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HE TWO MODES OF PROCESSING CONCEPT AND ELECTIVE VISUAL DEGRADATION

HE TWO MODES OF PROCESSING CONCEPT, recently eveloped in neurophysiology, posits two ndependent and dissociable modes of processing isual information. The "focal" mode is con-erned with object discrimination and iden-ification, or more generally, the question of what?". It is subserved primarily by the ortex and is typically well represented in onsciousness. Because focal functions involve igher spatial frequencies, they are optimal in he central visual field and systematically elated to both luminance and refractive error. he other mode of processing, referred to as ambient" vision, is concerned with spatial rientation or more generally the question of where?". The properties of the ambient mode differ along many dimensions in comparison with the focal mode. Although spatial orientation is certainly possible, if not superior, with the central visual field, it is adequate with stimulation of the peripheral retina in spite of its coarse resolution properties. Low spatial frequencies are sufficient for ambient functions and are less sensitive to both refractive error and luminance than focal functions. For example, the radial localiza-tion of single stimuli is unaffected by the energy content of a visible stimulus or by refractive error (1,2)*. Circular vection, the illusory sensation of self-motion induced by moving visual scenes, is only slightly in-fluenced over a wide range of stimulus para-

*Numbers in parentheses designate References at end of paper.

ABSTRACT

ecent developments which provide new insights nto night driving accidents are reviewed. elective Degradation: The mechanisms subserv-ng steering are different from those under-ying hazard recognition and these two modes of rocessing visual information are selectively mpaired at night. Although it is possible to teer a vehicle as well at night as during the ay, the ability to recognize and respond to nfrequent hazards is seriously degraded. Night yopia: Many individuals become nearsighted nder reduced illumination. The finding that his is a normal consequence of the passive re-urn of the accommodative system to an inter-mediate resting position has led to a procedure to ameliorate this effect. By determining the value of an individual's dark focus it is pos-sible to provide a special night driving pre-scription which effectively eliminates night myopia. Night driving will always be hazardous. To the extent the danger is caused by night myopia it can be fully corrected by a simple optical procedure. However, because part of the risk results from the unjustified self-confidence associated with the selective degra-dation of visual functions at night, other procedures are necessary.

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meters as compared with focal capacities (3,4), and postural stability is enhanced even by the presence of minimal luminance stimuli (5). With respect to consciousness, the ambient system is often poorly represented although by directing attention one can be aware of ambient activity.

A number of recent ablation studies with animals as well as observations of brain damaged humans have suggested that it is possible for some orientation ability to be spared despite loss of focal vision. Weiskrantz has referred to this phenomenon as "blindsight", and there is an interesting and provocative literature on this topic (6,7,8,9). For the present purpose, the demonstration that it is possible to walk while reading demonstrates the dissociability of and some basic characteristics of focal and ambient functions. Even though attention is dominated by the reading material, orientation in space is carried out confidently and accurately on the basis of peripheral stimuli at an unconscious or subconscious level. If illumination is lowered or the retinal image blurred, the ability to read is degraded but orientation is relatively unimpaired. A recent summary of the two modes of processing concept points out how a number of interesting problems in both basic and applied science can be fruitfully interpreted in terms of these emerging concepts (10).

Unlike vestibular stimuli, which normally lead to the sensation of body motion, visual motion stimuli allow for two perceptual interpretations, either object- or self-motion. A subject watching moving stimuli may perceive himself as being stationary in space (egocentric motion perception) or will experience the actually moving surroundings as being stable and himself as being moved. The latter illusion has been known for a long time but has not been thoroughly studied under experimental conditions until recently (for a review see reference 11). Visual perception of self-motion or circular vection is dependent both on the density of moving contrasts within the visual field and the total area of the stimulus. Additionally, with simultaneous presentation of foreground and background optokinetic stimuli, dynamic visual spatial orientation relies mainly on the information from the background (12). An analogous situation, which illustrates the dissociation of focal and ambient vision, exists while riding in a car at constant velocity where self-motion sensation is produced by a relative backward motion of the surroundings rather than the stable image of the car. The driver looking in the rear view mirror is able to detect and to pursue single objects with respect to himself and in relation to the environment without affecting the sensation of self-movement.

