EFFECT OF GLARE OVER THE PERFORMANCE IN AN INSPECTION TASK

by

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BACKGROUND

Light, vision and seeing are simple and common words but their commonplaceness does not conceal their basic importance to the human beings. And any factor of the work environment which is essential to efficient human activity may be an important parameter in the output of workers.

Lighting in industry plays at least a twofold part in obtaining efficient production. First of all by providing conditions that reduce fatigue to a minimum and providing an environment conducive to pleasant work, and secondly by its specialized application, whereby both the speed and accuracy of the process and therefore the product quality, are greatly improved.

For a better understanding of the subject of the present study, glare, one should consider some aspects of illumination such as vision, contrast, light sources, and illumination level.

Vision

Many authors discussed the structure and functions of the eye. Grollman (1969) described the eye as a transducer which converts light energy into electrical energy of nerve impulses that is conducted by the optic nerve to the visual cortex of the brain for interpretations as an image.

The main parts of the eye are the cornea, lens, retina, and the fovea. The retina, upon which images are focused by the cornea and lens, consists of eight distinct layers. The innermost layer consists of rods and cones, the actual light receptors of the eye. They are connected by the nerve fibers of the retina to the optic nerve. Semat (1961) pointed out that the retina is not uniformly sensitive throughout its area. Where the optic nerve enters the eye there is a blind spot and, a short distance away from this entry, is the fovea, the most sensitive part of the retina. In the fovea there are no rods, only cones. These cones are the smallest in the retina: cones located in other parts of the eye are much larger. Each of the 30,000 cones in the fovea has its own nerve thus producing the superior acuity of the fovea. Rods must share nerves. The peripheral area of the retina is almost exclusively made up of rods.

Cones are responsible for the color sensitivity of the eye. Rods are more sensitive than the cones and are responsible for night vision. In very dim light, colored objects are seen by the rods as shades of gray. Very faint objects can sometimes be seen by peripheral vision, where only the more sensitive rods are present, but they disappear when viewed directly by the less sensitive cones in the fovea.

Illumination Level

Keite and Gloag (1959) examined many facets of industrial lighting. They dealt in broad generalities and guides. In their discussion of principles of good lighting they included the amount of light, the size of detail, and the lightness of the work, as well as recommended levels of illumination for many industrial applications. In an analysis on controlling contrast of brightness it was explained that the eyes are naturally attracted to the brightest and most contrasting object in view.

It was demonstrated that consideration should be given to daylight in production requirements and this should be in the plant design stages, not after completion. Daylight can also produce shadows, especially in the case of larger machines. Glass areas need not be large but well planned. It was demonstrated how more illumination can be achieved with a smaller glass area simply with more even distribution of smaller windows. Windows must be cleaned regularly and therefore, the glass size, area, and accesibility should be designed together. Large areas of glass may cause problems of sun penetrations and sky glare. Twelve different plant construction schemes were considered and the resultant daylight floor distribution were plotted. Consideration was also given to the combination and artificial light.

Atkinson (1965) investigated whether lighting was appropriate for a given job. Eyes have not changed but illumination capabilities and required seeing tasks have, and unless real efforts are made to minimize visual difficulties, visual comfort and performance will suffer. The author stated that having enough light is a step in the right direction. Lighting levels, though, are really a question of balancing the cost of lighting against the waste of human effort and the loss of time and material which occurs when there is not enough of it. Atkinson ended with a list of seven questions which should be asked in investigating whether lighting is appropriate for a given job.

Tinker (1954) attempted to determine the degree to which illumination intensity chosen for comfortable reading was determined by the illumination level to which the eye was adapted. One hundred forty-four university students served two sessions of fifty minutes each. The subjects, before the initiation of the reading task had a 15 minute adaptation period at eight footcandles level or one at a fifty-two footcandle level. During the last five minutes of this period the subject was asked to do some sample reading of test materials. After this reading he was asked to compare different levels of lighting.

For the eight footcandle adaptation level, the comparison levels were 1, 2, 3, 5, 12, 18, 26, and 41 footcandles. For the fifty-two footcandle standard they were 18, 30, 41, 46, 59, 62, 71, and 100 footcandles. In both cases the choice frequency followed a normal distribution centered on the adaptation level. From an analysis of the frequency with which every intensity was chosen as best for easy and comfortable reading Tinker concluded that the preference for an illumination intensity was not a satisfactory method for determining the intensity of light needed for efficient visual work, due to the dependence of preference on previous levels.

An observation could be pointed out about the design of this experiment because the levels of comparison after each adaptation level were very different, thus there is the possibility that the subjects with the adaptation level of eight footcandles had could have had the same preferences as those of the subjects with the adaptation level of fifty footcandles if the two groups had had the same comparison levels. Furthermore, even in the case that the comparison levels had been the same and the choice levels had been different for each group, it would not mean that these preferences are definitive for efficient work. Rather it could be thought that the levels chosen are transitory. So, in Tinker's experiment it would be necessary an additional adaptation period at a certain level of illumination for the subjects which preferred that condition, and then to compare again different levels of illumination. Probably, after successive choosing there could be a tendency to select a common level as comfortable for efficient work.

Fortuin (1965) stated that the eye's power of resolution, its visual acuity, is dependent on the amount of flux incident on the retina or initially on the illumination of the scene being viewed. It was shown how visual acuity increased with contrast, was dependent on the luminance of the field of vision, and how visual acuity was affected by age. The older the subject investigated, the poorer the average visual acuity and his loss of visual acuity cannot be compensated for with reading glasses. Light needs increase with age.

In industry the key point of the problem is what visual acuity is necessary for the job in question. If difficult figures had to be recognized all day, eight hours a day, it would become very tiring even if individually the figures were easily recognizable. If this recognition were required over an extensive period of time the problem would not be ruining of the eyes, as is often thought, but rather that the correct interpretation of incomplete information picked up by the eye call for a great deal of effort. This quickly lends to fatigue, which is often accompanied by headaches, irritability, and similar symptoms. The question as to how great visual acuity requirements are is a matter of the need for good performance with comfort.

Blackwell (1959) reported on an eight year program of research in glare, contrast, and illumination. He concluded with the development of a method of determining illumination levels by converting a static laboratory task into normal field conditions. The areas reported in this report were: characteristics of visual performance, laboratory performance data for standard disk targets, field factors, the visual task evaluator, the standard visual curve, the standard lighting specifications procedure, evaluation of sample visual tasks, and future development of the method. He then extended his previous investigations for specifying illumination levels for various tasks (Blackwell, 1965). The former method was modified to include the fact that task difficulty depended importantly upon the physical characteristics of the lighting installations. The new method resulted in standard curves representing the relationship between task difficulty and quantity of illumination for a selected performance criterion. These curves were recommended by the author and adopted by the Illumination Engineering Society in 1959. Task difficulty was expressed in terms of the physical contrast of a standard luminous disk test object equal in difficulty to the task of interest. The measure of the task difficulty was obtained by the visual task evaluator, which involved equating the task with the standard test object at the visibility threshold. Once the value of difficulty was known, the required illumination was given by reference to the standard performance curve. This method was used to determine footcandle values for a selected task under four different types of lighting systems each of which had different luminaire arrangements. The empirical measurements were then compared to the calculated values for all systems and arrangements. Using this procedure the I. E. S. recommended levels of illumination suitable for a variety of applications.

