

SIGN LEGIBILITY AS A FUNCTION OF
SIGN LUMINANCE, AMBIENT ILLUMINATION,
CONTRAST DIRECTION, CONTRAST LEVEL,
AND AGE AND ADAPTATION
LEVEL OF OBSERVERS

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ABSTRACT

SIGN LEGIBILITY AS A FUNCTION OF SIGN LUMINANCE, AMBIENT ILLUMINATION, CONTRAST DIRECTION, CONTRAST LEVEL, AND AGE AND ADAPTATION LEVEL OF OBSERVERS

by FREDERICK N.[†] DYER

To extend the present limited amount of knowledge about the legibility of signs viewed under various night driving conditions, the following experiment was performed. Sixty observers from 18 to 81 years of age each read 60 sign presentations representing five levels of sign luminance, two levels of contrast, two contrast directions, and three letter heights. Observers were divided into three age groups of twenty each and four observers from each age group viewed the 60 presentations at one of five ambient illumination levels. Observers rode in cars equipped with odometers and legibility distances for the presentations were recorded by an experimenter in the rear seat. These distances were analyzed in an analysis of variance and means for the significant combinations of variables were obtained. Curves were plotted to illustrate these interactions and for use in determining sign luminance requirements for adequate legibility.

Legibility differed for different combinations of variables, and these differences were interpreted in terms of differing visual sensitivity resulting at the different levels of ambient illumination and also resulting from the illumination

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from the sign itself. The effects of initial differences in visual sensitivity because of age were also discussed.

Basic research needs were suggested for the understanding of reduced acuity resulting from blur which occurred for some of the presentations in the present study. Legend research which might improve night legibility was also discussed.

Terrence M. Allen

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By

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CHAPTER I: THE PROBLEM

Reflectorized sign materials have provided much greater sign legibility at night than the painted signs which they have to a large extent replaced. The increased legibility of these signs is due to the increased luminance that they provide when headlights shine on them. In brightly-lit urban areas engineers have found it necessary to further increase the luminance by artificial illumination. However, it is not known how much luminance is required at these areas to provide adequate legibility.

Purposes of the Study

Although the results of this study provide information about the process of reading signs at night, it was conducted for more practical purposes. The main such purpose was to obtain legibility data for various levels of sign luminance, viewed at different levels of ambient (surrounding) illumination. One reason such data was required was to determine the sign luminance needed to insure adequate legibility with oncoming headlight glare.

Another purpose of the study was to determine the effect on legibility of reduced contrast that occurs when the background as well as the legend (message) on the sign is illuminated. Such information would permit comparisons of legibility of reduced contrasts with the legibility of colored backgrounds (which also involve reduced contrast) which may be investigated in a future experiment.

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Now, let $\mathcal{A}$ and $\mathcal{B}$ be two arbitrary sets of formulas. We shall show that $\mathcal{C}(\mathcal{A}) \subseteq \mathcal{C}(\mathcal{B})$ if and only if $\mathcal{A} \subseteq \mathcal{B}$. We have already shown that $\mathcal{A} \subseteq \mathcal{B} \Rightarrow \mathcal{C}(\mathcal{A}) \subseteq \mathcal{C}(\mathcal{B})$. To show the converse, let us assume that $\mathcal{C}(\mathcal{A}) \subseteq \mathcal{C}(\mathcal{B})$ and that $\mathcal{A} \not\subseteq \mathcal{B}$. Then there is a formula $\phi \in \mathcal{A}$ such that $\phi \notin \mathcal{B}$. Since $\phi \in \mathcal{A}$, we have $\phi \in \mathcal{C}(\mathcal{A})$. Since $\mathcal{C}(\mathcal{A}) \subseteq \mathcal{C}(\mathcal{B})$, we have $\phi \in \mathcal{C}(\mathcal{B})$. But $\phi \notin \mathcal{B}$, so $\mathcal{B}$ is not closed under logical consequence. This contradicts our assumption that $\mathcal{B}$ is a set of formulas. Therefore, $\mathcal{A} \subseteq \mathcal{B}$. $\square$

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Since night legibility characteristics of the two contrast directions need further investigation (Allen and Straub, 1955), legibility was determined for both light letters on a dark background and for dark letters on a light background.

Another purpose was to compare different age groups of observers in their sign-reading performance. If differences were observed, it was hoped that relating these differences to known changes in vision that occur with age would provide information about the visual processes involved when signs are read at night. Also, if legibility distances were much lower for older drivers, it would indicate that older drivers should be included as observers when legibility requirements are determined.

Theory

For a dark rural road with no glare, Allen (1958) found legibility to be directly related to sign luminance up to a level of 10 ft.-Lamberts. Above this level, increases in legibility were slight, and at 100 ft.-Lamberts a decrease in legibility was noted. This finding of reduced legibility at high luminance may correspond to the reduced acuity at high target luminance found by Wilcox (1932) for a light target on a dark background. In this section a theoretical explanation of this decline in legibility at high luminance levels and a related theoretical explanation of the general reduction of legibility that has been found to occur at night (Forbes and Holmes, 1939) will be given.

The retinal image of a sharply defined contour is not itself sharply defined even though its perceptual counterpart usually is.

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This diffuseness of contour in retinal images was described by Fry (1955) and others and was referred to as taper of the retinal image. If the amount of light on the retina were plotted as the ordinate of a graph, a bar of light corresponding to the stroke of a white letter would appear in the shape of a bell instead of a rectangle.

Fry (1955) attributed this taper to several sources including the scatter of light that occurs because of particles and surfaces within the eye and also aberrant refraction of light by the lens, the cornea, and other parts of the eye. Fry was not concerned with the particular source of taper nor with the subjective perception of this taper. His treatise on blur was concerned chiefly with the form the taper would take given a point source, line source, or border of light. This information would be extremely useful, however, in designing sign legends to reduce the deleterious effect that the perception of this taper, i.e. blur, was on legibility. This section will attempt to relate these facts about the taper of the retinal image to blur as it is experienced and to suggest factors that increase the perception of this taper.

Despite an expansion of contour with increased target brightness known as irradiation that occurs (Wilcox, 1932), and which may be related to the steepness of the retinal image taper (Bartley, 1963), the normally refracting eye does not perceive the taper (as blur) under ordinary daylight viewing conditions. In near-sightedness (myopia), the taper would be expected to be large for distant, over-focussed objects. The blur that is reported by the myope is undoubtedly the result of perception of this taper. In far-sightedness a similar situation would exist for near objects.

Both with and without blurring, the expansion of contour would be expected to reduce acuity.

The myope must generally be made aware of his near-sightedness before he sees objects as blurred. This is not the case for the far-sighted person since by straining his accommodation he can perceive near objects as less blurred. The myope cannot reduce blur unless he squints or otherwise increases resolution. Since the myope's blur may not be recognized as such, it suggests that some reduction of acuity because of blur may always occur in normal vision too; but instead of being regarded as blur, it is taken for granted as the point where separate contours are no longer resolvable.

Another condition that increases the amount of blur occurs when a very bright object or light source is viewed. The taper of this retinal image would be correspondingly bright, and would excite receptor cells beyond the lighted contour. This probably accounts for the fuzzy, expanded contour of bright light sources. This illustrates the close relation of taper and acuity since as two light sources become brighter the distance between their expanding contours would decrease and resolution of the contours, i.e., acuity, would also decrease.

If the eye were partially or completely dark adapted, it is theorized that this expansion of contour would occur to a greater extent and would also occur with a less bright image, since the eye would respond to a taper of less brightness. Because of this, if a small amount of refractive error were combined with partial or

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total dark adaptation, blur would increase. This might provide a partial explanation of the condition of "night myopia", where myopia increases during darkness although the evidence that refraction itself is increasing is contradictory (Knoll, 1952). The larger than normal taper of slightly myopic eyes would be more readily perceived under these circumstances than during the day when the retina was less sensitive.

Even in eyes with normal refraction, pupil dilation during darkness would be expected to increase the amount of taper of retinal images. This is chiefly because the increased amount of lens area available for focussing the image permits an increased amount of aberrant refraction of the image. As suggested above, increased dark adaptation would tend to increase the amount of taper regardless of pupil size changes. The increased blur that results from these changes in pupil size and from adaptation may explain the general reduction of legibility at night.

On the basis of this theory of the perception of retinal image taper, it was predicted that as sign luminance in the present study increased, a point would be reached where taper from adjacent contours of the image would interfere with resolution of these contours and thus reduce legibility. This point of reduced legibility would differ as different combinations of legibility variables, such as contrast direction, were presented which changed the taper of the image contours and also changed the relative position of these contours. The point of reduced legibility would also be determined by the adaptation level of the eyes of the observer which would depend on

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the surrounding illumination and the glare. At the highest levels of surrounding luminance the adaptation level of the eyes might be sufficiently high to prevent the reduction of legibility.

Overview

Sign legibility, vision and other research that is applicable to the present study is reviewed in the next chapter of this thesis. In Chapter III, a preliminary experiment is discussed which examined the legibility of three-letter words to permit the selection of a homogeneously legible group of words for the main experiment. Also in Chapter III is a description of the procedures used to obtain daylight acuity data. This data was used to match groups for the main experiment.

The design and procedures of the main experiment are presented in Chapter IV. Chapter V contains the results of the experiment and in Chapter VI these results are interpreted and the implications for future research are discussed.

CHAPTER II: REVIEW OF LITERATURE

This chapter is divided into three sections. The first is an overview of legibility research which is intended to place the present study into a historical perspective. This section is also intended to illustrate the problems in legibility research and to examine experimental techniques that have been used in the past to determine legibility.

The second section is a more detailed account of night legibility studies, with emphasis on problems and findings that are pertinent to the present study. Where the theory of perception of tapered retinal images presented in Chapter I seems relevant, it will be used to provide an interpretation of these findings.

The third section deals with variables such as headlight glare and vision of the aging driver, which have not usually been considered in legibility studies. Research in these and other areas will be related to the present study. The effects of these variables on the tapered retinal image and its perception are also considered. Research on variables such as legend familiarity which were not investigated in the study was reviewed to aid in controlling these variables.

Sign Legibility Research

Early attempts to assess sign legibility were generally unsystematic. As pointed out by Forbes (1939), one technique that was not uncommon was for the individuals concerned to express their opinion as to the legibility of a certain combination of variables,

with the opinion of the person in charge determining the optimum legibility characteristics.

When more systematic investigation was attempted, little control of variables such as familiarity and word legibility was exercised. Also, statistical analysis of results was not carried out and a representative range of variables was seldom investigated.

A study subject to most of these criticisms was conducted by Mills (1933). He compared black letters on a yellow background, black letters on a white background, and white letters on a black background. This was done by measuring the percentage of correct readings of signs at various distances that were briefly exposed to the observers. The percentage of correct readings for black on yellow was 66 percent, for black on white this figure was 57 percent, and for white on black it was 59 percent. Reversals of the order of these percentages occurred at different distances, however, indicating that if a variance had been computed for these readings it would have been quite large and these differences may not have been significant. Mainly as a result of this study, however, black letters on a yellow background were chosen to be used for warning signs.

Two particularly vexing problems face the designer of a legibility experiment. One, already mentioned, is controlling the large number of variables that are always operating in such studies. A second problem involves the large amount of variation of the measuring instrument, i.e. the human observer, from observation to observation.

Perhaps because psychologists are often faced with difficult experimental problems, it was a psychologist who showed the way toward meaningful legibility research. Forbes (1939) met these problems by using a well-planned experimental design and an extremely large number of observations to increase the reliability of the measurements. His general experimental technique was to have the observers walk up to the sign or signs, marking the points at which they were able to read the legends.

Using this technique, Forbes (1939), Forbes and Holmes (1939), and Forbes, Moscovitz, and Morgan (1950) investigated such variables as day and night legibility, legibility of reflectorized materials, sign-reading with long and short sign exposures, legibility of upper and lower case letters, legibility of letters of different widths, and the effects of legend familiarity on legibility. The results of these studies and their meaning for the present study will be considered in the next sections of this chapter.

A large amount of research followed in the area of general sign legibility. Stroke width (Uhlener, 1941), contrast (Smythe, 1947), spacing (Lauer, 1947), and contrast direction (Kuntz and Sleight, 1950) were some of the topics investigated. The results of some of these studies will be treated later. Generally they were laboratory studies which dealt with specific legibility variables under a restricted set of conditions.

Breakthroughs in the construction of reflectorized materials resulted in considerable research on legibility of signs constructed with these new materials (Straub and Allen, 1956; Allen and Straub,

1955; Decker, 1961). This increased interest in sign brightness led to the first systematic studies of legibility with respect to this variable (Allen and Straub, 1955; Allen, 1958). These studies bear directly on the present one and will be described in detail in the next section. The finding in these studies, that legibility varies greatly as luminance changes, limits the usefulness of previous night legibility studies to the specific luminance that was used in the particular study. Unfortunately, many of these studies did not even report the level of sign luminance. It is to help fill this newly realized gap in knowledge about legibility at different levels of luminance that the present study was designed and conducted.

Instead of having observers walk up to the sign, the general procedure in these later field studies was to drive the observer toward the sign with an experimenter in the rear seat recording the reading distance from an odometer or from stakes along the roadside. This is an expensive procedure, but it closely represents the sign-reading task that a driver must perform.

Night Legibility Studies

The legibility data obtained using daylight or comparable illumination is of interest to researchers in night legibility, but no general transfer of these daylight findings to night applications should be attempted. The reason for this is most evident in the work of Berger (1944a, 1944b) who determined the optimal stroke widths for license plate numerals. A ratio of letter height to stroke width of twelve to one was found to be the most legible for white numerals on a black background during the day. At night, using white reflecting

numerals, this ratio increased to twenty to one and for luminous numerals (illuminated from behind) the ratio was about forty to one. Berger did not make photometric measurements of either the white reflecting or luminous surfaces. For this reason it is difficult to fit these findings into any overall view of night legibility. They are, however, excellent evidence that day and night legibility must be treated separately.

Berger's findings can be interpreted in terms of the theory of the perception of retinal image taper. At night as the taper of the image increased, both because of increased aberration due to pupil dilation and because of increased sensitivity of the retina due to dark adaptation, blur interfered with the resolution of adjacent contours and reduced the legibility of white numerals with wider stroke widths. This interference was reduced where the numerals were narrower in stroke width and bright contours were farther apart. It might be appropriate to speak of the narrow stroke width letters as "blurring to the optimal stroke width".

Sign Luminance

The most important variable in night legibility is sign luminance. Since legibility and acuity are closely related, the findings of Shlaer (1937) and Wilcox (1932) for acuity with different target and background luminance are included in this review of literature.

Shlaer (1937) measured acuity with a grating and a Landolt "C" presented against a background that varied in illumination from about .0001 to about 10,000 ft.-Lamberts. Observers were adapted to

the luminance and viewed the target through a 2 mm. aperture or "artificial pupil". After an early break in the curve at about .01 ft.-Lamberts, corresponding to the different acuity for rods and cones, acuity increased almost linearly to about 10 ft.-Lamberts. Acuity for higher luminance approached an asymptote that differed for the two targets. Maximum acuity for the "C" was 2.1 measured in terms of the reciprocal visual angle and only 1.6 for the grating.