A critical problem in vehicle guidance which can be better understood in terms of this approach is the high frequency of night driving accidents. Automobile accidents, of course, have multiple causes. The role of illumination is demonstrated, however, by studies which indicate that when other factors are held constant, accidents increase dramatically when illumination is lowered, particularly those involving collisions with pedestrians (13). It is well known that under twilight and nighttime conditions many visual capacities such as spatial resolution, stereoscopic depth perception, contrast discrimination, and reaction time are degraded. This is reflected in analyses of nighttime accidents in which drivers frequently report that they did not see a pedestrian or other obstacle in time to stop. In some cases, the sound of impact was heard before the driver was aware of the pedestrian (14). It is not necessary to read the visual literature in order to appreciate the fact that we simply do not see as well at night as during the day. What is curious, however, is that drivers typically do not reduce their speeds at night, even though they are most probably aware through personal experience, or even through knowledge of the literature, that their vision has been degraded.

A possible explanation for this paradox may be derived from the two modes of processing concept (15). Driving an automobile, in common with locomotion and vehicle guidance in general, involves two parallel tasks. Spatial orientation is accomplished by steering the vehicle, which requires continuous evaluation of the location of the vehicle relative to the road. In terms of the two modes concept, steering is concerned with "where" and is an ambient function. Driving also involves focal vision, the role of which is to monitor the roadway ahead for pedestrians, other vehicles and obstacles, to read traffic signs and monitor signals, and to judge the distance and speed of other vehicles. During daylight both the ambient and focal modes are operating at their maximal capacities. However, under twilight and nighttime conditions there is a selective degradation of the two modes. Focal visual functions are degraded, e.g., contrast sensitivity is diminished and spatial and stereoscopic acuity are reduced. (For many individuals the ability to appreciate detail is further degraded by a condition known as "night myopia" which will be discussed later.) On the other hand, the efficiency of ambient visual functions is not reduced by lowered illumination. As long as minimal visual stimulation is available, it is possible to steer the vehicle adequately. In terms of the performance information available to the driver, is the ambient mode which provides ontinuous feedback regarding the ability to steer the vehicle. Since the demands on focal vision are intermittent, its degradation is only rarely reflected in the operator's performance. The result of this selective legradation of visual function is that the lriver's self-confidence is inappropriate for the degraded focal visual function. Adding to the tendency to disregard focal degradation is the fact that since critical incidences involving focal vision while driving are rare their perceived risk is correspondingly low and they tend to be ignored (16). The net result of these factors is that drivers are typically unaware of focal degradation, rely on the efficiency of the ambient processes, and drive too fast to recognize and respond to infrequent hazards.

As is often the case, understanding the asic cause of a problem suggests methods for melioration. In the case of the high night-ime accident rate a number of possibilities re apparent. Obviously, illuminating ighways would be expected to be effective and his is supported by empirical observations. owever, economic considerations limit this ossibility. Other alternatives are to post ifferent maximum velocities for night and aytime driving conditions. Before the ntroduction of the uniform national 55 mph peed limit in the United States, only a few tates followed this practice, usually on ajor highways. To our knowledge, different peed limits have not been posted in areas here degradation of focal vision would be xpected to play a role in accidents with edestrians. Another possible measure is to ducate drivers regarding the potential angers associated with selective degradation f vision at night. This procedure would be xpected to be particularly effective for ounger drivers whose habits have not been stablished. The implications of selective egradation should also be communicated to edestrians and cyclists who should be ncouraged to take special measures to increase heir visibility at night in order to com-ensate for the loss of focal vision among rivers.

Another way to view the night driving ccident problems is in terms of the elf-confidence of the driver. It is not the azards and dangers of which we are aware which ause the most difficulty but rather those of hich we are not aware. Unjustified self-onfidence is often cited as the mechanism ccounting for the increase in accidents ollowing alcohol consumption. Alcohol is nown to increase self-confidence even at oncentrations which do not affect motor erformance. Considering the fact that the elective degradation of vision at night also produces an unjustifiable sense of self-confidence, the gruesome data on nighttime accidents involving drinking are somewhat more understandable.

ANOMALOUS MYOPIAS AND THE INTERMEDIATE DARK-FOCUS OF ACCOMMODATION

A long standing problem in visual science with implications for vehicle guidance has been that many individuals focus for near distances even when the object of interest is far away. Such inappropriate accommodation is maladaptive and is referred to as "anomalous myopia." The first report of an anomalous myopia was made in 1789 by Lord Maskelyne, Director of the Royal Greenwich Observatory, who noticed that he became nearsighted at night (17). This condition, referred to as "night myopia", has been a persistent problem for almost two centuries because it degrades the sharpness of the retinal image and interferes with the ability to appreciate distant detail under twilight and nighttime observation conditions. An analogous phenomenon occurs in daylight if visual detail is absent. When searching the sky or during a fog or snowstorm, the focus of many observers with normal distance vision corresponds to an intermediate distance, thereby reducing the probability of detecting small distant objects. Considerable attention has been devoted to this phenomenon, referred to as "space" or "empty field myopia", in military aviation (18).