Contrast

The contrast of a scene is the measure of the difference in light leaving various portions of the scene. Contrast is often specified as the amount of light leaving the darker portion, compared to that leaving the brightest part. In general, the greater the contrast the easier the visual task. Ricketson (1968) described contrast as a very general phenomenon occurring in any visual field in which differential stimulation exists. Contrast operates on one's ability to discriminate by subjectively exaggerating perceived differences in the visual world.

Blackwell (1963), in his investigation about glare, also determined that different lighting systems actually produce considerably different values of task contrast. Therefore, lighting can affect ease of seeing in two ways: by directly producing more task contrast and by the indirect effects of altering the operating characteristics of the eye, to allow it to see with less contrast. It thus becomes evident that the quality of lighting is important as well as the quantity.

Light Sources

The primary purpose of a light source is the production of light. The efficiency with which a lamp fulfills this purpose is expressed in terms of lumens emitted per watt of power consumed, that is, luminous efficacy. The optimal output from a theoretical monochromatic yellow-green (550 nanometers) light would produce approximately 680 lumens for each watt consumed. A theoretical white light source of maximum efficacy would produce about 200 lumens per watt. All practical sources produce radiation in the infrared and ultraviolet ranges and thus efficiency is less, due to this invisible as well as conduction and convection losses.

Incandescent lamps produce light by virtue of a wire or filament heated to incandescence by the flow of electrical current through it. The emission spectrum for this type of lamp depends on the filament and the bulb; the filament must operate in either a vacuum or an atmosphere of inert gas to prevent rapid disintegration due to oxidation. In general, the emission spectrum of the incandescent filament lamp is a band in the red-yellow area of the visible range. The incandescent filament lamp has a certain characteristic which makes it inherently inefficient as a source of light. The maximum possible efficacies are being approached and they are from 15 to 20 lumens/watt.

The electric discharge lamp produces light by an entirely different process, and is capable of achieving much higher efficacies. Some fluorescent lamps now provide over 80 lumens/watt and sodium lamps (lucalox) provide over 110 lumens/watt. The fluorescent lamp is not a filament but rather an electric discharge source. In this type of lighting fixture, light is produced predominantly by the fluorescence of phosphorus activated by ultraviolet energy from a mercury arc. Such lights consist of a tube having an electrode sealed into each end and containing mercury vapor at low pressure with a small amount of inert gas. The inner walls are coated with fluorescent powder. When the proper voltage is applied a flow of electrons results. Collisions between these electrons and the mercury atoms in their path cause the emission of radiation, chiefly in the ultraviolet range (253 nanometers). The fluorescent powders transform the ultraviolet radiation into visible light. The spectral energy distribution curve of a fluorescent lamp shows a continuous spectrum for the radiation produced by the phosphorus, plus lines from the mercury arc that are not absorbed by the phosphorus.

Lion (1964) studied the influence of different lighting systems giving the same level of illumination upon performance of manipulative and inspection tasks. Fifty-three students were given a battery of four tasks, once under tungsten light and once under fluorescent light. Three manipulative tasks consisted of size-grading ball bearings, needle threading, and measuring steel rods. The fourth task, a clerical one, involved reading columns of paired numbers. The constant 14 lumens per square foot was established by an 80 watt warm white fluorescent 40 inches above the working area or by a 100 watt clear tungsten bulb 60 inches above the working area.

It was shown that on the three manipulative tasks, subjects worked significantly faster under fluorescent light than under tungsten light but did not make significantly more errors. The type of lighting had no effect on performance of the clerical task.

Lion, Richardson, and Browe (1968) expanded the previous study by Lion (1964). The original study showed that the subjects worked significantly faster at the manipulative and inspection tasks under fluorescent light than under tungsten, and suggested that differences in performance might have been due to glare which was accentuated by the use of metals in the test materials. In this study the test objects were made of black plastic with a relatively low reflective surface.

Two tests were made which could be automatically scored by a magnetic scoring device located within a conveyor system. One of these tasks involved the inspection of plastic disks for surface flaws. Ten per cent of these disks contained flaws. The other inspection task involved the rejection of buttons with off-center holes. All faulty disks and buttons were made containing a light-weight washer which would respond to the magnet in the automatic scoring device. The components to be inspected were equally spaced 2 inches apart and traveled at a speed of 7 inches/second on the conveyor.

Forty-nine university students were tested under an illumination level of 30 lumens per square foot. This level was maintained by four 80-watt white fluorescent tubes or by four 200-watt clear tungsten bulbs all located on the ceiling. After completing the inspection task each subject was tested on the Bausch and Lomb Orthorator (Trimbly, 1959). The scores of five subjects were rejected due to poor visual acuity as revealed by the Orthorator.

The analysis of the results indicated that the effects of learning was demonstrated and that students studying art subjects worked significantly better than those studying the sciences. It was noted that subjects overlooked significantly fewer faulty disks under fluorescent light than under tungsten, but there were no significant differences due to lighting on the button-scoring task. It was suggested that the disk task, being a task of visual acuity was at a disadvantage under point-source illumination, however it is not clear why this should be the case.

GLARE

Having mentioned some general aspects of illumination, one may now consider the particular field which is the subject of this study, glare.

Glare is that condition in which any brightness or contrast interferes with the efficency or comfort of the visual process. Dealing with the general term "glare" one needs to make a distinction between discomfort glare and disability glare. These are different effects produced by glare and will not necessarily occur together. The main distinction between disability glare and discomfort glare is that the former affects directly the performance by reducing the visual efficiency to perceive contrast of an object against its background or by lessening the contrast itself. By contrast we mean a relative ratio of the source with its surround. In the disability glare the light diffussed inside the eye casts a bright veil across the scene; the brighter the veil, the more vision is impaired. Discomfort glare, on the other hand, refers to the feelings of annoyance because of some glare source in the visual field without necessarily any detectable impairment in the performance; it is associated with the brightness that the eye involuntarily struggles to avoid but it is compelled to transmit as a complaint to the brain.

Discomfort Glare

Most of the studies about glare deal with discomfort glare, but even in this field there are "a number of questions remaining unanswered and a completely satisfactory method with glare continues to be an elusive challenge" (Guth and McNelis, 1961).