Wilcox (1932) measured acuity with white bars against a dark background and found acuity increased to about .3 ft.-Lamberts then decreased for higher target luminances. Subjects were more adapted to the dark background than to the target luminance with this contrast direction. For this reason these findings may correspond more closely than those of Shlaer to the present legibility study, where observers were adapted to the surrounding illumination and not to the sign luminance.

In what was probably the first systematic study of the effect of sign luminance on legibility, numeral legibility was shown to increase as display luminance was varied from 3 to 10 to 31 ft.-Lamberts (Kuntz and Sleight, 1950). This was true for both contrast directions and for several different stroke widths.

Sign luminance levels of .1, 1, 10, and 100 ft.-Lamberts were used in a more extensive legibility study by Allen and Straub (1955). Both contrast directions, three letter series, and two levels of ambient illumination were included in the study. Discounting for the moment the significant interactions between sign luminance and these other variables, legibility was found to increase sharply up to 10 ft.-Lamberts with no further increase in legibility at 100 ft.-Lamberts.

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In another systematic investigation of sign luminance, Allen (1958) confirmed the findings of the above study in the field using the same levels of sign luminance. A decrease in legibility occurred in this study for the 100 ft.-Lambert sign luminance. This corresponded to a similar decrease for the light letters on a dark background in the above study.

All of these studies seem to indicate that increases in legibility result from increases in sign luminance up to a maximum legibility where further increases in luminance do not change legibility or else reduce it. However, it should be noted that the maximum legibility at night never reaches the daylight legibility level. Forbes and Holmes (1939) reported a 15 percent decrease in legibility at night. Allen (1958) reported an average daytime legibility of 88 feet per inch of letter height. The maximum night legibility in the study was only 74 feet per inch of letter height. This was a 16 percent decrease. Clues to the reasons for this decrease in legibility at night might be obtained from an examination of the interactions of luminance with other variables in these studies.

Contrast Direction Different studies of daylight legibility have reported contradictory findings about the relative legibility of light letters on a dark background and dark letters on a light background (Kuntz and Sleight, 1950). In their study of legibility for different luminances, Kuntz and Sleight (1950) found no significant differences between contrast directions. Since they used a small range of sign luminance, their results were of limited

generality. In addition, no indication was given whether or to what degree observers were dark adapted.

In the study of Allen and Straub (1955), the interaction between sign luminance and contrast direction was significant. They found white letters on a black background to be superior to black letters on a white background for the 1 and 10 ft.-Lambert luminances. This difference did not occur at either the .1 or 100 ft.-Lambert luminance levels. At the 100 ft.-Lambert luminance level legibility for the black letters on a white background was somewhat greater than for the 10 ft.-Lambert level, while with white letters on a black background a slight decline in legibility was noted from 10 to 100 ft.-Lamberts. Legibility did not differ for the two contrast directions at the .1 and at the 100 ft.-Lambert sign luminance levels.

One explanation of the above findings can be made using the theory of retinal image taper perception. For the .1 ft.-Lambert luminance level there is relatively little blur involved in the perception of both contrast directions and thus little difference in their legibilities. As luminance increased to 1 and 10 ft.-Lamberts, blur at the bright contours increased for both contrast directions but interfered with contour resolution more for the dark letters on a light background, where adjacent bright contours forming the sides of the letters were closer together; than for the light letters on a dark background, where the distance between adjacent contours was the distance between the letters themselves.

Thus at these two luminance levels legibility was interfered with somewhat by blur for the dark letters on a light background but was relatively unaffected for the light letters on a dark background. At 100 ft.-Lamberts blur was sufficiently great so that resolution of the contours for the light letters on a dark background was also affected despite the greater distance between contours, and legibility dropped to the level of that of the dark letters on a light background.

Letter Series The different letter series were developed to facilitate fitting words to the space available on signs. These series of letters differ principally in letter width, but also in stroke width and spacing. Forbes and Holmes (1939) found the wider series letters to be more legible than the narrow series letters for both day and night viewing.

Allen and Straub (1955) included three letter series: "A", "C", and "F" in their sign luminance study. They found legibility to be greatest for the wide series "F" letters, next highest for the series "C" letters, and least for the narrow series "A" letters. This difference in legibility held for all sign luminance levels.

The significant interaction in this study between luminance and letter series requires further attention. Although legibility increased for all letter series up to 10 ft.-Lamberts, the increase for the widest series "F" letters was much greater than that for the "A" and "C" series which had about the same increase. Also, instead of remaining constant from 10 to 100 ft.-Lamberts, legibility for the series "F" letters showed a further increase.

These letter series increase in stroke width, spacing, and overall width as their alphabet designator increases. Berger's (1944a) results showed that decreasing the stroke width increased legibility for the light letters on a dark background at the higher luminances. This suggests that the increased legibility of wider series letters must result from increased width or increased spacing or more likely from both in combination, for this contrast direction. If a wide, substantially spaced legend with narrower stroke width were developed for the light legend on a dark background contrast direction, it might prove more legible than any presently in use if made sufficiently bright. Increases in stroke width might also increase legibility for the dark letters on a light background, although such increases might require added letter width.

In terms of the theory of tapered retinal image perception, the increased width and spacing separates illuminated contours and allows resolution of these contours despite blur. A narrower stroke width for the light legend on a dark background and a wider stroke width for the other contrast direction would be expected to further improve resolution by further separating contours.

Ambient Illumination Allen and Straub (1955) investigated sign legibility at two levels of ambient illumination, .1 and .001 foot-candles, with illumination measured in a vertical plane at the subject's eye level. They found the lower sign luminance levels to be more legible at the lower ambient illumination level than at the higher ambient illumination level, and they found that higher

sign luminance levels provided greater legibility at the high ambient illumination level than at the lower ambient illumination level.

Subjects were given time to adapt to the level of ambient illumination, and these results are best explained in terms of the adaptation level of the eye. The greater sensitivity of the dark-adapted retinas with the low ambient illumination increased the legibility for low sign luminance levels, but also increased the perception of taper from bright contours at the higher sign luminance levels with a subsequent reduction of acuity. The converse situation occurred when eyes were adapted for the higher ambient illumination level. Legibility was lower for the lower sign luminance levels and higher for the higher sign luminance levels. The decreased retinal sensitivity that resulted in the low luminance level being seen poorly, also reduced perception of taper and increased acuity for the brighter letters.

Other Research Relevant to the Study

Glare Automobile headlights are the most obvious sources of glare to drivers at night. However, street lights, advertising signs, and even the sign itself may also be sources of glare. To help order these diverse effects of glare, two operational definitions of glare have been used. One is disabling glare, where visibility or acuity is reduced because of the glare source. Most authorities agree that contrast reduction because of scatter within the eye is the main reason for this reduction of vision (Duke-Elder, 1938;

Fry, 1954; Boynton, 1955). The other is discomfort glare, which is defined in terms of the discomfort that is experienced in direct or indirect viewing of a light source.

It would be expected that some discomfort accompanies disability glare in most instances. It is possible, however, to imagine instances with targets that are very dimly illuminated, where a light source producing sufficient veiling luminance to reduce contrasts substantially would not cause discomfort although reducing acuity greatly. A quasi-converse situation would occur when a strong peripheral source of light increased the visibility of bright targets (Duke-Elder, 1938). Discomfort glare would be expected to be present in such an instance. In the first case, disability glare would be present but only separate measures of acuity with and without it might detect it. In the second case, disability glare is not present although the person viewing the situation would probably think it was.

Fry (1954) offered a formal theory of glare based on contrast reduction of foveal images because of veiling luminance resulting from scatter of peripheral light sources. He reduced the amount of scatter that such a glare source would provide to an equation developed on the basis of the optical properties of the eye. This equation related the amount of veiling luminance to the brightness of the glare source and to the peripheral angle of the glare source. Predictions of veiling luminance from this formula for a particular source corresponded closely to the veiling luminance that was

experimentally determined to reduce visibility to the same extent as the glare source being measured.

However, it appears that contrast reduction alone cannot explain disability glare completely. Glare sources have also been shown to reduce the sensitivity of the retina (Bartley, 1963). When glare sources are extremely bright, producing pronounced reduction in retinal functioning, scotomatic or blinding glare is said to exist (Duke-Elder, 1938).

No present interpretation of glare readily explains the finding of Simonson (1958) who found the ability of subjects to discriminate fine wires against a dark background increased during two minutes of continuous exposure to a glare source. Average threshold wire size at the beginning of exposure was 340 seconds of arc. This decreased to 18 seconds of arc at the end of the two minute exposure period. If this 20-fold increase in visibility could be expected to occur generally when a glare source is encountered for a considerable period, it suggests that a long stream of oncoming headlights might cause less reduction in night vision than an occasional oncoming car with conditions of less traffic.

Roper (1958) and others have shown that headlight glare sharply reduced the ability to detect objects in the roadway. Little has been done, however, to investigate the effect of headlight glare on the legibility of signs. However, Forbes, Moscowitz, and Morgan (1950) in preliminary studies to determine the best level

of sign luminance to use in their study of the legibility of upper and lower case letters found a luminance level from 30 to 40 ft.-Lamberts gave definite blurring at longer distances. They observed, however, that glare from headlights of a car facing the observers increased the distance at which the signs could be read. No systematic measures of legibility under these conditions were made, but the finding suggests that headlight glare may have different effects on legibility with different sign conditions.

Vision of the Aged Driver Many physiological changes in the eye and changes in visual function are known to occur with age. The relation between the physiological changes and the functional changes is not always clear, however. In addition, no work has been done to determine the way these changes relate to a visual task such as reading signs at night. In this section, to help answer these questions, these findings about changes of vision with age will be interpreted in terms of the theory of retinal image perception outlined previously.

Perhaps the most familiar change in the eye with age is the reduction of accommodation. Accommodation is the changing of the refractive power of the crystalline lens of the eye to bring near and distant objects into focus. The actual rate of decrease in accommodation is remarkably uniform for an individual from year to year, and changes with age occur uniformly among individuals (Hirsch and Wick, 1959). Except for highly far-sighted individuals, accommodation is not involved in reading distant signs.

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However, these changes in accommodation would increase the need for accurate correction of any refractive errors that do occur in older drivers.

More directly involved would be the changes in the iris which reduce both the maximum and minimum size of the pupil (Hirsch and Wick, 1959). The reduced lens area used to focus images would be expected to correspondingly reduce spherical aberration, one source of retinal image taper. The smaller amount of light entering the eye would be expected to reduce acuity for the lower luminances but on the other hand might improve visual performance when very bright targets are viewed.

Another regular change in vision with age is a reduction in retinal sensitivity which is illustrated in the study of McFarland and Fisher (1955). With over 200 subjects ranging from 16 to 89 years of age, they found a correlation of .895 between age and absolute threshold. Threshold luminance for the 80-89 age group was over 200 times that of the 16-19 age group. Increases in threshold luminance for the last three decades were much sharper than those for the younger ages.

Luria (1958) in a similar study with a smaller age range found the contribution of the smaller pupils of the older subjects to this decline in sensitivity was minor compared to the decline in capacity of the retina.

Studies using critical flicker frequency as an index of retinal sensitivity (McFarland, Warren, and Karis, 1958; Copinger, 1955)

show similar decreases in sensitivity with age with decisive decreases at age 60.

Although the greatest age differences in retinal sensitivity occur at extremely low luminance levels, some difference also occurs at the levels of luminance used on highway signs. In terms of the theory presented in Chapter I, this reduced retinal sensitivity of the aged should reduce the amount of image taper that these people perceive, actually improving their acuity for bright objects such as illuminated letters, under some conditions.

A change in eyes with age that would be expected to increase the amount of retinal image taper is the increase in the amount of opacities in the ocular media that occurs with age. Mazow (1958) reported, "the senile vitreous contains opacities that range in size from 'dustlike' which are barely visible to larger aggregates that cast dark shadows on the retina".

The increased scatter of light by these particles may explain the increased sensitivity to glare that occurs with age reported by Wolf (1961). He presented Landolt rings at various distances from a fixed glare source to 200 subjects ranging in age from 5 to 85 years. The ability to locate the openings of the rings decreased with age. The younger the subject, generally, the nearer to the glare source that such discriminations could be made. For individuals of advanced age to perform as well as those of college age, luminance of the rings had to be increased about ten times. Although glare sensitivity increased throughout the age range, there was a sharp increase in the slope of the curve at age forty.

Wolf also found abnormally high glare sensitivity in cataract patients prior to surgery. After surgery, sensitivity was reduced to levels at or below that of normal subjects of the same age. Particles both in the lens and in the other ocular media thus appear to contribute to this increased glare sensitivity.

Other changes in the eyes of older persons including a yellowing of the lens and depigmentation of the iris are known to occur. Perhaps the implications of these and other changes for visual functioning are summarized in the reduced acuity that is found to occur on the average with increasing age (Hirsch and Wick, 1959).

Familiarity Perhaps the only non-visual variable investigated with respect to legibility is familiarity with the legend. Forbes, Moscowitz, and Morgan (1950) used three types of legends in their study of legibility for upper and lower case letters. One legend was scrambled letters, the second was place names that were familiar to the observers, and the third was the same place names presented a second time in different positions on the sign.

As the authors predicted, legibility distances were shortest for the scrambled letters, greater for the familiar place names, and greatest for the familiar names with knowledge. These differences held for both day and night viewing conditions, but during the day the difference between familiar words with knowledge and familiar words viewed for the first time was much greater than at night. The authors suggested this was because slight visual cues were present to the identity of these words during the day that were not available at night.

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Other Variables The large amount of variation of subject's responses from observation to observation implies that other variables exist which operate to change legibility. Familiarity might be described as a set which would facilitate sign reading. Other sets or expectations would also be expected to reduce legibility under some circumstances, such as when a cue provided by a highly legible letter of a word leads to an expectation for a different word than the one presented on the sign.

Changes in the eye which result from extraneous factors might also account for some of the large subject variability. The influence of emotions on the pupil of the eye have long been observed (Lowenstein and Lowenfield, 1962). Pupil changes have also been shown to occur because of interest and mental multiplication (Hess and Polt, 1960; 1964). Similar situations have been shown to produce changes in the accommodation of the eye (Pheiffer, 1955). Changes in both pupil size and accommodation would be expected to alter the retinal image.

Study of the sign-reading process itself might indicate other variables which also affect legibility. Until measures are developed to control such variables, legibility experiments must be carefully designed to cope with a large variation in observations.

CHAPTER III: PRELIMINARY WORK

Before it was possible to complete the design of the experiment, legibility information was required about the words to be used for the legend on the sign. In addition, data on observer acuity was required prior to setting up the groups of observers for the experiment proper. In this chapter two preliminary experiments are described that were conducted to obtain this information.