Although anomalous myopia has been extensively studied by the international vision community, particularly in a military context, until quite recently there has been no explanation which would permit prediction of its magnitude or provide an effective means for amelioration. The chief obstacle was the classical assumption that the focus of the relaxed eye corresponds to optical infinity.

While this point of view predominates in most if not all textbooks in physiology and physiological optics, an alternative viewpoint has appeared sporadically in the literature. This alternative suggests that the "resting position" of accommodation corresponds to an intermediate distance rather than to infinity. Two arguments have been advanced in support of an intermediate resting position. Theoretically, as pointed out by H. A. Schober, the muscles controlling accommodation, in common with other muscles, should not be expected to assume a resting or tonus position at one extreme of their range. He also suggested that many visual phenomena, including the anomalous myopias, can be more parsimoniously interpreted in terms of an intermediate resting position of accommodation (19).

About a decade ago, the availability of low-cost lasers made feasible the construction of an optometer which accurately evaluates accommodation without affecting its magnitude (20,21,22). This instrument can also be used in situations in which the anomalous myopias are typically exhibited. Utilizing this new methodology, the validity of the intermediate resting position or dark-focus was empirically confirmed. Figure 1 represents the frequency distribution of the accommodation distance of 220 college students in total darkness (23,24). All observers wore their normal corrections during the observations. The average resting position of this group is at an intermediate value of 1.52 diopters, corresponding to a distance of 65 cms (26 in). Only a few of the subjects demonstrated the classical infinity resting position. The most striking feature of these data, however, is the large intersubject variability. As is typical of most biological measurements, the data are described by a normal distribution. Corresponding to the subjects who demonstrate an infinity resting position, the dark-focus of others was as close as four diopters or 25 cms (10 ins).

Demonstration of the validity of the intermediate as opposed to the infinity dark-focus, together with the revelation of the marked intersubject variability, has provided the key to both predicting and correcting the anomalous myopias. If one assumes, as has been the case historically, that the resting

