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Effect of Illuminance on Human Work Performance, an assessment based on Lighting Laboratory experiment

Shafique Rahman*

Abstract: *The effect of illumination on human work performance seems to be more critical in the modern life, since a larger proportion of time human live in indoor under various lighting environments. From office to domestic works, lighting condition has a substantial influence on overall indoor environmental quality, occupant's productivity and comfort. At the same time, an optimum illuminance for specific purpose in a workplace would promote many attributes of sustainable physical environment. There are recommended illuminance for specific purposes suggested by national authorities in different countries. However, lighting researchers conducted various experiments on human performance under various recommended lighting environment and the prevailing standards were often reported improper by them. Thus any specific relationship between illuminance and human task performance still remain unclear and raises further need for research in the field.*

The present study observes the relationship between illuminance, color contrast of the task and task performance to determine any specific illuminance for maximum human performance. The experiment was conducted on a group of graduate level students of similar age. Based on a lighting laboratory experiment, conducted on these 71 subjects, the present study further examines how various illuminance and contrast level affects task performance. A questionnaire based survey completed with each session also relates the subjective impression of lighting with four different level of illuminances used in the experiment.

Keywords: *Task Performance, Illuminance, chromaticity, subjective impression, IEQ*

2.1 Introduction

In the recent years, the international concern for energy saving and low emissions widely focused on built environment (Liu et al. 2015, 02). Pursuing healthy, comfortable and low-emission buildings is often seen as a greater aspect of environmental and economical sustainability. Various researches reveal that work environment has numerous effect on the productivity and performance of workers and occupants. In order to improve human productivity, the very initial issue is always creating healthy working environment (Akbari et al. 2013). In the consequence, design and operation of buildings and the quality of indoor environment has been considered more critically in 21st century (Liu et al. 2015,).

Human work performance and productivity depends on a number of factors, however, lighting condition among those seems to have tremendous impact on task performance. Therefore, it is important to determine the illuminance level for every specific task in term of high performance and comfort for human. There are various lighting standards for appropriate task performance, i.e IES Lighting standard, CIBS etc.

However, researchers conducted field experiments with those recommended illuminance and reported the standards inappropriate in may earlier studies.

For example, as (Guiness, Boyce and Harker 1984) pointed, "Field measurements have shown that the illuminances used in kitchens tend to be much less than those recommended in

* Assistant Professor, Department of Architecture, Ahsanullah University of Science and Technology.

the CIBS (IES) Code". Another study among 101 homes reported the illuminance levels were found inadequate in majority of cases with those recommended by CIBS/IES (Simpson and Tarrant 1983).

As the earlier field studies rise question of the appropriateness of those recommended illuminance for various task performance, the present research, therefore, is an attempt to draw a specific guideline for highest level of human performance. The earlier studies may have shown variations in result due to the variable age group, education and intelligence of the subjects participated in the experiments.

In the present study a laboratory based experiment was conducted where the subjects were all of similar age and all from post graduate level studies. Therefore, it is expected that the age and intelligence will have no impact on their performance and the outcome can be assessed on the basis of illuminance.

The aim of this research is to determine a specific illuminance for highest level of human performance in the indoor environment and also observing the impact in the human performance under various increasing illuminance.

2.2 Research Question

Those variation between standards and dissimilarities in field studies raise the need for further study towards illuminance and their effect on task performance and the subjective impression of various luminous environment. The present research, therefore, examines human performance under various illuminance and investigates how changing illuminance for a specific task could affect human performance.

3.1 Literature Review- Background of The Study

Research in the field of Lighting, for example Productivity, Mood, Cognition, Chromaticity, web lengths, contrast, lighting related psychophysical impact are not a very recent topic. From silk weaving (Elton 1920), linen weaving (Weston 1922) typesetting by hand (Weston and Taylor 1926) to the recent works, literature shows more than 100 years of investigation in the field.