Word Legibility

Words differ in their relative legibilities. It is possible to control for these differences in a legibility study by including the words as a separate factor in the design of the study. This requires that each word be viewed under each experimental condition by the same observer the same number of times. Unless a small number of words and experimental conditions were used this would lead to an extremely large experimental design.

In the main experiment as many as 72 different observations were made by each subject. If a small number of words had been used repeatedly for these 72 observations, the words would have been memorized by the subjects and recognition distance (Forbes, Moscovitz, and Morgan, 1950) instead of legibility distance would have been the dependent variable for part of the observations.

To meet the problem presented by different word legibilities, 18 words of nearly equal legibility were selected for the present study. By doing this a separate design factor was not required for words. Also, a large enough number of words was used to reduce the

effects of familiarity and to permit easy counterbalancing of the familiarity effects that did occur. Space limitation on the illuminated sign to be used in the main experiment required the use of three-letter words. To select 18 three-letter words of equal legibility, the following preliminary experiment was conducted.

Procedure Sixteen observers each read 60 different three-letter words and the distance at which each word was read was recorded. The three-letter words were made up of the ten letters most frequently used in Michigan place names appearing on interstate highway signs. These letters were A, D, E, I, L, N, O, R, S, and T. The words were constructed with white one-inch letters on flat black two inch by five inch cards. Bureau of Public Roads standards for series "E" letters were used in construction of the letters and Michigan State Highway Department Interstate standards were used for spacing the letters. The cards with the words were presented against a black background. Letter brightness was about 10 ft.-lamberts.

Sixteen Michigan State Highway Department employees who were readily available were used as observers. Each of the observers viewed all 60 of the words once and ten particular words of the 60 twice. These dual presentations were made with one word in between. They were included to see if familiarity with the words would affect the distance at which particular words were read.

Observers started at a distance 126 feet away from the word and walked toward it. When they read it aloud correctly, they

effects of familiarity and to permit easy counterbalancing of the familiarity effects that did occur. Space limitation on the illuminated sign to be used in the main experiment required the use of three-letter words. To select 18 three-letter words of equal legibility, the following preliminary experiment was conducted.

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Observers started at a distance 126 feet away from the word and walked toward it. When they read it aloud correctly, they

stopped and read the distance from a measuring tape on the floor. They then returned to the starting point while a new word was readied for viewing. Guessing was discouraged. Observers were informed of wrong answers and continued to approach the word until they could read it correctly.

Results After the data for the 16 observers was collected, means and variances of the legibility distances for the words were then computed. Means for all of the words ranged from 75 to 101 feet. Variances ranged from 25 feet to 253 feet. Appendix A contains the 60 words with their means and variances.

Eighteen words with nearly equal means and low variances were selected for use in the main experiment. The words were: AID, ARE, NOT, ONE, RAT, RED, ROT, SAD, SET, SIN, SIT, SOD, SON, TAR, TEN, TOE, and TON.¹ Means for these 18 words ranged from 86 to 91 feet. The maximum variance for these words was 92 feet. Legibility distances were obtained against for these 18 words in the daylight acuity trials described below. These second legibility distances corresponded closely to those obtained at first. These distances are also presented in Appendix A.

Words with "L" in them all proved to be overly legible and none were used in the main experiment. Because of this only nine different letters were actually used.

One word, AID, had a very large variance during the daylight runs. NOD was used in its place for the main experiment.

The ten words which were presented twice showed an average gain in legibility for the second presentation of 3.6 feet. This was only four percent of the average legibility distance of the 18 words selected. Words with low variances showed the least gain in legibility distance from first to second presentations (see Appendix A).

Daylight Legibility

One hundred and fifty subjects were tested on their sign-reading ability during daylight hours a few weeks prior to the night experiment. This was done by making four trips by the sign and recording the legibility distances for the 12 words which were presented three at a time on the sign. These runs were made for two reasons. One was to obtain acuity and sign-reading-ability information on the observers that would be used in the night experiment. This data was used to match groups for this experiment so that a location group would not accidentally contain people of either all high or all low acuity.

The second reason was to familiarize observers with the night testing situation which was basically the same as that used during the day. It was anticipated that a large portion of any learning and performance increment which would result over succeeding trials would take place during these daylight runs.

Procedure The 18 words selected in the experiment described in the last section of this chapter were presented three at a time on a 48 inch by 48 inch sign face. This sign face was mounted at a height of six feet on the back of a pick-up truck parked at the curb of a little-traveled residential street.

Three different letter heights were used: 13.3, 10, and 7 inches, with the largest letters presented on the top of the sign and the smallest at the bottom. White letters were presented on a black background for these daylight runs. Bureau of Public Roads series "E" letters were used with Michigan State Highway Department standard spacing.

Observers were drive one at a time past the sign at 15 miles per hour. The run started 3,000 feet from the sign. Observers read the words as soon as they were able and the reading distance was recorded by an experimenter in the back seat from an odometer that measured distance in thousandths of a mile. Four runs were made per observer past the sign face. Between runs a man at the sign changed the three words so each observer viewed 12 different words during the four runs.

Results Means were computed for each observer and for each word. Legibility distances were divided by the letter height to make them equivalent for the different letter heights. A variance estimate for each observer was obtained by taking the range of his reading distances after eliminating the most extreme legibility distance from the 12 for an observer. Observers for whom this figure exceeded 25 percent of their average legibility distance were classed as alternates in the main experiment and used only if no one else was available.

Acuity of observers was also measured, using an Orthorater. Average daylight legibility for the observers was 73 feet per inch of letter height. Average Orthorate acuity was 10.0 which is equiv-

alent to 20/20 Snellen acuity. The correlation between the two measures was .7.

CHAPTER IV: MAIN EXPERIMENT

In the main experiment the effects and interactions of six variables were investigated. The variables were sign luminance, ambient or surrounding illumination, contrast direction, contrast level, and letter height. Included in the levels of the variable of ambient illumination were situations where the signs were read in the face of headlight glare. In addition, three different age groups of observers were compared in their ability to read signs at night.

This chapter is divided into four sections. The first three describe the variables under investigation, with one section pertaining to the sign, one pertaining to the locations of the sign, and one pertaining to the observers of the sign. The fourth section deals with the actual procedures used to obtain legibility measurements.

Sign Variables

Sign luminance, contrast level, contrast direction, and letter height were the variables manipulated at the sign itself. Each level of each of these variables was observed by each subject.

Sign Luminance Five luminance levels were included in the experiment: .2, 2, 20, 200, and 2,000 ft.-Lamberts. A sixth level, .02 ft.-Lamberts, was originally included in the study, but obtaining luminances so low proved very difficult, particularly in brightly-lit areas. Photometric measurement of this low level also was very difficult and only a small number of observations were made at luminance levels near .02 ft.-Lamberts. Sign

luminance refers to background luminance for dark letters on a light background and to legend luminance for the light letters on a dark background.

This range of luminance was considerably greater than that used in illuminated highway and advertising signs which is usually from 1 to 100 ft.-Lamberts. It was also greater than the range of brightnesses provided by headlights on reflectorized materials which is .4 to 3 ft.-Lamberts for distances up to 1200 feet from the sign for lower beams and from 1 to 50 ft.-Lamberts for similar distances with upper beams (Elstad, Fitzpatrick, and Woltman, 1962).

To provide the levels of luminance and the other variables described in this chapter, an internally illuminated sign was constructed by the Michigan State Highway Department. The illuminated sign face measured 48 inches by 48 inches. Additional space was needed at the sides of the sign for dimming ballasts and other controls and the total sign size was four feet by six feet. Ordinary illuminated signs have variations of luminance of 100 percent or more at different portions of the sign face. After considerable developmental work, variation across the sign was reduced to about plus or minus 15 percent at each luminance level.

Illumination was provided by 26, 40-watt, cool-white fluorescent tubes, each 48 inches long. Twenty-four of these were mounted horizontally, side-by-side, behind the sign face and two were placed vertically at the ends of the horizontal tubes. Shiny aluminum foil was crinkled and used to line the area behind

the fluorescent tubes. This was found to increase the illumination and to spread it evenly over the sign face. The translucent sign faces that covered the front of the tubes diffused and further evened the illumination across the face. Illumination was varied by changing the number of tubes lit at one time and also by varying the voltage to the tubes. For the lowest illumination levels a neutral density filter consisting of a large sheet of fine black broadcloth was used to cover the sign face.

The sign was mounted on a raisable platform on the back of a one-ton truck with the platform raised to a height of 14 feet above the roadway. The truck was parked perpendicular to the road and facing away from the road. The sign face was about five feet from the road and facing the observers.

Power for providing the sign luminance and for other needs was supplied from a generator and regulator mounted on the truck with the sign. A hydraulic unit was also mounted on the truck for raising and lowering the sign platform.

Contrast Direction and Contrast Level Different sign faces and different letters were used to provide the different contrast direction-contrast level combinations. These sign faces consisted of sheets of translucent plexiglass with transparent tracks glued to them. Letters were slid into these tracks to form the legend in the experiment. The actual construction of these faces and letters differed for the different contrast direction-contrast level combinations.

For the 100 percent contrast level with dark letters on a light background, the sign face was a plain translucent sheet of plexiglass with transparent tracks. The letters were constructed of nearly square slabs of transparent plexiglass with letters cut from black polyethylene glued to them. The actual size of the transparent slabs and the position of the letter on the slab were selected to provide the proper spacing for these letters when one such slab was butted up against another to form a word.

For the 75 percent contrast with dark letters on a light background, the same sign face was used but the letters were cut out of 25 percent transmission white polyethylene. Except for the different material of the letter cut-outs, the letter slabs were exactly the same as for the 100 percent contrast level.

For the 100 percent contrast with light letters on a dark background, a translucent face was covered with opaque black tape except for the area between the tracks. Black masonite slabs with letters cut out of them were inserted into these tracks to form the words. When this face was used, only the legend provided luminance.

For the 75 percent contrast with light letters on a dark background, a translucent plexiglass face was covered with 25 percent transmission white polyethylene except for the area between the tracks. The letters for this face were made of transparent plexiglass slabs with fitted pieces of the same white polyethylene with letters cut out of it glued to the plexiglass.

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In all cases, the letters used were made to the specifications for the Bureau of Public Roads series "E" standard alphabet. Spacing was the standard spacing for these letters recommended by the Michigan State Highway Department for Interstate highway use. Three different sets of the nine letters specified in Chapter III, which differed in height, were constructed for each sign face.

Letter Height Three different letter heights were used to permit three relatively independent observations for each trip up to and by the sign. The heights selected were 13.3, 10, and 7 inches. The fractional 13.3 inch height was selected because specifications existed in Michigan State Highway Department manuals for these letters.

For all sign faces, the larger letters were presented at the top, the 10 inch letters in the middle and the 7 inch letters on the bottom. With an average legibility of 50 feet per inch of letter height, the average reading distance of these words would be 665 feet for the top word, 500 feet for the middle word, and 350 feet for the bottom word. At 15 miles per hour, the speed at which legibility runs were made, the time between reading the top and middle words would be six seconds, and the time between reading of the middle and bottom words would be 5.5 seconds. When observers' reading distances were considerably less than this and the sign was much nearer prior to any readings, the drivers slowed the cars so that time would be available to read the separate words and for the experimenters to record the distances.

— The first of these is the fact that the
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of its internal structure and operations.

Spacing between words was 6.5 inches between the 13.3 and 10 inch legends and four inches between the 10 inch and 7 inch legends. The margin of illumination above the top word was 2.5 inches. This margin below the bottom word was four inches. Margins at the side of the sign were a minimum for the top word, ranging from 2.5 to 8 inches depending on the length of the word used. For the middle and bottom words the margins were at least six inches.

Ambient Illumination

To cover the range of ambient illumination, legibility was measured at three different locations. These locations provided both the lowest and highest ambient illumination that drivers would be expected to encounter, and also a medium ambient illumination typical of illuminated freeways. In addition, at the low and medium ambient illumination locations, the sign was viewed against headlight glare. This provided a total of five levels of ambient illumination. Each observer viewed the full range of sign variables at one of these five ambient illumination locations.

A rural blacktop road with very little traffic was used for the low ambient illumination locations. A distant house on the opposite side of the road from the sign provided the only illumination other than that of the sign. No actual measures of the ambient illumination were made, but the illumination at the eyes of the observer was as low as possible for a person sitting in the front seat of an automobile with the headlights on.

The medium ambient illumination location was the three lane half of a six lane boulevard. The observer was shielded from oncoming traffic in the opposite three lanes by shrubs and trees growing in the 60 foot wide median. Roadway illumination was provided by 400 watt mercury vapor luminaires 31 feet above the ground which were spaced at intervals of 150 feet. In addition to the street-lighting, a small amount of advertising lighting from two closed automobile dealerships was located along the route of the legibility run.

The actual location was eastbound Michigan Avenue between Lansing and East Lansing. The truck-mounted sign was located three feet from the curb about twenty feet in front of a luminaire. Pavement brightness was about three foot-candles below the luminaires to about one foot-candle between the luminaires. The average illumination in a vertical plane at the eye level of the observers was .2 foot-candles.

For the glare runs at both the low and medium ambient illumination locations, headlight glare was provided by parking cars on the left side of the highway with their lower beams burning and their engines running. These cars were spaced at 100 foot intervals in length of the legibility run and up to 200 feet beyond the sign. Twelve cars were used to provide headlight glare.

Washington Avenue, a six-lane, two-way street in downtown Lansing, was used as the high ambient illumination location. At the time of the experiment this was the brightest lit street in

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Michigan. Illumination at the road level eight feet from the curb ranged from 11 foot-candles under the twin 1000 watt luminaires to five foot-candles between the twin luminaires. These luminaires were 35 feet high and 119 feet apart. They were located on both sides of the street. Normal headlight glare from cars constantly travelling in the opposite direction contributed very little additional illumination to the total at this location, and no attempt was made to conduct legibility runs with and without glare. At this location the average illumination in a vertical plane at the eye level of the observers was 3 foot-candles.

At both the high and low ambient illumination locations the legibility runs were made in the right-hand lane, adjacent to the sign. At the medium ambient illumination location, the left-most lane was used in order to safely make the left turn required at this location to return to the starting point of the legibility run. Lateral distance to the sign face from the observer was 25 feet at this location instead of the six or seven feet at the other two locations.

The distance from the observer to the cars providing headlight glare was about 19 feet at the low ambient illumination location and about 11 feet at the medium ambient illumination location.

Observers

Sixty observers were used in the study. These observers were Michigan State Highway Department employees and retired Michigan State Highway Department employees. They ranged from

18 to 81 years of age. The only requirement for observers was that they possess a valid Michigan driver's license.

In the experiment these observers were divided into three age groups of 20 each. The age ranges for the three groups were 18 through 37, 38 through 57, and 58 and above. Ages of observers within the groups were distributed over the range of the group.

