DISCOMFORT GLARE AND TASK DIFFICULTY

by

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INTRODUCTION

Most satisfactory seeing conditions could be produced by providing adequate brightness in the entire visual environment, and it is the ultimate goal of lighting practice. To individuals performing tasks of critical seeing for prolonged periods, proper adjustment of all the brightnesses in the entire visual field is of paramount importance. Light is distinguished from the rest of the electromagnetic spectrum by its effect on the photoreceptors of man, through which, by photochemical and subsequent electrical changes, it produces the sensation of seeing. Sight is directly dependent upon the lighting level. The ability of the eye to detect differences in luminance, and detail of vision (visual acuity), both improve as the luminance is raised from low levels to high levels. Light, if sufficiently bright, can also produce discomfort. This is commonly referred to as "discomfort glare". Hence, if there is unwanted light in the visual field, the eye does not function at its full efficiency. If the luminance of part of the visual scene is too high for the state of adaptation of the eye, then the source of the high luminance is called a glare source.

There are two forms of glare effects, disability and discomfort glare. These are not mutually exclusive since conditions producing glare generally also cause discomfort. When bright light sources are introduced into the field of view of an observer, his ability to detect the presence of objects is reduced. The name given to this effect is "disability glare". "Discomfort glare", on the other hand, is an uncomfortable brightness relationship between the central and surrounding fields of vision (contrast) which are directly responsible for the comfort of the visual conditions but which may only show an indirect effect upon visibility, i.e., discomfort glare is discomfort but does not necessarily interfere with seeing.

In practice both effects of glare may arise from the same glare source, but in interior lighting at moderate levels of light the usual cause of complaint usually is discomfort rather than disability which the presence of light sources introduces to the visual field. Hence, the discomfort glare control is vital if luminaires are to be an unobtrusive and attractive element of building design, and is of great importance to the illuminating engineer. Lighting design for interiors has long been concerned with visual comfort and the avoidance of discomfort glare. Both direct and reflected glare exist in practical situations.

Empirical methods to quantify discomfort glare have been used to study the effect of different environmental conditions on discomfort glare in the absence of theory. An important aspect of empirical research on discomfort glare is that the observer is asked to make a subjective judgment. If a subject were to perform a few tasks, and was asked about the subjective evaluation of levels of glare, it might be possible to relate his or her level of comfort (or discomfort) to the toughness of the tasks. Different degrees of comfort are physical and / or psychological sensations and therefore appraisals can only be made by persons experiencing such sensations. Visual comfort varies greatly from one individual to another and even varies in a given individual from day to day. Though individual appraisals vary between extremely wide limits, the averages over observers may be consistently related to physical conditions.

The trend in illuminating engineering is towards greater aesthetic appeal, with emphasis on the pleasantness of the lighting environment rather than considering only the performance aspects of the lighting system and the discomfort glare control remains as an important aspect of the aesthetics of lighting.

Some Recent Glare Research

Research has been carried out in an attempt to relate discomfort glare to physiological changes produced by the glare source. Fugate and Fry (1956) have shown that under certain conditions, discomfort glare is related to the activity of the muscles which control the diameter of the pupil. While light reduces the size of the pupil, Fry and Fugate (1975) found that it is not the size alone that generates discomfort, rather it is the fluctuation in size, when the kind of control of the pupil response is effected by momentary and intermittent stimulation. They had also studied the role of the iris in generating discomfort glare, i.e., the way of relating discomfort glare to spontaneous fluctuations in the pupil. By the use of drugs to partially or completely immobilize the pupil, the role played by the pupil, can be segregated from other sources of discomfort, such as tension in the eyelid and facial muscles as well as the muscles that point the eyes in different directions. Such factors operate at high levels of luminance, but it is believed that the pupil plays an "initiating role" in discomfort reactions. While a discomfort reaction may be initiated peripherally (or "physiologically"), in order to obtain a verbal response, some "central processing" must take place. In fact, the Germans refer to disability as "physiological glare" and to discomfort as "psychological glare". In this central processing, it may be that there is some "pooling" of discomfort from different sources for example, glare and noise. Further if one is performing difficult work this might produce discomfort which cannot be distinguished from discomfort from glare, etc.

Bennett (1977) showed the particular relationship between the borderline of comfort and discomfort (BCD), a measure of insensitivity glare and three parameters : the background luminance, the source angle from the line-of-sight, and the source size.

$$BCD = 40\,(L)^{0.3} \cdot \exp\,(0.05\,A)\,/\,(S)^{0.6}\text{, where}$$

BCD (in footlamberts) is the borderline between comfort and discomfort,

L (in footlamberts) is the luminance of the background,

A is the source angle (in degrees) above the line-of-sight, and

S (in steradians) is the source size.

