of traveling. This finding contradicts the postulated tunnel vision at increased speed. However, the size of the useful field of vision seems to decrease when the driver deviates from the prescribed speed of traveling, driving either too fast or too slow. It is assumed that the resulting internal workload could exhaust the drivers' capacity and consequently cause perceptual narrowing, which is a peripheral manifestation of central overload. This idea is confirmed in other studies, which suggest that the functional or useful field of view is very sensitive to foveal demands. As the foveal primary task becomes more difficult, peripheral information extraction is perturbed, and it is perturbed increasingly as the retinal eccentricity of the peripheral information increases. This is the case even when compensatory adjustments are made for acuity loss.

Finally, Wood and Troutbeck (1992) investigated the importance of the visual field on driving performance. This was undertaken by simulating binocular visual field defects for a group of young normal subjects and assessing the impact of these defects on performance on a driving course. Constriction of the binocular visual field to 40 deg or less, significantly increased the time taken to complete the course, reduced the ability to detect and correctly identify road signs, avoid obstacles and to maneuver through limited space. The accuracy of road positioning and reversing was also impaired.

1.3. Implications for Design Interventions

Concerning what we have just presented, the reader might react by saying that interacting factors like visual deficits (normal or pathological), aging and drug-addictive behaviour, are beyond the control of highway engineers. Legislative measures ought to be taken, in order to remove from the highway "deviant" people. It is certainly true, as we mentioned, that researchers work hard to elaborate new visual standards for driving licensure. However, having too strict standards might result in "false positive" measures, preventing people from driving who are not more susceptible to accident than others. Another limit is sociological, in the sense that normality is always a relative affair. For instance, the average population age is increasing in western countries, and elderly people want to stay on the road. In this sense, the highway engineer will have to deal with this social context. From our point of view, this will, for instance, result in a necessary taking-into-account of the glare sensitivity of elderly people, requiring adjustment of road lightning or glare prevention from oncoming vehicles. The "useful field of view" concept might help in the positioning of road signs. Contrast sensitivity might be used to design visible road markings in adverse visibility conditions, and so on.

Finally, the reader will have noticed that motion sensitivity is often mentioned in what was just presented. From our point of view, this is no surprise, since the driver’s visual environment is, in essence, dynamic. We will now discuss more extensively this point. We will in particular present experimental work, trying to show how basic research might help clarify the complex domain of the visual information used in driving.

We will concentrate mainly on the control of steering and more precisely on the perception of heading. In this chapter, we will ignore interactions between the perception of self-motion and the perception of object-motion, which will be dealt with in the next chapter by Santos et al. Finally, we will try to suggest possible concrete outcomes for everyday highway design.

2. THE ROLE OF MOTION VISION IN DRIVING

2.1. Two Modes of visual information processing

In an important paper, Leibowitz et al. (1980) tried to relate the general problem of vehicle guidance to developments in the field of psychophysical and neurophysiological mechanisms in vision. They revisited the concept of two visual systems, considering that vision of space and vision of object identity may be subserved by anatomically distinct brain mechanisms, involving two parallel processes; one *ambient*, determining space at large around the body, the other *focal* which examines detail in small areas of space. The two modes of processing concept can best be described in functional terms. It posits two independent and dissociable modes of processing: (1) a “focal” mode that is in general concerned with the question of “what” and subserves object recognition and identification; (2) an “ambient” mode concerned with the question of “where” which mediates spatial orientation, locomotion, and posture, and of interest to us here, vehicle guidance.

Focal vision is present in central vision, where visual acuity is maximal. Today, it remains the quasi-exclusive aspect of visual processing addressed by visual requirements for obtaining a driver's license. On the other hand ambient vision seems to be at work throughout the visual field and exhibits coarse spatial resolution and good temporal resolution. It is moreover less sensitive than focal vision to large variations in stimulus parameters, being for instance quite effective in low luminance conditions.

