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ISBN 0-315-55683-8

Canada

Night Driving: Three Simulated Car Headlight Parameters as Static Distance Cues to Oncoming Vehicles

Thesis submitted as a partial requirement for the degree of Master of Science in Applied Psychology

Saint Mary's University

Halifax, Nova Scotia

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July, 1988

Thesis supervisor

Internal advisor

External advisor

External examiner

Student

ACKNOWLEDGEMENTS

I would like to express my gratitude to my thesis supervisor, Dr. Robert Konopasky for his patient guidance and for his long-distance supervision. Dr. James Darley deserves a lot of credit for his role as internal adviser and for agreeing to help on such short notice. Je veux aussi exprimer ma reconnaissance au Dr. Keith Fillmore, du département de physique, pour m'avoir aidée à mieux comprendre la matière, et pour avoir pris le temps de m'expliquer en francais comment écrire une thèse en anglais. Special thanks to Faizal Junus who spent several hours helping me buy the equipment and build the apparatus.

Mon retour aux études a été possible grâce à Roger Girard et son aide constante m'a permis de mener ce projet à terme.

Getting through this task was made less painful by the direct assistance and encouragement of the "without whom department"; these people have shown me the true meaning of friendship and for this I am forever grateful: Glen, Denise, the gang at AKC, Denis, Fernanda, Diane, and all the others for whom there is not enough room on paper but more than enough in my heart. To Norma, for teaching me English and for having faith in me, when even I did not, merci.

Danielle Fortier

TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

ABSTRACT

Many motor vehicle accidents involve a driver's misperceiving the distance to another vehicle. As headlight configurations are not standardized, drivers are confronted with headlights differing in size, separation distance, and brightness. These three headlight variables were investigated in independent laboratory studies, with regards to their effect on the estimation of distance of a simulated vehicle.

In each experiment, ten adult subjects estimated the distance to a simulated vehicle's headlights. "Headlights" were varied in terms of brightness, size, and separation distance between the lights.

The apparatus consisted of a long dark tunnel in which extraneous cues to the distance of the actual light stimuli were reduced. Dark adapted observers sat at one end and viewed light stimuli presented as one pair of "headlights" at a time. According to the method of magnitude estimation, three standards of distance in the form of three pairs of simulated headlights were presented to set a general scale of response. Test presentations of lights varied around the three standards, or target distances. The stimuli ranged from 40% less bright, less large, or less distance between the lights to 40% brighter, larger, or more separation distance, around the standard for specific target distances.

Both the effects of "target distance" and "levels of variation" were highly significant. Positive linear trends were found for both factors. Pairwise comparisons revealed that the power of discrimination in observers was better with the larger variation in size of lights, brightness, and distance between lights. The errors made in estimating the standards established were not significant; neither were correlations between age, years of driving experience and the error of these estimations.

Lack of consistency in discrimination between levels of variation in size of lights, brightness, and distance between lights prevents any strong suggestions about standardization of headlights in the three variables under study. On the other hand, further research on direct distance estimation from psychological scaling of physical stimuli is justified by the results obtained in these three experiments.

INTRODUCTION

PURPOSE

This study investigated the relationships between headlight characteristics and observers' estimations of the distance to the oncoming car. It was hypothesized that size, brightness, and separation distance of headlights serve as distance cues; it was suggested that these cues play a role in the decision-making process of a driver/observer.

The variables were investigated separately in laboratory, rather than the field, in order to exercise full control over these cues. The findings suggested that observers are dependent on these cues in estimating the distance to the "vehicle". It was suggested that non-standardized headlight parameters could confuse drivers. Field experiments in a natural context should be carried out to determine whether the findings of these studies would be replicated outside of the laboratory.

ACCIDENT STATISTICS

Failure to detect light signals both soon enough and to interpret them correctly has resulted in innumerable accidents in all modes of transportation.

According to the Nova Scotia Department of Highways, 17,918 accidents happened between January and December 1984, 170 of which were fatal. A disproportionate number of accidents happened during late afternoon (7%), or after dark where roadway lighting was missing (39%). Similarly, Perel, Olson, Sivak, and Medlin (1984) found the night time accident rates to be three times the day rates Sometimes, accidents are attributed to adverse weather conditions which, like rain and fog, restricted visibility and conspicuity of the vehicle.

Among the causes of accidents, "recklessness" of the operator, "inattention", "failure" to grant right-of-way, and following a car "too closely" resulted in many fatal and non-fatal accidents. But it may be that "recklessness" and other driver errors could be minimized by standardizing light signals provided by vehicles.

NIGHT DRIVING PERCEPTION

Motor vehicle accidents usually involve one of mechanical failure, environmental conditions, or human factors (Sivak,1984; Forbes,1972). Human factors can be studied profitably to reduce accidents. For example, visual perception follows some precise and constant laws to give us images of perceived objects on the retina of the eyes (Cornsweet, 1970); from those images, we make judgments and decisions. But if the objects to be perceived are arranged such that they are misinterpreted, the decisions can be disastrous.

Misperceiving the distance to an oncoming vehicle while passing another car or turning left are just such cases. In addition to the cues provided by the car itself such as its size, position, and velocity, several environmental cues are available to the driver, including the painted midline, painted posts, and the horizon to give her/him some idea of the stretch of road lying between the vehicles. In the night driving situation, the driver must face the same task and responsibilities (stay on the road, avoid obstacles, pedestrians, animals, steer clear of other vehicles, etc...) with a lot less visual information than during the day. In fact, the information is often restricted to the area lit by the headlights installed on the car. At night, the broad fields of view of daylight narrow to the region illuminated by artificial lighting; objects are seen under lower contrasts and non-uniform illumination, which makes detection difficult. As ambient light decreases, colors fade, shadows disappear, resolution is lowered, and object detail vanishes. Peripheral vision is reduced, causing the driver to modify search and scan behavior. Increased glare causes eye strain and fatigue and further increases the difficulty of detecting hazardous objects (Hukulak, 1982).

More specific visual cues for the depth and distance of an object are available in the daytime, such as linear perspective, texture gradient, interposition and relative size of objects, motion parallax, and even the size of the retinal image of an object (Boring, 1946; Holway & Boring, 1941); but at night, the number of cues available to the driver are reduced and the driver must rely on his/her perception of the light signals of an oncoming vehicle to judge its direction, speed, height, and distance. The difficulty of doing this is demonstrated in part by the poor performance of drivers in being able to stop safely, read signs, and follow the road path (Perel et al., 1984).

VARIABILITY IN HEADLIGHT SYSTEMS

Headlamps are the primary source of illumination for drivers on unlighted roads. The design goal of headlamps is to illuminate the roadway and potential hazards without subjecting oncoming drivers to excessive glare. There are a number of headlamp design characteristics which can influence driver vision including beam pattern, intensity, and lamp construction. Misaim, dirt, or incorrect voltage can also affect headlight performance and the driver's capability to avoid accidents (Finch, 1970).

Since present headlight standards are for the most part performance specifications of brightness and light output, considerable latitude is allowed in the size, shape, location, and other physical attributes of the lighting device. Beam intensity and pattern can vary from manufacturer to manufacturer (Henderson, Ziedman, Burger, and Cavey, 1984). In American-made passenger cars, trucks, and buses, a major difference lies in whether the two-lamp (7 inch diameter) or the four-lamp (5 3/4 inch diameter) system is used. In the latter system, the two lamps on the same side of the vehicle are arranged either horizontally, vertically, or diagonally.

There are unique problems associated with the design and use of a vehicle's forward lighting system

(Finch, 1970). It must project sufficient light ahead of the vehicle to reveal the roadway and nearby objects out to distances of about 200 meters or more. At the same time, the projected high-intensity beams should not seriously handicap the driver of an approaching vehicle, nor should the projected light interfere with the vision of a driver in a vehicle proceeding in the same direction ahead of the subject vehicle.

One of the major differences between European and American lamps is in construction (Perel et al., 1984). Contrary to American lamps, European lamps are not hermetically sealed and consist usually of a glass lens glued to a metal reflector. Although economical and more versatile in appearance, these lamps suffer from accumulation of dirt and moisture on internal surfaces and from the oxidation of the reflector, affecting lamp performance and durability. Another major difference between the two types of headlamps is the method of adjusting their aim. European lamps are aimed visually by projecting the beam on a screen which is subject to human error; U.S. beams are aimed mechanically.

Because headlight configurations are not standardized, oncoming vehicles present drivers with headlights differing in size, brightness, and separation distance as well as colour, number, shape, and combinations. The literature suggests that present vehicular lighting practices are associated with a high accident and fatality rate (Sivak 1984). Consistent with this observation, Allen (1966) examined data on highway safety and found that white running lights should always burn steadily, and locate the position of the vehicle best when placed low and kept at standard brightness, size, and separation distance.

A driver's state of expectancy is an important determiner of the perception of distance to an oncoming vehicle. Standardization of headlight design would allow drivers to develop consistent expectations of the distance to oncoming cars and would result in faster, more accurate decisions.

LITERATURE REVIEW

HISTORY

Headlamps, like many vehicle components, have evolved over a long period of time. The first lamps used on automobiles around the turn of the century were the same oil or kerosene carriage lanterns found on horse-drawn vehicles of the time (Finch, 1970). The need for better lighting quickly became apparent with the rapid rise in both the number and speed of motor vehicles on the road; by 1910 many cars were equipped with two acetylene-burning headlamps and with a red tail lamp (Devaux, 1970). At about this time, the electric lamp, which showed greater efficiency and operating convenience, made its first appearance on automobiles and was soon adopted as standard equipment for the growing motor vehicle population. Incandescent bulbs used with parabolic reflectors provided a beam of concentrated light, but unfortunately, was glaring to approaching drivers.

As the density of traffic increased, the need to design a meeting beam (low beam) became clear. In later years, electric headlamps improved light output, beam distribution, and effective light control. One of the most significant developments in the evolution of the headlamp was the introduction in the 1930s of the sealed-beam unit. Between 1955 and 1959, changes included fog caps near filaments, mechanically aimable beam units, and four-lamp systems. In the 1970's, rectangular two and four-lamp systems, and later still, quartz-halogen technology were introduced (Perel et al., 1984).

Despite obvious improvements in automotive lighting, there may be some question about whether all of the needs have been adequately met. The current thrust of automobile lighting research is for an improvement of visibility conditions and a decrease of glare when several vehicles approach each other.

ACCIDENTS

Even though there seems to be very little information specifically relating vehicle lighting to accidents (Davison, 1978; Sivak, 1984.), there is general agreement among authorities in the field that certain lighting problems exist and that improvements in these areas would benefit drivers (Olson & Sivak, 1983., Forbes, 1972) .

National statistics do generally show the fatal accident rates to be greater at night than in the daytime which is consistent with the notion that visibility is a problem.

HUMAN FACTORS: Driver vision

In an effort to understand the causes of traffic accidents, researchers have worked to identify the major perceptual factors related to traffic accidents. The main variable related to accidents is driver vision, the other human causes of accidents being fatigue, recklessness or inexperience, substance use, and old age.

Not all drivers are affected to the same degree by the nighttime visual environment which is associated with increased glare and decreased contrast sensitivity. For example, drivers with visual deficiencies such as poor peripheral acuity or night myopia often show more nighttime driving problems. Drivers who are fatigued are more adversely affected by the nocturnal environment because of the additional work required to scan the road and search for possible hazards (Perel et al., 1984).

The clinical measure of visual acuity, in terms such as 20/20, refers to the distance at which standard letters are legible. Visual acuity declines with lowered contrast and with reduced illumination, and it deteriorates with age, particularly after 50 (Versace, 1970). It is interesting to note that errors of perception by the driver are a major contributory factor to accidents and yet, the driver's level of vision is only weakly related to his accident's rate (Cobb, 1939; Burg, 1967; Hills and Burg, 1977; Davison, 1978; Hills, 1980).

METHODOLOGICAL PROBLEMS OF ACCIDENT STUDIES

The question of why the vision tests are so weakly related to driving performance has been partially answered by Burg (1971) who states that vision is only one of the many many factors which influence driving performance. Given the unspecificity of the two variables, that is, driver performance and quality of vision, it is unrealistic to think that one specific measure of one variable will necessarily correlate strongly with a specific measure of the other variable. Also, even if the visual potential of an individual is known, there is nothing to prove that he actually uses all that potential all the time when driving. A very important point made by Burg is that the visual functions actually utilized in driving may not be properly tapped by the vision tests used in research. As well, the reliability of the criterion measure of driving performance may be low, adding to other methodological problems like unsuitable samples which do not fairly represent the driving population, and lack of experimental or statistical control over relevant variables.

Methodological problems become obvious in analysing the data because of the lack of independence between the independent variables and particularly, because age is related to vision scores. Also, accident rates are rarely classified and compared to the appropriate vision scores (night time or day time); the proportion of accidents caused by poor night vision is substantially smaller than that caused by substance intoxication and fatigue. To be effective, night vision tests should employ illumination levels and adaptation conditions which are similar to what the drivers encounter in their night driving environment (city: mesopic conditions or higher illuminations; unlit highway: scotopic conditions.).

Still, the fact remains that most of the studies on visual acuity for static targets (common test for driver licensing vision requirements) and accident rates produced weak positive associations and usually only for certain subsamples of drivers which were either older or accident repeaters (Hills, 1980).

Hills and Burg (1977) suggested that more appropriate tests of both vision and perception should be developed which incorporate the complex visual tasks involved in driving. They added that eye marker studies (continuous film record of the driving scene produced with a superimposed spot of light indicating where the driver is looking at any instant) revealed the small proportion of the visual scene which a driver can see in detail in a flash, that is one or two seconds, and the crucial importance of scanning, searching, and predicting skills as well as the decision-making process.

NEW DEVELOPMENTS IN STUDIES ON DRIVER VISION

The current research trends at the Transport and Road Research Laboratory (TRRL) in Crowthorne, Berkshire, have shifted from acuity tests to tests of contrast sensitivity (Hills and Burg, 1977). Preliminary results with the new tests fired new hope in finding accident predictors, as the scores of the tests correlated strongly with drivers' observed speeds (deceleration) in fog, as compared to other visual acuity scores.