Since an observer viewed the sign variables at only one of the five ambient illumination locations, there were 15 age by location groups of four observers each. These groups were matched as well as possible on the basis of their daytime acuity scores. Matching of groups was hampered, however, by the smallness of these groups and by scheduling problems which arose since poor weather resulted in repeated cancellation of test runs. Possible effects of imperfect matching will be discussed in the Results chapter.

The observers were predominantly men. Almost all held positions of high occupational status. This was also true of the positions formerly held by the retired employees who acted as observers. In general, the acuity of the observers was excellent, including that of the oldest age group. Average Orthorater acuity was slightly better than 20/20 for the young and middle age groups and slightly less than 20/20 for the old age group.

Experimental Procedure

Observations were made on 25 evenings and were begun in late summer and completed in the fall of 1964. They were begun at night as soon as it was completely dark and when the equipment

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was ready. Time for observations varied at the different locations but was generally somewhat less than two hours per evening.

The observer sat in the front seat of a passenger car with the driver. An experimenter sat in the back seat where an odometer was located. This odometer was connected to a "fifth wheel" located at the rear of the car. It registered the distance traveled in thousandths of a mile. The smallest unit of distance was thus 5.28 feet. When the legibility run was started the odometer counter was started at zero. Experimenters recorded the number on the odometer as each word of the sign was read. When the sign itself was reached, the odometer counter was stopped and this figure was also recorded. The difference between these readings gave the legibility distance for each letter size.

Instructions for the observers were simple and exactly the same as for the daylight acuity runs they had made a few weeks before. They were to read the words as quickly as they could. If an observer read a word incorrectly he was told "Wrong" and was instructed to read it correctly.

Three observers were run per evening in three separate odometer-equipped cars. The cars maintained at least 300 feet distance between them at the low ambient illumination location. This was done to keep down the amount of illumination from headlights and taillights of one car in the visual field of the observer of another car. At the medium and high ambient illumination locations this was not necessary since automobiles contributed only a small fraction of the total illumination level.

Each observer made 20 runs past the sign (or 24 runs for the subjects for which .02 ft.-Lamberts sign luminance was used). These runs represented the five or six sign luminance levels being viewed for each of four contrast direction-contrast level combinations. Since a face change was required for each contrast direction-contrast level combination, all of the illumination levels for a particular sign face were completed prior to making this time-consuming change.

The order of presentation of sign luminance levels was randomized for each sign face. Three different words were used on the sign face for each sign luminance presentation. When six sign luminance levels were used for each sign face, a different random permutation of the 18 words whose selection was described in Chapter III was used for each sign face. At the locations where the lower sign luminance was dropped, only 15 of the 18 words of a random permutation were viewed.

With six luminance levels each word was viewed four times. With five luminance levels each word could have been viewed from zero to four times with the expected number of viewings per word being three and one third. This difference in number of viewings is not expected to have caused any difference in familiarity effects for the different locations. The order of presentation of the sign faces was counterbalanced for the subjects in an age by location group to spread these familiarity and other order effects evenly over the sign faces.

In order to be certain that sign luminance levels were as specified, measurement of the sign luminance was done prior to each run with a photometer mounted on another vehicle 30 feet in front of the sign. Three men were thus required at the sign during the experimental observations. One was required on the sign platform to change the legend, one down below to change the sign luminance, and one at the photometer to measure luminance.

CHAPTER V: RESULTS

Significant differences occurred in the study for the different levels of luminance, contrast direction, contrast level, and letter size. In addition, many interactions of these variables, both with each other and with the variables of ambient illumination and age, were significant. Results of the analysis of variance are presented in Table 1. Means for the main effects are presented in Table 2. The significant interactions are represented in Figures 1 through 11.

The results will be treated variable by variable in the following order; luminance, ambient illumination, age, contrast direction, contrast level, and letter size. Discussion of the interactions of two or more variables will be delayed until the main effects for the interacting variables have been considered.

Sign Luminance

Well over one half of the total variance in the study is accounted for by the variable sign luminance. Interactions of luminance with almost all of the other variables are also highly significant and these interactions will be discussed under the separate headings that follow. Examination of the means for the main effects for this variable (Table 2) indicates that legibility increased sharply as luminance increased up to about 20 ft.-Lamberts. Beyond 20 ft.-Lamberts, further increases in legibility were slight for these overall averages. Interactions of sign luminance with ambient illumination and with contrast direction gave somewhat different results, however, and these will be considered in following sections.

Table 1: Analysis of Variance

Source of Variation	SS	df	MS	F
Between Subjects		59		
A (Ambient Illumination)	51573.1	4	12893.3	
B (Age Groups)	10664.1	2	5332.0	
AB	62692.3	8	7836.5	
Subjects Within Groups	329563.3	45	7323.6	
Within Subjects		3540		
C (Contrast Direction)	21991.2	1	21991.2	63.4***
AC	1662.0	4	415.5	
BC	2404.0	2	1202.0	3.47*
ABC	4569.9	8	571.2	
C x subj. w. groups	15607.1	45	346.8	
D (Contrast Level)	29699.5	1	29699.5	121.3***
AD	721.5	4	180.4	
BD	350.6	2	175.3	
ABD	1929.7	8	241.2	
D x subj. w. groups	11021.0	45	244.9	
CD	54.5	1	54.5	
ACD	855.1	4	213.7	
BCD	87.1	2	43.5	
ABCD	1242.0	8	155.2	
CD x subj. w. groups	8975.5	45	199.4	
E (Sign Luminance)	655010.0	4	163752.5	328.6***
AE	52202.7	16	3262.7	6.55***
BE	3705.5	8	463.2	
ABE	11129.3	32	347.8	
E x subj. w. groups	89705.3	180	498.3	
CE	5340.2	4	1335.1	10.8***
ACE	3914.7	16	244.6	1.99**
BCE	765.9	8	95.7	
ABCE	5426.8	32	169.6	
CE x subj. w. groups	22165.4	180	123.1	
DE	1234.6	4	308.6	2.73*
ADE	1820.7	16	113.8	
BDE	233.9	8	29.2	
ABDE	2209.0	32	69.0	
DE x subj. w. groups	20340.1	180	113.0	
CDE	1292.8	4	323.2	3.1**
ACDE	1731.8	16	108.2	
BCDE	914.3	8	114.3	
ABCDE	2107.3	32	65.9	
CDE x subj. w. groups	18714.7	180	104.0	

Table 1 (continued)

Source of Variation	SS	df	MS	F
F (Letter Size)	7429.3	2	3714.7	21.5***
AF	966.2	8	120.8	
BF	770.8	4	192.7	
ABF	2632.5	16	164.5	
F x subj. w. groups	15567.6	90	173.0	
CF	4073.4	2	2036.7	41.8***
ACF	1091.7	8	136.5	2.8**
BCF	626.6	4	156.6	3.2**
ABCF	823.7	16	51.5	
CF x subj. w. groups	4383.0	90	48.7	
DF	1578.6	2	789.3	20.3***
ADF	197.7	8	24.7	
BDF	138.8	4	34.7	
ABDF	661.4	16	41.3	
DF x subj. w. groups	3490.4	90	38.8	
CDF	616.1	2	308.0	6.95**
ACDF	717.3	8	89.7	
BCDF	47.2	4	11.8	
ABCDF	736.9	16	46.1	
CDF x subj. w. groups	3992.4	90	44.3	
EF	5082.2	8	635.3	13.1***
AEF	2193.5	32	68.5	
BEF	543.4	16	33.9	
ABEF	2331.7	64	36.4	
EF x subj. w. groups	18472.4	360	48.5	
CEF	1222.9	8	152.9	3.95***
ACEF	1312.6	32	41.0	
BCEF	1689.1	16	105.6	2.73***
ABCEF	2526.7	64	39.5	
CEF x subj. w. groups	13029.7	360	38.7	
DEF	487.0	8	60.8	
ADEF	1820.9	32	56.9	1.55*
BDEF	603.6	16	37.7	
ABDEF	2391.7	64	37.4	
DEF x subj. w. groups	13171.0	360	36.6	
CDEF	682.4	8	85.3	2.21*
ACDEF	1735.5	32	54.2	
BCDEF	645.4	16	40.4	
ABCDEF	2414.7	64	37.7	
CDEF x subj. w. groups	13900.8	360	38.6	

*** Significant at the .001 level.

** Significant at the .025 level.

* Significant at the .05 level.

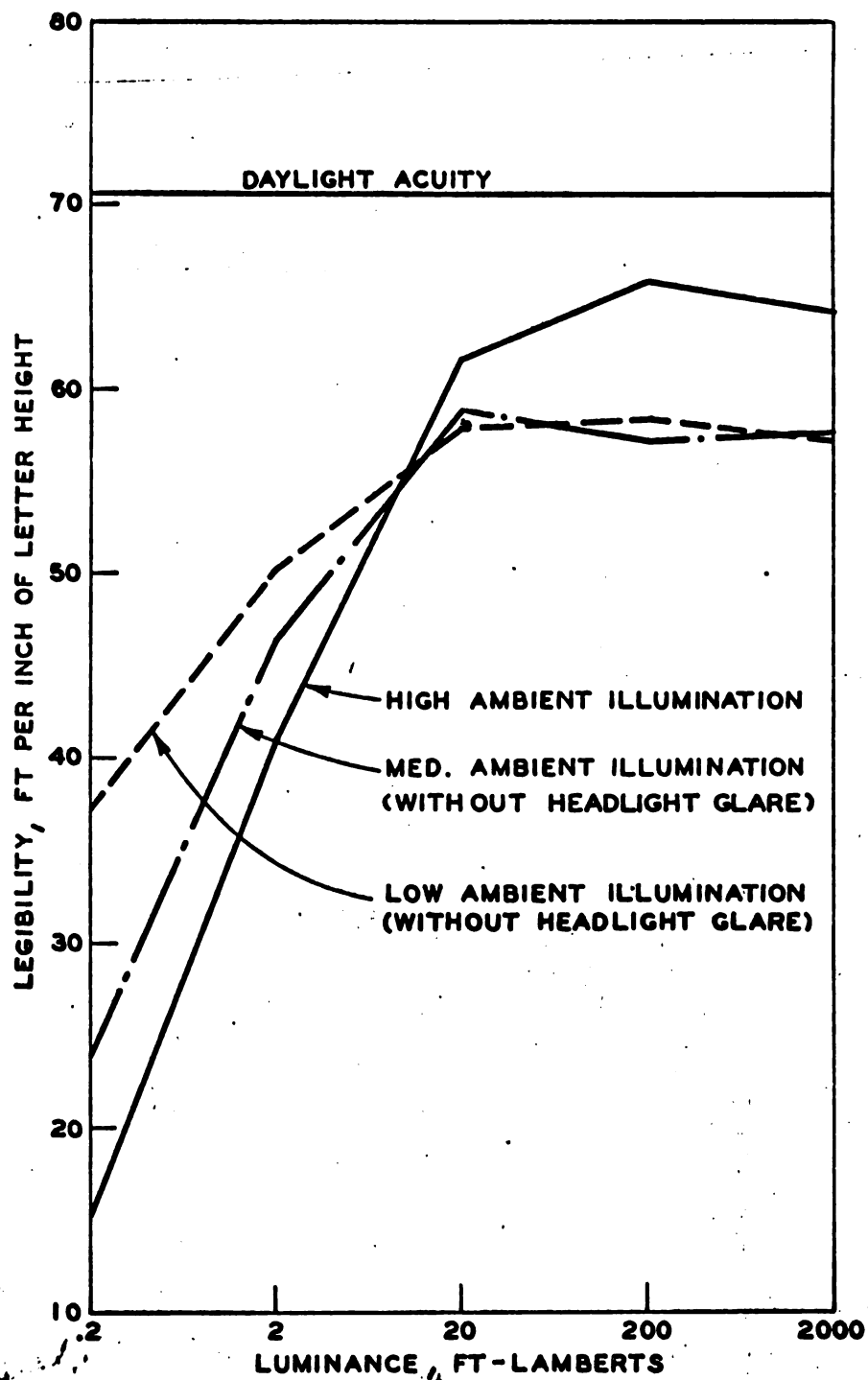
Table 2: Overall Means for Sign Luminance, Ambient Illumination, Age, Contrast Direction, Contrast Level, & Letter Size

		Mean Legibility, feet per inch of letter height.
Sign Luminance		
.2	ft.-Lamberts	25.0
2	ft.-Lamberts	46.8
20	ft.-Lamberts	59.2
200	ft.-Lamberts	60.5
2,000	ft.-Lamberts	60.5
Ambient Illumination		
Low		52.4
Medium		48.9
High		49.6
Low with Glare		49.4
Medium with Glare		51.8
Age		
18-37		50.5
38-57		51.7
58 and above		49.0
Contrast Direction		
Light legend, dark background		52.8
Dark legend, light background		48.0
Contrast Level		
100 %		53.3
75 %		47.5
Letter Size		
7	inches	51.5
10	inches	51.2
13.3	inches	48.5