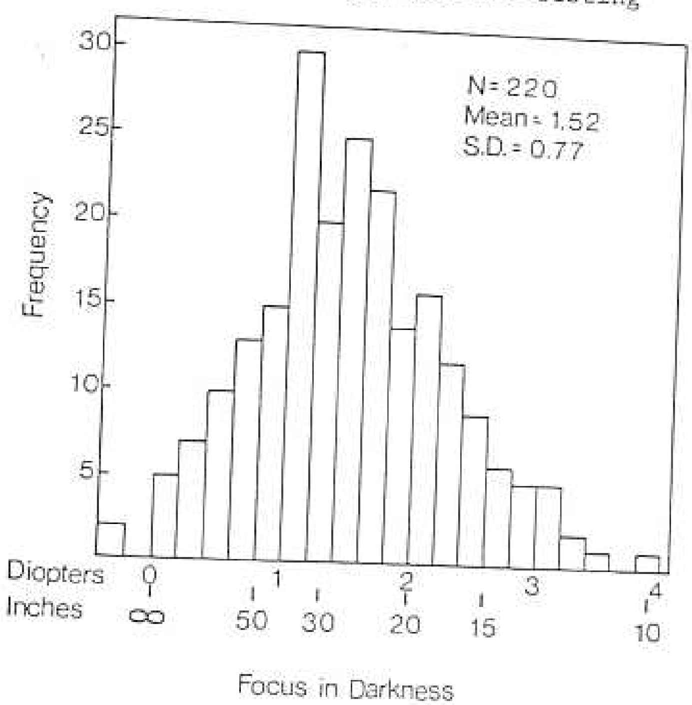
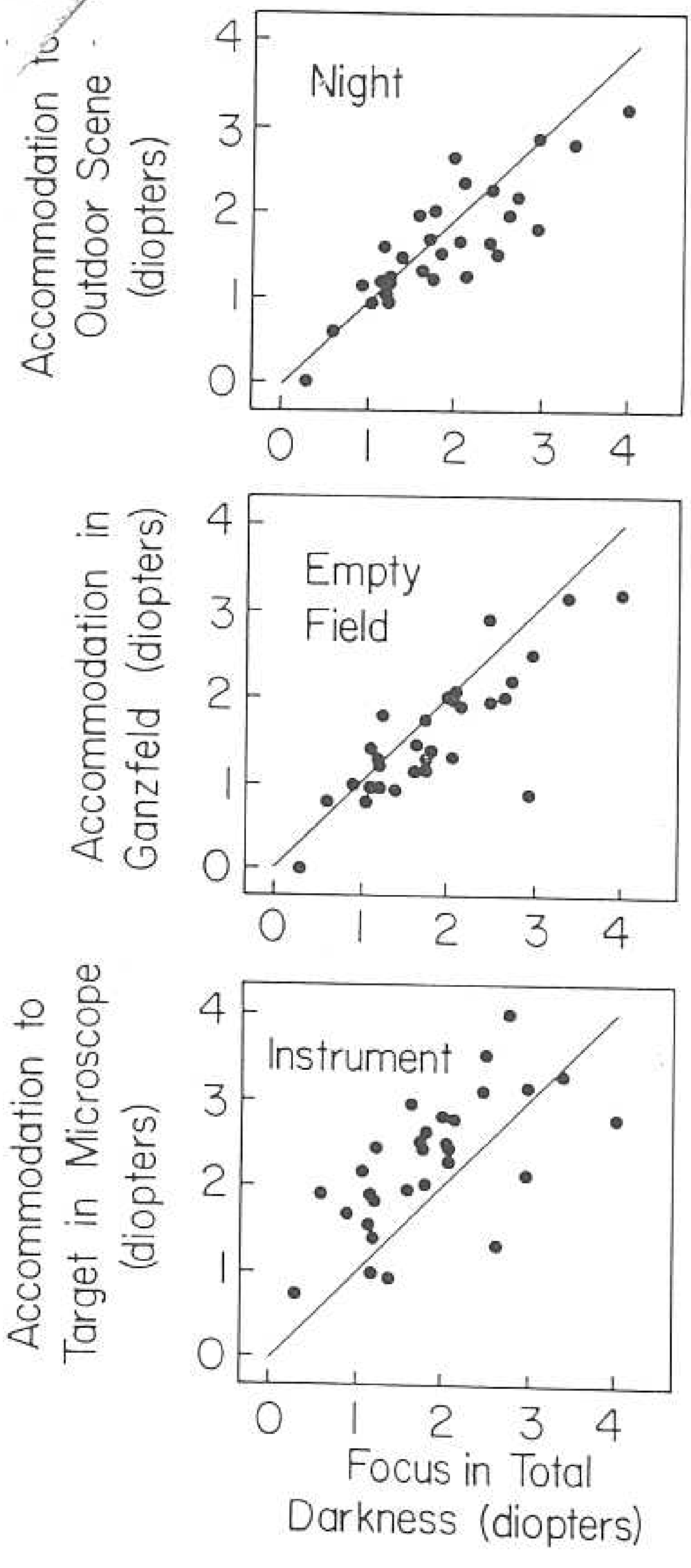


Fig. 1 - Frequency distribution of the magnitude of the focus in total darkness, as measured with the laser optometer, for 220 college-age observers. After Leibowitz and Owens, 1978 (24)

position is at infinity, then any accommodation to a distance nearer than the object of interest must represent an active maladaptive process. Alternatively, if the resting or tonus position of the accommodative system corresponds to an intermediate position, then any interference with the efficiency of the accommodative feedback loop would result in a passive return of accommodation toward the dark-focus. Furthermore, given the large intersubject variability of the dark-focus, anomalous myopias would also be expected to demonstrate comparable individual differences. Those subjects with an infinity dark-focus should not show any anomalous myopia, while those with near dark-focus values would tend to exhibit anomalous myopia in an amount related to their individually characteristic dark-focus values. There are a number of advantages to this latter interpretation: 1) It eliminates the paradox of an active maladaptive response for a system which is normally highly efficient, 2) it accounts for the failure of previous theoretical explanations to successfully handle the problem of intersubject variability, and 3) it suggests a simple test of its validity. Specifically, the magnitude of anomalous myopia should be predictable from the individual subject's dark-focus and should be correlated for all viewing conditions in which accommodation is degraded even though the stimulus conditions for specific anomalous myopias differ. In the case of night myopia, lowering illumination would be expected to interfere with accommodation because it restricts the ability of the neural structures to process contrast in the retinal image. For space myopia, even though illumination is high, there are no focusable contours available to provide the error signal necessary for the accommodation reflex. In both cases, the anomalous myopia should be proportional to the dark-focus.