Other laboratory tests like Dynamic Visual Acuity, Kinetic Visual Acuity, and Angular Movement Test have been developed recently to look at other aspects of driver vision. The Dynamic and Kinetic Visual Acuity tests use moving targets that the "driver" must identify or stop with a foot pedal. The association coefficients between those tests and accident records have been superior to those for static acuity. The Angular Movement test is a test for detection of movement and uses two small light sources and their separation distance to simulate a decelerating preceding car. Another test called Motion in Depth simulates the same situation by using a disc shaped target with variable size. The last two tests have also shown positive associations with conviction and accident records.

At the University of Michigan Transport Research Institute (UMTRI), computer programs which predict seeing distance to various targets as a function of the headlamps selected, their location and aim, target position, and other variables are being developed

(Sivak, 1984).

ENVIRONMENTAL VARIABLES IN DRIVER PERFORMANCE

Along with human factors, environmental variables play an important role in driving performance. Gordon and Schwab (1979), and Schwab and Capelle (1979) summarized the highway engineer's concerns with environmantal cues such as signs and markings, and the crucial question of measurement of visibility, legibility, and conspicuity. Gordon and Schwab (1979) consider the following as the most important environmental factors: the size and shape of the object; the contrast between the object and the background; the luminance adaptation level to which the eye is previously exposed, and the time available for seeing. In order to investigate these variables, they ran a typical laboratory study of visibility where trained observers guessed in which of seven positions a faint disk of light appeared. Results showed that the target diameter and background determined the detection of the disk and that increases in background luminance corresponded to decreases in threshold contrast, all consistent with the theory on brightness perception (Hurvich and Jameson, 1966).

Laboratory studies have also helped narrow down the conditions of detectability of an object to the four most significant: visual size of the object , its luminance and colour contrast with its background, the luminance level of the background, and the proximity and intensity of any glare sources in the field of view (Hills, 1975).

GLARE AND HEADLIGHTS

One specific area that has received a great deal of attention in headlight research is glare. Glare produces two effects, glare discomfort and disability glare (interference with vision). Small glare spots, even though they are off the axis of view, reduce forward visibility because of the adapting response of the eye and because the glare light scatters within the medium of the eye ball, producing a luminous veil that masks the scene being viewed (Hartmann, 1963). Visual objects having only marginal contrast will disappear from view; the veiling effect rapidly declines with increase in the off-axis angle to the glare source.

Most work on glare (Mortimer, 1974; Pulling, Wolf, Sturgis, Vaillancourt, and Dolliver, 1980; Hukulak, 1982; Sturgis and Osgood, 1982) has been done in connection with highway lighting and the illumination of commercial and industrial work places. The interest is shared by lighting engineers who have been working for years to develop an ideal headlight system which would allow maximum visibility distance and minimum dazzling for oncoming drivers. Right now, results show that low-beam headlamps are inadequate for safely revealing low-contrast objects, even at legal driving speeds (Olson and Sivak, 1983).

The physiological bases of glare impairment in aging revealed that it is due to gradual degeneration of the eye lens. Its tissue can develop small growths which cause variations in the index of refraction of the lens material from one part of the light path to another. In turn, those variations result in the degradation of the image contrast and in the difficulty of the eye in seeing low-contrast objects at night. Other components of the eye have been known to suffer tissue degeneration and contribute to the scattering of light over the retina, namely the cornea and the vitreous body.

Pulling et al.(1980) found that decreasing headlight glare resistance with increasing age can have a significant impact on the ability of the drivers to drive under many night conditions. Similarly, Sturgis and Osgood (1982) found in their study that visual acuity decreased significantly with both increasing age and decreasing background luminance. In addition, threshold target luminance (amount of light necessary to be perceived) increased significantly with age, and glare had a multiplicative effect on threshold target luminance which was independent of age.

Pulling et al.'s (1980) suggestions to help solve the glare problem included the following: polarizing headlights which offer many technical and economical problems (Yerrell, 1976); glare screens (basically anything that will stop light from the oncoming car from reaching the driver's eyes) in medians, ramps, and bridges; road delineation as a partial aid to the driver; highway lighting, which reduces the glare; and driving restrictions for people with low physiological glare thresholds.

Screening tests

The most common measure of vision used to screen driver license applicants, at least in the United States, is static foveal visual acuity, or the ability to resolve spatial detail under normal illumination.

It is clearly an unacceptable screening procedure since the quality of vision is highly variable under low illumination conditions (Pulling et al., 1980). A number of night time vision testing procedures based on the measurement of contrast sensitivity or static acuity under glare and/or reduced illumination were developed in laboratory, and it was found that the veiling effect of glare increases with age; as well, contrast sensitivity declines with age over a wide range of luminance conditions in the absence of glare (Hartmann, 1963). One of the implications from Pulling et al's, and from Sturgis and Osgood's results is support for the usefulness of a static visual acuity test procedure in identifying drivers who have substandard low-luminance vision.

Improvements in headlights

It appears from Sivak (1978), Yerrel (1976), and Mortimer (1976) that high intensity lamps with a dual intensity system (high for daytime, lower for night time) or even a triple intensity system (highest intensity for fog conditions) would circumvent the glare problem. In Europe, the tail lamps are much brighter than on north american cars and present advantages for fog conditions, but they also emit too much glare to following drivers at less than 35m.

In glare studies, one thing that stands out is the lack of conformity of low-beam lamps to the photometric standards developed by the Federal Motor Vehicle Safety Standards 108, which were taken from those of the Society of Automotive Engineers (SAE), (Olson and Sivak, 1983; Perel et al., 1984). Guidelines for design and quality control are not uniform in the industry and there is a possibility that some lamps will provide more or less glare than specified in the standards. This variability is not quantitatively known and questions arise as to whether absolute limits should be set for standards based on operating safety. The accident literature to date has not clearly indicated that there should be mandatory changes in photometric values of low beams based on safety criteria.

In order to determine what changes in automobile low-beam lighting specifications might improve night time performance, Olson and Sivak (1983) carried out a literature review, and then completed several laboratory and field studies to investigate discomfort glare, foreground illumination, beam colour, and system performance of headlamp beams. From the recommendations on photometrics made in the first phase of the project, they built an experimental set of lamps which allowed subjects to perform better in a target identification study than did other standard and experimental lighting systems.

Discomfort glare studies which followed, using the 9-point DeBoer rating scale (from 1 = unbearable to 9 = just noticeable) (Olson and Sivak, 1984; Hartmann, 1963; Pulling et al., 1980) showed that it was the range of stimuli presented to the subjects that had a significant effect on judged comfort, and that subject age or beam colour had practically no effect. The yellow headlamps used in France, which are supposed to be better than regular white lamps in fog, were found to have no objective advantage (Devaux, 1970).

Light performance studies

Differences in characteristics between automobiles and trucks were examined, specifically driver eye height, headlamp mounting height, and lamp aim (Mortimer, 1974). With computer simulations at nighttime, he measured visibility distributions and direct and indirect mirror glare discomfort, and concluded that low beams on trucks should not be mounted at more than about 0.71m from the ground level. But as of now, there is still a lot of variability in lamp mounting height on trucks.

The studies on foreground illumination showed that an increased level caused the subjects to look further away from the car and that different levels had no effect on target identification distance (Versace, 1970; Davison, 1978). Although the experimental lamps designed by Olson and Sivak (1983) were better for target identification, they did not outperform other systems when it came to safely revealing low-contrast objects at legal maximum speeds. "Real-world" conditions like wet-road glare, rainfall, fog and so on are problems which the system cannot eliminate. The current goal is an ideal system for all weather conditions and minimal glare discomfort.

The Transport and Road Research Laboratory in Crowthorne, U.K. did attempt to develop headlamps with changeable beam patterns and a beam being controlled by the light from oncoming vehicles. The "Autosensa" worked with two shutters with controllable positions, and a detector between the two, which sent the controlled signals (Kaghazchi, 1975). This device turned out to be larger, more sophisticated, and like polarized headlights, much more expensive than a regular headlight; the project was shelved.

CONSPICUITY

Even though headlamps were primarily intended to provide visibility of roadway and objects, they also serve to increase the recognition of a vehicle or vehicle conspicuity. Vehicle design indicated that vehicle conspicuity is an important goal. For example, three-light identification clusters and mud flaps on buses and trucks, retroreflective material on bicycle pedals and tires and on motorcycles all help define those vehicles as well as enhance the perception of what the vehicle is doing. The importance of studying the link between vehicle conspicuity and the probability of accident involvement becomes clear when one listens to accident reports which invariably will include: "I just did not see..."

The most important aspect of vehicle conspicuity, the ability to attract attention, is strongly dependent on the driver's own attention state. In turn, the driver's focus is influenced both by his internal processes as well as by the external environment. Age, alcohol, drugs, fatigue, and experience can all affect the information processing rate and thus, the efficiency with which drivers can respond to and integrate the conspicuity characteristics presented by other vehicles.

Unfortunately, depending on the type of study, it is very difficult to isolate conspicuity factors from general perceptual and visibility factors, when looking at accident data. Controlled field studies usually give adequate data with good validity but this methodology is limited because of its cost. Accident causality studies are only partially useful because it is difficult to isolate some factors from others in naturally occurring phenomena (Henderson et al., 1984).

In terms of the visibility of the vehicle (conspicuity) and criteria for improvement in that field, Allen (1966) had some very precise views on vehicle lighting. He claimed that vehicle conspicuity would be enhanced by lights on the front and back of the car being lit at all times. He also pointed out that colour of the lights was important and should be white for the headlights, blue-green for tail lights which should be about 24 inches above the pavement on all vehicles: "Localization is better at night if fill-in light falling on the vehicle and on the highway is also provided, and if reflectorisation is used to outline the vehicle" (Allen, 1969, p.99).

Daytime running lights

Research on the added safety effects of driving with lights on at all times has been extremely convincing (Grescoe, 1984). So much so, that the traffic-safety experts at Transport Canada suggest that new cars should be equipped with daytime running lights like those on Scandinavian cars. Since 1972, Finland has required that headlights always be on during the winter; Sweden made the use of low-beam headlights or special automatic running lights a year-round law in 1977; private companies in the U.S. have conducted similar research and all of the evidence suggests a significant reduction in daylight collisions (Grescoe, 1984).

Our provincial laws used to require that car headlights be on from half an hour after sunset to half an hour before sunrise, but researchers at Transport Canada's Road and Motor Vehicle Traffic Safety Branch have recommended a full hour extension of lights on at dawn and dusk. New Brunswick was the first province to implement the dusk-dawn lights-on extension, but more provinces are starting to "see the light".

A probable cause of many daytime collisions is inaccurate judgement of distance and closing times in passing situations. Drivers are extremely poor in estimating gap times and distances in overtaking situations and other conflict situations such as merging and intersection manoeuvres (Rumar and Berggrund, 1973. These judgements seem to depend, in part, on lighting. Vehicles were judged to be closer as their headlight intensities increased (Horberg, 1977). Attwood (1976) obtained judgements of minimum safe passing distances in a closed course study in simulated passing situations with a lead car and an oncoming car. He used three headlight conditions, on, dim, and off, and two ambient illumination levels, dusk-dawn and daytime. Attwood found that headlight intensity had a significant effect on mean safety gap, the distance needed to pass a car safely. This distance decreased steadily from the "on" position towards the "off" position; the lights-off condition at the dawn-dusk illumination level resulted in hazardous judgements.

It seems that the use of headlights during the day increase the conspicuity of the vehicle and its contrast with the background, as well as the awareness of other drivers. They might slow down or refrain from passing a preceding vehicle because they judge a lit vehicle to be closer than it really is. Allen (1969) found that drivers stayed closer to the centre of their own lane when an oncoming car had its low beams on.

Daytime motorcycle-car collisions were studied to provide insight in the matter of daytime running lights. Accident statistics in American states which required motorcycle lights to be on at all times were compared to statistics in states which did not have this requirement (Waller and Griffin, 1981). They found that lights-on laws reduced motorcycle daytime accidents by about 3% to 5%, with an additional reduction in daytime multi-vehicle/motorcycle accidents. In response to the compelling evidence on daytime running lights, most major car manufacturers implement these lighting devices on vehicles made after 1987 or 1988. Attwood (1981), formerly from Transport Canada, estimated that the annual cost of using existing low beams as daytime lights would be about $25 per vehicle, and might be less if cars were equipped with lower-voltage running lights (See Appendix I).

APPRECIATION OF DISTANCE

The next section provides an introduction to distance estimation which will be discussed more extensively in the specific literature section on perception of distance.

The nature of drivers' responses to degraded visibility conditions, be it rain, snow, fog, or unlit highways, is of particular interest. Henderson et al. (1984), defining safe speed in terms of distances at which other vehicles and objects are likely to be detected and a safe stop is still possible, report that drivers generally exceed safe speeds in nearly all conditions of substandard visibility.

Visual cues for distance and depth perception

Appreciation of distance is sometimes linked with depth perception, although depth generally refers to the perception of the distance of two objects relatively to each other. The notions of overlapping of contours, stereoscopic effect, convergence, and accommodation are all related to perception of depth. Convergence is negligible for objects farther away than about 2 meters, and accommodation is almost the same;

the stereoscopic effect (the two eyes observe the object from slightly different vantage points resulting in small differences in the images on the two retinas which the brain interprets as a distance) can be measured to a large distance but is really not very effective after approximately 100 meters.

At night, few distance cues are available and distance estimation depends largely upon the size of the visual object. In the case of vehicles, this would be indicated in part, by the spacing between tail lights or headlights. Thus, the visual angle subtended by the lights is the primary stimulus for making a distance estimate (See Appendix C).

The luminous intensity of the visual object also affects our estimate of distance; the dimmer headlights are, the more distant we judge the car to be. However, brightness is apparently greatly dominated by visual angle in judging distance, so that a pair of dim lights might not seem to be much farther away than a pair of equally spaced bright lights at the same distance (Cornsweet, 1970; Coules, 1955).