Some specific effects found by research include the following. Babiker (1977) has shown that prediction of noise annoyance and discomfort glare could not be made from those personal characteristics which were tested. Ahmed and Bennett (1978) found for very short durations (0.6 second) that the BCD declined with increasing duration (it is similar to Bloch's law), then increased. This was true when the glare source was placed along the horizontal line-of-sight as well as when it was 15 degrees above the line-of-sight. However, the degree of discomfort was greater when the light was along the line-of-sight. Lulla and Bennett (1981) have shown that for a greater range of adjustment a glare source in an experiment, BCD settings were higher. This range effect is consistent with various sensory range effects found in other areas, in particular, in studies where observers selected "acceptable" noise level. The result is also predicted by Adaptation Level Theory. The implications of these findings are that discomfort from glare may be triggered by a peripheral physiological event such as in the pupil, but that there must be "psychological processing" also.

Pilot Study

A pilot sudy was undertaken by Madhavan and Kumar (1982) in which 20 observers performed a particular cognitive task with three levels of difficulty, and evaluated the magnitude of discomfort using a glare source. The concept of "borderline between comfort and discomfort" or "BCD" was used as a measure of discomfort glare. The result of the experiment showed that the observers had evaluated the magnitude of discomfort glare to be maximum after performing the toughest task. The discomfort glare tends to be lower as the toughness of the task decreases. Apparently, the glare criterion which the observers were using did not shift much in the experiment, resulting in small differences in the mean BCD's. Analysis of variance was performed for the three dependent variables, viz , vote on the Borg Perceived Exertion Scale, the time taken to perform the tasks, and the BCD setting. While the null hypothesis was rejected in all the three cases, the Duncan's Multiple Range Test for the vote on the Borg Perceived Exertion Scale reflected that the tasks were not significantly different in their difficulty, and the mean BCD's are not significantly different for all the three levels of difficulty of task, and it was concluded that further research was needed with better distinction of toughness of task.

PROBLEM

While it was expected that task difficulty would influence discomfort glare sensitivity, a pilot study suggested that better distinction of the task difficulty was called for in the present research. This study has been conducted to find whether the discomfort glare varies with different levels of toughness of task. A concept called borderline between comfort and discomfort or BCD was used as a measure of insensitivity to discomfort from glare.

The hypothesis for this study was : Greater task difficulty makes one more sensitive to discomfort glare.

METHOD

Task, Informed Consent, and Instructions

When the observer reported to the laboratory, he was asked to read a description of the experiment entitled "Informed Consent and Instructions" (Figure 1), a description of the four tasks entitled "Tasks Description" (Figure 2), "Instructions for Glare" (Figure 4) and to indicate his willingness to participate in the experiment by filling out the form "Personal Data" (Figure 5).

Apparatus

The apparatus consisted of a two foot radius hemisphere set on edge. An aperture was placed at the pole (0 degrees) along the horizontal line-of-sight, to give a source size of 0.0000314 steradian. The hemisphere was constructed of posterboard painted white. A facerest was fixed at the opposite end and in line with the aperture at a distance of 2.5 feet from it along the horizontal. A fixture with an incandescent lamp (1000 Watts, 120 Volts) as the light source was arranged behind the aperture in the hemisphere at the opposite end of the horizontal axis from the facerest. The lighting fixture had a frosted glass cover to provide a diffused light providing a maximum luminance of 85000 cd/sq.m. An autotransformer with one side common to line (120 Volts, 60 Hz) was used to control the brightness of the source. The background luminance was produced by an incandescent lamp placed behind and above the observer in such a way that it was out of his range of vision. The background luminance was set to a value of 0.3426 cd/sq.m.

This is an experiment on discomfort glare and task toughness. At the beginning of the experiment, you will be asked to adjust a small light source, directly on your line-of-sight, from a low brightness upwards to a level which is not quite uncomfortable. At no time do I want you to adjust the light to a level which is extremely uncomfortable. Then you will perform one of the four tasks, a brief idea of which is given in "Tasks Description" (Figure 2). Then you will be asked to adjust the light source to five glare levels. Similarly the remaining three tasks would be asked to be performed and the light source would have to be adjusted as before.

There would be no discomfort, or annoyance, or risk from the experiment, however you are free to stop your participation at any time. The experiment will require around two hours of your time. Naturally, I would certainly appreciate your paticipation till the completion of the experiment, so that I can get the data I need. If you have any questions, now or later, feel free to ask me.

Having read all the instructions, I hereby freely agree to be a subject in the research entitled :

" Discomfort Glare and Task Difficulty".

<u>Figure 1 - Informed Consent and Instuctions</u>.

<u>Task 1 (Easy puzzle)</u>

You will put together 24 pieces of a 15" X 12.5" jigsaw puzzle.

<u>Task 2 (Easy measurement)</u>

A telescopic gauge and a calculator are provided. You are required to measure the diameter of ten holes that were drilled and reamed to 0.4370" ,and calculate the mean and standard deviation of the holes.(Figure 3).