Luckiesh and Guth (1949) presented a paper about brightness at the borderline between comfort and discomfort (BCD). This research was performed on a basis of 50 subjects varying in age from 20 to 40 years. From this group the individual BCD brightness ranged from 315 to 1600 footlamberts. A group of 10 subjects, representative of the previous 50, were then chosen to complete the experiments.

The remaining experiments consisted of testing the influence of field brightness, the influence of size source, and the influence of source position in the vision field. When this data was analyzed and the appropriate modifications made to existing theoretical formulae, the result was a nomogram for calculating the factors which combine to determine the BCD brightness of the source. Included in this figure were the brightness of the source and the background, the position index, the solid angle involved, and finally the BCD range with the 830 footlamberts being the center average.

Petherbridge and Hopkinson (1950) in their extensive work with discomfort glare, investigated the effects of glaring light sources on comfortable vision. Six subjects who were experienced in the technique of making subjective appraisals were used. It was determined that the discomfort from a glare source depended on the source brightness, intensity, and apparent area; the displacement of the source from the direction of view; and, the general brightness of the surrounding which determined the adaptation level of the eye. The authors also discussed methods of reducing glare.

Guth (1951) discussed relations for critical and casual seeing. It was stated that the results obtained made possible a simple and logical method of calculation to determine the permissible brightness of source in a visual environment or the expected degree of sensation which might be induced by proposed or existing lighting systems.

Guth (1952) evaluated his earlier conclusions that a simple and practical equivalent from multiple sources of equal brightness and areas which were located above the line of vision was the total of the individual areas located at the position of the source closest to the line of vision. In this experiment the observers were required to adjust the brightness of a test source located on the horizontal line of vision in the test room so that the initial sensation received from the particular installation being compared was the same as that from the test source. The results obtained showed that the indices of sensation for each of the lighting installations and for the corresponding test source were in close agreement.

Fugate and Fry (1956) investigated the relationship of pupil size and the borderline between comfort and discomfort (BCD). They attempted to determine the role played by constriction of the pupil size of the human eye as associated with brief exposures of light in producing discomfort. The advantages they associated with this procedure were: 1) the results could be correlated with the subjective data, 2) the pupillary response to brief exposures of light could be evaluated in terms of changes in pupil size, and 3) the use of brief exposures of light permitted the measurement of blink reaction time.

In this study it was found that the contraction of the iris is one of the factors contributing to discomfort. This was supported by the fact that paralysis of the iris of one eye with the drug homatropine produced no significant change in the BCD level of the other eye. Paralysis of both eyes at the same time was shown to greatly decrease the threshold of discomfort in all but one subject. All the subjects found it quite intolerable under paralysis of both irises to walk outside and face the sky.

Guth and McNelis (1959) reported the development of a discomfort glare evaluator. It was stated that by obtaining BCD data with the portable evaluator it was possible to relate any observer to those who participated in the early laboratory investigations. It was found that there was a direct relationship between BCD brightness and field brightness. This straight line relationship agreed with previous studies.

Allphin (1961) reported the results of a project in which 109 inexperienced observers adjusted luminaire brightness in a simulated office to their BCD. It was reported that there was no correlation between age and the brightness chosen for BCD. Neither eye color nor the wearing of glasses showed any correlation with the brightness selected for BCD.

Guth and McNelis (1961) reported progress that they had been making in their investigations of discomfort glare. Using again the momentary exposure method, the observers were required to adjust the brightness of a test source until the sensation produced by it was at the borderline between comfort and discomfort. It was emphasized that the comparison source brightness, subjective ratings, and the indices of sensation were not measures of glare sensation nor would they demonstrate whether one experimental condition was twice as glaring as another. They only represented subject evaluations of relative discomfort to which computed glare ratings could be related.

Guth (1963) reported a new and improved chart for converting subjective ratings into discomfort glare estimates. In his attempt to arrive at a uniform approach to the evaluation of discomfort glare, he summarized all the data that he had gathered to the date. Consolidating other data with his own, Guth obtained a meaningful method of evaluating discomfort glare.

Atkinson (1966) provided a summary report of discomfort glare research at Cornell University. Using paid subjects from the student body of the College of Engineering, the following results were obtained:

1) The glare function, in its "classical" form as determined from studies on small sources, appeared to be valid for large sources to the point where the source occupied a very large (one fifth) part of the visual field.

2) Even when the sources occupied a large part of the visual field, the remaining surround area influenced the glare sensation; lower source luminances were required to cause a given degree of glare in a darker surround than in a lighter surround.

Disability Glare

Regarding disability glare only a few investigations have been performed. Holladay (1926) and Stiles (1928) established a reliable method of assessing the reduction of visual ability to perceive contrast. Holladay found that the effect of a glare source on the visibility of an object could be quantified in terms of an equivalent veiling brightness over the field. This veiling brightness being equal to KE/θ^n where K and n are constants, E is the illumination from the glare source in the plane of the observer's eye perpendicular to the line of sight and θ is the angular separation of the glare source from the observer's line of sight. Another way in which this concept is expressed is that the level of brightness to which the eye is adaptated is artificially raised by the glare source to a higher level.

Stiles (1929-1930) presented a brief sketch of the scattering theory removing deficiencies in the Holladay's discussion. The author considered the illumination of the fovea centralis as made up of the light refracted in the eye system to form the light scattered in the eye media or reflected at the surface of separation of these media. He defines two kinds of background brightness, the first one is that which, in the abscence of glare would lead to the same brightness threshold as is actually obtained in the given glare conditions; the pupil areas in the two cases having the normal values appropriate to the glare background brightness and the actual glare conditions respectively.

As experiments and theory lead to serious discrepancies, Stiles concluded that the observed rise in the threshold in the presence of glare is due principally to causes other than the light scattered in the eye media, and that the scattering effect can play only a minor role in the phenomenon.

Stiles (1931) suggested a method for defining a glare figure and to show how it can be applied to the case of streetlighting installations.

Stiles and Crawford (1937) studied the effect of glaring light source on extrafoveal vision. They considered the position of an object in the visual monocular field as specified in a system of polar coordinates with the eye as the origin and the direction of vision as pole. The aim of this study was to discover whether for 5^{o} parafoveal vision and also for more remote extrafoveal points the formula $\beta = B + kE/\theta^{n}$ was valid. In this formula B is the uniform brightness of the field, E is the illumination at the subject's eye, θ is the angular distance from a test object to the illumination cource and k and n are constants whose values are approximately 10 and 2.

Christie and Fisher (1966) carried out experiments on disability glare because in Britain the Holladay-Stiles formula had usually been said to indicate that disability glare is negligible in noncutoff street lighting. And a reexamination of this question indicated, on the contrary, that disability glare is important and that erroneous conclusions may be reached if disability glare is neglected when calculating revealing power (a measure of visibility).