Ambient Illumination

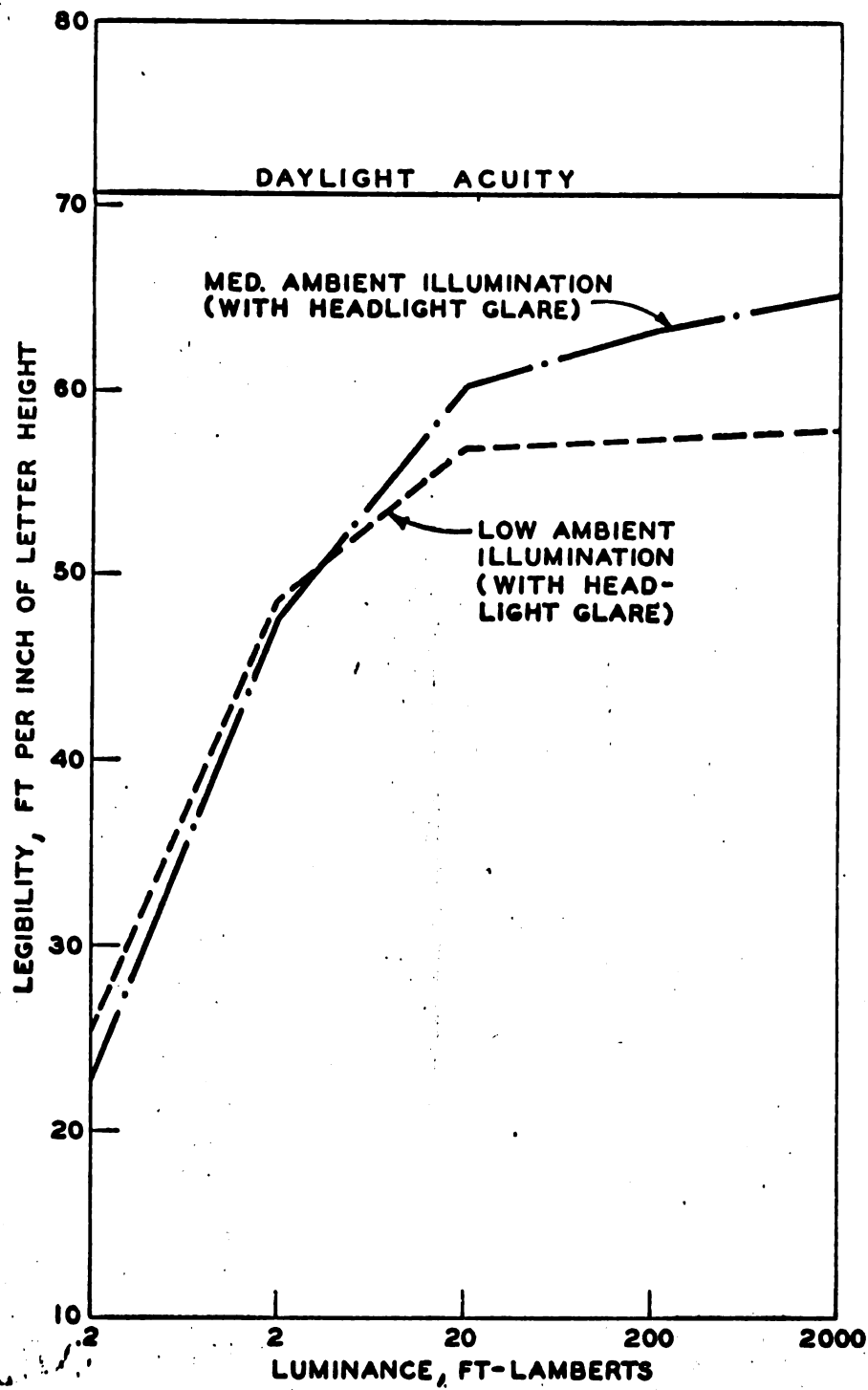
The overall average differences between the means for the five levels of ambient illumination were small (Table 2), and these differences were not significant. Ambient illumination and age both show this lack of significant main effects. Differences in these two variables include differences between subjects. The other variables in the study were viewed by all observers and even smaller differences in main effects for these variables were significant because of the resultant increased precision of the design for these variables. These overall differences for ambient illumination were not significant despite adjustment of the legibility data on the basis of daylight acuity of observers to compensate for poor matching of groups on the basis of daylight acuity.

The interaction of ambient illumination and sign luminance was highly significant. Curves illustrating this interaction are presented in Figures 1 and 2. At the lowest sign luminance level, legibility distance at the ambient illumination location was over twice that for the high ambient illumination location. The opposite condition held at high levels of sign luminance, with legibility distances for the high ambient illumination location about 15 percent higher than those for the low ambient illumination location. Findings of legibility for the levels of sign luminance at the medium ambient illumination location were intermediate to the comparable findings for the high and low ambient illumination locations (Fig. 1).



Locations x Luminance, I

Figure 1



Locations x Luminance, II

Figure 2

Glare at the low and medium ambient illuminations reduced legibility at the low levels of sign luminance. At the medium ambient illumination location, glare resulted in an increase in legibility for the high sign luminance levels (Fig. 2). Results at this location with glare were approximately equivalent to the results at the high ambient illumination location.

For no sign luminance level at any ambient illumination location did maximum legibility reach the level obtained for the observers during the day. However, the daylight legibility level was almost reached at high ambient illumination, which would be expected to provide near daylight viewing conditions.

These findings suggest the need for increased sign luminance beyond that provided by headlights on reflectorized materials, at locations with high ambient illumination or with headlight glare and moderate ambient illumination. However, practical recommendations for adequate levels of sign luminance would be better made with consideration of significant differences that occurred between the two contrast directions. Such recommendations are delayed until the discussion of the ambient illumination by contrast direction by sign luminance interaction in a later section of this chapter.

Age

Differences in main effects were even smaller for the three age groups than for the ambient illumination locations, and since this variable also reflected differences between subjects, these differences were not great enough to be statistically significant. The interaction of age with ambient illumination also included

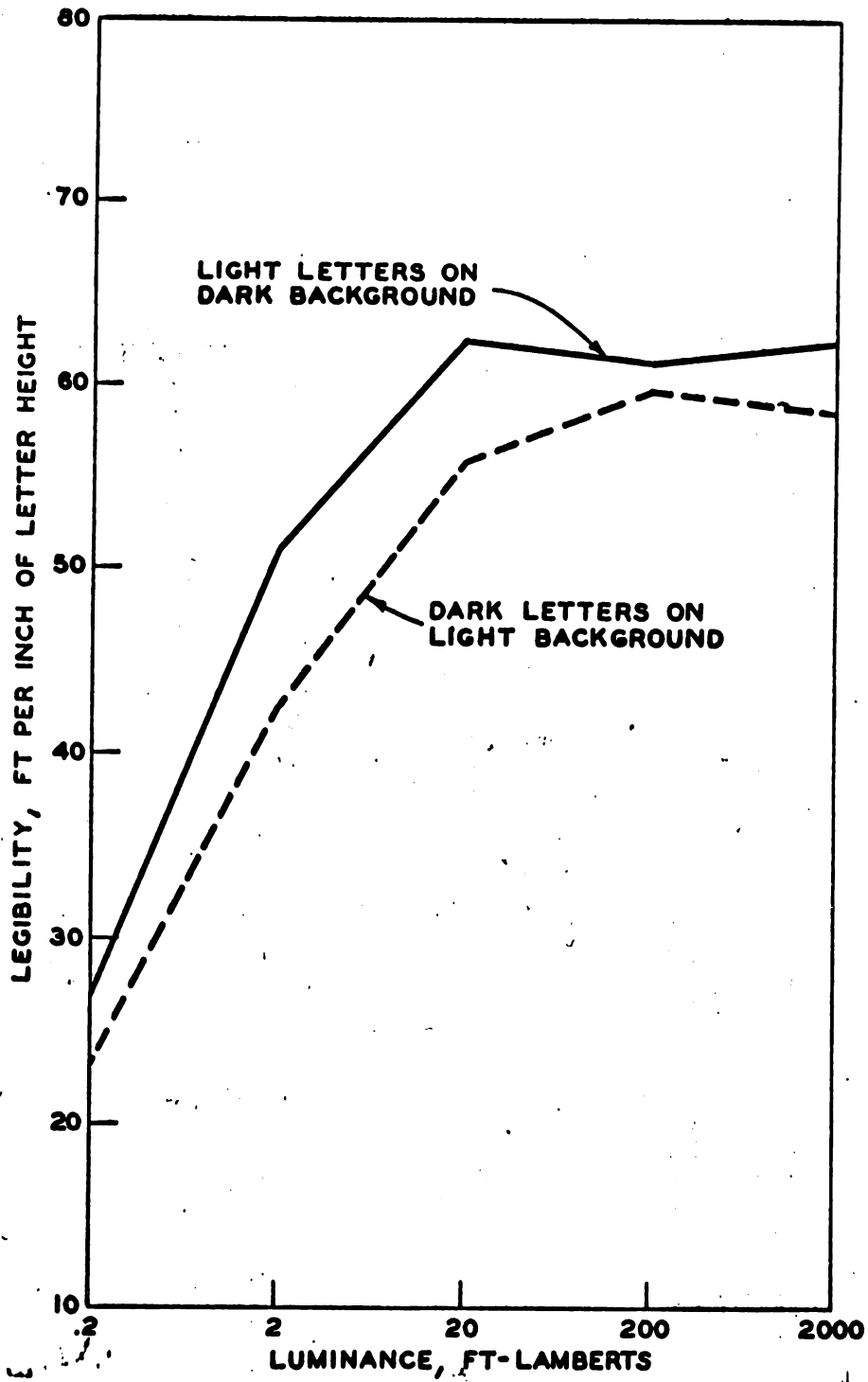
differences between subjects and this interaction was not significant either. Several interactions of age with contrast direction and with letter size were significant and they will be discussed under the headings of these variables.

Differences that did occur between the age groups correspond to initial differences in acuity and it seems safe to assume that averaging over the total range of variables, the old group did about as well as the other age groups, who did poorly for some combinations of variables, particularly high luminance levels and the dark letters on a light background.

Contrast Direction

The superiority of light legend on a dark background over dark legend on a light background was highly significant. This superiority held for all levels of sign luminance, but was greatest for the two and 20 ft.-Lambert levels as indicated by the significant interaction between sign luminance and contrast direction (Fig. 3). This corresponds to earlier findings by Allen and Straub (1955). Since this is the typical range of average luminance of illuminated signs, these findings argue strongly for the use of this contrast direction instead of dark legend on a light background for such signs when similar letter series and stroke widths are used.

The contrast direction by sign luminance by ambient illumination interaction was also highly significant. The curves of Figure 4 illustrate this interaction and perhaps are the most useful for determining required sign luminance levels for the different ambient illumination levels.



Contrast Direction x Sign Luminance, all locations

Figure 3

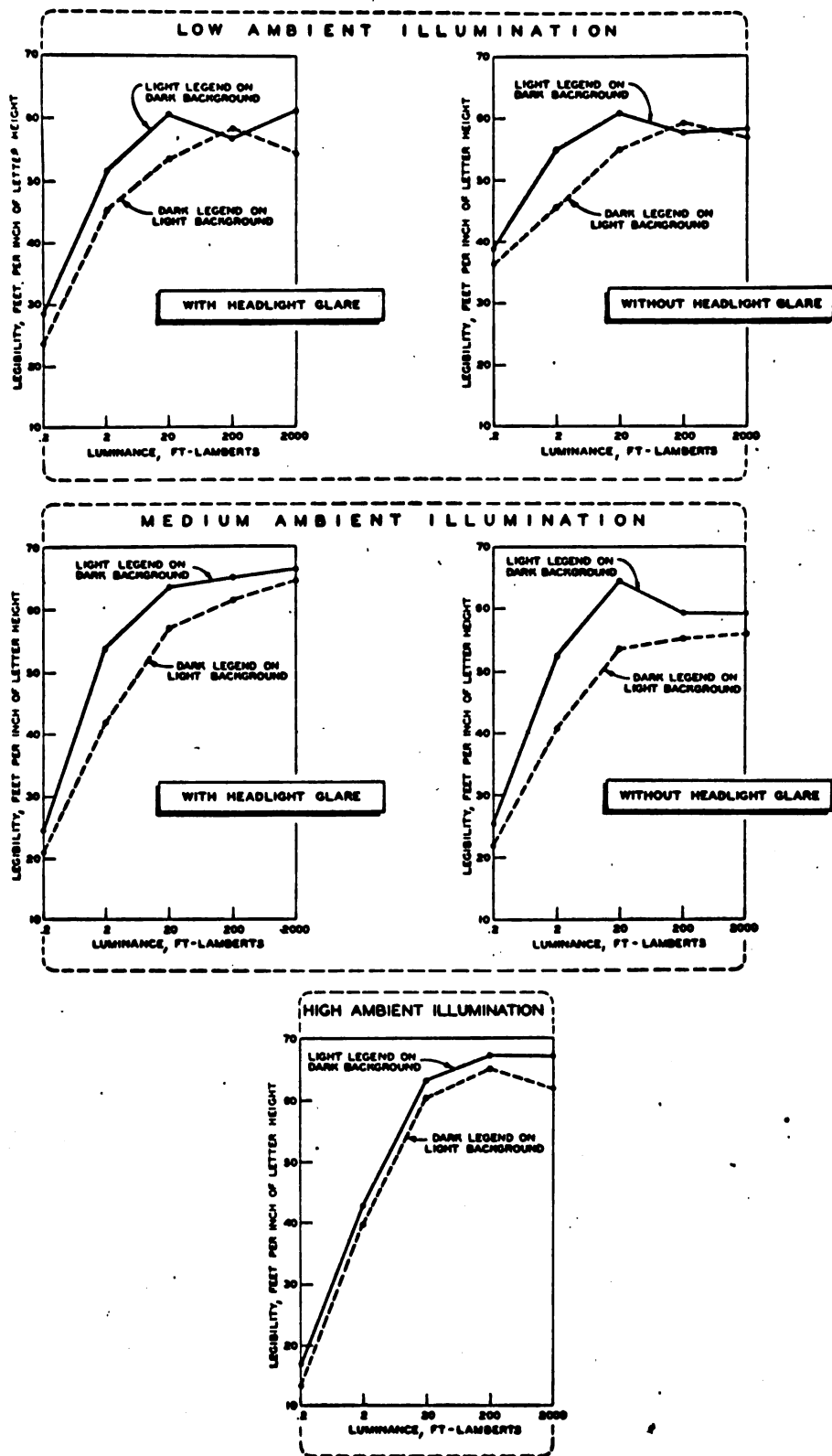


Figure 4

Legibility is greatest at low levels of sign luminance for the low ambient illumination location without headlight glare. To obtain 90 percent of the maximum legibility obtainable at this location for light legend on a dark background about two ft.-Lamberts of sign luminance would be required.

As ambient illumination increases (considering the addition of headlight glare as an increase in ambient illumination), increasingly greater amounts of sign luminance are required to reach 90 percent of the maximum legibility obtainable for that ambient illumination location. The amount of sign luminance which would be required for this purpose ranges up to about 15 ft.-Lamberts at the high ambient illumination location. Even higher sign luminance levels would be required at each of the ambient illumination locations for the dark legend on a light background to achieve 90 percent of maximum legibility for this contrast direction.

Although 90 percent of maximum legibility was chosen arbitrarily, it does represent a point on the curves with legibility plotted against sign luminance, where reductions of luminance of 50 percent or more would not reduce legibility by a very great extent. The variability of luminance across illuminated sign faces is usually at least plus or minus fifty percent and it is important that average luminance be at least as great as the luminance level required for 90 percent of legibility in order to avoid large decreases in legibility.

The light legend on a dark background curve of Figure 4 in the upper right-hand corner is comparable to the legibility curve

obtained in the field study of Allen (1958) with a similar rural location. Although his legibility distances were generally higher, the shape of the curve in the present study is very similar to the shape of the curve obtained by Allen. The lower legibility level found in the present study is partly explained by the use of more combinations of variables with low legibility such as reduced contrast. Also, higher acuity prevailed in the younger sample of observers in Allen's study and he corrected legibility distances for reaction time.

The difference between contrast directions was much smaller at the high ambient illumination location (bottom curves in Fig. 4). It would appear that this ambient illumination closely approaches daylight where it has been reported that there is little or no difference in legibility for the two contrast directions (Kuntz and Sleight, 1950).

Except at the high ambient illumination and the medium ambient illumination with headlight glare, legibility declined from 20 to 200 ft.-Lamberts for the light legend on a dark background. A possible explanation for this dip in legibility and for the differently shaped curves for the two contrast directions will be given in the next chapter.