<u>Task 3 (Difficult measurement)</u>

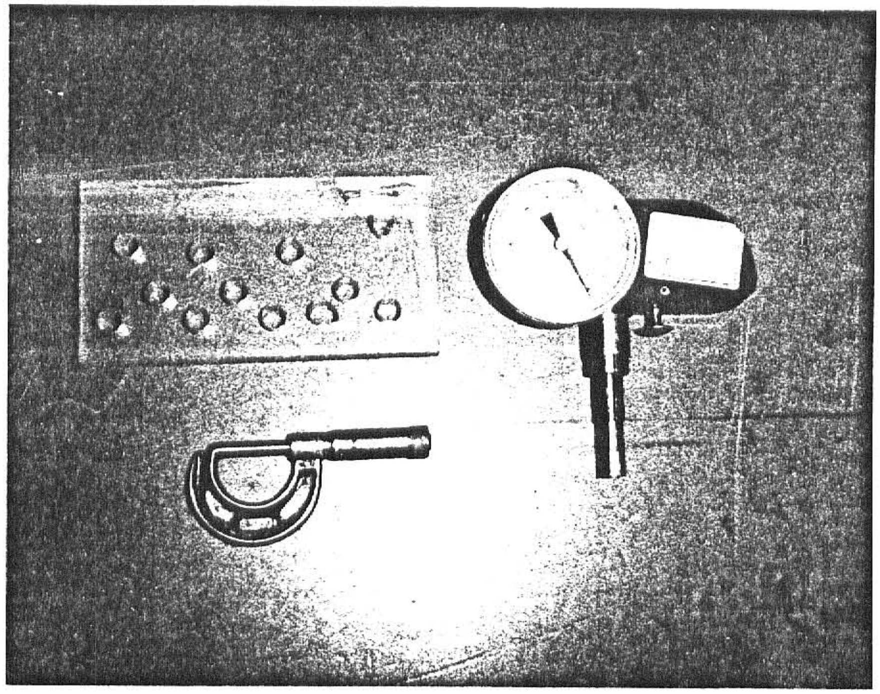
A height gauge, a vernier caliper, a pocket comparator, and a calculator are provided. Measure the appropriate dimensions of the component and calculate the weight, given that the density of the material as 7.87 gms/cc.(Figure 3).

<u>Task 4 (Diffcult puzzle)</u>

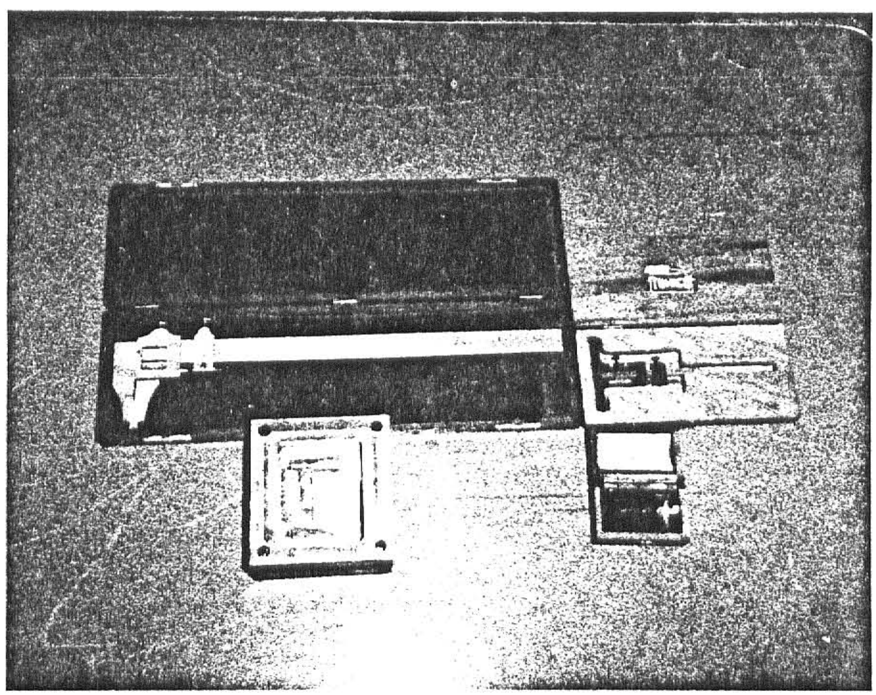
An outline of a part of a jigsaw puzzle is given. You are expected to put together 52 pieces and assemble a part of the puzzle.

Note : The 12" vernier calipers, the 6" vernier depth gauge and the 1" micrometer caliper have a least count of 0.001". A division in the telescopic gauge is 0.0001" and has been set at zero using the micrometer gauge to measure 0.4370".