The results of this study suggest that the law of variation of the disability effect with angle may differ slightly from that indicated by the Holladay-Stiles formula. There is an indication also that the magnitude of the effect may vary with the distribution of luminance over the field of view. An interesting by-product of work is that it shows a clear variation of visibility glare with age of the observer.

Reading (1966) undertook the investigation of the readaptation times of drivers when subjected to glare from oncoming headlamps, and, at the same time the study of the effect of ageing over the same reaction. The observers were confronted with a moving headlamp and required to detect possible hazards in photographic representation of street scenes. These hazards, viewed by projection, depicted such instances as pedestrains crossing an unlit road, or stepping from behind stationary vehicles. On perceiving the hazard the driver pressed a foot pedal, thus giving a measure of his readaptation time plus his reaction time. The age range was from 18 to 54 years.

It was found that the times of readaptation are dependent on age, and that for both glare illuminants there is at least a twofold increase in the length of readapatation time between the upper and lower age limits. This is in accordance with published data that retinal illumination decreases threefold between 20 and 60 years, and is partly attributable to changes in the pupil diameter and the yellowing of the linticular nucleus of the lens.

The author suggested that, particularly for the younger age groups, the readaptation times are significantly lower in the presence of the white glare source. In the higher age range the times of readaptation more nearly approached one another where, under these scotopic conditions, the aging eye would suffer more in white light since the light of short wavelengths caused veiling glare due to the increase scatter in the older ocualr media. Also, the experiment showed conclusively the value of light clothing for pedestrians at night.

Gandara (1970) attempted to relate glare location and performance in two tasks. Each task was executed in no glare conditions and under two different glare locations. One task was an assembly job and for this purpose a wooden board, 10" x 7.5" x 1" with 63 holes drilled on it was used. The work consisted in connecting, by using the type of wires used in wiredboard accounting machines, between two of these holes. The subject got the board with 5 wires on it and was asked to fill it with 10 more wires. The experimentor recorded the time required to add 10 wires using a decimal minute stop watch.

In the other task the subject received a sheet of paper with series of letters printed on it. He was asked to cross out, for three minutes, the consonants placed on both sides of the letter "I", at intervals of one letter. This procedure was repeated four times for each condition of glare and the number of letters crossed in each condition was the mean.

Six graduate students without pay worked in the experiment and no restrictions were made as to their vision ability, race, or any other factor. Their age ranged from 19 to 34 years.

The experiment was performed in a booth 76" x 78" x 36" wide, all walls and ceiling are white. The illumination level at the work place was 19 footcandles. In this room there are two holes at different heights which give the glare source at 15^o and 40^o with respect to the line of sight of the subjects, in this form different levels of glare were obtained. The experiment was done in two sessions (one for each task) with four days in between and the sequences of the work conditions balanced the learning and fatigue effects.

The criteria used were:

a) Time to insert 10 wires.

b) Letters crossed in three minutes.

c) Number of errors.

It was found that:

a) There were no errors in the assembly task but in the inspection task there were significant differences between the errors in no glare condition versus glare at 15^o and 40^o.

b) In the assembly task there were significant differences among the time spent under each illumination condition.

c) Even though the mean value of number of letters crossed during the three minutes periods under no glare condition was greater than in the glare conditions, the difference was not significant.

The author suggested that another study should be done in order to investigate the effects of different levels of glare over a long period because the difference in letters crossed although insignificant in this experiment, could indicate a trend which may be significant in a longer period. Also, he proposed to consider the effect of these conditions from the physiological point of view because in his investigation it was not possible to say whether the insignificance of the difference in letters per minute is due to adaptation or because of the subject's strain overcoming the effect of the glare source.

PROBLEM

As discussed very little research has been conducted on the disability effects of glare. A primary objective of this study is to add to this knowledge. With reference to the previous work by the author, several extensions are proposed. First, it is desired to extend the performance period to increase the likelihood of glare effects, while more closely simulating normal work situations. Second, physiological measures will be gathered to determine whether the glare conditions produces general stress conditions which might underlie any observed performance decrements. Finally, visual acuity will be measured to determine whether this aspect of vision suffers from the glare and thus, might affect task performance.

The task studied in the present experiment is an inspection job which ressembles the clerical work executed with proof sheets and in general several inspection tasks in which small defective items should be found out by examination. While perhaps the most common situation of disability glare is that of drivers subjected to oncoming headlamps, there are many other cases in which because of defective illumination conditions (direct or reflected glare) people are faced with disability glare.

METHOD

Task

The task was self-paced and it consisted of crossing the consonants placed on both sides of the letter "I", at intervals of one letter. This task can be seen from the following example which has the same dimensions of the sheets used in the experiment:

HYJIKMJNUJKIKYGTRFIKMLPOIJNHBVCDXSAIEWSQAZXIJMNKLOPIUJIYHGTBV
HYGBZIXHNIJIKJNHOIQIKOIQIOIIOIQXIJMNHBGYBVFCDRESXZAWQEUJIKLNB
UJNHBGVFZIZOIIUMNBHGVFRDEIUJNHBGVFTRDECXSIXHBGFDSXZABHGYIXTJI
JNHBGVFZIUJNHBVFCDIUKOPIUJHNBZAIYIJHNAIZGFRFIEGYHFIEDCXBNJHUH
NHIUYTGVFRDZIKJUNHYBGTVFIUJKIKUJNHBIXHNJHBGVFIZRFDEZIKZIUJHYB
GVFCDXIUIXUIIUXIJHNBGVFCDIKESIEFIEFVCGHJFVCXZAWQSOIQIOIQIOKJN

For each period, which lasted 10 minutes, the subjects received eight sheets. Each sheet had different number of letters to cross but the total per period was the same. None of the subjects was able to cross all the letters in any period.

The experiment was conducted in the same booth used previously by the author (Figure 1) and two levels of glare were produced by changing the vertical angle formed by the line of sight of the subject and the line from the observer's eye to the glare source. In the no glare condition the glare source was turned off and the light in the booth was produced from light sources behind the subject.

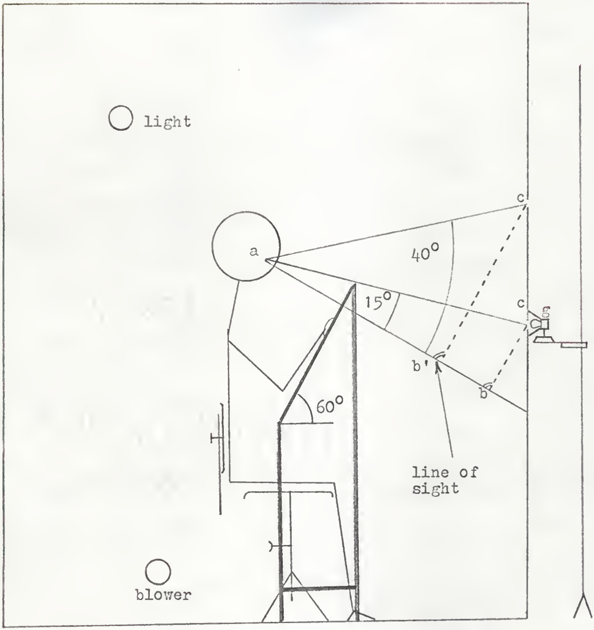

Figure 1. Graph showing the lateral view of the booth.