Perhaps, brightness is the less salient cue because we are not as good at judging differences in brightness. The subjective brightness of a light does not change if the lamp area and the candlepower are both doubled. As an approximation, the luminance of a lamp must increase tenfold to appear twice as bright subjectively, depending upon the driver's adaptation state and individual differences (Stevens and Stevens, 1963).

Distance estimation

Hoffmann and MacDonald (1978) attempted an investigation of different conditions on the judgement of the distance of a small light placed near the road surface. They examined the power law relationship between perceived distance and real distance in outdoor versus indoor (by means of a film presentation) experimental situations. As the film presentation offered visual stimuli in a two-dimensional plane, it was impossible for subjects to use binocular parallax, motion parallax, or accommodation in judging the distance.

Nonetheless, they did find that, using the method of fractionation ratio (FR), the perceived fractional distance was significantly correlated with real distance yielding straight line regressions; the value of the power law exponent was less than 1 in 27 out of 30 cases.

TAIL LIGHTS

The literature and research on car headlights deals primarily with performance of light systems and glare discomfort. Although it is clear that variability in front light systems is problematic, researchers have not spent much time examining the effects of basic variables such as size of headlights, their separation distance, and their brightness, on the estimation of the distance of the oncoming car.

In order to learn more about these variables, two other areas were explored: the literature on tail lights, and the principles of psychophysics. The latter will be discussed in the literature section on perception of distance. A rather extensive discussion of tail light research is presented here because the variables studied are directly related to the present study.

Some of the cues of movement perception are changes in the pattern of stimulation on the following driver's retina which accompany a change in the relative position of the preceding vehicle's tail lights (Janssen, 1977). Changes in the configuration of tail lights can serve as cues to movement detection.

The changes in light configuration used by drivers are a change in the horizontal angle between the tail lights and a change in the angular size and apparent brightness of each separate light.

Work on the effects of functional separation and color coding of tail lights upon driver performance has measured reaction time, errors made, and number of missed signals (Olson and Sivak, 1983; Colbourn et al., 1978; Janssen, 1977; Janssen, Michon, and Harvey, 1976; Post, 1975). The evidence from these studies suggests that: "The standard configuration commonly employed on domestic and foreign automobiles up to the present time is not as effective as some of those which have been investigated experimentally" (Olson and Sivak, 1983, p. 1178).

In his literature review of applied research on rear lighting and signaling, Sivak (1978) focused on colour, spacing, position, and intensity.

Colour

With regards to the colour issue, there is lack of agreement among researchers; experimental results both support and oppose a change from red to an alternate colour. For instance, drivers perceive red lights as further away than amber, green, or blue lights at equal intensities and distances (Rockwell and Safford, 1968); on the other hand, red lights seem to enhance conspicuity of the vehicle in fog and during daytime (Post, 1975).

Spacing

Overall results from studies reviewed by Sivak (1978) show that the wider the horizontal spacing between tail lights, the better was reaction time, perception of tail lights, displacement threshold of the leading vehicle, and percent missed signals in the case of signal lights.

The rationale for mounting presence lights as far outboard as possible was explained by Janssen (1977). Two types of changes in the leading vehicle's configurations of lights have sufficient potency to fulfill a cueing function. The first one is a change in the visual horizontal angle between the tail lights of the leading vehicle subtended at the following driver's eye; the second is a change in angular size or apparent brightness of each separate light. Research indicates that relative movement of the leading vehicle will be detected on the basis of the former factor long before changes in size or brightness can come into play as sources of information (Janssen, 1977; Parker, Gilbert, and Dillon, 1964). So, a wide distance between the presence lights gives a better range of perception than a narrow distance.

Position of tail lights

When position of tail lamps was examined, the reaction time of the following driver was shorter when brake lights were mounted at the roof line of the preceding vehicle as opposed to a standard tail light system (Sivak, 1978; Sivak, Post, Olson, and Donohue, 1981).

Intensity

In terms of lamp intensity, the common finding was that increased intensity led to better detectability of lights, more efficient detection of closure, faster initiation of car control movements, lowest peak deceleration force magnitude, and higher attention-getting value. However, some researchers disagreed on the effect of the intensity of lights on their apparent distance (appearing nearer or farther). Moore and Smith (1966) found that more intense signals appeared nearer and higher mounted lights appeared further away; they concluded that the distance to cars could be more accurately judged if the tail lamps had a standard intensity and mounting height. Rockwell and Safford (1968) report no effect of intensity on perceived distance.

Visual angle

When the criterion is perception of the change in headway, rather than absolute distance, it is more accurately accomplished when the visual angle is as wide as possible. Neither tail light intensity nor individual sizes even begins to approximate the potency of the visual angle to the two tail lights in determining the judgement of headway change (Parker et al, 1964). Since spacing between the tail lights is also an important stimulus for estimating absolute distance, it would appear desirable that all tail lights be spaced at a standard dimension (Reilly, Gilbert, Dillon, and Parker, 1965).

Parker et al.'s study (1964) was concerned with an evaluation of the visual cues used by a driver at night as he decides he is overtaking the vehicle in front of him. The cues investigated were the following: change in apparent area (size) of tail light surfaces; change in apparent brightness; and change in the visual angle subtended by the tail lights. Two of the variables were kept constant and the third one was manipulated, being the cue on which the driver had to decide whether to overtake the preceding vehicle or not. Their results show that the level of visual angle and the level of brightness were found to be significant, while the level of area was not, suggesting that the ability of a driver to detect a rate of closure is influenced by how far apart the tail lights are and how bright they are, but not by how large they are.

Reilly et al.(1965) also examined the visual information available from the vehicle tail light systems, namely, the angular velocity cue provided by the increase in the visual angle subtended by the two tail lights as a driver approaches these lights, and the manner in which this information might be used by a driver as a basis for specific vehicular control actions. Reilly et al. found that specific characteristics of tail light systems had a significant effect on braking behaviour. A system with large, bright lights set at a maximum separation (60 inches) produced a consistently better braking response than any other system. Their recommendation was that vehicles which presently have only one tail light, for example, motorcycles, should have two lights because the detection of headway and relative velocity is easier from angular than size-brightness cues.

The consequences of misjudging absolute distance are not very serious when the vehicle being followed is far away. However, estimates of distance become progressively less accurate with distance (Versace, 1970). As one gets closer, the whole vehicle soon becomes visible, and the visual angle subtending the tail lights is no longer the only significant stimulus for estimating distance. Indeed, once the vehicle is reasonably conspicuous, the phenomenon of size constancy also becomes manifest. This psychophysical effect (Cornsweet, 1970) dominates the influence of visual angle and perspective geometry. In fact, once the vehicle is close enough to be recognized as a familiar object, headway judgements will be largely based upon this recognition rather than strictly upon tail light spacing (See the familiar-size hypothesis in the section on perception of distance). But standard spacing of tail lights to achieve more stable judgements of absolute distance is essential at high speeds, under reduced visibility, and beyond the point at which one can see the whole vehicle. Henderson et al. (1984, p. 2794) noted: "The absence of standardization of tail lamp mounting location, especially lamp separation, if currently as poor as it was in 1956, may be in part responsible for the increase in night rear-end collisions" .

LITERATURE ON PERCEPTION OF DISTANCE

In order to evaluate the parameters involved in the study and to provide the subjects with a realistic simulation of headlights at various distances, the literature relating size, brightness, and distance of objects was examined. These principles were considered in designing the apparatus. The next section describes the relevant concepts and principles of perception such as the retinal image, cues to distance, and psychophysical methods for estimating distance.

Structure of the eye

The eye is a sort of spherical jelly-like mass surrounded by a hard shell, the sclera, which is white and opaque except at the front part where the transparent cornea lies. Light from an external object enters the eye through the cornea, passes through the pupil whose opening is delimited by the iris, goes through the crystalline lens behind the pupil, and is absorbed at the back of the eyeball by the inner surface of the choroid which is covered by the retina. The action of the curved surfaces of the cornea and the crystalline lens causes divergent light rays coming from the various points on an object to converge and form the object's image on the surface of the retina. This membrane contains about 118 million rods and 6 or 7 million cones; these photoreceptor cells have different functions. The rods are hypersensitive to light but not to colour, and do not allow good definition of images; the cones perform well in bright light only and give detailed, coloured images.

The blind spot is the point of exit of the optic nerve and contains no photoreceptors. The macula is a small depression at the center of the retina, which holds an even smaller, rod-free region called the fovea centralis; at this point, cones are thinner and more densely packed than anywhere else in the retina, so the images provided are the sharpest and most detailed.

The dioptric mechanism of the eye allows for two automatic adjustments which operate through a neuromuscular feedback loop to change the characteristics of the system as the characteristics of the light entering the eye change. First, when the amount of light markedly increases or decreases, the iris muscles react to narrow or widen the diameter of the pupillary opening and in this way to restrict the total range of illumination to which the retina is exposed. Second, the ciliary muscles alter the shape of the crystalline lens to change its focusing or accommodation properties as the eye is directed toward nearer or farther objects.

Perception

In the transfer of information from a three-dimensional world onto a two-dimensional retina, some aspects of a stimulus are directly represented on that surface while others are not. Size and shape of an object exist both in the external world and on the retina. On the other hand, the dimension of distance or depth cannot be directly represented there.

The size of an object, particularly of its retinal image is the first thing that we perceive. However, it is the observer's awareness of distance that helps an object far away look as large as the object placed nearer (Boring, 1946). At short distances, the brain takes into account certain sensory data that indicate the distance of projection of the retinal image and corrects the perception, with certain monocular and binocular cues, of distance or depth.

VISUAL CUES TO DISTANCE

The next most essential element in the perception of visual space is the perception of distance and depth. Similar to estimating the size of the retinal image, it involves both retinal and muscular sensations. The terms "depth" and "distance" should not be used interchangeably. Distance in the present context, means the distance between the observer and the stimulus; depth usually refers to the distance between two objects placed on a non parallel plane away from an observer and is relative. In these studies, distance to simulated headlights was estimated. In order to simulate various distances, the apparatus was made to resemble a night driving situation devoid of any exterior lighting; all cues to distance of the simulated vehicle, which were "placed" at "long distances" from the viewer, were eliminated except the light stimuli from which the distance of the "car" was to be estimated. This presentation minimized the use of retinal and muscular feedback to the subjects in making their estimates of distance.

Binocular cues

In binocular vision, a basic element for perception of depth and distance is convergence. This is a muscular, non-visual cue. The eyes tend to turn towards each other when observing on nearby objects and to focus at infinity when viewing objects farther away. With learning and experience, one utilizes muscular tension as a cue to a particular object's distance.

The other principal binocular cue is called binocular disparity. Objects that lie nearer or farther than a specific fixation distance associated with a specific convergence degree project their retinal images on non-corresponding areas of the two retinas. The disparity will equal the change in convergence that follows shifting from one point to the other, and will be a depth cue to the distance at which any point lies.

In simulating distances with the experimental apparatus, it was important to prevent anything from suggesting to observers that the stimuli were near them. So, all stimuli were kept in the same plane, sufficiently far from the observer to make binocular cues ineffective.

Monocular cues

In monocular vision, the corresponding physiological cue to convergence is the muscular and kinaesthetic sensation of accommodation where the ciliary muscles pull on the crystalline lens to alter its convexity and focus on near or far objects. This muscular signal, however, is not effective at far range. For the reasons stated above, convergence and accommodation were eliminated by placing the light stimuli more than 7 meters from the observers.

Other monocular visual cues which could not have played any role in our design include height on a two-dimensional plane, aerial perspective, and shadowing.

Motion parallax is defined as the experience of objects nearer the observer, appearing to move to the side more and faster than distant ones when the observer's head moves. To prevent subjects in these studies from moving their heads and using this distance cue, they were asked to place their chins in a chinrest during the experiment.

The following visual monocular cues to distance derived from geometry, were minimized in these studies. Linear perspective is the impression that parallel lines, for example a railroad, converge in the distance. The apparatus did not provide this cue.

Overlapping of objects and texture gradient are geometric monocular cues which were also excluded from this study; subjects were presented with stimuli in the same plane and the distance gradients in the tunnel were eliminated. Binocular vision was used.

The size of lights is an important distance cue and was carefully investigated in these sudies. Using size as a cue, subjects normally respond to objects in terms of their relative size and their familiarity with the object. The relative size cue works in this way: Of two similar shapes presented together or in close sucession to a viewer, the one with the larger retinal image will appear nearer, and this was the basis for our experiment on size variation of simulated headlights.

The familiar size cue helps observers judge the distance of a familiar object when both its retinal size and actual size are known. This became an essential part of the present studies, as real distance to the light apparatus was short and long distance was only simulated by the use of small lights and cue reduction. By suggesting to the viewers that they were looking at "car headlights", the stimuli characteristics and distance estimation had to be viewed in the context of driving on an unlit highway at night.

ESTIMATION OF DISTANCE FROM RETINAL AND FAMILIAR SIZE

Since the distance from an observer to an object is estimated, in part, from the perceived size of the object and from the retinal size as well, the relationships between size and distance were considered in the design of the studies.

If the size of the retinal image is assumed to be the sole cue to size, and if all depth or distance perception is ignored, the law of retinal image or visual angle applies (Appendix A), whereby the perceived size of an object is taken as simply proportional to the size of its retinal image (or visual angle), and therefore inversely proportional to the distance of the object. This law was applied in calculating the size of the light stimuli according to the target distances selected for the studies.

In these experiments, the simulation of distance was achieved by providing observers with stimuli that subtended small retinal images and by asking subjects to imagine that these stimuli represented a car's headlights. By using the familiar size principle, we were able to recreate the context of observation of headlights, and further suggest the existence of great distance. Consistent with Holway and Boring (1941), Boring (1946), and Gilinsky (1951), having eliminated other distance cues, and obtaining the subjects' cooperation in "viewing" the lights as belonging to an automobile, subjects were "forced" to depend on size of a familiar object as a cue to distance.