In an earlier research, a Chicago based company, Western Electric, conducted a study to improve worker's performance. Workers of the industry with same level of experience used to assemble wound coils under a range of illuminance range 260–750 lx. The experiment was performed in different combination of lighting. During the experiment with initial illuminance participants showed a slow but steady improvement in output of their performance. However, when the illuminance reached 33 lx, the members of the test group reacted that they couldn't flexibly see what they were doing and their output dropped. The research drew the outcome as lighting is a minor factor among many other factors that affect the task performance (Boyce. R 2002 . Human Factors in Lighting).

Also a technical work cannot be compared with desk jobs and research outcome cannot be considered similar for any task performed at office or in the classroom.

On the other hand, a significant impact on performance with the change of lighting identified by Stenzel, A.G in 1962. The experiment conducted over 4 years in a leather factory on the workers productivity. Within this 4 years of research, Stenzel changed the lighting fitouts in the factory, which increased illuminance level 350lx to 1000lx. The result dramatically changed after illuminance has been changed. Stenzel noticed a remarkable upgrade in the performance with the increased illuminance (Stenzel 1962). Figure 1 summarizes the

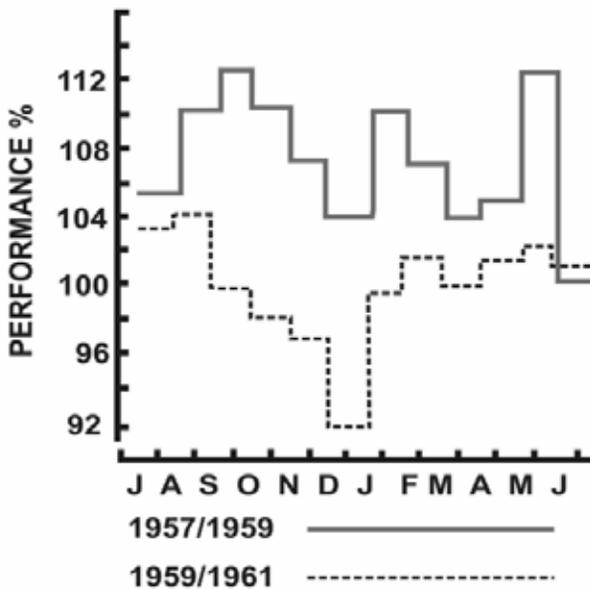


Figure 1: Shows the level of performance before and after lighting condition changed in the factory workers experiment conducted by Stenzel, A.G

Figure re-created from the data adopted from (Boyce Robert. 2002 . Human Factors in Lighting).

experiment result of Stenzel. A.G. The green line in the figure shows the performance level of the workers after illuminance increased to 1000lx.

The experiment in the factory was carried out for 4 years. A long span of time may also improve the efficiency of workers as they were involved in the same task. Thus the lighting cannot be claimed as the only reason for changing performance.

Alike aforementioned variations in those two experiments, there are more diversified issues addressed by various researchers. However, the most distinctive factor would influence the current study is the laboratory based experiment. As Peter Boyce mentioned, a laboratory experiment doesn't provide a real world situation, however, provide greater experimental control and reduce the variance in the measurements. (Boyce2011)

In an experiment led by industrial workers, or office workers has an argument with the type of task they have performed has greater impact on performance.

For example, a type writer is not expected to show a big difference in performance based on lighting condition, since it is a practice oriented task. And the performance must have driven by the proficiency and experience of the typewriter. As Boyce.R noted that, for an operative work lighting cannot produce work output, it depends on worker's skill (Boyce. R. 2002 . Human Factors in Lighting).