$\underline{g}$ = glare source
$\overline{bc}$ = vertical distance from the glare source to the line of sight (angle - 15°)

$\overline{b'c'}$=vertical distance from the glare source to the line of sight (angle = 40°)

In order to avoid changes because of different statures of the subjects an adjustable chair was used. The text for the inspection was printed in a strip of paper 2 inches wide in order to minimize variations of the vertical angle.

The ambient noise was about 45 db, the illumination level was 65 footcandles at table height and the environmental temperature ranged between 69 and 78^{o} F. The experiment was conducted in one three-hours session at different hours of the day (Table 1). The reflectance of the walls of the booth and surface of the table was 46% and that of the sheets 34%.

Experimental Procedure

The subject received the written instructions before going into the booth and then, when he was ready to start, he heard the same instructions from a tape recorder. At the end of the instructions he heard a regressive counting from two to zero, and as soon as he heard "zero" he started to work. After 10 minutes the tape recorder ordered the subject to stop.

The experiment lasted three hours. The first ten minutes were for adaptation to the work environment and to reduce nervousness and learning. Then the subject worked during 50 minutes under a determined illumination condition, and at the end of this time he had ten minutes rest followed by another 50 minutes of work under a different condition, and so on.

After each ten minutes period of work under a definite condition there was a test of the visual acuity, the heart rate was recorded and the performance during this period was

TABLE 1

Sequence Used in the Experiment and Hour of the Day

Subject	Condition[+]			Hour of the Day
1	1	2	3	5:00 - 8:00 PM.
2	1	3	2	5:00 - 8:00 PM.
3	2	1	3	5:00 - 8:00 PM.
4	3	2	1	1:30 - 4:30 PM.
5	2	3	1	8:30 -11:30 AM.
6	3	1	2	1:30 - 4:30 PM.

1 = No Glare

2 = Glare at 40^{0}

3 = Glare at 15^{0}

registered. All the subjects worked alone in each one of the three conditions and they followed the sequences shown in Table 1 in order to eliminate bias and counterbalance fatigue and learning effects. When the subject had completed his work, he was asked what condition he liked the best and to make a judgment about the glaring effect of that condition in which he had just been working compared with a theoretical condition figured as being at the BCD.

Criteria

Speed of Performance. Speed of working was taken as the number of correct letters crossed per period (10 minutes).

Accuracy of Performance. The meaning of this parameter is the number of errors committed per period. By error is understood a wrong letter crossed or the omission to cross some letter which should be crossed.

Visual Acuity. This criterion was determined by using a Landolt broken circle with a gap of 1/40". It was placed at a distance in which the subject was unable to perceive the gap, then the experimentor approached the circle to the subject's eye until the subject detected the slot in the circle. Afterward the experimenter covered the circle, changed the position of the gap, and asked the subject to determine again the position of the gap. Depending upon the subject's determination, whether it was right or wrong, the circle was moved away or approached to the subject's eye and a new determination was asked. Repeating this operation it was possible to measure the maximum distance of perception for each subject. By trigonometrical operations this criterion may be expressed in minutes of arc.

Heart Rate. The heart rate is the number of heart beats per minute. Each time the heart beats, a small electrical potential is generated. By placing electrodes on either side of the chest this potential can be picked up and transmitted by radio transmitter to a receiver. There the individual heart beats can be converted into heart rate, that is, heart beats per minute. These data are recorded continuously on ruled graph paper by a recorder. In this experiment an E & M telemetry equipment was used and a Beckman Dynograph was utilized to record the heart rate.

Heart Variability. Heart variability is a variation in the rhythm of the heart beats. It is measured as a standard deviation from this rhythm. Heart variability is being studied as an index of the subject's level of stress. A high heart variability value means a low stress level. As the heart variability decreases the stress has been found to increase.

Subjective Judgments. Two aspects were considered in this criterion. In the first one the subject was asked which illumination condition he found comfortable or, if not comfortable, what he liked the best. In the second aspect the subject tried to think of a lighting condition which was just glaring enough that it was at the borderline between comfort and discomfort. That is, if it was less glaring it would be comfortable. If it was more glaring it would be uncomfortable. After the experiment was completed the subject compared that kind of condition with the lighting conditions in which he had been working. Then he was asked to make a judgment about how glaring those conditions were in relation with that at the BCD and gave a number which expressed that relation. For instance, "it is one tenth as glaring".

Subjects

Six male students at Kansas State University were paid for the hour in the experiment. None had any experience with this kind of experiment. Their age varied between 20 and 29 years (Table 2) with a mean of 25.5 years. There were one B.S., four M.S., and one Ph.D. candidate. Only one (#4) wore eyeglasses.

TABLE 2

Subjects' Personal Data

Subject	Nationality	Age
1	India	23
2	U.S.A.	20
3	S. Domingo	29
4	U.S.A.	23
5	Ghana	29
6	Netherlands	29

Apparatus

The experiment was performed in a booth 78" x 76" x 36" wide (Figure 1). In the rear of the booth, in the central part, there were two holes of four square inches each one in order to obtain the positions of the glare source at 15^{o} and 40^{o}. The glare source was outside the booth and could be moved up and down for the experimenter in order to project the light directly through these holes. In the rear there was also a window through which the subject could look at the Landolt broken circle during the visual acuity test. This window was opened only for this test.

In the lateral walls, in the upper part, there was a hole in each wall in order to illuminate the booth with the light sources that were fixed outside the booth before these holes. In the lower part of the right wall there was a hole in order to put the nozzle of a blower used to remove the heat produced by the light sources.

Inside the booth and fixed on the floor there was a table whose shape is shown in the Figure 1. The surface of this table was from the same materials as that of the walls. The location of the table into the booth was determined empirically so that neither the lateral lights produced any kind of glare nor the subject projected any shade over the surface of the table.

RESULTS

Speed of Performance

Looking at the means for each condition (Table 3), the best performance was in the no glare condition but this advantage was not statistically significant (Table 4).

Considering the effect of time (Table 3) the second period presents the highest number of letters crossed and then there is a gradual decrement. These differences were statistically significant (Table 4).

The differences between subjects were statistically significant as well as the interactions between conditions and subjects (Table 4).

Accuracy of Performance

The results for this criterion (Table 5) indicate some advantage for the no glare condition and, as in the speed of performance criterion, the condition with the glare source at 40° is in the second place, but the differences were statistically insignificant (Table 6).