This manipulation was similar to the work done by Baird (1963), in which he varied the length of rectangular strips of light (6 to 24 inches) and showed them to observers under reduced conditions. The real distance of the strips from the observers was kept constant at 25 feet and the observers were told that all the strips were one foot long. Observers were asked to estimate the distance to the strips. The estimates differed significantly as a function of the length of the strip. The means of the estimates came close to what the distances would have been, if the strips really had been one foot long.

Familiar objects as cues to distance

In the literature on the relationships between the size and distance of an object, it is clear that retinal size and absolute distance were not the only important parameters (Gogel, 1968; Harway, 1963). Past experience of the observer with the object came to be recognized as a factor in the estimation of the distance of the said object and research turned towards the "familiar size" hypothesis (Hochberg and Hochberg, 1952). It seems that realistic representations of familiar objects do indeed affect the distance judgements made by subjects who have been instructed to judge distance relationships, in the absence of the usual distance cues under some circumstances (Dinnerstein, 1967; Gogel and Mertens, 1967; Ono, 1969).

Ittelson (1951) obtained distance judgements when the only cue was the size of a known object. As predicted, the observers used the retinal size of the familiar object to make their distance estimates. In the absence of definite distance cues, subjects can estimate a distance appropriate to the assumed size of the stimulus, from the suggestions of the experimenter. In our case, the participants were told to ignore the surroundings and imagine that the lights they were seeing were the headlights of a car.

Hastorf (1950) found that when subjects were shown a disk of light under reduced conditions, and were told it was a ping-pong ball, they judged it to be at a closer distance than when they were told that it was a billiard ball, even though two thirds of the subjects saw that the disk was not really a ball. From those results, it appears that observers do not even have to believe that the stimulus is actually the size they are assuming it to be.

Gogel and Mertens (1967) found that when subjects were using absolute retinal size (as opposed to relative) to determine the distance of playing cards, their estimates were highly variable and inaccurate beyond 5 feet. They remarked that the decrease in accuracy with distance can vary with the type of familiar object used and suggested that objects which are usually viewed at greater distances might be perceived more accurately at greater distances.

Ono (1969) studied the familiar-size hypothesis and found that past experience is a cue to distance whereby the perceived distance of a familiar object becomes a function of the visual angle subtended by the object from a particular distance. His results indicated that unless the object's characteristics were potent and salient enough, the observers did not use the familiar size as a cue.

In these experiments, the context of cues was greatly reduced so that the retinal image produced in the subjects' eyes could suggest great distance from a familiar object, a car. A standard stimulus was presented as a reference point.

The following subsection deals with the theory on light intensity and brightness.

PHOTOMETRIC TERMINOLOGY

Brightness is a psychological term that expresses the subjective impression made by a light source. Candlepower is a measure of the luminous intensity of a source of light. Luminance refers to the luminous flux per steradian that leaves a unit area of the surface in the direction of measurement; it applies to a source of light or a surface. The illumination is a measure of light falling on a surface, for example, one lumen per square foot is a foot-candle. The level of illumination decreases inversely with the square of the distance from the light source. The illuminance measurements were to be used as a constant standard in the separation distance and size experiments, and on their own with variation levels in the brightness experiment. This particular study was concerned with suprathreshold light intensity values and the interpretation of the luminous flux of the headlights in terms of distance judgements.

NIGHT VISION

The human visual system adjusts itself over an enormously wide range of luminance (McKenzie, 1959). The eye adapts to the light by adjusting its sensitivity inversely to the prevailing level of illumination. Adaptation to bright light is usually well accomplished in about a minute or so, but dark adaptation takes considerably longer. Such a process depends upon the initial state of adaptation and the new level of illumination, and it can take between ten and thirty minutes to adapt to the dark. Under ordinary driving conditions at night, the driver is far from being completely dark adapted since his own headlights produce a certain brightness on the pavement in the foreground (Hukulak, 1982).

Binocular vs monocular observations

Even after the problem of distance cues was generally solved, a decision still had to be made about allowing subjects to use one or two eyes. To approximate field conditions as closely as possible, binocular observation was allowed. It is known that the dark-adapted absolute threshold is found to be better with two eyes than with one (Hurvich and Jameson, 1966). In addition, although the non-threshold brightness of an object seen binocularly is just about the same as its brightness when viewed monocularly (because of an averaging process by the visual system called Fechner's paradox), binocular vision seems to be better for discriminating brightness differences by making the excitable neural tissue related to both eyes available for the task. Binocular vision added the advantage of making these laboratory experiments more ecologically valid.

MAGNITUDE SCALING

The relationship between a dimension of measurable stimulus units and a dimension of psychological perceptual units is not linear. Our studies were concerned with this type of relationship because the physical variables were first observed by the observer which then made a subjective distance evaluation based on the specific parameters. Psychophysicists of the last and present centuries have argued over the form and validity of such theoretical formulations. It is now generally accepted that the conditions of experimentation and the variables measured will determine if the function is logarithmic or exponential.

Trying to find a valid method of measuring perceptual units from physical ones, Stevens in the 1950's, applied the method of magnitude scaling to the problem of apparent brightnesses for stimuli of different luminances (Hurvich and Jameson, 1966). Stevens' subjects' judgements were numerical estimates of brightness magnitudes. In order to obtain such numerical estimates, one light of given luminance was selected from the total series to be presented and a specific number assigned to the level of apparent brightness produced by this "standard" stimulus. Each stimulus in the test series was then presented successively, usually in random order, and the observer assigned to each of the test lights a number expressing the perceived brightness of the given test stimulus relative to that of the standard. This methodology was compatible with the purpose of our studies and a slight variation of it was used.

ESTIMATION OF DISTANCE FROM BRIGHTNESS

Brightness as an indicator to distance was studied by Farnè (1977). He was concerned with the value of brightness as such an indicator and he investigated the effects of varying the context of a given target on the perceived distance of the target. Farnè concluded that the relationships of targets with their common background was a better indicator of distance rather than the relationship between the isolated targets, and other things being equal, the object having the higher brightness contrast with the background is perceived as the nearer.

Similarly, Coules (1955) showed that brightness affects distance judgements independently of retinal disparity and convergence. Thus, brighter objects appeared nearer than dimmer objects and a brighter object farther away was equivalent to a dimmer object that was nearer.

PURPOSE AND RATIONALE OF THE STUDY

The present study investigated whether size and brightness of "headlights" and separation distance between the "headlights" affected estimates of distance to those lights.

For these experiments, the problem of measure of units along the psychological dimension was approached by translating apparent size, separation distance, and brightness impressions of simulated car headlights into a distance judgement unit. We restricted ourselves to a single condition of observation (either separation distance, size, or brightness of simulated headlights) and exposed a pair of identical light stimuli at a time, in an otherwise darkened room. When one variable, for example, size of the "headlights", was being manipulated, the two others (separation distance between lights and brightness of lights) and the duration of the exposure were kept constant for all trials.

Given the information on each variable through literature review and psychophysical theory, the following hypotheses were formed:

The separation distance between simulated headlights, the size, and brightness of those pairs of light stimuli will act separately as distance cues to a simulated familiar object, namely a car's headlights; it is predicted that observers will be able to estimate the simulated distance of the car on the basis of variations in one of these three parameters around a standard when the other two components are kept constant. The direction of response is also predicted to change inversely to the magnitude of the variable. An increase in the attribute of the lights is expected to cause a decrease in estimated distance; inversely, a decrease in the parameter will cause observers to estimate distance to be farther than the standard.

EXPERIMENT I:

Effects of Separation Distance between Simulated Headlights on Estimation of Distance of Lights

Method

Subjects

Subjects were recruited mostly from a university population. Seven women and three men, between 23 and 37 years old participated in this study. They were volunteers and did not receive any monetary incentive for their participation, although the students who were enrolled in Introductory Psychology classes were given a maximum of four points to their final semester grade, proportional to the duration of their participation. The criteria used for selection of subjects were at least three years driving experience and self-report of good vision, even if with correction.

Apparatus

The apparatus was built to simulate headlights at a long distance under night viewing conditions. A dark tunnel was built to create the illusion of distance to the lights (Appendix D); it measured 7.32 m long, 68 cm high, and 76 cm wide, and was nailed to the floor of a stage which was 90 cm off the floor. The wooden and cardboard structure was sprayed with mat black paint to prevent spurious light reflection. At the viewer's end of the tunnel, there was an adjustable chair in front of which was a small platform (extending from the stage) on which subjects could rest their arms. A chinrest was mounted on the small platform, restraining the viewer's head movements (Appendix E). The stimulus lights could be observed through a horizontal slit 15 by 10 cm made in thick mat cardboard, placed approximately one meter into the tunnel, and subtending an angle of about nine degrees at the viewer's eyes. A small cloth flap was used to cover the view of the tunnel between presentations of stimuli.

At the other end of the tunnel, light fixtures were mounted on a track equipped with a dimmer and connected to a clock to control the presentations of lights. Incandescent spotlights of 25 W were used to simulate partially collimated light at distances of 250, 500, and 1000 ft (Appendix F).

Plastic lids sprayed with mat black paint were fitted over the light fixtures, providing a surface in which to punch the different pairs (5) of holes needed for the simulation of different distances. For the target distance (TD) at 250 feet, there was only one hole per lid and two fixtures were used; the holes were 15 mm in diameter and separation distance between the inside edges of the holes varied from 62 mm to 145 mm. At T.D.500, there were two holes per lid, one fixture used, each hole measuring 8 mm in diameter and the distance between them ranging from 31 mm to 72 mm. Finally, at T.D.1000, there were also two holes per lid, the holes measured 4 mm in diameter and the distance between them varied from 15 mm to 36 mm (See Table 1). A photometer was used to determine the amount of light passing through the holes. This allowed the experimenter to regulate the dimmer and control the amount of light presented.

TABLE 1

Dimensions in mm of apertures and separation distance.

	Levels				
	40%+	20%+	S	20%-	40%-
TD250					
Size	21	18	15	12	9
Sep.dis.	146	125	104	83	62
TD500					
Size	11	9	8	6	4
Sep.dis.	73	62	52	42	31
TD1000					
Size	6	5	4	3	2
Sep.dis.	36	31	26	21	16

S = standard.

The size of the holes was determined by extrapolating from the actual size of the headlights on a 1976 Chevrolet Chevelle. The formula: $\theta = d/r2 = D/r1$ (Appendix B), was used, where θ is the angle subtended by the stimulus; D is the distance between the real headlights; d is the distance between the simulated headlights and r1 is the distance between the viewer and the real headlights; r2 is the distance between the viewer and the near point. The angle subtended by both sets of headlights is the same in the viewer's eyes but one set is smaller than the other in reality, and the distance between the two small lights is determined by the ratio mentioned in the formula above. In summary, the size of the headlights being proportional to the separation distance (for this particular pair), once the separation distance is known, then the size of the headlights can be determined (Appendix C).

The experimenter worked behind a thick curtain, in front of which the light stimuli were displayed, and used a red light to change the lids on the light sources (Appendix F). The curtain prevented the viewer from seeing beyond the light stimuli at the end of the tunnel. The lighting in the room was kept to a minimum to avoid affecting the dark adaptation in the subject's eyes and also to avoid providing the viewer with extra distance cues. The red light, hanging on the experimenter's side of the curtain, minimized the illumination of this area.

A 1976 Chevrolet Chevelle's characteristics were used to provide an arbitrary standard for size, separation distance, and brightness of headlights at

100 feet. Two types of stimuli were presented to the subjects. The first type was called "standards of distance to a vehicle" and consisted of a pair of lights representing headlights of the appropriate size, separation distance, and brightness of the Chevrolet at the target distance of 250 feet; two other standards had the same characteristics as headlights of the vehicle at 500 feet and 1000 feet.

The second type of stimuli was called "experimental" and included the standard as a median value, plus four variations in separation distance of headlights: lights 20% closer together than the standard, lights 20% farther apart, lights 40% closer together, and lights 40% farther apart. Each target distance (standard) used the same variations, thus subjects saw the three standards prior to every trial and three different sets of five pairs of lights in the whole experiment. This order of events is better illustrated in point form:

TABLE 2

Order of presentation of light stimuli.

I	Three standards of lights at 250, 500, and 1000 ft. in random order.
II	All five experimental pairs of lights (standard plus four variations), randomly ordered, corresponding to one of three target distances.
III	Standards once more.
IIII	Experimental lights once more.
I	Standards.
II	Five experimental pairs of lights corresponding to another of the three target distances.
III	Standards.
IIII	Experimental lights.
I	Standards.
II	Five experimental pairs of lights corresponding to the last target distance.
III	Standards.
IIII	Experimental lights.

Procedure

The participants were required to answer a questionnaire about their age, driving experience, and vision. Then, they read the instructions and the experimenter made sure the participants knew what to do by accompanying them to the viewer's area and showing them how to enter the cubicle and to cover and uncover the viewing slit in the cardboard at the end of the tunnel.

After the ten minute period of dark adaptation in the testing room, the experiment started. To minimize accommodation and convergence effects, the subjects sat at 6.1 m from the stimuli. At this end of the tunnel, the chair was adjusted so that the subjects could comfortably see the lights at the other end of the tunnel through the opening in the cardboard. To minimize autokinetic movement effects, the viewer's head was immobilized on a chinrest throughout the experiment.

The subjects were asked to manipulate a dark cloth panel during the experiment to cover the opening in the cardboard in between the presentations of stimuli. In this way, the subject could not see the hands of the experimenter changing the apparatus.

The order of presentation of stimuli was determined by using a 5 by 5 Latin square and by assigning subjects to five different combinations of the standard and variations. Thus, each combination was presented to two subjects (See Table 3).

TABLE 3

Order of presentation of target distances and levels of stimuli according to subject number (Size and separation distance).

TARGET DISTANCES

	1	2	3		2	1	3	Subjects
1	1	3	2		3	1	2	1, 4, 7, 10
2	2	1	3	=	1	2	3	2, 5, 8
3	3	2	1		2	3	1	3, 6, 9

1 = TD 250
2 = TD 500
3 = TD 1000

LEVELS

	1	2	3	4	5		4	1	2	5	3	Subjects
1-	1	5	4	3	2		4	1	2	5	3	1, 6
2-	2	1	5	4	3		3	5	1	4	2	2, 7
3-	3	2	1	5	4	=	2	4	5	3	1	3, 8
4-	4	3	2	1	5		1	3	4	2	5	4, 9
5-	5	4	3	2	1		5	2	3	1	4	5, 10

1 = 40% more 2 = 20% more 3 = standard 4 = 20% less
5 = 20% less.