It is not only illuminance that could affect performance. Numerous attributes together creates the physical environment, for example colour, lighting, spatial layout, etc (Smolders, Kort, and Cluitmans 2012). Therefore, chromaticity of the visual stimulus in any task would

have influence on task performance. For example, Spenkelink in 1996 noted that a number of researches claim that performance improves with the higher level of contrast (Spenkelink 1996). Another research suggests that the colour of the character has effect on reading performance. In an experiment by Imbeau, D 1989, twenty-four subjects of both gender, tested with reading words presented on two displays written legends while driving a simulated vehicle in nighttime condition. The words were presented in eight different chromaticity. The results indicated that subjective performance was influenced by the change in chromaticity. (Imbeau, Wierwille and Laurie (1989). Apart from the change in illuminance, a change in contrast with the visual stimulus also examined, the present study explores whether chromaticity affects task performance or subjective impressions of the lighting.

The factors focused on various other studies are diversified. Even there were also 'photon-neuron' response, 'psycho-somatic' response - neurological, hormonal, psychological, motivational, emotional, and experiential factors considered in light-performance relationship. (Preamble et al. 1997) Therefore, it is not a few issues that can define an authentic and specific statement on lighting and performance relationship. The current study is limited to two major variables, change in illuminance and change in contrast. And it further attempted to understand the relationship among task performance and those two variables. This study generally considered the research inquiries,

- How task performance differs with change in illuminance. In the experiment task performance measured on the correct response in a given visual task and the time of completion.
- How changes in contrast level affect task performance
- Whether task performance predictive of subjective impressions of the lighting

4. Research Methodology

4.1 Selection of Task for Experiment

Previous studies have shown that there is a controversy in the type of task and many claimed that task type may affect the task performance and wouldn't be fairly judged towards the relationship with illuminance. To avoid task related complicacy, the type of task selected in the current study is a Landolt C chart, which was first introduced by British researcher Weston in 1945 (Eric, S .1986. Work Places: The Psychology of the Physical Environment in Offices and Factories). Landolt C Chart with two different contrasts and two different diagrammatic combinations were presented chronologically to the participants. Figure 2 and Figure 3 are the sample of tasks performed in the experiment.

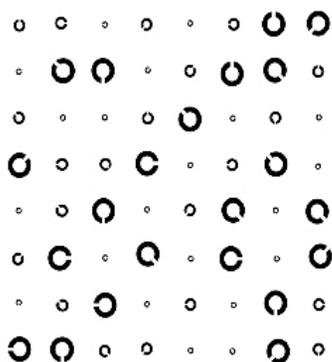


Figure 2: Landolt C chart with contrast ratio 4.5



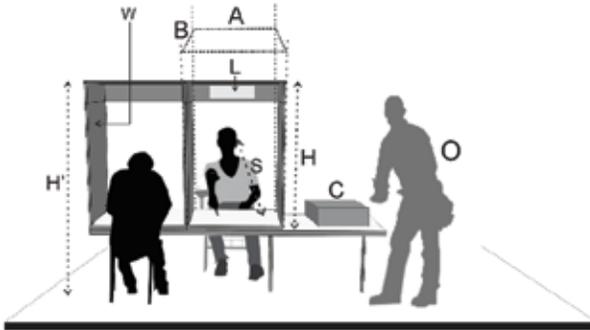
Figure 3: Landolt C chart with contrast ratio 1.5

4.2 General Information

Experiment General Information	
Experiment Performed	The University of Sydney lighting research laboratory.
Number of Subjects	71 participants
Age Group of subjects	28-35 years
Sex	50% M & 50% F
Educational Background	Post Graduate Level Students
Illuminance levels	50lx, 100lx, 200lx and 400lx.
Light Engine	-3050 K CCT light engines (LED). -Uniform lighting condition. -Thermally stabilized and no flickering.