An interaction that is significant at the .05 level occurred between age and contrast direction. The difference in legibility distance for the contrast directions is five feet per inch of letter height for the young age group, 6.6 feet per inch of letter height for the middle age group, but only 2.8 feet per inch for

the old age group. This small difference between contrast directions for the old age group suggests a similarity between the performance of the old age group at all ambient illumination locations and the performance of all age groups at the high ambient illumination, for which the difference between contrast directions is also small. A theoretical explanation for this similarity will be given in the next chapter.

Contrast Level

The 12 percent average superiority of legibility for the 100 percent contrast level over that for the 75 percent contrast level represents a highly significant difference in legibility for the two contrast levels. The interaction of this variable with sign luminance was significant at the .05 level. It can be seen in Figure 5 that this interaction was not large. Differences in legibility are nearly constant for the different luminance levels, although the gap between the curves narrows at the .2 and 2,000 ft.-Lambert levels.

This reduced legibility for reduced contrasts corresponds to findings of reduced acuity with reduced contrasts (Blackwell, 1946; Cobb, 1945). The finding suggests that typical freeway signs using white letters on colored backgrounds may produce legibility somewhat lower than would be obtained with completely dark backgrounds. If this is true, it suggests that these backgrounds should not be made bright relative to the legend. Further research is needed, however, to determine whether and to what extent, color contrast increases legibility over that obtained for similar achromatic contrast presentations.

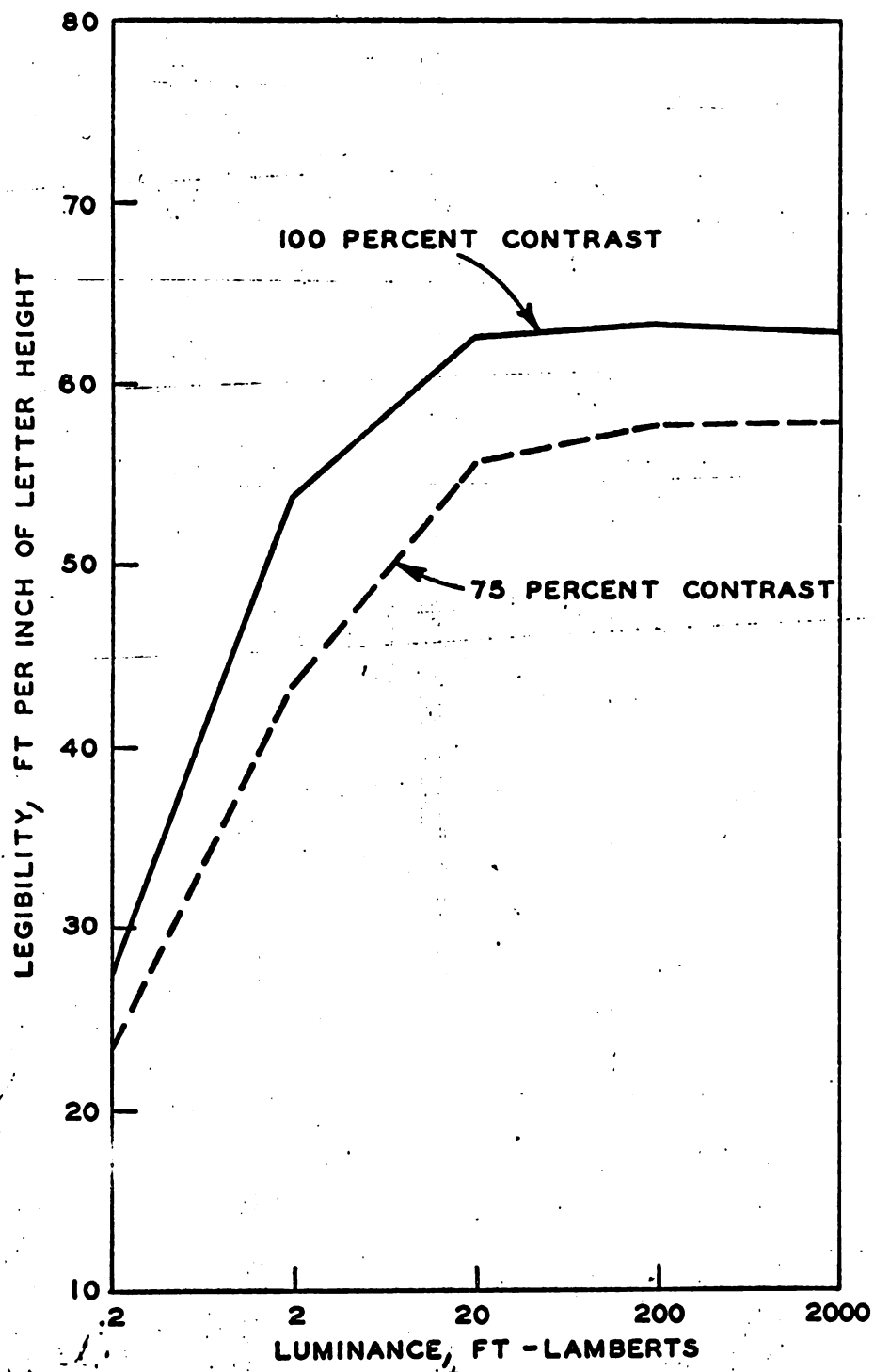


Figure 5

The contrast direction by contrast level by sign luminance interaction was also significant, but it appears to be directly related to much more significant interactions that occur between contrast level and letter size. This interaction will be treated with these other interactions in the next section of this chapter.

Letter Size

The differences that occurred between letter sizes and the interactions with this variable were largely unexpected. Forbes and Holmes (1939) found legibility somewhat higher for smaller letters in terms of feet per inch of letter height, but Forbes, Moscowitz, and Morgan (1950) and Allen (1958) found little difference between letter size in their studies of night legibility, with legibility slightly greater for the larger letters. The different contrast directions which may have accounted for these two different sets of findings were both used in the present study and no overall differences were expected to occur for letter size. Instead, the significant main effect differences indicated that the seven and ten inch letters were more legible than the 13.3 inch letters (Table 2).

Instead of relating these differences in legibility to differences in letter height or position on the sign face, it is more useful to consider them in terms of the different reading distances from the sign that occur when reading the different sized letters. The factor that appears to be related to the differences in legibility for the different letter sizes is the

amount of light from the sign that is entering the eye. This light entering the eye appears to change the adaptation level, and perhaps the pupil size, resulting in increased legibility for medium and bright sign presentations. Considering this factor of the amount of light entering the eye, legibility would be expected to be greatest for the smaller letters which are read nearer to the sign.

The luminance by letter size interaction was highly significant, and, as would be predicted considering the factor of the amount of light entering the eye, the differences between the letter sizes increased with increasing luminance. The interaction of letter size and contrast direction, which is better referred to as the interaction between reading distance and contrast direction, was highly significant. Differences between letter sizes are slight for the light legend on a dark background, but for the dark legend on a light background legibility in feet per inch of letter height increased sharply as the letter size decreased, i.e., as the sign was read at a smaller distance.

The contrast level by letter size interaction was also highly significant. An analogous situation occurred to that for the interaction of contrast direction and letter size which was just mentioned. For the 100 percent contrast there was not much difference in legibility for the different letter heights (averaging over both contrast directions). For the 75 percent contrast level, legibility increased sharply as letter size and reading distance decreased.

All of these interactions, plus another significant interaction between contrast direction, contrast level, sign luminance, and letter size, are illustrated in Figure 6. The pattern of low legibility for 13.3 inch letters, medium legibility for 10 inch letters, and legibility highest for the 7 inch letters appeared most clearly in the lower right curve where 75 percent contrast and dark legend on a light background appear together. The pattern reappeared for the dark legend on a light background with 100 percent contrast and appeared again, though less distinctly, for the 75 percent contrast with the light legend on a dark background. For the 100 percent contrast level with the light letters on a dark background the pattern did not appear, although even in this case a tendency towards the pattern appeared at the highest sign luminance level.

The interactions illustrated by these curves strongly support the hypothesis that the amount of light entering the eye from the sign itself may affect the adaptation level. Where the pattern did not appear, for the 100 percent contrast level with light legend on a dark background, the total area of sign luminance would be at a minimum. With 75 percent contrast for this contrast direction, where the pattern did appear, the background luminance would be added to the legend luminance and would almost triple the amount of light reaching the eye. With the dark on light contrast direction, where the pattern appeared most strongly, seven times as much total illumination was present at the sign face as was present for the 100 percent contrast level with light legend on a dark background.

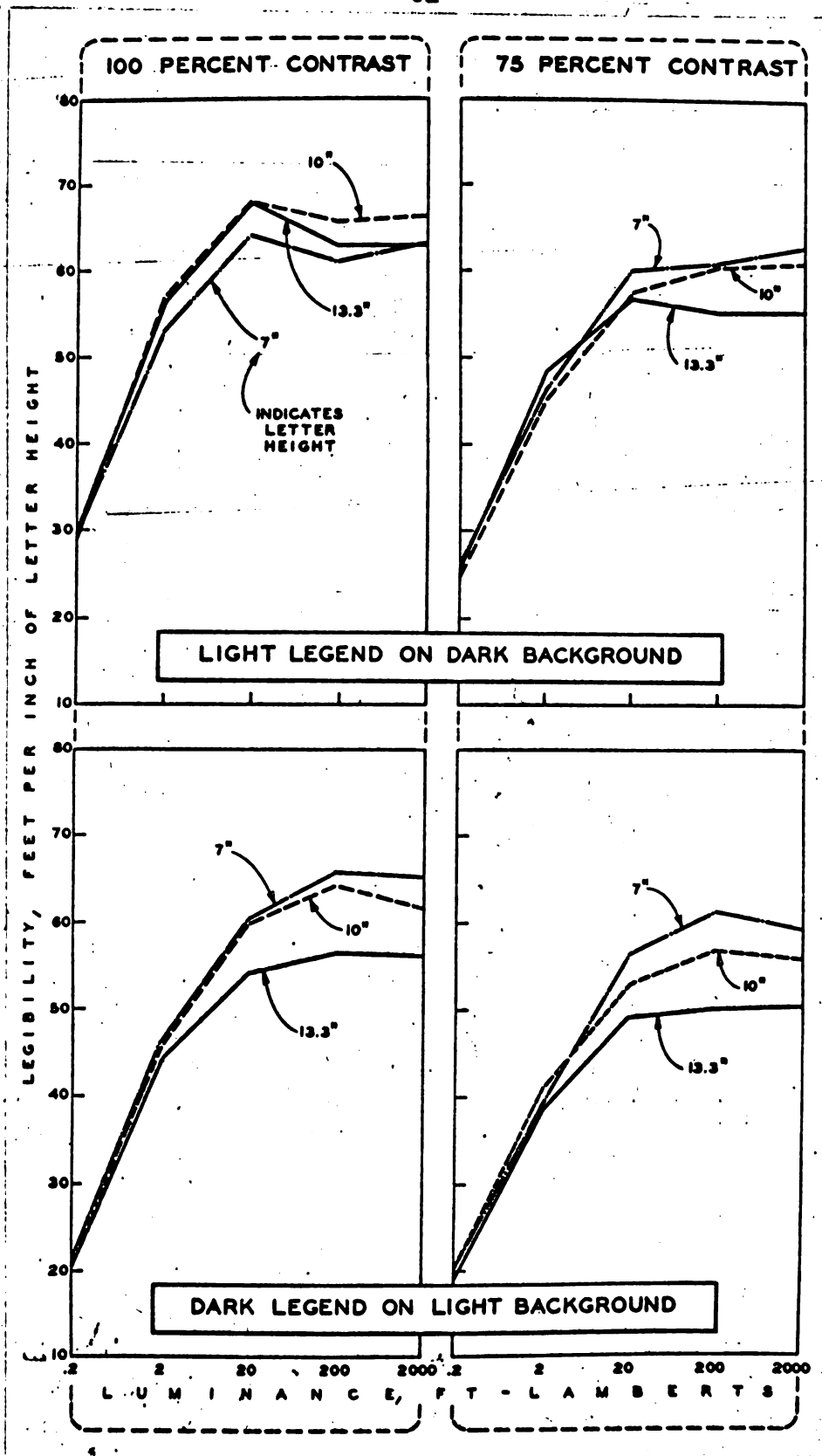


Figure 6

Differences in total sign illumination for the dark legend on a light background would be negligible for the two contrast levels and the differences appearing in the lower two sets of curves in Figure 6 can be attributed to other factors.

Further support for this hypothesis is derived from the fact that differences in legibility for the three letter sizes increased sharply with increasing luminance. Even for the 100 percent contrast level with light legend on a dark background, where total illumination at the sign face is minimal, there is still a tendency at the highest sign luminance level for the pattern of high legibility for the small letters and lower legibility for the higher letters, to appear.

This finding of different legibility with different reading distances may occur because the observers were free to gaze continuously at the sign face. This allowed time for the eye to become light-adapted by the sign itself, and this adaptation increased legibility for the brighter levels of sign luminance (See Chapter VI). It is probable that legibility for the driver of an automobile would not show this increase with decreasing reading distance to as great an extent, because less time would be spent looking at the light-adapting sign. Because of this, the general decrement found for dark letters on a light background may be even greater than this study indicated. Further research controlling viewing times would be required to confirm this speculation, however.