First, subjects were presented with and told to remember the three standards of "distance" to a simulated vehicle. When a standard was presented to the subject (in no particular order), the experimenter always indicated clearly the simulated distance to the vehicle. The order of the target distances was also randomized (Table 3) and the experiment was divided into three parts.

For the first part, the experimenter showed a pair of lights which could be the same or a variation of one of the standards, and asked the viewer to estimate the distance of the lights of the presumed car in feet. The choice of the non metric scale for viewer response was based on the assumption that the subjects would be more familiar with the imperial unit system than with the metric one. None of the subjects found it difficult to make their estimates in feet. Subjects were not given feedback following trials, that is, they were not told whether they were correct, or whether they overestimated, or underestimated the distance of the simulated vehicle. The size of the holes of each target distance stimuli was kept constant. Brightness for each target distance stimuli was kept constant by measuring the amount of light presented in each case and adjusting the dimmer appropriately.

After having estimated the distance of the first five pairs of lights, the subject was again presented with the standards. Immediately afterwards, the same five pairs of light stimuli were presented again, in the same order. In this way, subjects were presented with each experimental pair of light stimuli twice. The same procedure was repeated for the other two target distances (TD 500 and TD 1000): standards, five pairs of stimuli, standards, same five pairs of lights. The three standards were thus seen six times each and each experimental pair of lights was seen twice, for a total of fourty-eight presentations per subject. It should be noted that the standard was also used as the median value in the experimental trials. The experiment took approximately 40 minutes per subject. No time limits were imposed for the estimation of distance but since the presentations of stimuli only lasted one second each, the rate of answering was regular and fairly rapid.

EXPERIMENT II:

Effects of Size of Simulated Headlights on Estimation of Distance to Lights

Method

Subjects

Different subjects from the first group were recruited mostly from a university population. The same selection criteria as in Experiment I were used, that is, at least three years driving experience and good vision, the use of corrective glasses being allowed. Six women and four men from 22 to 33 years old volunteered. They did not receive any monetary incentive for their participation, although the students who were enrolled in Introductory Psychology classes were given a maximum of four points to their final semester grade proportional to the duration of their participation.

Apparatus

The same apparatus as in Experiment I was used but different plastic lids were constructed in order to present variations in the size of the holes rather than the distance between the holes (Table 1). At T.D. 1000 feet, the standard size and separation distance were 4mm and 26mm, respectively; variations in the size of the holes ranged from 2.4mm to 5.6mm. At T.D.500, the size of the standard was 8mm and the holes were 52mm from each other; variations in size went from 6.4mm to 11.2mm. At T.D.250, the standard size and separation distance were 15mm and 104mm, respectively; the size variations ranged from 9mm to 21mm.

Procedure

The participants completed exactly the same procedures as those in Experiment I. They answered the questionnaire, read the instructions, and waited ten minutes to establish dark adaptation. Then, presentation of light stimuli started and the subjects verbally estimated the distance of the simulated car headlights. The separation distance and brightness of the lights were kept constant, while the size of the lights was varied above and below that of the standard.

The order of presentation of stimuli was determined by using a 5 by 5 Latin square and by assigning 10 subjects to five different combinations of standard and variations (Table 3). The order of the target distances 250, 500, and 1000 feet was also randomized.

First, subjects were presented with and told to remember the three standards of distance to a 1976 Chevrolet Chevelle. Then, the experimenter showed a pair of lights that could be the same or a variation of one of the standards, and asked the viewer to estimate the distance of the lights of the presumed car in feet. The experimental stimuli were: standard size, lights 20% smaller, 20% bigger, 40% smaller, and 40% bigger than the lights of the standard. The five pairs of stimuli were presented in the same order twice, the first and second set of trials being separated by a presentation of the standards. Subjects were not given feedback following trials.

The same procedure was repeated for each target distance: standards, five pairs of stimuli, standards, the same five pairs of lights (Table 2). The three standards were thus seen six times each and each pair of lights was seen twice, for a total of fourty-eight presentations. The experiment took approximately 40 minutes per subject and no time limits were imposed.

EXPERIMENT III:

Effects of Brightness of Simulated Headlights on Estimation of Distance to Lights

Method

Subjects

Most of these subjects were recruited from a university population and they were different from the subjects in the first two groups. The criteria used for selection were the same as in the previous experiments: at least three years driving experience and good vision, the use of corrective glasses was permitted. Five women and five men aged 19 to 38 years old took part in this experiment. They did not receive any monetary incentive for their participation, although the students who were enrolled in Introductory Psychology classes were given a maximum of four points to their final semester grade proportional to the duration of their participation.

Apparatus

The same apparatus as in Experiments I and II was used. The lids corresponding to each standard, that is, 250, 500, and 1000 ft., were used since the separation distance and size of holes were kept constant in this experiment. Only the amount of light was varied between presentations. The brightness corresponding to the standard and variations was determined on the basis of photometric measurements taken from the headlights of the Chevrolet Chevelle and the application of an inverse-square law to distance from a point light source. However, actual units of light intensity were not used as the photometer was calibrated in relative units. Also, as it was impossible to obtain exact calibration of the dimmer, the 20% variation could not be firmly determined. Only the standard and 40% variations above and below the standard were used. Photometric measurements were taken from the experimental light sources and the dimmer was regulated to match approximately the intensity values obtained from the car.

Procedure

The participants completed the same procedures as in the two previous experiments. They answered the questionnaire, read the instructions, and waited ten minutes to establish dark adaptation. Then, light stimuli were presented and the subjects verbally estimated the distance to the simulated car headlights. The separation distance and size of the lights were kept constant, only brightness varied in one value above and one below that of the intensity standard.

The order of presentation of stimuli was determined by using a 3 by 3 Latin square and by assigning subjects to three different combinations of standard and variations. The order of the target distances, 250, 500, and 1000 feet, was also randomized.

TABLE 4

Order of presentation of target distances and levels according to subject number (Brightness).

Target distances

	1	2	3	2	3	1	Subjects
1	1	3	2	2	3	1	1,4,7,10
2	2	1	3	1	2	3	2,5,8
3	3	2	1	3	1	2	3,6,9

1 = TD250
2 = TD500
3 = TD1000

Levels

	1	2	3	1	2	3	Subjects
1	1	3	2	1	2	3	1,4,7,10
2	2	1	3	3	1	2	2,5,8
3	3	2	1	2	3	1	3,6,9

1 = 40% more, 2 = S, 3 = 40% less

Subjects were not given feedback following trials. Standard size and separation distance being constant, the experimental stimuli were: standard brightness, 40% dimmer, and 40% brighter. The three standards were thus seen six times each and each pair of experimental lights was seen twice in association with one target distance, for a total of thirty-six presentations. The experiment was open-ended and took approximately 30 minutes per subject. The presentations of stimuli only lasted one second each, the rate of answering was regular and fairly rapid.

RESULTS

EXPERIMENT I

Effects of Separation Distance Between Simulated Headlights on Estimation of Distance to Lights.

Separation distance between simulated headlights varied over five levels for each of three target distances (TD 250, TD 500, and TD 1000 feet), while the two other variables, size and brightness, remained constant. The first level was 40% over the standard separation distance at a particular TD, so the lights were farther from each other; the second level was 20% farther apart; the third level was the standard separation distance at the particular TD; the fourth level was 20% closer together than the standard; the fifth level was 40% closer together. All three TD's were divided in this way, each with five experimental pairs of lights. Each of the 15 test combinations was presented twice and the data used in the analyses were the arithmetic means of the two distance estimates obtained from each pair of experimental lights.

Analysis of variance

An analysis of variance with repeated measures was employed. Separation distance was highly significant: $F(4,36) = 40.6$, $p < .01$. The second factor, distance from viewer, was also highly significant: $F(2,18) = 73.15$, $p < .01$. Interaction between the two factors was not significant.

Tukey's Honestly Significant Difference Test was used to compare all 15 means. This test uses the increasing order of magnitude between the means rather than serial order to proceed with pairwise comparisons, so that the order was not exactly 1 to 15, but rather 1, 2, 3, 6, 4, 7, 5, 8, and then in real order up to 15 (See Table 5).

The paired-comparisons analysis showed that although estimates of distance generally increased in a linear fashion with distance between stimuli, such estimates were not always consistent between adjacent levels, that is, levels that differed only by 20%. In fact, even when the difference between the stimuli was 40%, the discrimination rate was only 66.6% for TD 500, and only 33.3% for both TD 250 and TD 1000.

For means number one to five, corresponding to TD 250, adjacent means were not significantly different

(Figure 1). The middle value, corresponding to the standard at 250 feet, differed only from mean number 5, the 40% decrease in the separation distance between the headlights.

Means number six to ten, at TD 500 also failed to show any significant difference between adjacent means. This time, the middle value, corresponding to the standard at 500 ft. proved significantly different from the two extreme values, that is, 40% increase and 40% decrease in separation distance, means number six and ten, respectively.

At TD 1000, a pattern similar to the one observed at TD 250 was revealed. The middle value, number 13, differed significantly from the 40% decrease in separation distance only (number 15), and the first two means, numbers 11 and 12 also differed significantly from that value, but the rest of adjacent pair comparisons were not significant.

TABLE 5

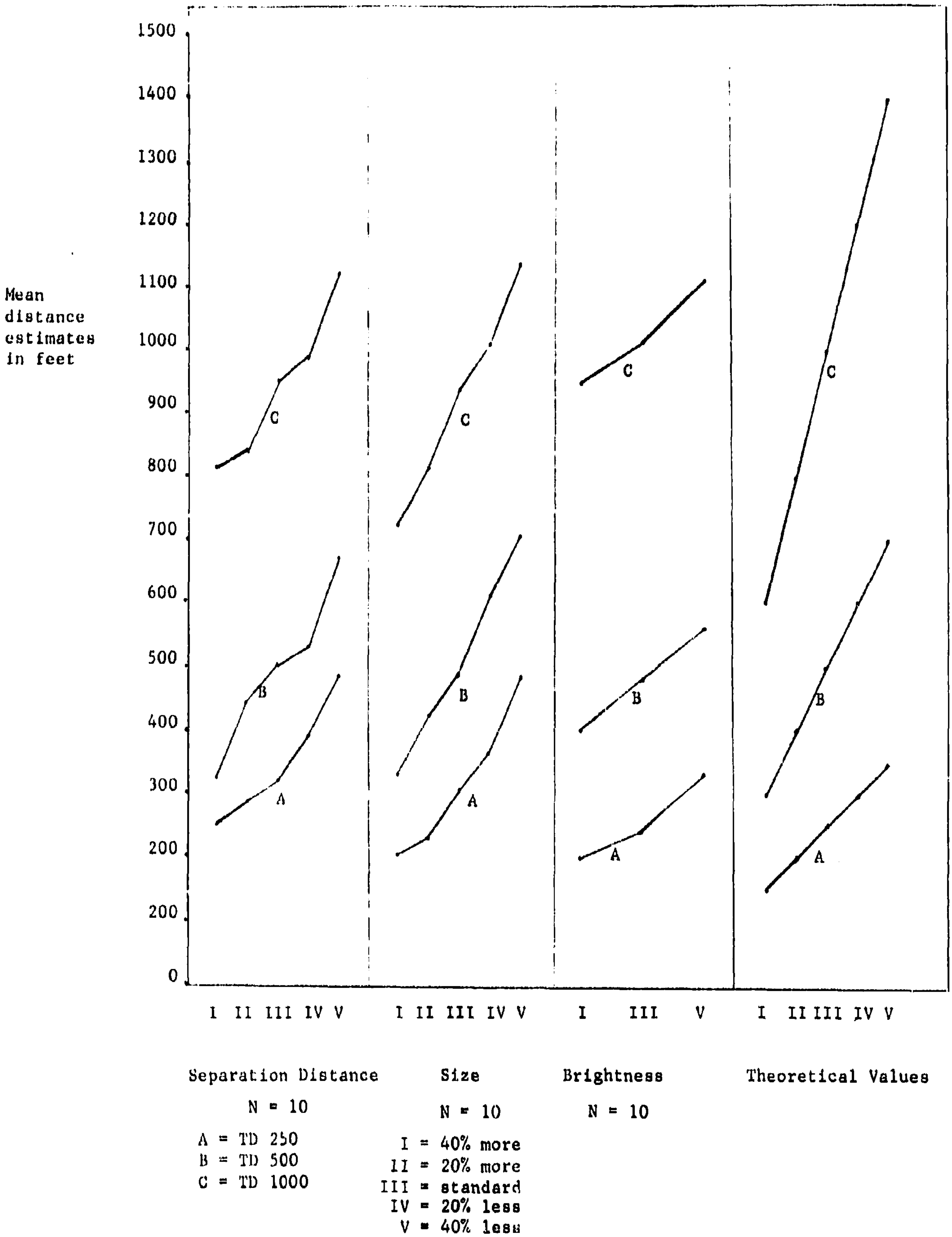
Pairwise comparisons for separation distance.

The means are in ascending order of magnitude.

	1	2	3	6	4	7	5	8	9	10	11	12	13	14	15
1	-														
2	.03	-													
3	.07	.04	-												
6	.07	.04	0	-											
4	.14	.11	.07	.07	-										
7	.19	.16	.11	.11	.04	-									
5	.24	.21	.16	.16	.09	.05	-								
8	.25	.22	.18	.18	.11	.06	.01	-							
9	.28	.25	.20	.20	.13	.09	.04	.02	-						
10	.42	.39	.34	.34	.27	.23	.18	.16	.14	-					
11	.56	.53	.49	.49	.42	.37	.32	.31	.28	.14	-				
12	.59	.56	.51	.51	.44	.40	.35	.33	.31	.17	.02	-			
13	.70	.67	.62	.62	.55	.51	.46	.44	.42	.28	.13	.11	-		
14	.73	.70	.66	.66	.59	.54	.49	.48	.45	.31	.17	.14	.03	-	
15	.87	.84	.80	.80	.73	.68	.63	.62	.59	.45	.31	.28	.17	.14	-

The underlined numbers are significant; the mean number at the far left of an underlined value is significantly different at the .01 level from the mean number at the top of that column.