Question 1 Entirely Satisfactory		Question 1 Entirely Unsatisfactory
Question 2 Extremely Easy		Question 2 Extremely Difficult
1	2	3
4	5	6
7		
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Question 3 Virtually None		Question 3 A Great Deal
Question 4 Incredibly Well		Question 4 Incredibly Poorly
<p><i>Figure 5: The scale used in questionnaire response. Response 1 is the positive response for all four questions. As response rises toward 7 reflects level of dissatisfaction.</i></p>		

4.2 Description of the Lighting Booth



A = 1m, B=1m,
H = 1.4m, H'=2.2m,
L = LED Light engine,

C = Illuminance Control Panel,
S = 45cm,
O = Operator,
W = White Surface

Figure 4: a sectional perspective drawing shows all dimensions of the lighting booth where the experiment was performed.

The experiment conducted in two booths, Figure 4: a sectional perspective drawing shows all dimensions of the physical layout.

4.3 Description on the Experiment Procedure

Two participants performed the task in the booth at a time. During experiment in each session participants completed one Landolt C Chart either with high or low contrast. The illuminance was randomized with four different levels 50lx, 100lx, 200lx and 400lx.

Completion time, number of accuracy and correlated illuminance were recorded. After each session, each participant completed a questionnaire which reflects the level of comfort correlated with the task he/she has performed. Figure 5 shows the comfort scale related to questionnaire response. All these data have been used for result and analysis.

5. Result and Discussion

In order to analyze the result, the data from 71 subjects primarily divided in two broad categories, those are low contrast and high contrast Landolt C charts. The major variables measured are number of correct response and time for completion. To simplify the analysis average of each category has been considered. In present study data average presented in the graph for comparison.

Figure 6 represents four different illuminances with two different contrast of task types along with the X axis. Y axis has two representations, Y axis left for correct response and Y axis right for completion time.

From the figure 6 it is seen that the average correct response for high contrast was similar (51.2-51.7) for all four illuminances. However, larger variation indicated by completion time.

Completion time was lower in 50lx and 200 lx, whereas it rises under 100lx and 400 lx. The same trend was noticed for low contrast Landolt C chart. Completion time was lower for 50lx and 200lx and higher for 100lx and 400lx.

In term of effect of illuminance the average result didn't show any significant difference with four different illuminances and correct response. On the other hand comparing completion time it is not a chronological downward or upward trend which could indicate any specific outcome. However, both variables were fluctuated in a minor range with the difference of illuminances.

Therefore, it can be appraised that illuminance has influence on task performance, but it is difficult to predict the degree of this effect. Further clarification would be derived by the questionnaire response in each sessions. Responses from all sessions were divided in two broad categories and the average for each question response plotted in a graph, shows in Figure 7. From Figure 7 it is seen that the average for all four questions under four different illuminances have substantial variations. Where response was always lower (2.19-2.9) under 50lx illuminance level. Lower value in response represents higher satisfaction.

Whereas response value gradually increased as the illuminance increased. Highest level in dissatisfaction noticed under 400lx both for high and low contrast. Similarly it was seen from the Figure 6 that under 400lx performance drooped slightly. Therefore, it can be indicated that level of satisfaction and comfort in visual task decreases with the increase in illuminance above 400 lx. However, task performance didn't gradually decreased with the gradual increase of illuminance. Therefore, it doesn't indicate any specific illuminance level under which performance was significantly higher. Even though, minor fluctuation in performance was noticed. In addition extensive illuminance 400lx shows downward performance in term of both completion time, correct response and questionnaire response. Which may compare with the research finding of Western Electric company in Chicago experiment, noted by

(Boyce,R. 2002 . Human Factors in Lighting) where workers reported they couldn't perform efficiently when illuminance increased.

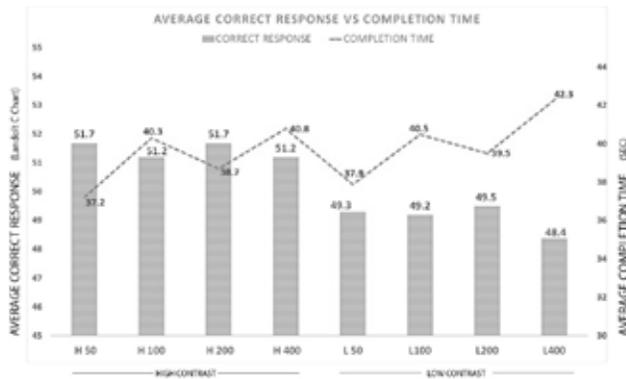


Figure 6: Average response in task performance and time for completion illustrated for both high and low contrast Landolt chart sessions. Graph shows all summarized result for four different illuminances.