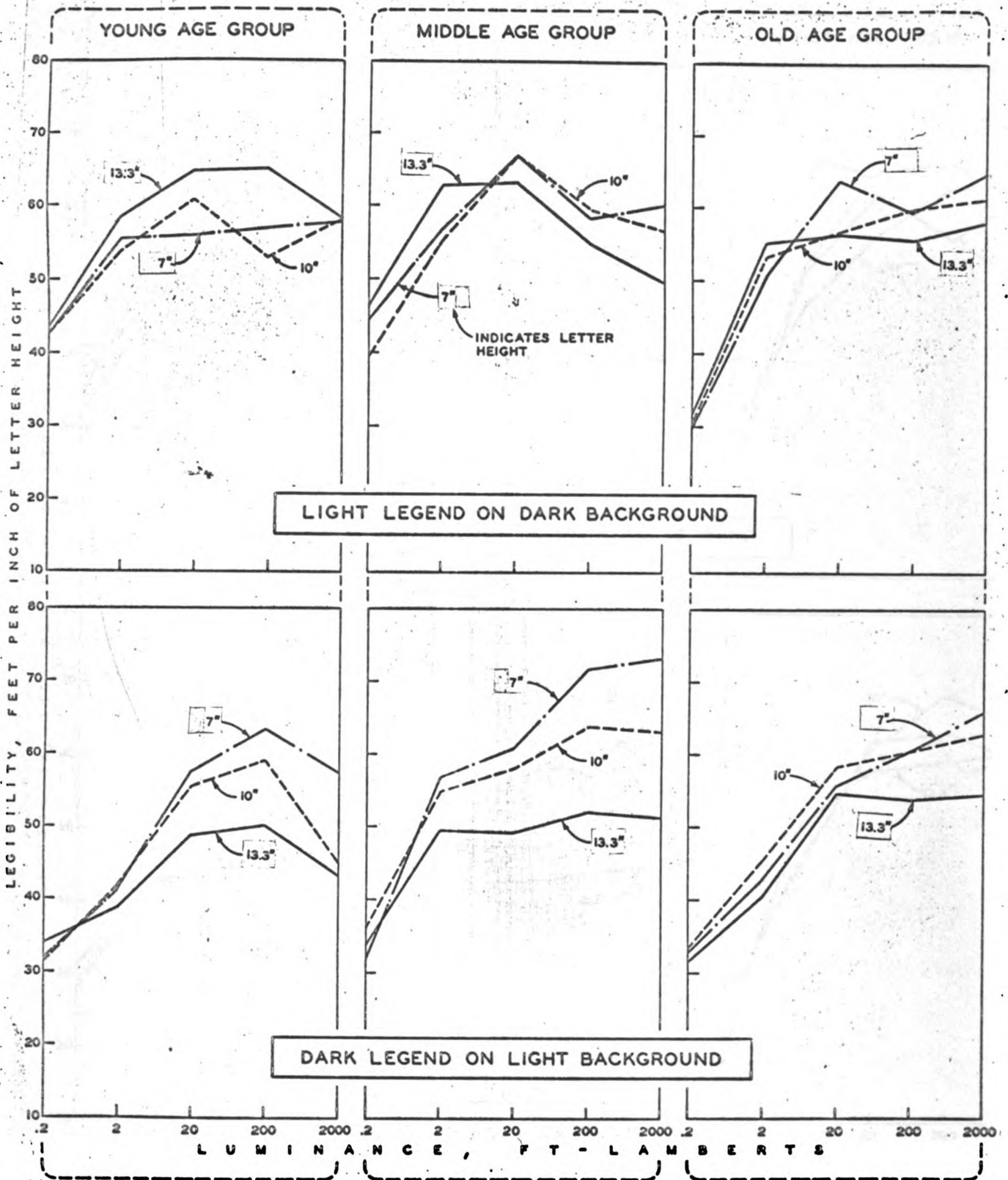
Other Interactions

Figures 7 through 11 illustrate the age by ambient illumination

by contrast direction by sign luminance interaction. This interaction was not itself significant, but the curves serve to illustrate interactions that were. They also provide a comprehensive display of the results of the study with each plotted point representing eight observations, those of the four subjects within an age by ambient illumination group for both contrast levels.

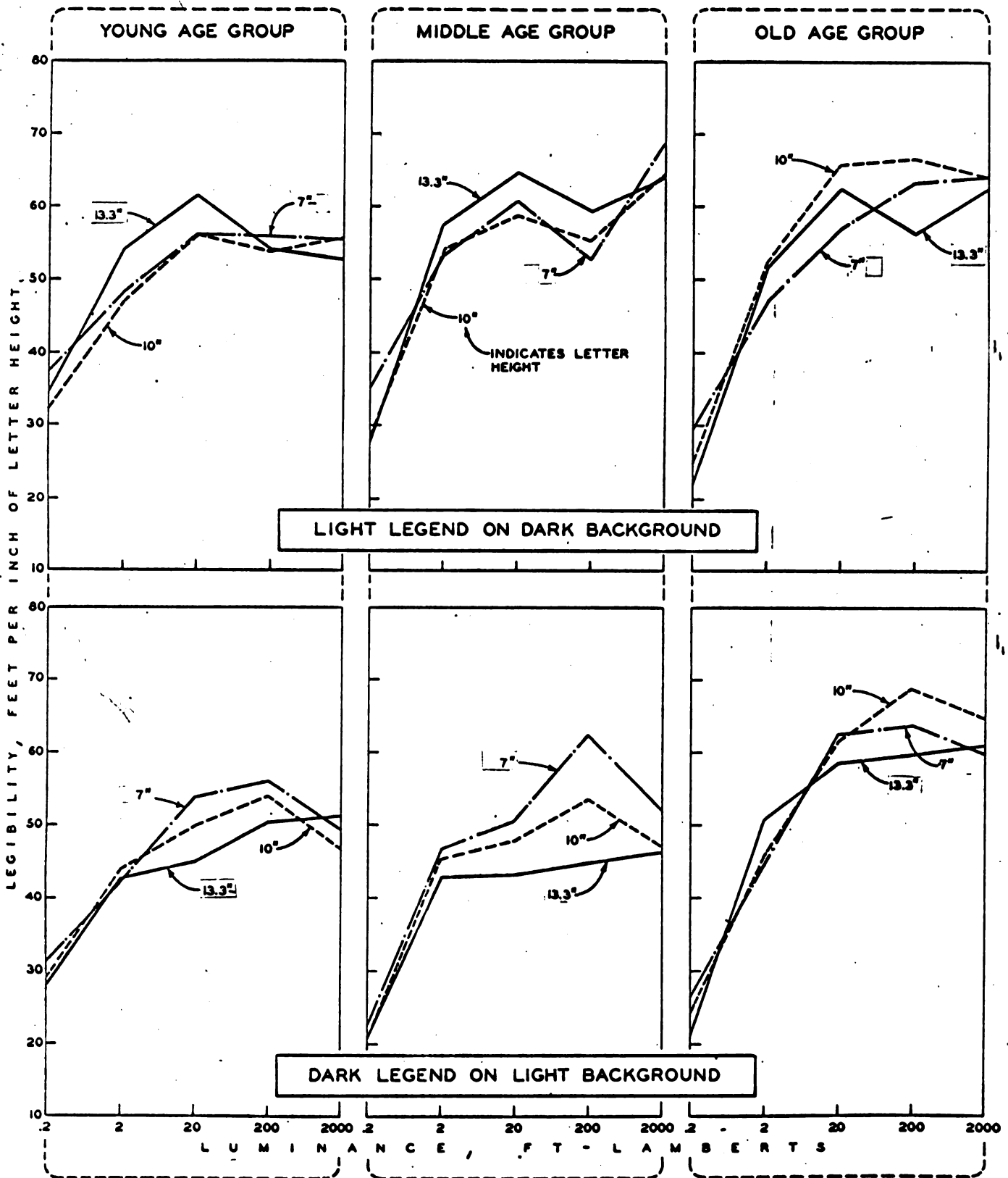
The ambient illumination by contrast direction by letter size interaction was significant. This interaction is illustrated by the fact that for the light legend on a dark background, the relative positions of the curves representing the different letter size legibilities differ from one ambient illumination to another. At the lower ambient illuminations the 13.3 inch letters were most legible suggesting that position on the sign was determining legibility. As the ambient illumination increased, there was a change to the more typical pattern of highest legibility for the smaller letters.

For the old age group the more typical pattern occurred at all locations. Only the young and middle age groups showed the interaction described above. This age group difference is represented by the significant age by contrast direction by luminance by letter size interaction. Another difference between age groups represented by this interaction involved the dark legend on a light background. Differences in legibility occurred between all three letter sizes at higher luminances for the young and middle age groups, but for the old age group the curves for the 7 and 10 inch letters did not differ appreciably, although the 13.3 inch letters showed typical reduced legibility.



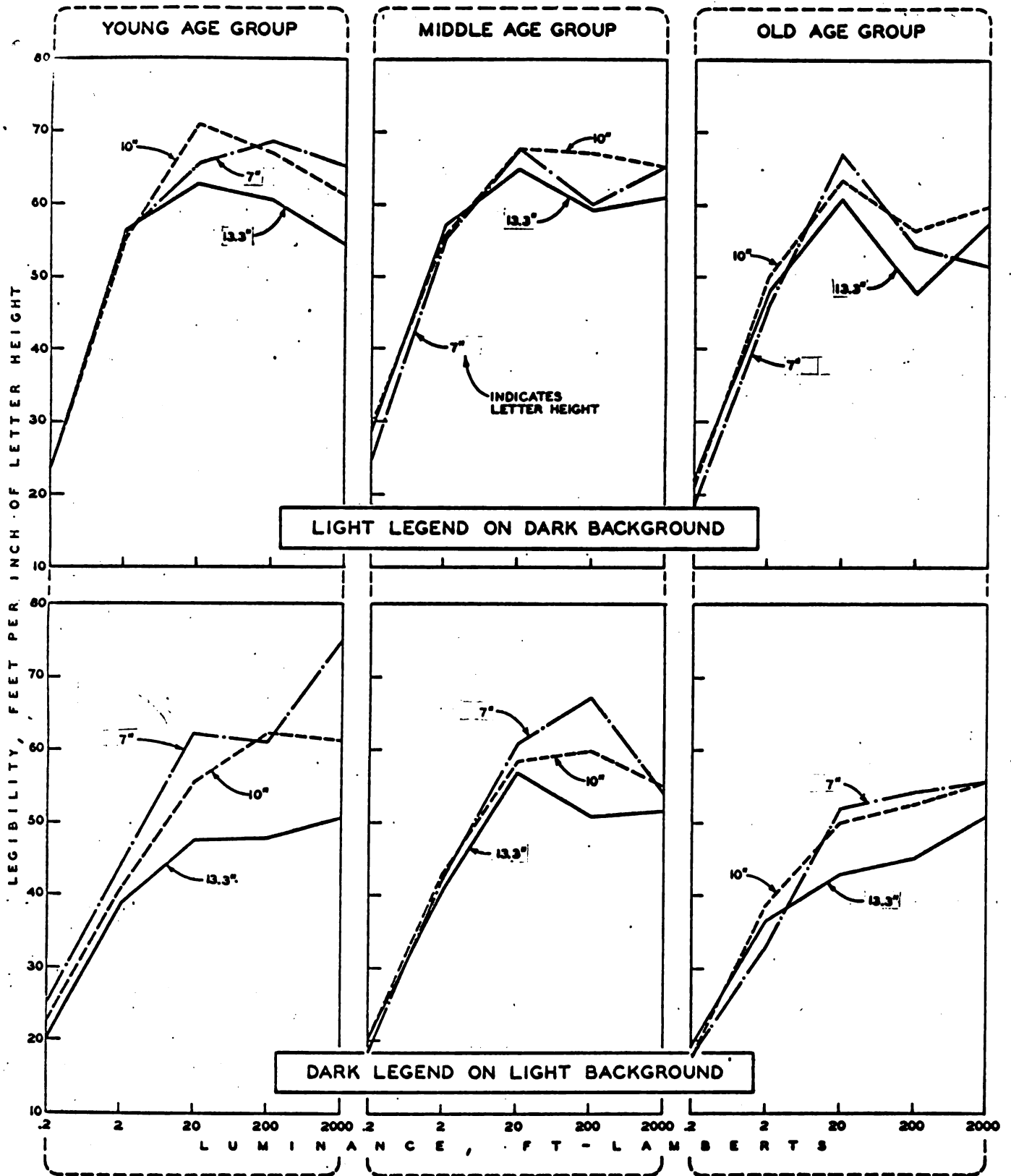
Low Ambient Illumination

Figure 7



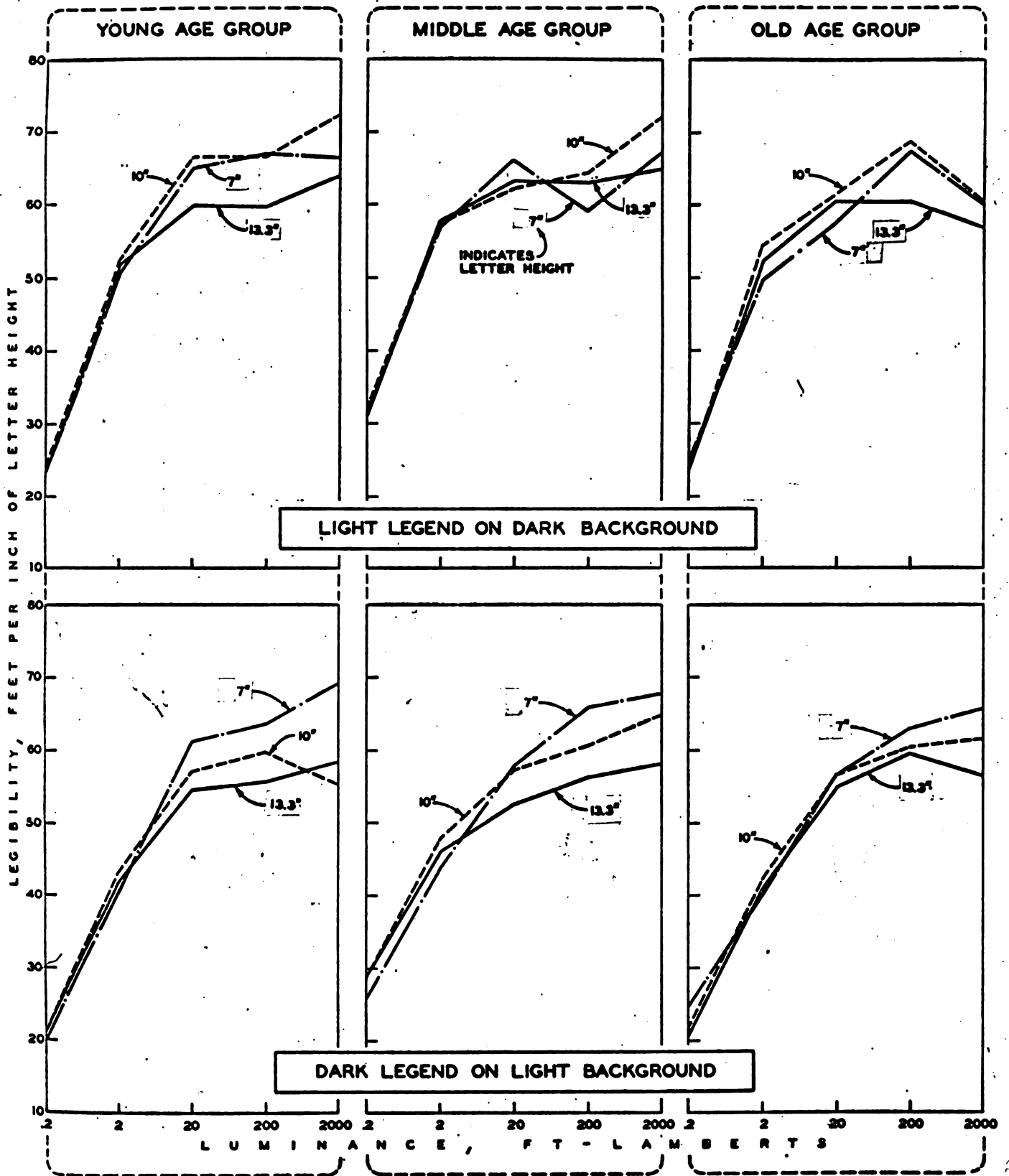
Low Ambient Illumination with Headlight Glare