<u>Figure 2 - Tasks Description</u>



Task 2



Task 3

Figure 3 - Picture of Tasks

"There is a concept called borderline between comfort and discomfort" or "BCD". First take the control and increase the intensity of the light to a high level. Look at the light !. Most people would say that this level of light is uncomfortably glaring. Now take the control and turn the light down until it is at a low level. Look at the light !. Most people would say that this level is comfortable, that is, not glaring. Now somewhere in between these two extremes should be a point of change, a threshold, where the light is at the borderline between comfort and discomfort. This is what we call BCD. <u>This point should be such that the light is not annoying or uncomfortable for you, but if it were any brighter it would be uncomfortable</u>. Take your time to find your BCD point. It may take a little time at first to decide whether the light is comfortable or not. Adjust the brightness up and down until you find your BCD. <u>Do not set the brightness at the borderline of tolerable and intolerable since this is a higher level</u>. <u>Similarly, do not use the pleasantness ... comfortable criterion ... this is a lower level</u>. BCD is between these two criteria. Now I want you to make your first adjustment to BCD. Take your time, run the control back and forth as much as you need. When you have completed your adjustment signal the experimenter to record the setting. Now go ahead.

<u>Figure 4 - Instructions for Glare</u>

Name ____________________ Local Phone ______________________

Today's Date ____________ Time _______ Major ______________

Birthdate __________ Sex M F Fr Sp Jr Sr Gr Fy

Color of eyes ___________ Do you wear glasses ? Yes No

Are these of some special type, such as tinted, bifocals

contact lenses ? __________________

If you are aware of it, what is the nature of visual

problem ? ____

____

____

Do you wear eye make-up ? Yes No Color of your hair_____

Number of hours of close work done during the

past week except watching television___________ hours.

Have you been exposed to any other conditions which might

irritate your eyes ? Please describe ______________________

____

____

If you are associated with the field of lighting, in what

capacity and for how long ? ________________________________

Have you participated in experiments concerning lighting ?

Yes No How many ? ________

Comments ____

____

____

Figure 5 - Personal Data

Experimental Design

The subject was asked to sit with his face in the facerest looking horizontally at the glare source. Before performing any of the four tasks, the observer adjusted the glare source to the following five levels of glare :

Barely discernable

Pleasant

Borderline between pleasant and comfortable (BPC)

Comfortable

Borderline between comfort and discomfort (BCD)

The subjects were asked to take their own time to find their BCD. These were recorded as the initial voltage readings, measured across the lamp, in the "Data Sheet" (Figure 6). Then one of the tasks was selected randomly and the subject was asked to perform the task under normal ceiling lighting (1500 lux on work) and the time taken to perform the task was recorded in decimal minutes using a stopwatch. Immediately after the subject had completed the task, he was asked to rate the toughness of the task just performed in "Rating of Tasks" (Figure 7). Then the subject was asked to adjust the glare source to the five levels of glare as before. The remaining three tasks were also given to be performed by selecting them in a random order, and the same procedure repeated.

Glare Level		Initial	Task 1	Task 2	Task 3	Task 4
Barely Discernable	cd/sq.m.					
	volts					
Pleasant	cd/sq.m.					
	volts					
Borderline between pleasant and comfortable	cd/sq.m.					
	volts					
Comfortable	cd/sq.m.					
	volts					
Borderline between comfort and discomfort	cd/sq.m.					
	volts					
Time in decimal minutes						
Vote on Borg Perceived Exertion Scale						
Order of Task performance						

Subject Number ________

<u>Figure 6 - Data Sheet</u>

	Task 1	Task 2	Task 3	Task 4
6-|-	______	______	______	______
7-|- Very very easy	______	______	______	______
8-|-	______	______	______	______
9-|- Very easy	______	______	______	______
10-|-	______	______	______	______
11-|- Fairly easy	______	______	______	______
12-|-	______	______	______	______
13-|- Somewhat hard	______	______	______	______
14-|-	______	______	______	______
15-|- Hard	______	______	______	______
16-|-	______	______	______	______
17-|- Very hard	______	______	______	______
18-|-	______	______	______	______
19-|- Very very hard	______	______	______	______
20-|-	______	______	______	______
21-|-	______	______	______	______

Subject Number _____

<u>Figure 7 - Rating of Tasks</u>

Independent Variables

The two independent variables of the design are the subjects (blocks) and the task type.

Dependent Variables

The three dependent variables of the design are the time taken to perform each of the four tasks, the vote on the Borg Perceived Exertion Scale for the difficulty of the four tasks, and the BCD readings subsequent to the four tasks.

Subjects and Recruitment Procedure

An incidental sample of 21 subjects was chosen from among the graduate and undergraduate students of the Department of Industrial Engineering. The age of the subjects varied from 20 to 28. All were male. Six of the 21 subjects wore glasses. The number of hours of "close work" done during the past week besides watching television by the subject before participating in the experiment varied between 3 to 80. The subjects were asked to participate upon their availability. Care was taken to see to it that all the subjects participating in the experiment were very familiar in solving jigsaw puzzles and in the area of measurement using vernier calipers, micrometer caliper, pocket comparator, depth gauge. A session lasted for just above 2 hours.