FIGURE 1: Distance estimation as a function of three parameters



Trend analysis

A trend analysis using orthogonal polynomials was also employed. It revealed a significant, positive, linear trend for the factor levels of separation distance: *F* linear = 172.35, $p < .01$. For the factor target distances, significant linear trends were found: *F* linear = 126.39, $p < .01$. None of the comparisons between the levels of the two main factors was significant.

Tests of significance of mean difference from assigned value at standard

At the start of the experiment, the three standards for the target distances were shown to subjects and identified. Then, five experimental pairs of light stimuli corresponding to one of the target distances were presented, including the standard at that particular distance. Following those, the three standards were shown and identified again, and the last trial of the five pairs was done again in the same order. This procedure was repeated for the other two target distances, in random order for each subject. Since the subject was given reference points before each series of five pairs of stimuli, one would have expected that when the subject was presented with the "experimental" standard (the one included in the five pairs of lights), she/he would judge it at or close to the distance assigned to it during the presentation of standards.

Six trials were done in total, two for each target distance (2 x 3) where subjects were required to estimate the distance of the simulated headlights. The arithmetic means of the distance estimates to each of the five experimental pair of lights < (pair 1 trial 1 + pair 1 trial 2) / 2 > over the two trials were calculated. From each subject's mean response to the experimental target, the distance assigned to the standard, that is, 250, 500, or 1000 feet, was subtracted to obtain a positive, negative, or zero difference. These individual differences were averaged (from ten subjects), yielding three mean differences (75, 5,-50), one for each target distance. Each of those three means was subjected to a t-test to determine if, as a whole, the group had overestimated or underestimated the standard. The means were not significantly different than 0.

Correlations

Was error in estimating distance to the standards (when presented as test stimuli) related to personal characteristics of the subjects? The difference between the subjects' responses to the presentations of the standards and the assigned values to the standards was calculated. Then, those difference values were correlated with two personal criteria obtained from the subjects: age and number of years of driving experience.

TABLE 6

Correlations between error in distance estimation of experimental standard and personal variables for separation distance.

TD 250	n = 10
AGE	R = -0.29, $p < .4$
EXP	R = -0.34, $p < .3$
TD 500	n = 10
AGE	R = 0.52, $p < .15$
EXP	R = 0.61, $p < .1$
TD 1000	n = 10
AGE	R = -0.31, $p < .35$
EXP	R = -0.32, $p < .32$

No significant link could be established between age or years of experience and digression from the assigned value of the standard.

EXPERIMENT II:

Effects of Size of Simulated Headlights on Estimation of Distance to Lights.

Size of the headlights was varied over five levels for each of the three TD's (250, 500, and 1000 feet). The levels were distributed around the standard value of each target distance: 40% smaller, 20% smaller, 20% bigger, 40% bigger. Similarly to the first experiment, subjects judged each combination twice and the arithmetic means of each pair were used as data.

F tests

The data were submitted to a 5 x 3 repeated measures. The size of headlights factor was significant: F (4, 36) = 60.27, $p < .01$; target distance also proved statistically significant with an F (2, 18) = 75.94, $p < .01$. The interaction between factors was non significant.

Tukey's Honestly Significant Difference Test was applied to all 15 treatment means, arranged in ascending order of magnitude on the dependent variable. Pairwise comparisons revealed similar patterns as those found for separation distance.

Among the five means at target distance 250 feet, no significant differences were found in any pairwise comparison. At target distance 500 feet, the only significant comparison was between the two extreme values, numbers 6 and 10, that is, between 40% increase in size and 40% decrease in size (80% difference). The standard, middle value was not significantly different from any other mean. At target distance 1000 feet, the last mean corresponding to a 40% decrease in size of headlights was significantly different from the first two means of that section, namely, 40% increase in size, and 20% increase in size. None of the comparisons of the 20% or 40% magnitude was significant.

TABLE 7

Pairwise comparisons for size.

The means are in ascending order of magnitude.

	1	2	3	6	4	7	8	5	9	10	11	12	13	14	15
1	-														
2	.03	-													
3	.09	.06	-												
6	.12	.09	.03	-											
4	.16	.13	.06	.03	-										
7	.25	.22	.16	.13	.09	-									
8	.28	.25	.18	.15	.11	.02	-								
5	.24	.21	.19	.16	.12	.03	.05	-							
9	.41	.38	.31	.28	.24	.15	.12	.12	-						
10	.49	.46	.40	.37	.33	.24	.21	.21	.08	-					
11	.52	.49	.42	.39	.35	.26	.24	.23	.11	.02	-				
12	.60	.57	.51	.48	.44	.35	.32	.32	.19	.11	.08	-			
13	.73	.70	.64	.61	.57	.48	.45	.45	.32	.24	.69	.13	-		
14	.81	.78	.72	.69	.65	.56	.53	.53	.40	.32	.29	.21	.08	-	
15	.93	.90	.84	.81	.77	.68	.65	.65	.52	.44	.41	.33	.20	.12	

The underlined numbers are significant; the mean number at the far left of an underlined value is significantly different from the mean number at the top of that column.

Trend analysis

On obtaining significant values of the *F* test, orthogonal polynomials were applied to the data in a trend analysis. The factor levels of size was consistent with a positive linear function: F (linear) = 107.85, $p < .01$. The second factor, target distances also showed significant linear trends: F (linear) = 94.86 at $p < .01$. Similar to the results of the first experiment, the comparisons between the levels of the two factors did not show a trend.

Tests of significance of mean difference from assigned value at standard

Following the six presentations (two trials per target distance), the two distance estimates for each experimental standard were averaged for each subject. The value of the particular standard (250, 500, or 1000 feet) was subtracted from the mean response to the experimental standard for each of the ten subjects.

The ten values, positive, negative, or zero, were used to define the variability of response in the group; they were also averaged to give an estimate of the difference from the assigned value of the standard for that particular TD; the same procedure was executed for the other two target distances (50, -15, -60). In the *t* tests that were used, the three means were not significantly different from 0; on the average, estimated of distance to the standards were close to the values assigned to the standards (*t* values of 0.369, 0.169, and 0.558 were obtained).

Correlations

Subjects' distance estimates of the experimental standards was examined as a function of biographical variables. For each target distance two comparisons were made, difference from assigned value of standard against age and against driving experience. The resulting R values are as follows:

TABLE 8

Correlations between error in distance estimation of experimental standard and personal variables for size.

TD 250 $n = 10$	
AGE	$R = 0.29, p < .4$
EXP	$R = 0.001, p < .9$
TD 500 $n = 10$	
AGE	$R = -0.1, p < .85$
EXP	$R = 0.44, p < .022$
TD 1000 $n = 10$	
AGE	$R = -0.62, p < .07$
EXP	$R = 0.53, p < .12$

No significant link could be established between age or years of driving experience and digression from the assigned value of the standard.

EXPERIMENT III:

Effects of Brightness of Simulated Headlights of Estimation of Distance to Lights

Brightness of "headlights" was varied over three levels for each of the target distances, that is, 250, 500, and 1000 feet. The levels of brightness were as follows: standard brightness of simulated headlights at 250 feet, lights 40% brighter, and 40% less bright. The same variation was maintained for the other two target distances. Nine experimental pairs of light were presented to each subject, each pair of stimuli was presented twice and the two distance estimates were averaged.

F tests

The data were analyzed and the 3 x 3 repeated measures design showed highly significant results for the two main factors. Levels of brightness significantly affected estimation of distance to the simulated headlights: F (2, 18) = 26.22, $p < .01$; levels of target distance were also significant: F (2, 18) = 319.81. Again, the interaction was not significant, F (4, 36) = 0.265, $p < .89$.

Tukey's Honestly Significant Difference Test was applied to the nine treatment means, ranked in order of magnitude. All pairwise comparisons between adjacent means (Table 9) were significant except for numbers 1 and 2 at target distance 250 feet, that is, between standard and 40% decrease in brightness. It might be noted that in this study, the minimum difference between each pair of light stimuli was 40%. In the two previous studies, the light stimuli varied by 20% and 40% around the standard.

TABLE 9

Pairwise comparisons for brightness.

The means are in order of magnitude.

		1	2	3	4	5	6	7	8	9
		.20	.24	.33	.40	.48	.56	.95	1.03	1.11
1	.20	–								
2	.24	.04	–							
3	.33	.13	.09	–						
4	.40	.20	.15	.06	–					
5	.48	.28	.23	.14	.08	–				
6	.56	.36	.31	.22	.16	.08	–			
7	.95	.75	.70	.61	.55	.47	.39	–		
8	1.03	.83	.78	.69	.63	.55	.47	.08	–	
9	1.11	.91	.87	.78	.71	.63	.55	.16	.08	–

The underlined numbers are significant; the mean number at the far left of an underlined value is significantly different from the mean number at the top of that column.

Trend analysis

A trend analysis indicated that levels of brightness appeared to follow a positive linear curve: F (linear) = 27.4409, $p < .01$. The factor target distances showed significant linear properties: F (linear) = 392.06, $p < .01$. Once more, the interaction between the two factors was not significant.

Tests of significance of mean difference from assigned value at standard

Following the six presentations (two trials per target distance), the two distance estimates for each experimental standard were averaged for each subject. The value of the particular standard (250, 500, or 1000 feet) was subtracted from the mean response to the experimental standard for each of the ten subjects.

The ten values, positive, negative, or zero, were used to define the variability of response in the group; they were also averaged to give an estimate of the difference from the assigned value of the standard for that particular TD; the same procedure was executed for the other two target distances (-5, -20, 30). According to the t tests, the three means were not significantly different from 0; on the average, estimations of distance to the standards were close to the values assigned to the standards (*t* values of 0.176, 0.572, and 0.316 were obtained).

Correlations

The difference between the subjects' response to the presentation of the experimental standards and the assigned values of the standards was calculated. Then, those difference values were correlated with age and number of years of driving experience for each target distance. The resulting correlation coefficients are as follows:

TABLE 10

Correlation between error of estimation of experimental standard vs age and driving experience for brightness.

TD 250	$n = 10$	
AGE	$R = .44$,	$p < .23$
EXP	$R = 0.26$,	$p < .44$
TD 500	$n = 10$	
AGE	$R = -0.13$,	$p < .82$
EXP	$R = -0.1$,	$p < .9$
TD 1000	$n = 10$	
AGE	$R = -0.22$,	$p < .67$
EXP	$R = -0.28$,	$p < .45$

Once more, the variables were not related to one another.

DISCUSSION

GENERAL FINDINGS

Effects of separation distance, size, and brightness of simulated headlights on estimates of distance

In separate studies, it was demonstrated that the distance between simulated headlights, their size, and their brightness significantly affected the estimates of distance to these lights. The smaller the gap between the lights, the farther away the lights were perceived. As well, the smaller and the dimmer the "headlights", the farther away they were judged.

These results are consistent with the literature on tail lights which confirmed the effects of size, brightness, and separation distance between tail lights on the judgement of distance to the preceding vehicle (Parker et al., 1964; Reilly et al., 1965; Moore and Smith, 1966; Janssen, 1977). As well, our results on the effects of light intensity also confirmed the past research on daytime running lights (Horberg, 1977; Attwood, 1976; and Allen, 1969), and other laboratory studies on brightness (Taylor and Sumner, 1945; Coules, 1955; Farné, 1977).

Effects of variations around the standard

How sensitive are we to changes in separation distance between "headlights", size, and brightness of "headlights", and how accurately can we use these changes in estimating distance to car headlights? The effect of the levels of the three variables was also significant and yielded significant linear trends in response from 40% decrease in stimulus value to 40% increase. However, a closer look at subjects' response patterns showed much less sensitivity than first expected. Observers did not consistently discriminate between the "smaller" levels of variation. Subjects did respond accurately to most of the standards. Some additional consideration of the contrast emitted by the stimuli is in order. In the experiment on separation distance between simulated headlights, the contrast with the background was constant for all the stimuli because size and brightness were kept constant. In the size experiment, the contrast with the background probably did not change very much over the various light stimuli, either.

However, brightness is usually dependent on the size of the aperture in front of the light. Since we kept the size and separation distance constant during the brightness experiment, the characteristics of brightness may have been affected. If people associate big headlights with a lot of blinking and a high level of luminance, then presenting them with different "sizes" of the same intensity alone may not have triggered a change in their estimation of distance.

The brightness study varied test light stimuli over three levels at each target distance. It is unfortunate that a finer gradation of light intensity could not be included. The change in the intensity level of the light stimuli is associated with a change in subjects' response (the estimate of distance to the light), although it could be argued that it was the increased contrast with the background which affected the estimates.

Distribution of response

In general, people tended to give distance estimates (to the light stimuli) that were close to the value of the standard. Few subjects estimated any of the lights at more than 1000 feet even when the lights were 40% closer together than the standard at 1000 feet, 40% smaller, and 40% less bright than the standard. Was it reluctance to use any number higher than 1000 because of its status as a "limit" or was it lack of discrimination ability? Certainly, there was no problem in subjects making estimates of less than 250 feet, so the limit effect cannot be invoked as such. In the separation distance experiment however, people did tend to overestimate slightly the lowest level of distance (40% more).

One last possibility is that this centralizing of response behavior may correspond to a natural tendency of subjects in a repeated measures design to keep their answers centered around the middle value. Such behaviour was frequently observed by researchers and reported by Stevens (1958).

Error of standard estimation

In terms of the identification of the standards at each target distance in the separation distance experiment, observers were able to recognize the standards at TD 500 and TD 1000 quite consistently (70% and 60% of subjects, respectively). However, at TD 250, only three subjects gave exact distance judgements when presented with the standard. This standard (separation distance at 250 feet) was the biggest of all three, insofar as the lights were large, bright, and widely spaced, and provided subjects with the largest stimulus visual angle. It is difficult to explain the difference in ability of subjects to accurately estimate the distance to this standard when the two others were recognized and accurately estimated at least in 6 cases out of 10. Perhaps the increased light associated with this standard contrasted too much with the impression of a far distance.