Visual Acuity

Considering the means for this criterion (Table 7), the no glare condition shows the best result and the condition with the glare source at 40° is in the second place. These differences were statistically insignificant.

The greatest differences in visual acuity stem from the subjects as well as from the interactions between conditions and subjects. These differences were statistically significant (Table 8).

TABLE 3

Speed of Working Expressed as Letters Crossed per Period

Condition	Period	Subject 1	2	3	4	5	6	Mean
	1	339	435	399	424	476	494	427.8
	2	431	411	428	444	531	591	472.6
No Glare	3	357	396	432	498	443	570	449.3
	4	364	364	381	451	434	517	418.5
	5	398	419	349	406	374	493	406.5
	Mean	377.8	405.0	397.8	444.6	451.6	533.0	434.9
	1	376	508	350	442	362	613	441.8
	2	432	521	371	421	353	594	448.6
Glare at 40^{o}	3	442	463	346	482	357	584	445.6
	4	382	410	333	471	352	505	408.8
	5	386	453	359	424	401	529	409.2
	Mean	403.6	471.0	351.8	448.0	356.0	365.0	430.8
	1	398	435	411	400	396	415	409.1
	2	468	492	449	431	416	477	455.5
Glare at 15^{o}	3	409	488	388	371	456	446	426.3
	4	362	454	327	355	417	444	393.1
	5	393	445	384	427	430	427	429.3
	Mean	406.0	462.8	391.8	396.8	423.0	455.8	422.7

Grand Mean = 432.4

TABLE 4

Analysis of Variance of Number of Letters Crossed

Source of Variance	df	MS	F
Period (P)	4	7146.54	6.244+
Condition (C)	2	1402.43	1.225
Subject (S)	5	35700.98	31.194++
P x C	8	978.87	.855
C x S	10	7801.27	6.816++
P x S	20	492.19	.430
Error	40	1144.49	

+$p < .05$

++$p < .01$

TABLE 5

Number of Errors

Condition	Period	Subject 1	2	3	4	5	6	Mean
	1	12	7	9	5	19	3	9.16
	2	16	4	10	0	10	3	7.16
No Glare	3	23	4	8	2	20	6	7.50
	4	29	2	5	0	18	5	9.83
	5	35	0	15	3	14	4	11.83
	Mean	23.00	3.40	9.4	2.00	16.20	4.2	9.09
	1	14	6	5	3	7	3	6.33
	2	27	3	3	2	10	4	8.16
Glare at 40°	3	24	7	10	4	17	11	12.16
	4	29	2	7	4	21	3	11.00
	5	20	5	14	4	18	12	12.16
	Mean	22.80	4.00	7.80	3.40	14.60	6.60	9.96
	1	23	3	2	1	17	3	8.17
	2	25	5	3	1	17	9	10.00
Glare at 15°	3	16	6	8	3	19	5	9.50
	4	26	13	5	3	15	7	11.50
	5	17	10	15	2	16	13	12.16
	Mean	21.40	7.4	6.6	2.00	16.80	7.4	10.26

Grand Mean = 9.77

TABLE 6

Analysis of Variance of Number of Errors

Source of Variation	df	MS	F
Period (P)	4	55.01	3.380
Condition (C)	2	2.41	.148
Subject (S)	5	865.05	53.161++
P x C	8	9.47	.581
C x S	10	11.18	.687
P x S	20	18.26	1.122
Error	40	16.27	

++$p < .01$

TABLE 7

Visual Acuity Expressed in Minutes of Arc

Condition	Period	Subject 1	2	3	4	5	6	Mean
	1	.74739	.71625	.71625	.71625	.81857	1.06111	.79597
	2	.75394	.71625	.71625	.71625	.83446	1.10192	.80651
No Glare	3	.74739	.71625	.71625	.71625	.82644	1.03554	.79302
	4	.74094	.71625	.71625	.72838	.82644	1.03554	.79397
	5	.74739	.71625	.71625	.72838	.82858	1.08797	.80414
	Mean	.74741	.71625	.71625	.72111	.82689	1.06441	.79872
	1	.75394	.74393	.71625	.71625	.73461	1.07437	.78989
	2	.74739	.72838	.71625	.71625	.76741	1.10192	.79626
Glare at 40°	3	.76061	.71625	.71625	.71625	.85950	1.16114	.82167
	4	.75394	.71625	.71625	.72838	.85950	1.10192	.81270
	5	.76061	.71625	.71625	.71625	.85950	1.10212	.81183
	Mean	.75529	.72421	.71625	.71867	.81610	1.10829	.80647
	1	.76741	.71625	.71625	.71625	.88608	1.03554	.80630
	2	.75394	.71625	.72838	.71625	.88608	1.10192	.81713
Glare at 15°	3	.75394	.71625	.71625	.71625	.88608	1.14600	.83581
	4	.74739	.77432	.71625	.76061	.90473	1.14600	.84149
	5	.76741	.75394	.71625	.75394	.92419	1.08797	.83395
	Mean	.75802	.73540	.71868	.73266	.89743	1.10348	.82428

Grand Mean = .80982

TABLE 8

Analysis of Variance of Visual Acuity

Source of Variance	df	MS	F
Periods (P)	4	.001156	2.48
Conditions (C)	2	.005145	11.07
Subjects (S)	5	.321839	692.57++
P x C	8	.000620	1.33
C x S	10	.001680	3.61+
P x S	20	.000523	1.12

+$p < .05$

++$p < .05$

Heart Rate

This physiological criterion was used to find out under which illumination condition the subjects worked more comfortably and with less strain.

The lowest mean heart rate occurred at the no glare condition and the means for the condition with the glare source at 40^{o} and 15^{o} were very close (Table 9). The differences were statistically insignificant (Table 10).

With this criterion, as with the speed of performance, the differences between subjects and interactions between conditions and subjects were statistically significant (Table 10).

Heart Variability

Considering the means with this criterion the standard deviation for the no glare condition was lower than that for the glare conditions. The standard deviation for the two glare conditions were very close (Table 11).

The only statistically significant difference was that between subjects (Table 12).

Subjective Judgment

Each subject evaluated the condition with the glare source at 15^{o} as the most glaring, and the condition which the subjects liked the best was the no glare condition. In the evaluation of the illumiantion condition in which they worked all of the subjects considered the glaring level at the no glare condition as a fraction of the glaring level of that condition which they thought was at the BCD. The illumination at the glare conditions was found to be more glaring than that of the BCD (Table 13).