Figure 8



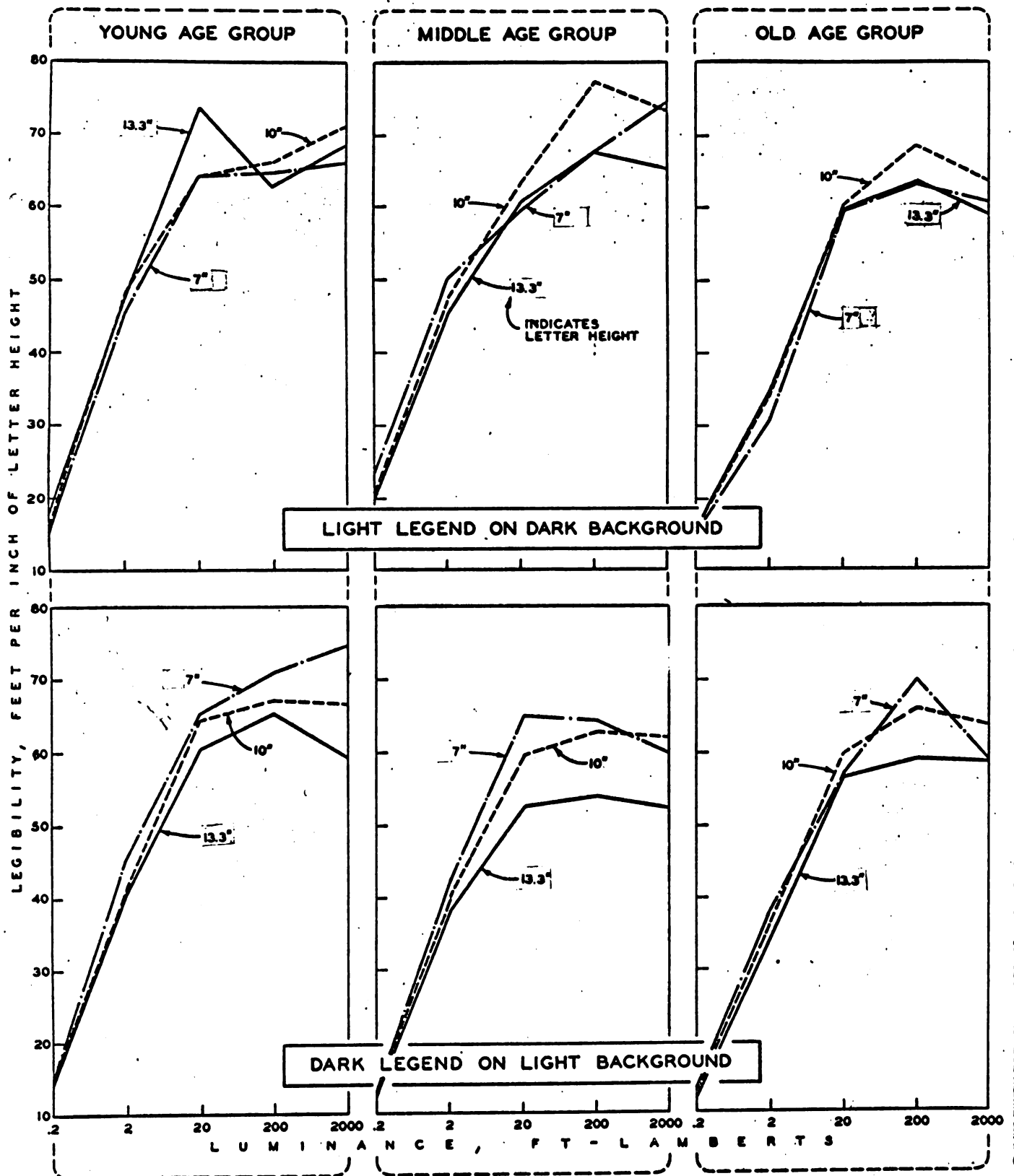
Medium Ambient Illumination

Figure 9



Medium Ambient Illumination with Headlight Glare

Figure 10



High Ambient Illumination

Figure 11

None of the interactions that included both ambient illumination and age were significant. This was probably due more to large differences of subjects within age by ambient illumination location groups that occurred than because there were no observable differences. Consideration of the curves of Figures 7 through 11 suggest many differences between age by ambient illumination groups which were probably not peculiar to the particular subjects that made up these groups.

One example of a possible difference is illustrated in Figure 11 for the dark legend on a light background at the high ambient illumination. Although the pattern of higher legibility for lower letter sizes occurred for the young age group, legibility declined somewhat at 2,000 ft.-Lamberts for the seven inch letters for the middle age group and declined even more sharply at the high luminance level for the old age group. This suggests that there is an upper limit to the facilitation of legibility by the amount of sign illumination entering the eye, and that this limit is reached earlier by the older observers.

Generalizability of Results

Although these results were obtained with an internally illuminated sign, the similarity of the findings to those of Allen (1958) indicated that they can be applied to flood-lighted signs and probably also to signs illuminated by headlights if the luminance of the sign is known.

Series "E" letters were used in the present study and it would be expected that legibility would be reduced if narrower series letters were used. Relative differences, however, would be expected to remain similar between ambient illumination locations, contrast directions, contrast levels, and sign luminance levels. If the wider series "F" letters were used increased legibility would probably result, but again there would be little reason to expect differences in relative legibility for the various variables.

Changes in stroke width for the series "E" letters might produce considerable amounts of change in legibility, which would be expected to differ for the two contrast directions. It would appear that further experimentation in this area could produce substantial improvement in night legibility, considering the findings of Berger (1944a, 1944b).

Contrast levels lower than those used in the study might be expected to reduce legibility to greater extents than occurred for the 75 percent contrast. Practical applications where contrast is reduced would very likely involve colored backgrounds, and further work is also needed to determine the effect of color contrast on legibility.

Although very high sign luminance levels provided high legibility, their use might sharply reduce night visibility for dim objects in the roadway, both near the sign and for some distance beyond it, particularly if the sign were a large one near the roadway. The smaller amount of luminance at the sign with the light legend on a dark background would be expected to reduce visual sen-

sitivity less, and this is another reason beside the higher legibility for this contrast direction, which argues for its general adoption for illuminated signs.

CHAPTER VI: DISCUSSION

For the different levels of ambient illumination, legibility either increased for the full range of sign luminance levels, increased to a maximum and remained there for higher levels of sign luminance, or reached a maximum to be followed by a decline. The conclusion to be drawn from this is that under certain conditions some factor reduces legibility at high sign luminance levels. This chapter will provide an explanation of this inhibition of legibility and the diverse results it produces with different combinations of variables.

Considering only the .2 and 2 ft.-Lambert levels of sign luminance and the high and low ambient illumination levels, legibility was much higher for these sign luminance levels at the low ambient illumination levels. This is best explained in terms of the high visual sensitivity of observers at the low ambient illumination, with the eyes of these observers responding much more strongly to low sign luminance levels than the eyes of the high ambient illumination observers. Visual sensitivity is here considered to represent a combination of retinal sensitivity and pupil size which would be expected to operate in the same way.

Considering the top three sign luminance levels and the same ambient illumination levels, just the opposite results occurred. Exactly the same explanation is in order, however. The highly sensitive eyes of the observers at the low ambient illumination level responded to the taper of the bright contours of the sign, i.e., the low levels of luminance that extend beyond the contour itself (Fry, 1955). This perceived taper or blur

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interferes with resolution of these contours. The less sensitive eyes of the other group did not perceive this taper, and legibility continued to increase for this group.

Given that reduced visual sensitivity results in higher legibility for bright legends, the findings of high legibility for smaller letter heights and low legibility for the greater letter height become explainable. Bartley (1963) reported that short duration glare sources reduced retinal sensitivity. The observer continuously viewed the illuminated sign in the present experiment. It is reasonable to infer that the sign itself served to reduce the visual sensitivity of these observers.

Sensitivity would be expected to be less for the seven inch letters since more time would have been spent looking at the illuminated sign when these letters would be read, and perhaps more importantly, the area of the image of the sign face on the retina would be much larger. Sensitivity would be reduced more with the higher luminances and the differences in legibility for the different letter heights appear most strongly for the higher luminances. Other evidence that increased luminance entering the eye increased legibility was presented in the last chapter. The mechanism would appear to be the same as that which produced higher legibility for bright sign luminances at the highest ambient illumination. Decreased visual sensitivity reduced the perception of retinal image taper or blur.

Perception of retinal image taper also provides an explanation of the reduced legibility that occurred for the dark legend

on a light background compared to legibility for the light legend on a dark background. Lighted contours are separated only by the thickness of the stroke for the dark legend on a light background. For the other contrast direction, the space between bright contours can be considered as falling into two categories. One is the space between elements of a letter such as the distance between the parallel strokes of an "E". This category of between contour distance would be comparable to the between contour distances of the dark legend on a light background.

A second category of inter-contour distance would occur for the distances between the illuminated letters. These distances would be greater than the first category of inter-contour distances and the stroke width distances separating contours of the other contrast direction. When blur is perceived, impairing the resolution of contours, the less separated contours would be most difficult to resolve. For the light legend on a dark background, it would be expected that resolution for the second category of inter-contour distances would still be possible at a point when resolution was not possible for the elements of individual letters. Even with letters like "E" and "H" that might be completely blurred, the separation of these blurred letters would provide some legibility clues. Many letters such as "I", "T", and "A" would not suffer particularly in legibility from blurring of adjacent elements within the letters, and legibility for the light legend on a dark background would be that much more facilitated.

An example that illustrates these differences between contrast directions would be a solitary "I" in the middle of a sign. With a dark letter on a light background, the adjacent contours of the letter would be expected to approach each other and fuse as blur increased and the letter would effectively disappear. With a light letter on a dark background, it would be expected that identity of the letter would be maintained almost regardless of the expansion of contours of the letter by blurring.

The reduced visual sensitivity that occurs at the high ambient illumination probably results in little perception of blur for either contrast direction and probably accounts for the reduced differences between the two contrast directions at this ambient illumination level. Similarly the reduced difference between the two contrast directions for the old age group may be accounted for by the reduced visual sensitivity that accompanies age.

The two categories of distance between bright contours for the light legend on a dark background suggest an explanation for the dip in legibility that occurred for this contrast direction at the three "lowest" ambient illumination levels. (The reason the dip does not occur at the other ambient illumination levels may be that visual sensitivity was too low to perceive the blurring involved in this explanation.) It was suggested previously that blurring of letter elements does not reduce legibility for the light legend on a dark background to the extent that such blurring reduces legibility for the other contrast direction. The

dip in legibility at 200 ft.-Lamberts may have occurred because the perception of blur had increased until resolution of the second category of inter-contour distances was also impaired. When this occurred, the effect of blurring on legibility became nearly equal for the two contrast directions.

Other differences between age groups and between ambient illumination levels can be explained by the different capacity to perceive blur. Following the dip in legibility that occurred for the light legend on a dark background, a further rise in legibility occurred for some age by location groups at 2000 ft.-Lamberts. For the young age group such rises did not occur except at the two highest ambient illumination levels. This suggests that only at these levels was the high retinal sensitivity of this age group reduced enough so the sign luminance itself could further reduce visual sensitivity and change the reaction to blur.

At the low ambient illumination the middle age group did not show an increase following the dip at 200 ft.-Lamberts, but it did show this rise following the dip at the other ambient illumination locations, except at the high ambient illumination where visual sensitivity is apparently too low at 200 ft.-Lamberts to produce the initial dip itself for this age group. Similar results occurred for the old age group with the dip in legibility itself missing at the two high ambient illuminations, however.

A similar explanation can be applied to the lack of difference in legibility for the different letter sizes that occurred for the old age group relative to the large differences in legibility

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for the different letter sizes for the young and middle aged groups for the dark legend on a light background. The initially less sensitive eyes of the old age group would be less capable of further desensitization and thus the perception of blur would be changed less for this age group as the sign was approached.

Further Research Needs

Research designed explicitly to investigate the factors that result in the perception of retinal image taper is needed. A way of doing this would be to measure acuity for targets of different brightness while maintaining visual sensitivity constant. The process could then be repeated at different levels of visual sensitivity, with visual sensitivity determined by interspersing threshold light sources between acuity targets. This procedure would also permit determination of the amount of reduction of retinal sensitivity and the amount of pupil change that occurred because of the targets themselves. In addition, observers of different ages investigated with this technique would provide more accurate information on the effects of age on visual response.

It is doubtful that blur could be eliminated in the reading of highway signs at night, however, and other research could be directed toward reducing the deleterious effects of blur. The separation of bright contours could be increased by reducing stroke width for the light legend on a dark background and by increasing stroke width for the dark legend on a light background. Several such stroke widths could be presented at a series of sign luminance levels and legibility determined.

Another related approach to the problem of reducing the effects of blur would be to design individual letters so that taper from the contours of the letters would correspond to traditional letter forms, although the actual contours might appear quite different. Such a procedure might result in narrow stroke width for parallel letter elements and sections of letters removed where letter elements join. A basis for such research would be Fry's (1955) treatise describing the form that the taper of the image of various light sources takes.

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APPENDIX A

Legibility Means and Variances of 69 Three-Letter Words

Word	Mean	Var.	Mean of Day Acuity Runs	Word	Mean	Var.	Mean of Day Acuity Runs
AID	90.9	48	91.1	OIL	97.4	56	93.8
AIL	89.3	150		ONE#1	90.0	70	
AIR	94.9	70		ONE#2	93.1	131	
ALE	99.8	86		ORE	78.4	67	
AND	94.9	105	89.8	RAN	82.3	59	86.5
ANT#1	90.0	127		RAT	86.0	77	
ANT#2	95.7	253		RED	89.7	91	
ARE	88.4	92		RID	81.2	99	
ART	89.4	205	86.3	ROD	84.2	51	83.9
ATE	94.0	66		RON	75.0	58	
DAN	83.8	68		ROT	85.7	41	
DEN	88.6	66		SAD	89.0	49	
DIE	85.0	86	87.7	SAT	87.8	117	88.5
DIN	85.0	72		SEA#1	91.7	88	
DOE#1	78.2	73		SEA#2	94.0	56	
DOE#2	83.2	44		SET	85.7	43	
DON	82.6	97	86.6	SID	79.4	88	88.4
DOT	82.4	119		SIN	86.7	84	
EAR	88.8	185		SIR#1	82.2	53	
EAT	88.5	222		SIR#2	84.9	154	
LAD	97.4	102	87.5	SIT	88.8	30	87.5
LED	92.0	190		SOD	85.8	25	
LET	95.0	88		SON	89.7	35	
LID	99.7	125		TAN	88.7	98	
LIE	99.7	120	89.5	TAR#1	88.3	47	89.5
LIT	98.7	128		TAR#2	92.6	54	
LOT#1	92.4	35		TEA	101.2	56	
LOT#2	93.7	46		TED	93.3	128	
NET	88.4	162	91.2	TEN	91.1	58	91.2
NOD	86.4	88		TIE	85.9	80	
NOR	80.4	85		TIN	88.7	101	
NOT	88.4	43		TOE	86.5	64	
OAR	82.7	72	87.0	TON#1	87.7	92	87.0
OAT#1	83.4	68		TON#2	89.6	116	
OAT#2	88.8	53					

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