RESULTS

The data collected (Appendix A) was analysed using a completely Randomized Block Design (RCBD). Bartlett's test for the homogenity of variance of the dependent variable natural logarithm of Borg Perceived Exertion Scale (Table 1), natural logarithm of the time taken to perform each of the tasks (Table 2), and BCD settings in candellas per meter square (Table 3) show that the variances are not significantly different as the Chi-Square test failed to reject the null hypothesis at 5% significance level. This confirmed that the Analysis of Variance could be performed on the dependent variables.

The ANOVA of the dependent variable Borg Perceived Exertion Scale (Table 4), the Duncan's Multiple Range Test for Borg Perceived Exertion Scale (Table 5), the ANOVA of the dependent variable , the time taken to perform the tasks (Table 6), the Duncan's Multiple Range Test for the time taken to perform the tasks (Table 7), the ANOVA for the dependent variable, BCD settings in candellas per meter square (Table 8), and the Duncan's Multiple Range Test for the BCD settings in candellas per meter square (Table 9) were performed with 5% chosen as the significance level.

The ANOVA for the three dependent variables mentioned rejected the null hypothesis, and the

Duncan's Multiple Range Test showed significant differeces in the mean values of the Borg Perceived Exertion Scale, the time taken to perform the tasks, and the BCD settings. The BCD readings obtained covered a wide range of values. The lowest value of BCD was 2597 candellas per meter square and the highest was 46936 candellas per meter square, with an overall mean of 18949 candellas per meter square.

The following were the results obtained :

(1) The toughness of the tasks were significantly different as can be seen from the Duncan's grouping for Borg Perceived Exertion Scale (Table 5).

(2) The time taken to perform a task increases as the toughness of the task increases as can be seen from the Duncan's grouping for the time taken to perform the tasks (Table 7).

(3) The discomfort glare decreases as the toughness of the task increases. This is clearly depicted in Duncan's grouping for the BCD settings in candellas per meter square (Table 9).

(4) There are significant differences among the subjects in their evaluation of BCD as can be seen from the F value of "BLOCK" in the ANOVA of the BCD settings in candellas per meter square (Table 8).

TABLE 1

Bartlett's test for homogeneity of variance for Log(E) (Borg Perceived Exertion Scale)

Ho : BPES variances are homogeneous for all the four tasks

t=4, n=21, f=n-1=20, C=1+(t+1)/3ft=1.0208333

Task	Sample Variance	Log (E) (Variance)
1	0.0187719	-3.9753942
2	0.0387302	-3.2511356
3	0.0353784	-3.3416538
4	0.0443917	-3.1147028
	Mean = 0.034318	Total = -13.682886

M = f (t Log(E) (Mean) - Total Log(E) (Variance))

= 20 ((4) (-3.3720853)-(-13.682886)) = 3.8909

Chi-Square(calculated) = M / C = 3.811494

Chi-Square(0.05,3) = 12.838

As, Chi-Square(calculated) < Chi-Square(0.05,3), we FAIL TO REJECT the null hypothesis Ho.

HENCE THE BPES VARIANCES ARE HOMOGENEOUS.

TABLE 2

Bartlett's test for homogeneity of variance for

Log(E) (Time taken to perform the tasks)

Ho : The variances of time taken to perform the tasks are homogeneous

t=4, n=21, f=n-1=20, C=1+(t+1)/3ft=1.0208333

Task	Sample Variance	Log (E) (Variance)
1	0.1123419	-2.1862084
2	0.1095708	-2.2111844
3	0.0883919	-2.4259749
4	0.2241032	-1.4956486

Mean = 0.1336019   Total = -8.3190163

M = f (t Log(E) (Mean) - Total Log(E) (Variance))

= 20 ((4) (-2.0128908)-(-8.3190163)) = 5.349062

Chi-Square(calculated) = M / C = 5.2398976

Chi-Square(0.05,3) = 12.838

As, Chi-Square(calculated) < Chi-Square(0.05,3), we FAIL TO REJECT the null hypothesis Ho.

HENCE THE TIME VARIANCES ARE HOMOGENEOUS.

TABLE 3

Bartlett's test for homogeneity of variance for BCD setting in candellas per meter square

Ho : BCD variances are homogeneous for all the four tasks

t=4, n=21, f=n-1=20, C=1+(t+1)/3ft=1.0208333

Task	Sample Variance	Log (E) (Variance)
1	130294000	18.685424
2	132222000	18.700113
3	177667000	18.995544
4	202976000	19.128722

Mean = 160789750 Total = 75.509803

M = f (t Log(E)(Mean) - Total Log(E)(Variance))

= 20 ((4)(18.895725)-(75.509803)) = 1.46194

Chi-Square(calculated) = M / C = 1.04

Chi-Square(0.05,3) = 12.838

As, Chi-Square(calculated) < Chi-Square(0.05,3), we FAIL TO REJECT the null hypothesis Ho.

HENCE THE BCD VARIANCES ARE HOMOGENEOUS.