In a test of this hypothesis, the magnitude of anomalous myopia was determined while: 1) viewing a distant target under twilight illumination (night myopia), 2) observing a bright field without contours (space myopia), and 3) while viewing a high contrast target under bright illumination in a microscope (23). This latter condition, designed to produce "instrument myopia", has minor performance implications but is of interest here because it represents still another example of anomalous accommodation. In this case, the small exit pupil of the microscope eliminates the need for accommodation. The magnitudes of anomalous myopia obtained under these three viewing conditions are presented in Figure 2 as a function of the dark-focus of the individual subjects. On these plots, if accommodation corresponds to the individual subject's dark-focus, the data should fall along the slanted



ig. 2 - Magnitudes of night, empty field, and nstrument myopia as a function of the focus in he dark. Each point represents a datum for an ndividual subject who observed in all three ituations. After Leibowitz and Owens, 1975 23)

lines. It is apparent that the anomalous myopias can be accurately predicted from the dark-focus values, and that the magnitude of the anomalous myopia for individual subjects is the same for all three viewing conditions. The agreement is better for night and empty field observation conditions than for instrument viewing presumably because the eyepiece of the microscope influences convergence which in turn induces accommodation as a result of the normal coupling between accommodation and convergence.

With the ability to predict the magnitude of anomalous myopia and to understand the underlying mechanism, the means for amelioration follow logically. In the case of night myopia, a number of previous studies indicated that viewing through a negative lens sometimes resulted in improvement. However, some subjects were not helped at all while still others saw more poorly. In view of the intersubject variability in the dark-focus, these results would now be expected. Based on this variability, it was hypothesized that any correction should be related to the individual subject's dark-focus value. This assumption has been successfully tested in both field and laboratory studies (25) which demonstrated the optimal visual correction for driving at night or under simulated night driving conditions to be approximately one-half of the individual's dark-focus value. In laboratory and field studies based on this rule, all of the subjects tested so far with a dark-focus nearer than infinity have demonstrated improvement in their ability to appreciate detail under twilight and nighttime observation conditions. Similar results have been reported in laboratory studies of space myopia. In this case the detection of a small target in a bright unstructured field is significantly improved by a correction which corresponds to the subject's dark-focus value (26,27). Within an aviation context, a significant improvement in the sighting range for small objects in the atmosphere would be expected with this correction. The difference between the approximately half dark-focus correction for night myopia and the full dark-focus correction for space myopia follows naturally from the specific basis of accommodation degradation. Under nighttime driving conditions the stimulus to accommodation is reduced but not completely eliminated, but with space myopia there is no stimulus to accommodation whatsoever, and accommodation returns completely to the dark-focus.

The empirical demonstration of the validity of the intermediate dark-focus and particularly the large intersubject variability has provided a simple yet effective basis for understanding and ameliorating the anomalous myopias. The general rule is that for visually demanding conditions, including but not limited to night driving and aviation, improvement in the quality of the retinal image will result from a spherical correction which shifts the distance at which no accommodative effort is required to or toward the distance of the object of interest. This correction eliminates or reduces the need for active accommodation and the potentially deleterious effect of focusing errors resulting from interference with the accommodative feedback loop.

The findings regarding the dark-focus of accommodation imply that vehicle driver licensing evaluations should include a test for night myopia since wearing a special prescription would be expected to substantially improve nighttime visual performance. Data on a university aged population in the United States (17-21 years) indicate that, based on an assumed nighttime refractive error equal to one-half the dark-focus, 76 percent of this group would be at least 0.5 diopter nearsighted at night, 26 percent would have a night refractive error of at least one diopter and four percent more than 1.5 diopters. The significance of these levels of optical blur can be appreciated when one considers that refractive errors of 0.25 to 0.5 diopter are typically corrected clinically and a non-correctable spherical error of 2.5-3.0 diopters corresponds to legal blindness in the United States.

It should be pointed out that our current understanding of this problem does not permit an immediate translation into driver licensing procedures. Problems of individual visual and oculomotor characteristics, the effects of driving conditions and habits, and the role of experience and age remain to be analyzed clinically. However, at present we have strong evidence that a correction corresponding to approximately one-half the dark-focus is a good first approximation, as it has been shown to increase image clarity at night in both laboratory and field studies (25). Such a correction should therefore contribute to the efficiency of vision under reduced illumination conditions.

CONCLUSIONS

Night driving will always be hazardous. To the extent that the danger is caused by night myopia, it can be fully corrected by a simple optical procedure. However, since part of the problem has to deal with the unjustified confidence which follows from the selective degradation of focal and ambient vision, other techniques are required. These include making drivers aware of the selective nature of visual loss at night, increasing the visibility of hazards, and promotion of driving regulations which take these basic visual functions into account.

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