On the other hand, comparing the differences between two different contrast levels there is a clear consistent variation reflected by the Figure 6.

The average performance dropped widely with the low contrast landolt C chart. Similarly time of completion reached to the highest point with the 400lx illuminance in low contrast sessions.

Figure 7 shows increased level of dissatisfaction under low contrast. Therefore it can be defined that level of color contrast has clear impact on task performance. High contrast improves the efficiency and also decrease dissatisfaction. Which is similar to the research finding by (Imbeau, Wierwille and Laurie 1989) where they found a clear improvement in task performance with higher contrast level.

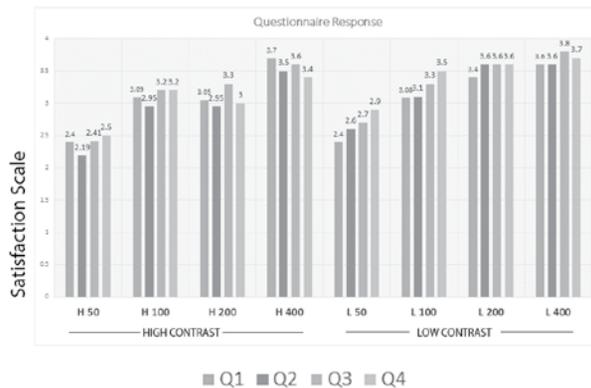


Figure 7: Average questionnaire response in different sessions for all for four illuminances and two different contrast levels.

6. Finding Summary and Limitations

Illuminance has impact on human performance. Based on the current experiment drawing a specific relationship between task performance and illuminance seemed difficult. It has been noticed from the analysis that increasing illuminance could enhance performance to a certain level, but excessive illuminance causes droop in performance and also reflects higher dissatisfaction level.

The present study has some limitations too. The experiment was only based on four different level of illuminances. Result could have been different for more higher than 400lx or lower than the 50lx. On the other hand, illuminance level was increased 200 lx to 400 lx directly without any performance level measured in between. Steeping up the illuminance from 200 lx to 400 lx gradually could indicate the highest performance of specific illuminance and after which level performance started to fall down. Which is a shortcoming of the study.

Task performance is not predictive of subjective impressions of the lighting. With the data derived from the experiment it was seen that under same lighting levels, different subjects has different performance and even has different response according to their level of satisfaction. Literature and earlier researches did not extensively evaluated the contrast and performance relationship.

The present research clearly indicates that Color contrast has significant impact on performance. From the analysis it was seen that higher contrast gives better performance and also increased satisfaction among the subjects.

7. Conclusion

According to the analysis presented above, it can be concluded that a change and improvement in lighting has an effect on productivity. Which also notified by many of the earlier researches, but the present study examines the scenario in a laboratory environment. The current study reveals that increasing level of illuminance primarily increase human performance. After a certain level which was 400 lx in this experiment, a downward trend in performance observed. Also, the analysis reflects that illuminance has significant impact on the level of satisfaction of the subjects.

On the other hand, change in contrast shows a clear consistent change in task performance. High contrast image shows improvement in human performance.

In the study, the assessment of the relationship between illuminance, contrast levels and task performance is represented as a range of comparisons. Thus, the current study provides a scenario of human performance under different illuminances in a designed laboratory environment, thereby it serves as a methodology and database to support future studies, reporting on illuminance for building indoor environment and helps the relevant professionals to appraise the present investigation for further studies.

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