Correlations between error in standard estimation and personal variables

In analyzing the error of standard estimation further, the error values were plotted against subjects' age, sex, and years of driving experience. None of the correlations was significant. One would not have expected a particular trend according to sex, but age and years of experience were expected to minimize error.

METHOD AND PROCEDURE

Can we assume that drivers have a sort of "biological yardstick" allowing them in certain conditions to measure or estimate the real distance of a remote object? This methodology did not provide a clear answer since observers used standards as comparative stimuli. The values assigned to the standards were not arbitrary, rather they corresponded to the physical attibutes of one car's headlights in the field. But distances assigned to the standards may have seemed arbitrary to the subjects. Furthermore, similar to the limit effect, all distances may have been viewed only in relation to that of the standards. To prevent such an effect, standards which were not part of the experimental values, could be employed to determine if the effect of the stimuli was potent.

Magnitude estimation

It may be unrealistic to generalize from these studies to the field. Our scale values were obtained by determining the central tendency of judgements for each stimulus, while a driver usually does not get the opportunity to make various guesses about the distance of an oncoming vehicle. Furthermore, because of the wide range of velocity of vehicles, there is often not enough time to make distance judgements. Drivers are not trained to associate certain distances with particular light configurations. It would be unusual if the only cues available were the three studied in these experiments. Finally, the variables investigated in these studies would covary in the field. Still, the results obtained from these experiments suggest additional laboratory and field work to determine whether headlights should be standardized in terms of separation distance, size, and intensity.

The observer was asked to make quantitative judgements of distance based on perception, that is direct scaling, because this method minimizes the steps involved between the physical stimuli and the observer's response. In these studies, a context in which the observers could match numbers (estimates of distance) to their perceptions without using their own arbitrary scale, was created. Subjects were provided a frame of reference in which three standards were shown and labeled to represent distances x, y, and z. The manipulation and adjustment of the stimuli was done by the experimenter, as opposed to other scaling methods like category scales or fractionation estimation. The observer then measured the difference in distance between the standards and the variations.

Because this procedure was equivalent to the method of constant stimuli rather than adjustment, and also because our standard was always the middle value in the set of observations, it seemed to limit the variation in response. This probably is one of the causes for the clustering of the estimations around the middle value. By allowing the subject to adjust the comparison stimulus, one could reduce the effect of the context set by the use of standards.

Apparatus

Was the illusion of a distant car with headlights facing the viewer successfully achieved? A condition of almost complete cue reduction was applied; binocular vision was used but convergence, retinal disparity, and accommodation were reduced by having the stimuli stationary at over six meters from the observer. Texture gradient and linear perspective were virtually nonexistent. Diminishing the visual angle subtended by the stimuli to 2 degrees or less helped reduce the stereoscopic vision effect; there was no aerial perspective, interposition, or shadows. A chinrest also prevented motion parallax. The only clues remaining were relative retinal size of objects, and the familiar or assumed size clue. Although the object was not a car, subjects were told to act as if it were and to assume they were dealing with a car's headlights.

It might be preferable in the future to increase the dimensions of the apparatus in order to make it more realistic. The problem lies in calculating the exact dimensions that would permit maximum subject performance.

Distance estimation is not a common, everyday task and most subjects admitted spontaneously that they were "bad" at it. The apparatus and methodology did provide a good way of examining the relationships between three physical attributes of "headlights" and estimates of distance to the lights. Most of the literature on size-distance invariance (Gogel, 1978; Dinnerstein, 1967; Gilinsky, 1951; Boring, 1946) and brightness-distance relationships (Farnè, 1977; Coules, 1955) required subjects to use general responses such as "nearer" or "farther" than a stimulus (which was also present for direct comparison).

POTENTIAL IMPROVEMENTS

In future studies, it would be worthwhile to change a few details in order to add flexibility to the manipulation of the variables.

A more precise dimmer would be an asset; a photometer with absolute rather than relative units should be used for the light intensity measurements; the viewer's end of the tunnel should be improved to resemble the inside of a car; also one should use a more accurate method of changing the stimulus parameters; as well, alignment of lights should also be manageable.

A 750 feet target distance could be added to the experiment and would provide equal interval coordinates to the curve. It probably would be a good idea to increase the number of trials for each pair of stimuli as well as the number of subjects per presentation order. This would allow the geometric mean (a better representative) to be used as a measure of central tendency, rather than the arithmetic mean which was used in our experiments.

Lastly, with more accurate photometric measurements, it would be possible to look at the form of the function between the physical stimuli and the psychological response. Psychological magnitude is typically a power function of stimulus magnitude specified by the value of the exponent (slope) in a log-log plot, and, usually, stimulus magnitude increases faster than response magnitude. But as the value of the exponent varies widely from one sense modality to another, it would be interesting and useful to find out the relationship of the two continui (physical and perceptual) in these conditions.

IDEAL CONDITIONS

If the whole experiment could be done again without any restrictions in funding, manpower, and time, it would be done at night in the field with real headlights (mounted on a portable track). Although it would not be possible to eliminate all clues to distance, other than the lights, this study might prove easier and provide more useful information.

With special headlights, it would be possible to plan a complete series of experiments. Variables could be examined separately, as in the present studies, then they could be combined in a multivariate experiment. Performance could be observed under different conditions: with or without a standard, with a distance reference that could be an object or a person.

Static targets were the only feasible method for this experiment but, realistically, one should allow the target lights to move and require subjects to make a distance judgement at a designated point along its route.

It would be interesting to study the effects of ambient light on the estimates of distance of the oncoming car. The ambient light from one's own dashboard and headlights may affect one's judgement of distance.

Another interesting variable would be the different light systems available in today's vehicles. One could look at distance judgements when the oncoming car is using regular high-beams or halogen high-beams, and the interaction with these systems and lights of different size, separation distance, and intensity.

Most people who participated in the experiments expressed the fact that they normally do not estimate the distance to an oncoming car. Rather they try to figure out how much time is required to execute a certain manoeuvre, such as overtaking a preceding vehicle or making a left-hand turn at an intersection with free-flowing traffic. Velocity of both the oncoming vehicle and the driver's vehicle becomes a major factor in the decision-making process and time-estimating will most likely be a major subject in the future of headlight research.

To date, research has concentrated on glare effects and environmental variables (Hukulak, 1982; Pulling et al., 1980; Gordon and Schwab, 1979; Hills, 1975.). The three studies reported in this thesis indicate the promise of research on headlights as they affect estimation of distance to an oncoming vehicle.

CONCLUDING COMMENTS

Olson and Sivak (1984) expressed their concern about the lack of agreement on a set of standards for the automobile lighting system. Hills (1980) comments that once the causes of accidents have been identified through research, the remedies become apparent: for high-risk or problem drivers, better screening tests; for hazardous stretches of highway, lighting and delineation as well as warning signs; for conspicuity of vehicles, appropriate and effective lighting systems. Several possible changes in vehicle lighting have been proposed to aid the driver, for example, multilevel brakelights; colour and position differentiation between brakelights, signal lights, and tail lights; and roof-mounted brakelights, just to name a few. Although some changes are already being implemented by some companies on their 1988 models

(Ford, Honda), these changes required thorough justification through years of research and agreement of the industry.

Sivak (1983) commented in his review of the literature on various aspects of vehicle headlighting, representing the results of a substantial investment of time and money. According to him, there exists a considerable knowledge of vision (under low luminance conditions) and other relevant concerns, and the problems of vehicle headlighting should have already been solved. But unfortunately, this is not true. For example, there are two quite different low-beam lighting systems in use today, each with its enthusiastic advocates.

The appropriateness of the lighting device (size and type of the light sources) to the driver's inherent needs should be taken in consideration as well as its cost, in the expectation of producing improved driver behaviour which in turn would mean less accidents and enhanced community economy. The studies on simulated headlights reported in this thesis suggest that standardization of headlights may have beneficial effects on driver performance.

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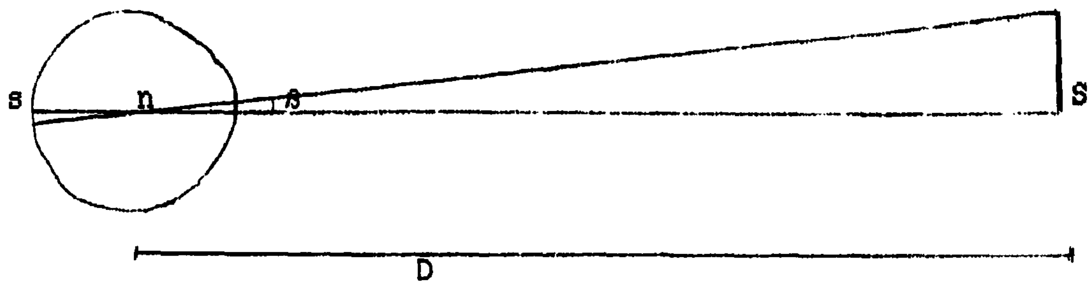
APPENDIX A

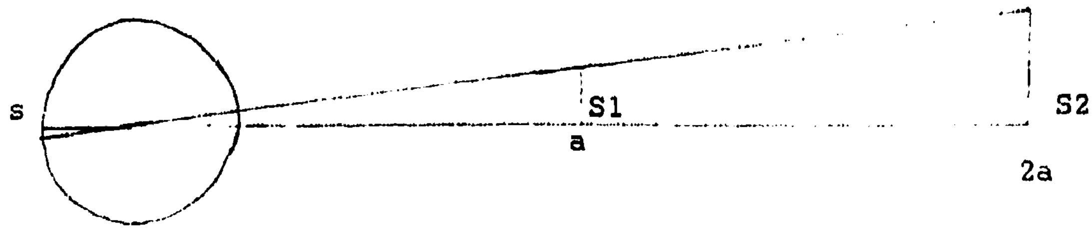
1. Law of visual angle or retinal image.



$\tan ß = S/D$, $s/n = S/D$.
s: size of retinal image
S: size of object
n: nodal point to retina
D: object to nodal point

The size of the retinal image that is subtended by some object of physical size S varies inversely with the distance of the object from the eye, so $s \propto S/D$.

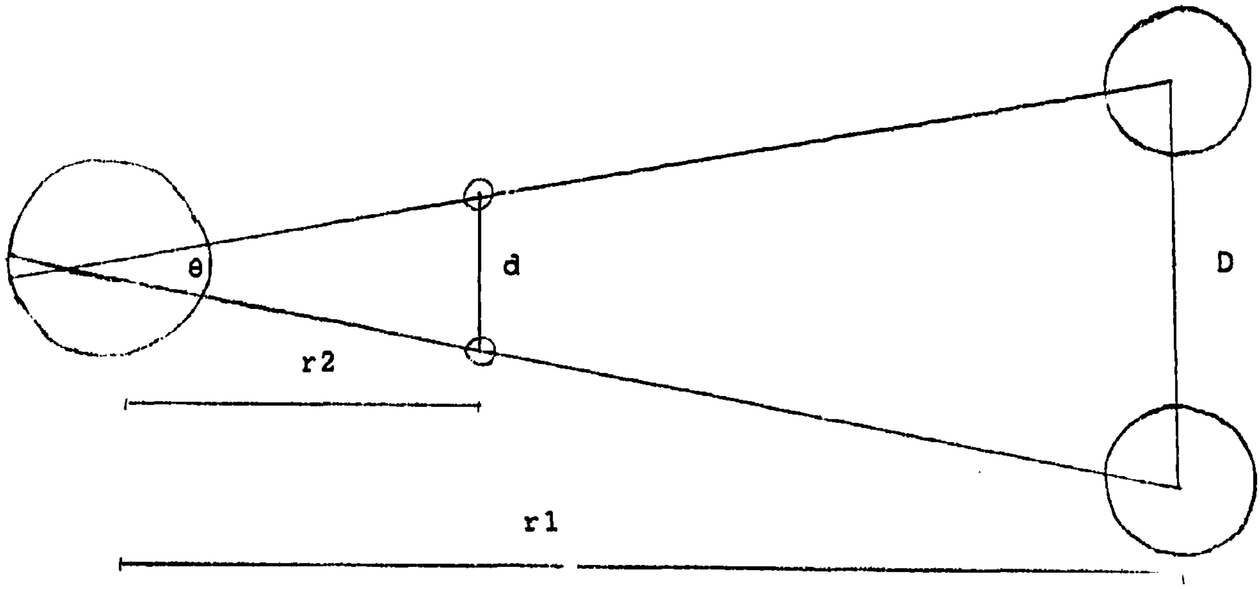
2. Distance and retinal image.



For a fixed retinal image, the ratio of size to distance is constant.

APPENDIX B

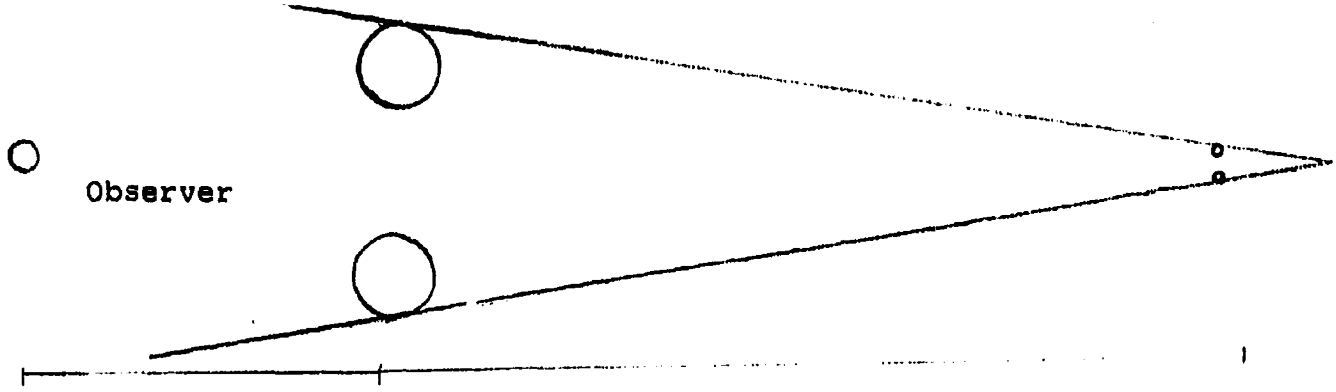
1. Methode for obtaining the proportions of headlight stimuli according to distance.