TABLE 9

Heart Rate in Beats per Minute

Condition	Period	Subject 1	2	3	4	5	6	Mean
	0	72	78	84	72	84	66	76.0
	1	66	78	84	66	72	60	71.0
	2	78	78	84	66	72	60	73.0
No Glare	3	72	72	78	72	72	60	71.0
	4	72	78	78	72	72	60	72.0
	5	72	78	78	72	72	60	74.0
	Mean	72	76.8	81.6	69.6	72	61.2	72.2
	1	66	84	90	72	90	60	77.0
	2	66	84	90	72	78	60	75.0
Glare at 40^{o}	3	72	84	96	72	84	60	78.0
	4	72	84	90	72	84	60	77.0
	5	78	84	84	66	84	60	76.0
	Mean	70.8	84.0	90.0	70.8	84.0	60.0	76.6
	1	72	78	90	78	72	72	77.0
	2	72	78	78	78	78	66	75.0
Glare at 15^{o}	3	72	90	78	78	72	66	76.0
	4	72	78	78	78	72	66	74.0
	5	90	84	78	78	72	66	78.0
	Mean	75.6	81.6	80.4	78	73.2	67.2	76.0

Grand Mean = 74.9

TABLE 10

Analysis of Variance of Heart Rate

Source of Variance	df	MS	F
Period (P)	4	8.40	.576
Condition (C)	2	170.80	11.716
Subjects (S)	5	825.28	56.613++
P x C	8	12.30	.843
C x S	10	92.08	6.316++
P x S	20	16.08	1.103
Error	40	14.58	

++$p < .01$

TABLE 11

Heart Variability Expressed in Seconds

Condition	Period	Subject 1	2	3	4	5	6	Mean
	1	.01664	.02501	.05628	.01783	.03651	.04309	.03256
	2	.01847	.02647	.01918	.02573	.02211	.03324	.02420
No Glare	3	.03317	.04150	.01918	.01887	.02562	.03225	.02843
	4	.04750	.02132	.03199	.01492	.02212	.02995	.02797
	5	.03591	.02984	.03834	.02581	.01887	.02864	.02957
	Mean	.03034	.02883	.03299	.02063	.02505	.03343	.02855
	1	.04909	.03659	.01600	.02561	.01996	.03488	.03035
	2	.05500	.05398	.01600	.00020	.03137	.03488	.03221
Glare at 40°	3	.03400	.02695	.02828	.01632	.02062	.05308	.02988
	4	.05196	.04721	.03518	.01492	.02233	.04401	.03594
	5	.04036	.05890	.05240	.02573	.02695	.03687	.04020
	Mean	.04608	.04473	.02957	.01656	.02425	.04074	.03371
	1	.03945	.02462	.04044	.02463	.01973	.03317	.03034
	2	.05618	.01995	.04707	.01995	.01444	.02999	.03126
Glare at 15°	3	.04715	.04044	.04395	.01491	.02000	.03601	.03374
	4	.05282	.03562	.05691	.01849	.02562	.04303	.03875
	5	.03538	.02232	.04106	.02132	.02212	.04542	.03127
	Mean	.04620	.02859	.04589	.01990	.02038	.03752	.03303

Grand Mean = 0.03175

TABLE 12

Analysis of Variance of Heart Variability

Source of Variance	df	MS	F
Periods (P)	4	.000083	0.85
Conditions (C)	2	.000234	2.41
Subjects (S)	5	.001119	11.53+
P x C	8	.000079	0.81
C x S	10	.000220	2.27
P x S	20	.000060	0.61

+$p < .05$

TABLE 13

Subjective Judgment Results

Subject	Comfortable Condition	Fraction of "Borderline Between Comfort and Discomfort" that Each Condition was Judged by Each Subject		
1	No Glare	.5	2	3
2	No Glare	.5	2	3
3	No Glare	.25	2	4
4	No Glare	.75	1.5	2
5	No Glare	.1	1.5	3
6	No Glare	.5	2	5
	Mean	.502	2.02	3.04

DISCUSSION AND CONCLUSIONS

Glare did appear to have an effect on subjects' speed of performance in this experiment. The best speed of performance was under no glare conditions (434.9 letters per period) and the speed of performance under the conditions with the glare source at 40^{o} (430.8 letters per period) was the second best. In the author's previous study the speed of performance under no glare, glare at 40^{o}, and glare at 15^{o} were 65.85, 64.04, and 61.35 letters crossed per period (in that case the period lasted three minutes). In both studies the differences were only suggestive due to the lack of statistically significant results.

The fact that there were no significant changes in speed of performance in these experiments could be because the angles used in the experiment are too large to produce disability glare. Holladay (1926) and Stiles (1928) in their experiments about disability glare used angles between 1^{o} and 25^{o}. The range used by Stiles was between 1^{o} and 10^{o} and that used by Holladay was between 2.5 and 25^{o}. In the formula of the equivalent veiling brightness, $\beta = KE/\theta^{n}$, Holladay's values for K and n were 9.2 and 2.0, and the correspondent values used for Stiles were 4.2 and 1.5. Subsequently Stiles' revised values were 7.0 and 2.0. The magnitude of the equivalent veiling brightness calculated at different angles and using these values of K and n are presented in the Table 14. It is noticeable that the results are very similar when the angle is closed

TABLE 14

Equivalent Veiling Luminance, in Foot-Lamberts, for Several Angles (Θ) Using Different Values of K and n+

Angle Θ Degrees	Holladay's Values $9.2/(\theta)^2$	Stiles' Values $4.16/(\theta)^{3/2}$	Stiles' Revised Values $7.0/(\theta)^{1.8}$
2.5	1.472	1.052	1.345
5	0.368	0.372	0.386
5.5	0.304	0.323	0.325
6	0.255	0.283	0.278
15	0.041	0.072	0.053
25	0.014	0.033	0.021
40	0.006	0.016	0.009

+ E is put equal to unity

to 5^{o}. These facts and the scarce difference in the speed of performance obtained under different levels of glare in the present study suggests that disability glare is produced only at low values of θ. Another posibility is that the task used in this investigation was too simple visually and the subjects were able to preserve their speed of performance even in the face of strenuous illumination conditions. This hypothesis could be tested by using the same illumination conditions with a more difficult visual task. A third posibility could be that disability glare produces only a slight decrement in performance, whatever the task was, when the effect is considered over a range of one hour or less.

The differences among periods were statistically significant. Considering the means of periods in each condition it was found that the second period presented the highest mean. It seems that in the task used in the experiment there is a warming up period which facilitated the increase of the performance and then there was a slow deterioration because of fatigue or annoyance or both.