Relationships between ambient vision, motion perception and the control of self-motion were notably investigated by Brandt and his co-workers. They showed that stimulation of the peripheral visual field with moving patterns could induce, in a stationary observer, a powerful sensation of being him/herself in motion in an otherwise stable environment. The sensation of self-motion is a common visual illusion, which may be perceived while gazing at moving clouds, streaming water, or when a train moves on the adjacent track in a railway station. This compelling sensation of body movement can even affect postural balance. One might assume that these illusions are inferences based upon the conscious or unconscious assumption of a stable environment, so that when the environment does in fact move, the observer infers that he himself is moving. This interpretation would be consistent with the individual’s past experience as the entire visual surround seldom moves uniformly under natural conditions unless the body moves relative to the earth. Psychophysical evidence is presented indicating that motion-vision plays a predominant role not only in the perception of self-motion but much more generally, in dynamic spatial orientation.

2.2. The concept of optic flow

This approach to the problem of the visual basis for the control of locomotion was also formalized by Gibson (1979), who introduced the concept of ***optic flow***, to describe the transformations of the light pattern (optic array) projected onto the entire retina during motion of the self. In an "interactionniste" approach, he suggested that our motion through the environment produces a pattern of optic flow, which specifies the properties of our displacement. At this point, understanding the information in optic flow requires an analysis of its properties. In the original analyses, the laws of linear perspective were used to derive the changing optic array of a moving observer. Optic flow is described as a two-dimensional motion field. Figure 3 represents optic flow resulting from pure translational motion of an observer over a flat surface, which can be an equivalent of a road depicted by random dots dispersed on the surface.

In this figure, all optical motions radiate outward from a common "focus of expansion", which corresponds precisely to the direction of locomotion. From this example, it is easily conceived that such an analysis led researchers to suspect that a new whole body of visual information was potentially available to a moving observer. One question was whether human observers were able to perceive such information, with sufficient precision for effective control of locomotion (or vehicle steering).

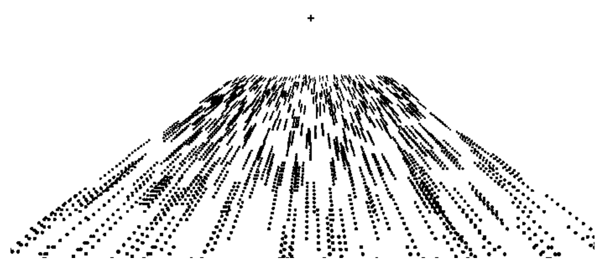

Figure 3. Optical trajectories generated by linear forward motion relative to the ground. Element motions seem to emanate from a common point (the cross at the top of the figure), the focus of expansion of the optic flow, which corresponds to the observer's direction of travel (heading direction).

2.3. Useful information in optic flow

In the seventies, the first experimental studies concluded that heading judgments from optic flow were quite inaccurate. In conditions were subjects had to point in the direction of perceived focus of expansion during visual simulations of forward motion, heading errors were of the order of 5 to 10 degrees. Considering that safe control of steering requires an accuracy of about 1 degree, these results led researchers to doubt the usefulness of optic flow in the control of locomotion.

Important steps forward were later realized by William Warren, at Brown University, revisiting the question (see Mestre, 1992, for a review). These authors suggested that these poor results might be due to methodological problems, including the observer's task. They designed a new protocol, in which observers were presented with visual displays simulating motion relative to a ground surface populated with random dots (quite similar to Figure 3, above). After seeing the motion, observers had to decide (in a two-alternative forced choice procedure), whether it looked as if they were heading towards the right or the left of a target line located on the ground. With this procedure, it was found that heading accuracy was of the order of 1 degree.

This result is of significant importance. It suggests that the information is by essence of a relativistic nature. In other words, drivers do not have to judge their direction of heading in an absolute sense, but ***relative*** to the road environment. They want to know whether their trajectory is aligned with the road, which is exactly what was found in these experiments. In the related problem of speed estimation from optic flow, we found similar results, showing that, whereas absolute speed is only given within a scale factor, variations in self-speed are perceived with a precision of 5-10%.

Two other points are worth noting. First, as can be expected if ambient vision is involved in optic flow perception, manipulations of dot density in the optic flow revealed that the perception seems not to depend on the location of a singularity, like the focus of expansion, but rather relies on the perception of the ***globality*** of the optic flow.

Secondly, in subsequent experiments on the perception of heading during curvilinear motion, were the focus of expansion is missing, the idea that subjective judgments depend on the global optic flow structure was confirmed.