$\theta = d/r2 = D/r1.$

APPENDIX C

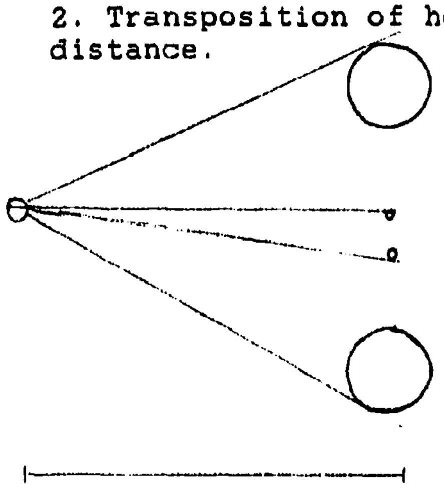
1. Regression of headlights into distance.



Viewing distance 6.7m

228,478,or 978 ft.
Target distances minus viewing distance

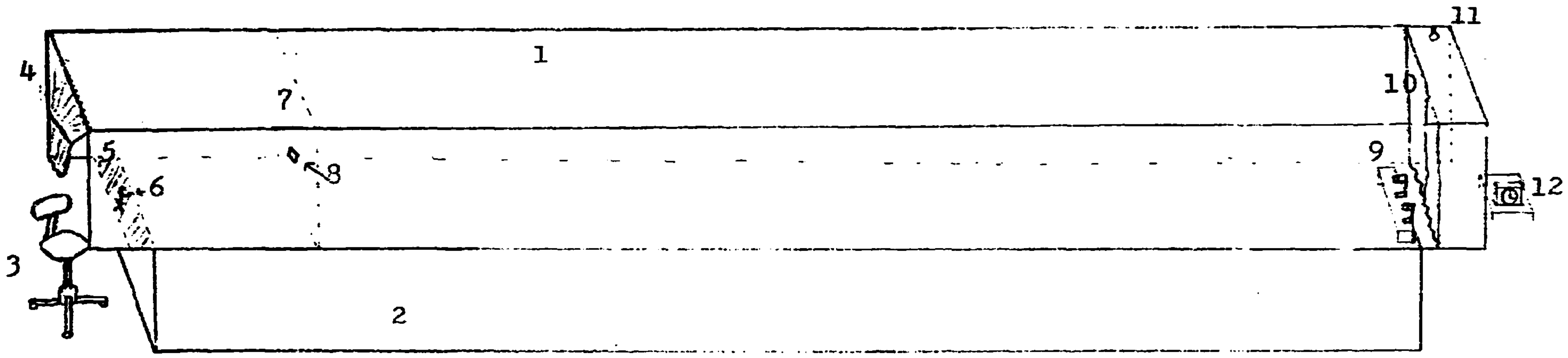
2. Transposition of headlight stimuli to proximal viewing distance.



Viewing distance
Cue reduction and a smaller visual angle lead to illusion of greater distance.

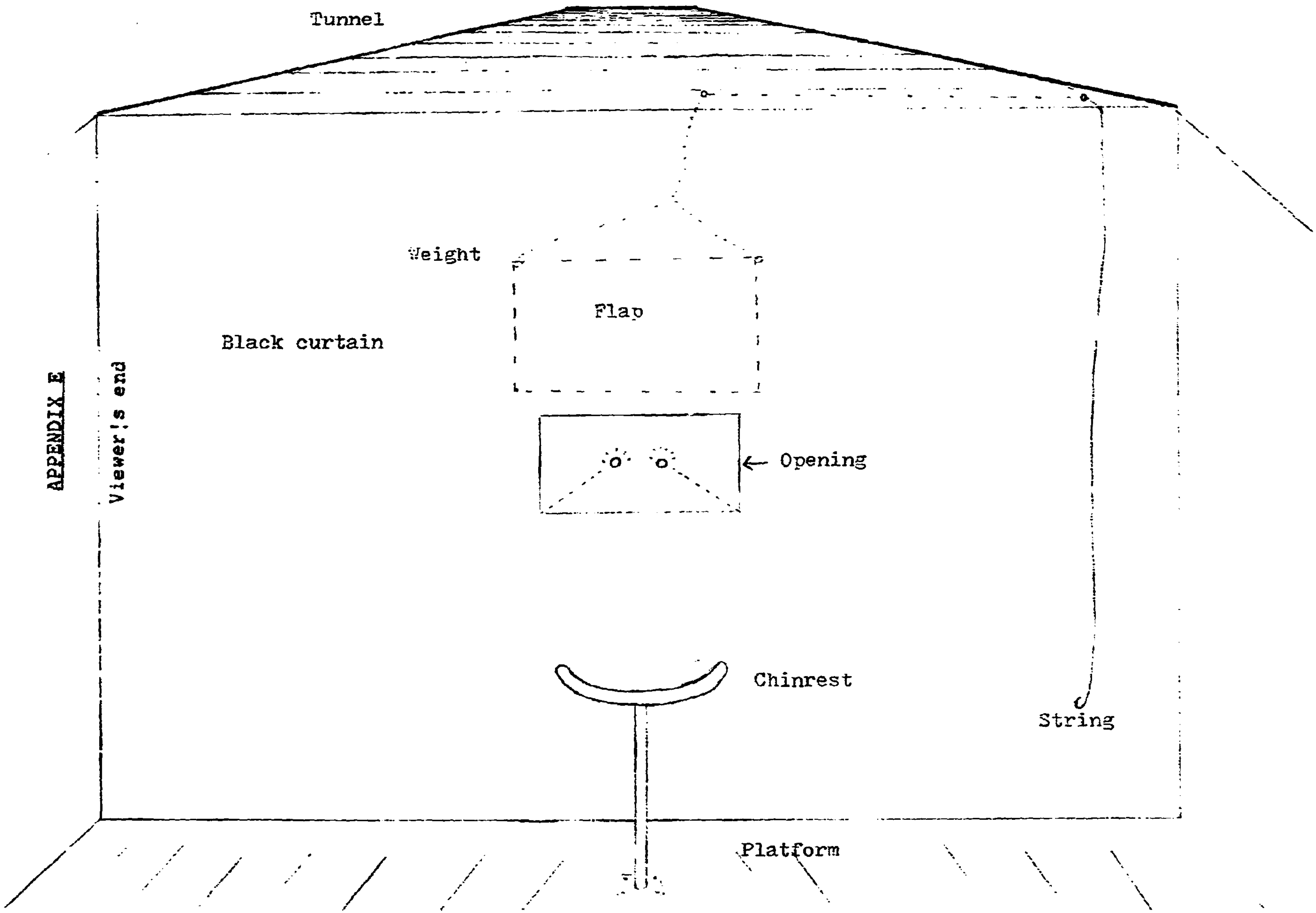
APPENDIX D

Apparatus



1. Tunnel
2. Stage
3. Adjustable chair
4. Curtain
5. Small platform
6. Chinrest
7. Black cardboard
8. Opening
9. Light fixtures
10. Curtain
11. Red light
12. Clock

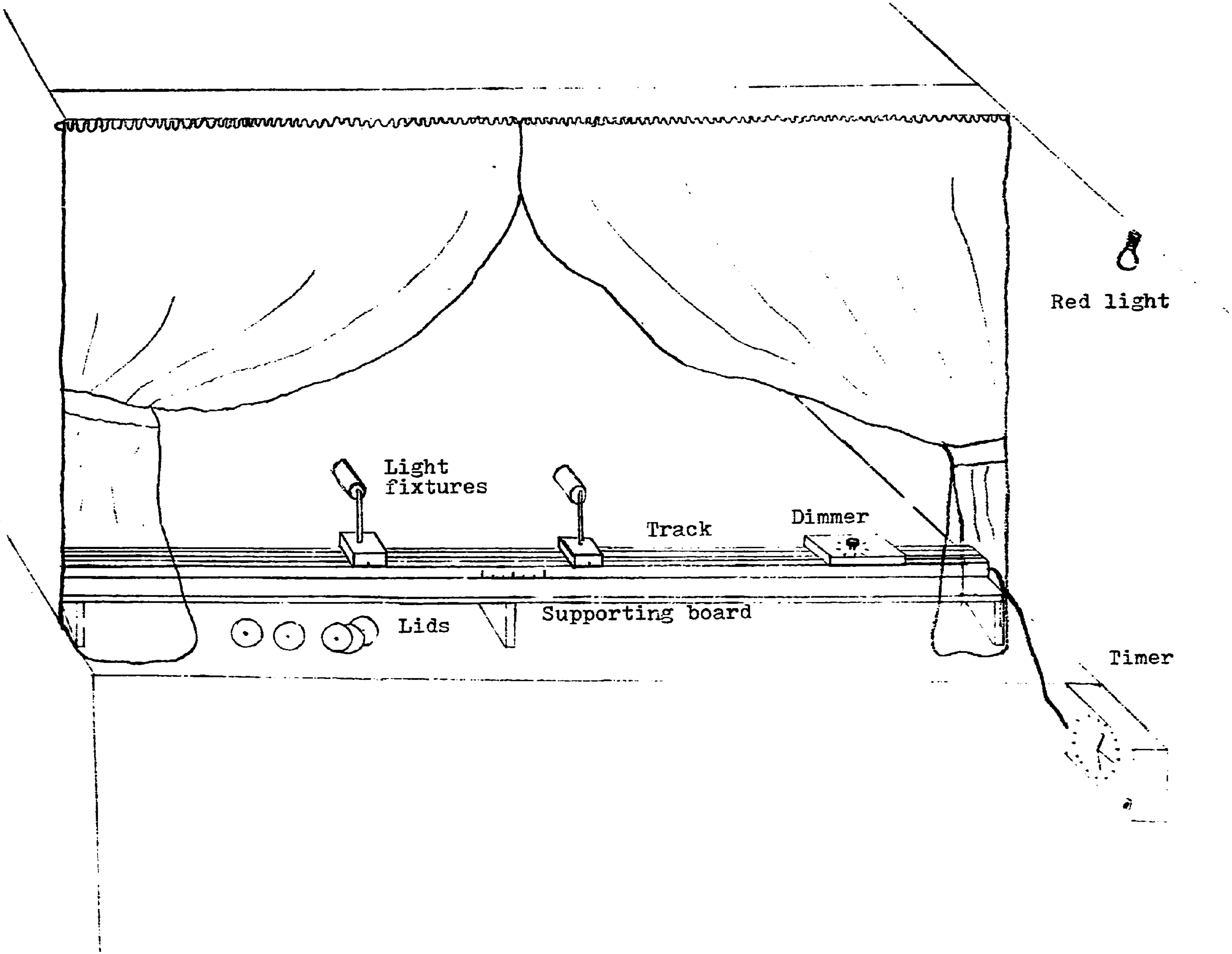
APPENDIX E



Tunnel
Weight
Flap
Black curtain
Viewer's end
Opening
Chinrest
String
Platform

APPENDIX F

Experimenter's end



APPENDIX G

INSTRUCTIONS

The experiment in which you are about to participate deals with a simulation of car headlights at night.

You will be presented with light stimuli and will have to make judgements of the distance between you and the different stimuli. It is important that you try to represent yourself in a driving situation and ignore the surroundings as much as possible.

The whole experiment should take approximately 35 minutes but you are free to go at any time; I only hope that you will stay for the entire duration of the experiment. Here are your instructions, do not hesitate to ask the experimenter to repeat them, if you need to hear them again.

ONCE YOU ARE AT THE VIEWER'S END, PUT YOUR CHIN IN THE CHINREST AND LET THE EXPERIMENTER KNOW IF ANY ADJUSTMENTS ARE NEEDED. WHEN THE ADJUSTMENTS HAVE BEEN MADE, THE EXPERIMENTER WILL ASK YOU TO PULL ON THE STRING THAT COMES THROUGH THE CEILING ON YOUR RIGHT, IT WILL LIFT THE SMALL BLIND IN FRONT OF YOU.

YOU WILL THEN SEE THE FIRST LIGHT STIMULI AND THE EXPERIMENTER WILL GIVE YOU SOME INFORMATION ABOUT IT. THEN, YOU WILL BE ASKED TO LET THE STRING GO TO LOWER THE BLIND AGAIN WHILE THE EXPERIMENTER CHANGES THE STIMULI.

YOU WILL HAVE TO OPERATE THE BLIND IN THIS MANNER FOR EACH PRESENTATION. YOUR ONLY OTHER TASK WILL BE TO SAY OUT LOUD YOUR ESTIMATION OF THE DISTANCE BETWEEN YOU AND THE DIFFERENT LIGHT STIMULI.

FOR NOW, YOU WILL SIT IN THE DARK FOR A FEW MINUTES AND YOU WILL BE ASKED FOR INFORMATION ABOUT YOURSELF AND YOUR DRIVING EXPERIENCE. IF YOU ARE INTERESTED IN DETAILS OF THIS EXPERIMENT, I WILL BE GLAD TO ANSWER YOUR QUESTIONS WHEN WE ARE FINISHED.

Your help is greatly appreciated,

Danielle Fortier

APPENDIX H

QUESTIONNAIRE

Experiment name:

Subject number:

Presentation order:

Name:

Age:

Sex:

Years of driving experience:

Accidents daytime:

night time:

Eye or vision problems:

Introductory Psychology: yes
no

MATERIALS

Photometer: Pasco Scientific Lux Variable
Model 9152
Sensitivity scale: 1000-300-100-30-10-3-1
Serial number: 203-0243

Lights: CGE Miniature Floodlight
25w, 120V

Dimmer: Variac

APPENDIX I

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