TABLE 4

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: BORG PERCEIVED EXERTION SCALE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
MODEL	23	676.13095238	29.39699793
ERROR	60	292.28571429	4.87142857
CORRECTED TOTAL	83	968.41666667	

MODEL F = 6.03 PR > F = 0.0001

R-SQUARE	C.V.	STD DEV	BPES MEAN
0.698182	18.5214	2.20713130	11.91666667

SOURCE	DF	ANOVA SS	F VALUE	PR > F
TASK	3	545.46428571	37.32	0.0001
BLOCK	20	130.66666667	1.34	0.1900

TABLE 5

ANALYSIS OF VARIANCE PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: BORG PERCEIVED EXERTION SCALE

NOTE: THIS TEST CONTROLS ERROR RATES AT DIFFERENT LEVELS DEPENDING ON THE NUMBER OF MEANS BETWEEN EACH PAIR BEING COMPARED. ITS OPERATING CHARACTERISTICS SOMEWHAT RESEMBLE FISHER'S UNPROTECTED LSD TEST.

ALPHA=0.05 DF=60 MSE=4.87143

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN GROUPING	MEAN	N	TASK
A	14.095	21	3 (DIFFICULT MEASUREMENT)
A			
A	13.667	21	4 (DIFFICULT PUZZLE)
B	12.238	21	2 (EASY MEASUREMENT)
C	7.667	21	1 (EASY PUZZLE)

TABLE 6

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: TIME TAKEN TO PERFORM THE TASKS IN MINUTES

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
MODEL	23	9233.46618810	401.45505166
ERROR	60	3786.65344048	63.11089067
CORRECTED TOTAL	83	13020.11962857	

MODEL F =	6.36		PR > F = 0.0001

R-SQUARE	C.V.	STD DEV	MTIME MEAN
0.709169	41.5897	7.94423632	19.10142857

SOURCE	DF	ANOVA SS	F VALUE	PR > F
TASK	3	7741.64440952	40.89	0.0001
BLOCK	20	1491.82177857	1.18	0.3009

TABLE 7

ANALYSIS OF VARIANCE PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: TIME TAKEN TO PERFORM THE TASKS IN MINUTES

NOTE: THIS TEST CONTROLS ERROR RATES AT DIFFERENT LEVELS DEPENDING ON THE NUMBER OF MEANS BETWEEN EACH PAIR BEING COMPARED. ITS OPERATING CHARACTERISTICS SOMEWHAT RESEMBLE FISHER'S UNPROTECTED LSD TEST.

ALPHA=0.05 DF=60 MSE=63.1109

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN GROUPING	MEAN	N	TASK
A	28.265	21	3 (DIFFICULT MEASUREMENT)
A			
A	26.945	21	4 (DIFFICULT PUZZLE)
B	16.864	21	2 (EASY MEASUREMENT)
C	4.331	21	1 (EASY PUZZLE)

TABLE 8

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: BCD SETTING IN CANDELLAS PER METER SQUARE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
MODEL	23	11683658028.03602	507985131.65374
ERROR	60	1746648949.27514	29110815.82125
CORRECTED TOTAL	83	13430306977.31116	

MODEL F =	17.45		PR > F = 0.0001

R-SQUARE	C.V.	STD DEV	CPMS MEAN
0.869947	28.4715	5395.44399	18950.30721429

SOURCE	DF	ANOVA SS	F VALUE	PR > F
TASK	3	567083081.16462	6.49	0.0008
BLOCK	20	11116574946.87141	19.09	0.0001

TABLE 9

ANALYSIS OF VARIANCE PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: BCD SETTING IN CANDELLAS PER SQUARE METER

NOTE: THIS TEST CONTROLS ERROR RATES AT DIFFERENT LEVELS DEPENDING ON THE NUMBER OF MEANS BETWEEN EACH PAIR BEING COMPARED. ITS OPERATING CHARACTERISTICS SOMEWHAT RESEMBLE FISHER'S UNPROTECTED LSD TEST.

ALPHA=0.05 DF=60 MSE=29110816

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN GROUPING	MEAN	N	TASK
A	21582	21	4 (DIFFICULT PUZZLE)
A			
A	21345	21	3 (DIFFICULT MEASUREMENT)
B	17363	21	2 (EASY MEASUREMENT)
B			
B	15511	21	1 (EASY PUZZLE)

DISCUSSION

That the major source of variation in BCD is individual differences, is consistent with the findings of previous studies on discomfort glare, as can be seen from the high value of F for the BLOCK (19.09) (Table 8).

One assessment of the difficulty can be made in terms of the time taken to perform the task (Table 7) and the Borg rating (Table 5). It is seen that the difficult puzzle (Task 4) and the difficult measurement (Task 3) are grouped together, though the time taken to perform the former was higher, indicating that the subjects were not able to clearly draw a line between the difficulty of these tasks. The time results were : Difficult measurement 28.2 minutes, difficult puzzle 26.9 minutes, easy measurement 16.9 minutes, and easy puzzle 4.3 minutes. An ANOVA showed these times significantly different overall. A Duncan's test showed the difficult tasks are not different from each other but different from the two easy tasks, and the two easy tasks were different from each other.