It was also noted that judgments are then dependant on the ***visual trajectories over time*** in the flow. This suggested that the perception of heading requires longer time than the simple detection of a moving object, for instance. This relatively slow processing of motion information for the perception of the three-dimensional structure of the environment is a classical result in psychophysics.

Finally, for ***small radii of curvature***, a deterioration of performance was systematically observed, with a tendency to underestimate the radius of curvature, when motion relative to the ground was simulated. This last result might have implications for the design of road curvature. However, more data are required on this point, given that visual displays stimulated only the central part of the visual field, whereas peripheral vision might play a crucial role here.

3. OTHER SOURCES OF INFORMATION FOR THE CONTROL OF STEERING

Having demonstrated that the optic flow triggered by our own displacement is a useful source of information for the perception of heading, and thus logically involved in the control of steering, it would be far too limited to draw conclusions from experiments using a random dot environment. The road environment is more complex, and contains more sources of information.

3.1. The role of edge lines

Gordon (1966) already noted that "when the moving vehicle is aligned with the highway, each point on the road border and lane marker falls on the angular position previously occupied by another point of the border, and the road assumes a ***steady state appearance***" (see Figure 4).

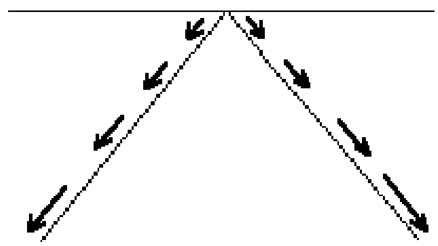

Figure 4. Schematic representation of a steady-state appearance assumed by the optic flow due to the road edge lines, when the driver's trajectory is perfectly aligned with the road. The same principle applies to perfect alignment with a curved roadway (see also Figure 5).

We are then confronted with what Gibson called a "higher-order" (visual) parameter. Whereas we just noticed that drivers are keen to use optic flow to control their trajectory, we now find that they are able to use its stable appearance to steer their vehicle, using edge lines. We can then say that driving corresponds in this case to a tracking task, the problem being to maintain visual stability of edge lines. Riemersma (1981) demonstrated that, during simulated road driving, edge line motion was an effective visual cue for the control of heading and lateral control. One interesting consequence of this is that, under nighttime conditions, delineation systems appear to be a privileged visual cue for facilitating driving on straight and curved roads.

3.2. The role of the visual road environment

It has often been suggested that the road environment itself can modulate the perception of self-motion. For instance, we will have more of a sensation of increased speed while driving along a small road bounded by trees, than on an empty highway. Denton (1980) describes an experiment in which he systematically distorted the geometry of the road layout, in simulation conditions. He used a bituminous-like pattern, on which transversal white stripes were drawn. The spacing between bars was exponentially reduced. Results clearly show that subjects reduced their speed, when confronted with these patterns that gave a visual sensation of increased velocity of self-motion. We will not go into technical details here; let's assume that edge-rate - the rate at which the bars drifts in the visual field - is a good cue for speed perception. In a field-study in the UK, they indeed found a reduction in speed following this setup near dangerous roundabouts (see also Hills, 1980).

In the domain of heading perception, recent studies report distortions in the perceived heading direction, due to asymmetries in optical velocities in the right and left peripheral visual field. For instance, subjects tend to perceive themselves as heading towards the side where the highest optical velocities were present. Although much care has to be taken before translating this kind of result to a real driving situation, it suggests that the actual road environment might play a direct role in the way visual motion information is processed. This could have important implications for the design of a road environment. Much work is needed here, both fundamental and applied. But just imagine that, on a road with trees on just one side, this type of misperception of heading might actually occur. This could first explain certain weird accidents on small empty roads; it may secondly favor a new approach to the road architecture process.

To conclude this part, let us make two further remarks. First, it becomes obvious that the road environment structure plays a role in the perception of a car's trajectory. In this sense, we propose that the "objects" along the road, including road signs, might also play a role. This approach suggests only that every road element has to be taken into account in a "dynamic visual approach" to driving. In research, it corresponds to a new viewpoint on optic flow, suggesting that object-based information has to be taken into account. Secondly, the role of singular objects might be greater than we think. A singular object might capture attention, and induce an eye fixation on it. We do not want to get into the problem of eye movements here. However, Land and Lee (1994) showed that, in curve negotiation, the eyes tend to fixate the inside edge of the road near a point known as the "tangent" or "reversal" point of the road, which is a point where the inside of the curve changes direction (Figure 5). This suggests that subjects pick up useful information there, and that attracting their attention (and eyes) towards the outside of the curve (with road signs for instance) might not be the brightest idea in mankind (for road safety).