Considering the differences between subjects by this criterion, which were statistically significant, it is worthwhile to point out that the two best performances were sixth and second subjects' (Table 15). Incidentally, these subjects are the extremes in the group from the age, visual acuity and educational level standpoints. The sixth subject had the worst visual acuity and was in the highest age and educational level,

TABLE 15

Means of Each Parameter in Each Condition in the Sequence Followed by Each Subject

	Task Order	Subject 1	2	3	4	5	6
Sequence	1st	No Glare	No Glare	Glare 40°	Glare 15°	Glare 40°	Glare 15°
Followed by	2nd	Glare 40°	Glare 15°	No Glare	Glare 40°	Glare 15°	No Glare
the Subject	3rd	Glare 15°	Glare 40°	Glare 15°	No Glare	No Glare	Glare 40°
Speed of	1st	377.8	405.0	351.8	396.8	356.0	455.0
Performance	2nd	403.6	462.8	397.8	448.0	423.0	533.0
Letters/Period	3rd	406.0	471.0	391.8	444.0	451.0	565.0
Number of	1st	23.0	3.4	7.8	2.0	14.6	7.4
Errors	2nd	22.3	7.4	9.4	3.4	16.8	6.6
Letters/Period	3rd	21.4	4.0	6.6	2.0	16.2	4.2
Visual	1st	.75	.72	.72	.73	.82	1.103
Acuity	2nd	.76	.74	.72	.72	.90	1.064
Minutes of Arc	3rd	.76	.72	.72	.72	.83	1.108
Heart	1st	72.0	76.8	90.0	78.0	84.0	67.2
Rate	2nd	70.8	81.6	81.6	70.8	73.2	61.2
Beats per min.	3rd	75.6	84.0	80.4	69.6	72.0	60.0
Heart	1st	.03034	.02883	.02957	.01990	.02425	.03303
Variability	2nd	.04608	.02859	.03299	.01656	.02038	.02855
Seconds	3rd	.04620	.04473	.04589	.02063	.02505	.03371

and the second subject had very good visual acuity capacity and was in the lowest level from the age and educational point of view. The fact that the sixth subject complained about intense headache and general discomfort at the end of the experiment could suggest that this subject was highly motivated and strived to maintain a high level of performance the face of strenuous conditions by increased expenditure of effort.

There is a learning effect involved in the task performed in the experiment which undoubtedly served to obscure the glare effects. Observing the mean of letters crossed per subject in each condition it is found that in general the highest mean corresponds to the last condition in which the subject worked (Table 15). In the subjects number one, two, three, and four the difference of mean speed of performance per period between the first and the last condition in which the subjects worked was between 66 letters (Subject 2) and 40 letters (Subjects 1 and 3) with a mean of 48 letters. The correspondent differences for the fifth and sixth subjects were 95 and 110 with a mean of 104.5 letters. Thus it is probable that the significant interaction between subjects and conditions stems from the subjects' different order of glare conditions. The accuracy, or number of errors per period, presented some advantage (lower number of errors), in the no glare condition. In this condition the mean of errors per period was 9.09 errors and the correspondent figures for the illumination conditions with the glare source at 40^{o} and 15^{o} were 9.96 and 10.26 errors. With this criterion the only statistically significant difference was that among the subjects.

Considering the visual acuity it was found that the mean values per period with this criterion under no glare, glare at 40°, and glare at 15° were .79872, .80647, and .82428 minutes of arc. Thus, even though these differences were not statistically significant, the no glare condition presented the best visual acuity. The only differences were those among the subjects and the interactions between conditions and subjects. The meaning of this interaction is that, in general, the visual acuity capacity is affected by the illumination conditions, with this effect more detrimental under the most severe conditions of glare. However, this effect is not the same for each subject, so, the changes in visual acuity were more perceptible in the fifth and sixth subjects (Table 15). Because these subjects are the oldest, it would be possible to relate the highest impairment in the visual acuity capacity with the highest level of age. The same effect was observed by Christie and Fisher (1966).

When the heart rate is brought into consideration it is observable that the no glare condition is advantageous (lowest heart rate) for the subjects. Because of the significance of the difference among the subjects and the interactions between conditions and subjects it is worthwhile to point out that when the first illumination condition in the sequence was the no glare condition (first and second subjects, Table 15), there was a tendency for the heart rate in the other conditions to rise. When some glare condition was in the first place in the sequence a trend to lower the heart rate was observed (Table 15). The fourth and fifth subjects, whose last illumination condition was without glare (Table 1), presented their lowest heart rate during this step (Table 9 and 15). Even though the differences were statistically insignificant, it appears that the lowest heart rate is associated with the no glare condition.

The heart variability criterion presented its lowest mean during the no glare condition. This result is not in agreement with the interpretation of the heart variability (Cahill, 1969) which relates the decrease of heart variability with a high stress. Further investigation is necessary about this parameter in order to know with some certainty the nature of the relation between stress and heart variability and whether this relation is the same whatever the kind of task used in the experiment. The only significant difference with this criterion stems from the subjects. Incidentally, it must be pointed out that whatever the illumination sequence followed by the subjects, all of them showed the highest heart variability in the last illumination condition in which they worked (Table 15). The advocates of the interpretation of the high heart variability as an index of low stress could argue that in the last step of the experiment the subjects were relaxed and at home with their task.

Although the subjects had no previous training in glare evaluation, the opinion survey positively indicated that the no glare condition was the most comfortable. At this point it is worthwhile to observe that whatever the sequence of illumination conditions followed by the subjects, at the end of the experiment they selected this no glare condition in common as comfortable.

Considering the six criteria together it seems that the subjects worked under the effect of disability glare. In general the no glare condition was the best and the illumination condition with the glare source at 15° was the worst one from the standpoints of speed of performance, number of errors, visual acuity, heart rate and subjective judgment. When the heart variability was brought into consideration the results in this study were not as expected because the highest heart variability was produced under the most unfavorable condition and coincided with the highest heart rate.

In the task used in the present investigation there were learning effects and fatigue. These two factors may confuse the effect of the different illumination conditions because, in the case of learning, it could counteract the action of glare over the performance, and the detrimental effect of fatigue, due to the illumination conditions or to the task itself, could be misinterpreted as a consequence of glare.

From these considerations it can be concluded that further investigation is required in order to study the effects of disability glare over the performance. It would be preferable to use some task in which the learning effect is certainly reduced and with the glare source very close to the line of sight.

The practical implications of this kind of investigations are reduced, the only familiar situation of disability glare is that on the roads and streets from oncoming lights, but in some jobs, particularly when the operator has to manipulate pieces of reflecting metals there could be disability glare.

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EFFECT OF GLARE OVER THE PERFORMANCE IN AN INSPECTION TASK

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ABSTRACT

An inspection task was performed under three illumination conditions: without glare, with a glare source at 40° and with a glare source at 15° above the line of sight.

Six male subjects worked in the three conditions for 150 minutes and six criteria were recorded: speed of performance, accuracy, visual acuity, heart rate, heart variability, and subjective judgment.

Although some of the differences were not statistically significant, results tend to show that glare has a detrimental effect in an inspection task. A by-product in this study was the suggestion that disability glare increases with age of the observers.

It was observed that the heart variability increased through the experiment in all of the subjects whatever the sequence followed in the illumination conditions.