The mean Borg ratings were : difficult measurement 14.1 (between somewhat hard and hard), difficult puzzle 13.7 (between somewhat hard and hard), easy measurement 12.2 (between fairly easy and somewhat hard), and easy puzzle 7.7 (between very very easy and easy). An ANOVA showed that these were significantly different. A Duncan's test showed the identical order and separation of the four tasks as that produced by performance times.

The mean glare settings were : difficult puzzle 21,600 cd/sq.m., difficult measurement 21,300 cd/sq.m., easy measurement 17,400 cd/ sq.m., and easy puzzle 15,500 cd/sq.m. An ANOVA showed that these to be highly significantly different and the Duncan's test showed the two difficult tasks to be equivalent, the two easy tasks to be equivalent to each other, but with the difficult and easy pairs of tasks different from each other.

For these four tasks no difference was found between task types, but differences were found in difficulty in terms of their associated BCD. As the BCD gets larger it indicates that the subject is less sensitive to glare. (He has to increase the source's luminance to achieve the same effect.) Also, the more difficult tasks took appreciably more time to perform. This was the time spent in a well lighted room (1500 horizontal lux on the working plane). With a longer "light adaptation period", it may very well have been that a bright glare source just was not seen as so glaring. Hence, the subjects were, due to this cause, might have been less sensitive to glare as the BCD's showed.

It is expected that the results of this research would go a long way in designing practical situations, where a particular type of task is done at various stages and places in a more complicated manner (which may be due to the practical limitations as well as manufacturing and assembly constraints). Examples of above would be in the assembly of wrist watches and inspection of machined components before unloading from the machine center mention a few.

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APPENDICES

APPENDIX A

RAW DATA

Task	Subject	BPES	Ft-lm	Cd/Sq.m	Time(min)
1	1	6	2880	9866.9	4.12
2		11	2490	8530.7	11.19
3		17	4625	15845.2	36.36
4		15	3400	11648.4	13.17
1	2	7	2490	8530.7	5.11
2		12	2490	8530.7	9.70
3		11	3400	11648.4	18.56
4		16	4370	14971.6	40.18
1	3	8	4370	14971.6	3.02
2		12	5500	18843.0	18.94
3		15	6270	21481.0	33.67
4		13	4880	16718.9	24.51
1	4	9	11100	38028.6	9.18
2		10	2880	9866.9	21.63
3		10	4370	14971.6	29.62
4		14	7800	26722.8	44.76
1	5	9	1650	5652.9	4.71
2		13	2880	9866.9	17.03
3		13	2880	9866.9	40.01
4		12	3400	11648.4	27.00

Task	Subject	BPES	Ft-lm	Cd/sq.m	Time(min)
1	6	7	2880	9866.9	4.17
2		16	4370	14971.6	31.77
3		10	4370	14971.6	39.07
4		14	3800	13018.8	19.29
1	7	7	4880	16718.9	4.38
2		12	5500	18843.0	22.07
3		15	6270	21481.0	31.99
4		18	4370	14971.6	27.57
1	8	6	1900	6509.4	4.33
2		12	2880	9866.9	22.52
3		17	2880	9866.9	40.59
4		8	2220	7605.7	19.35
1	9	7	12200	41797.2	3.16
2		8	11100	38028.6	9.53
3		12	13550	46422.3	15.90
4		16	13700	46936.2	25.93
1	10	10	1900	6509.4	3.39
2		13	2490	8530.7	10.78
3		14	2880	9866.9	20.64
4		19	4370	14971.6	45.42

Task	Subject	BPES	Ft-lm	Cd/sq.m	Time(min)
1	11	7	1190	4076.9	4.47
2		13	1900	6509.4	20.20
3		14	2880	9866.9	33.48
4		9	1650	5652.9	23.67
1	12	8	7800	26722.8	3.33
2		14	7800	26722.8	20.01
3		13	8620	29532.1	19.92
4		12	13500	46251.0	24.51
1	13	8	2880	9866.9	5.20
2		9	3800	13018.8	11.82
3		11	4370	14971.6	18.65
4		14	6980	23913.5	48.20
1	14	7	2880	9866.9	4.76
2		9	3800	13018.8	11.26
3		13	6980	23913.5	22.40
4		14	11100	38028.6	18.21
1	15	9	1020	3494.5	2.85
2		13	1190	4076.9	20.54
3		16	2490	8530.7	23.60
4		13	1420	4864.9	12.74