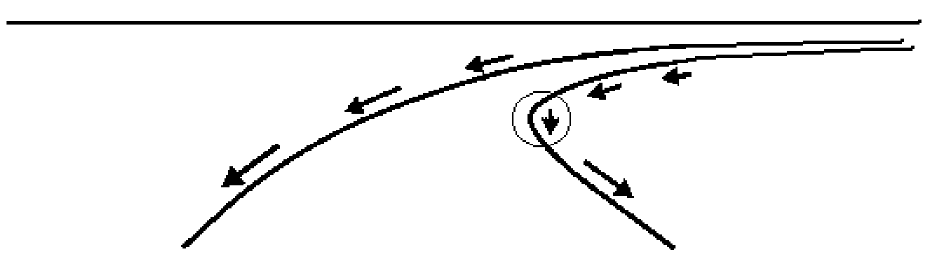

Figure 5. While negotiating a curve, drivers tend to fixate a region (circled) where the inside edge of the road changes direction. This is also the point where the horizontal component of the optical motions of the road markers changes direction (from leftward to rightward in this case).

4. CONCLUDING REMARKS

"Take the driver's point of view! " might be the principle message from this short review about the implications of vision for safe driving. The reader engineer might however think that this is a casual attitude, leaving him/her with all the work, from basic studies to concrete solutions for highway design. Thus, we can try to be a little more specific.

The role of motion vision in driving has been emphasized here. Obviously, it seems important to depart not only from the bird's eye view of the highway, but also from a static point of view. The control of steering is in essence a dynamic control process and it involves of course dynamic visual information. This is not to say that basic visual functions are not involved. We tried to introduce a few, such as contrast sensitivity, night vision or peripheral vision. What is important to understand here is that the main problem is to fill the gap between basic clinical evaluations of vision and the globality of the driver's task. For instance, from what we introduced here, the engineer might want to reconsider the design of edge lines, making sure that they are visible in fog. However, this honorable approach does not guarantee that an accident will not occur on the precise part of the highway where a real test will be conducted, just because a driver fell asleep or makes use of the clearly visible edge lines to drive to fast. This is an extreme example, but it is true that attentional and cognitive factors, tiredness, experience of driving and perceptual style are a few amongst the many variables involved in car driving safety.

Another problem concerns the transfer from laboratory results to real conditions. One solution, as we already mentioned, is to design prototypes that can be tested in real conditions. It is surely true also that driving simulators have a role in this process, enabling researchers to test visual hypotheses in interactive situations as opposed to evaluating passive observers' judgments.

Finally, there is a major concern about a quantitative aspect of the problem. Different people have different visual capacities. We saw briefly the effect of aging and of drugs on visual functions and the risk of car accidents. There are significant efforts, specifically in the US, to update visual standards for obtaining a driver's license. However, as we already said, finding correlations between visual functions and accidents is difficult, partly because of the multi-factorial aspect of driving. In addition, social factors come into play inside an aging population that wants to keep a certain level of independence. This means that the highway engineer will have to work for the common population, which is of course a vague and loose concept. In the end, I would like to stress that it appears more and more that the highway has become a 24-hours life place, and that trying to improve its architecture in terms of safety requires the collaboration with highway engineers of many specialists in vision.

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RECOMMENDED READING

There are many excellent books about visual perception. A most readable is:

Rock, I (1984). *Perception*. New-York: Scientific American Books

Concerning the role of optic flow in the control of self-motion:

Gibson, J.J. (1979). *The Ecological Approach to Visual Perception*. Boston: Houghton Mifflin.

Gordon, D.A. (1966). Perceptual mechanisms in vehicular guidance*. Public Roads, 34*, 53-68.

Finally, for a survey of visual factors in driving:

Hills, B.L. (1980). Vision, visibility and driving. *Perception, 9,* 183-216.