Task	Subject	BPES	Ft-lm	Cd/Sq.m.	Time(min)
1	16	8	7800	26722.8	2.75
2		11	9580	32821.1	14.21
3		13	12200	41797.2	21.76
4		12	11100	38028.6	20.21
1	17	7	758	2596.9	2.43
2		13	900	3083.4	13.70
3		16	1020	3494.5	20.16
4		13	758	2596.9	14.31
1	18	9	7800	26722.8	6.14
2		11	11100	38028.6	15.98
3		13	12200	41797.2	38.06
4		15	13500	46251.0	54.93
1	19	7	3400	11648.4	6.86
2		11	4880	16718.9	17.17
3		15	5500	18843.0	30.79
4		10	4370	14971.6	33.21
1	20	7	5500	18843.0	2.62
2		17	7800	26722.8	12.52
3		20	9580	32821.1	33.18
4		16	6980	23913.5	9.69

Task	Subject	BPES	Ft-lm	Cd/Sq.m.	Time(min)
1	21	8	7800	26722.8	3.98
2		17	11100	38028.6	21.58
3		18	13500	46251.0	25.15
4		14	8620	29532.1	18.99

Task 1	Easy jigsaw puzzle
Task 2	Easy measurement and calculation
Task 3	Difficult measurement and calculation
Task 4	Difficult jigsaw puzzle
Ft-lm	BCD setting in footlamberts
Cd/Sq.m	BCD setting in candellas / meter^2 1 footlambert = 3.426 candellas / meter^2
Time(min)	Time taken in minutes to perform the task
BPES	Borg Perceived Exertion Scale

APPENDIX B

CALIBRATION

Glare responses of the subjects were recorded in voltages of the light settings. To convert these voltages readings into the corresponding luminance values, the following calibration procedure was adopted. A Spectra Brightness Spotmeter, manufactured by Photo Research Corporation 3000 N. Hollywood Way, Burbank, California 91505, was placed in the position of the test subjects and was pointed at the glare source such that it was focussed. The brightness of the glare source was adjusted from zero to fifty volts of the voltmeter with an increment of one volt and at each step, the voltage reading and the corresponding footlambert reading of the photometer were recorded. A step size of five volts was chosen from fifty to one hundred and ten volts and the procedure was repeated. A computer program was written to obtain an equation for the curve fitting these points of volts and footlambert.

APPENDIX C

SPECIFICATION OF INSTRUMENTS

(1) 12" Vernier Calipers, Least count 0.001", manufactured by Brown and Sharpe manufacturing Company, Rhode Island, USA.

(2) 1" Micrometer Caliper, Least count 0.001", manufactured by The L. S Starrett Company, Athol, Massachusetts, USA.

(3) 6" Vernier Depth Gauge, Least count 0.001", manufactured by TUMICO, Tubular Micrometer Company, St. James, Minnesotta, USA.

(4) Pocket Comparator, Developed and manufactured by Bell and Howell Company, USA, Distributed by National Tool Company, 11200 Madison Avenue, Cleveland 2, Ohio.

(5) Telescopic Gauge to measure an inside diameter of 0.437", Least count 0.0001", manufactured by The Comtor Company, Waltham, Massachusetts , Serial Number 20719, Model P2.

(6) Casio fx-29 Scientific Calculator.

(7) Glare source - Sylvania 1000 W, 120 V, 25 HR incandescent lamp.

(8) Transformer (Glare source) - Variac W 20 MT 3 autotransformer, with one side common to line (120 V, 50-60 Hz) and load (0-140 V, 18 A), manufactured by General Radio, USA.

(9) Micronta, 22-201U voltmeter, custom manufactured in Korea for Radio Shack, A Division of Tandy Corporation, Fort Worth, Texas 76102.

(10) Background luminance source - 100 W, 120 V incandescent lamp.

(11) Transformer (Background luminance) - Model 3107, Serial Number 1061 autotransformer, manufactured by Vactec. Inc., Maryland Heights, Missouri 63043, USA.

(12) Model 3107, Serial Number 1061 Vactec Photometer, manufactured by Vactec, Inc., Maryland Heights, Missouri 63043, USA, (was used to measure the background luminance).

(13) Serial Number 2374, Code 1905-SB Spectra Brightness Photometer, manufactured by Photo Research Corporation, 3000 N. Hollywood Way, Burbank, California 91505, USA, (was used to measure the luminance of the glare source).

DISCOMFORT GLARE AND TASK DIFFICULTY

by

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ABSTRACT

An experiment was conducted in which twentyone observers performed two types of cognitive task with two level of difficulty in each and evaluated the magnitude of discomfort glare using a glare source. The concept of "borderline between comfort and discomfort" or "BCD" was used as a measure of discomfort glare. The result of the experiment showed that the observers had evaluated the magnitude of discomfort glare to be maximum after performing the easiest task. It was found that the discomfort glare is lower as the toughness of the task increases. The glare criterion which the observers were using shifted much in the experiment, resulting in big differences in the mean BCD's. Statistical tests showed that the mean BCD's are significantly different for the two levels of difficulty of both category of tasks. Hence, it can be concluded that as the level of difficulty of a task increases, the discomfort glare decreases.