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Employees' Perception of Lighting Conditions in Manufacturing Plants: Associations with Illuminance Measurements

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ABSTRACT

Background: The aims of this study were to evaluate the employees' subjective assessments of different aspects of lighting condition as well as task area illuminance in manufacturing plants.

Methods: This field study was conducted between March and May 2013, in three packing plants (Saveh, central Iran). Data were collected by questionnaire and measurement of the task area illuminance levels. Data were analysed using contingency coefficient test, Spearman's correlation analysis and non-parametric Friedman tests.

Results: The recommended illuminance levels were not met in 46.9% of the work areas. This finding was in agreement with the employees' perception of light level, and with low satisfaction with lighting in the work environment. Adverse effects of lighting condition on job performance, changing posture for better viewing of the work area and eye tiredness were reported as 64%, 33% and 31% of the employees, respectively. Satisfaction with lighting was negatively correlated with the age of respondents (r=-0.229; *P*<0.010). The employees' satisfaction with lighting was also highly correlated with the employees' subjective assessments of the light level (r=0.779; *P*<0.001), type of artificial light sources (r=0.591; *P*<0.001), light colour (r=0.50; *P*<0.001) and use of daylight (r=0.254; *P*<0.004). The type of artificial light sources was correlated with job performance (r=0.311, *P*<0.001) and eye tiredness (r=0.273; *P*<0.002).

Conclusions: The findings highlight the potential usefulness of subjective assessments to supplement objective measures and provide a more holistic approach to lighting design and planning.

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Introduction

Interaction between people and their surrounding environment is one of the most important issues in all working environments. There are several factors that constitute a working environment including environmental factors (i.e. light, noise, vibration, heat and cold). Study of the relation between people and their working environment is known as environmental ergonomics, which is one of the main branches of ergonomics. In this field, the effects of environmental factors on the occupants can be studied in terms of the effects on satisfaction, performance, health and safety. For example, a number of previous studies have highlighted the importance of the environmental conditions in workplace assessments [1-7]. Workers may be exposed to different environmental conditions and the human body's response to the environmental factors depends on a number of factors including physical, physiological and psychological as well as individual differences [8]. Therefore, it is necessary to conduct studies in each working context to see how these factors will affect the people in that occupation.

Poor lighting conditions of work environments can adversely affect the health and safety and job performance of the occupants of a workplace [9-13]. According to EN 12464-1 (Light and lighting – lighting of work places, Part 1 indoor work places), adequate and appropriate lighting is required to enable people to perform visual tasks efficiently and accurately [14]. According to this standard, the visual task requirements for industrial activities involving paper and paper goods does not vary significantly, and the recommended illuminance level for paper and cardboard manufacture and processing is 300 lx. This document highlights the importance of qualitative and quantitative needs (in addition to the required illuminance) for good lighting practice. According to this document, three basic human needs should be satisfied: 1) visual comfort (i.e. where the employees have a feeling of well-being which can also indirectly contribute to a higher productivity), 2) visual performance (i.e. where the employees can perform their visual tasks, even under difficult circumstances and for a longer duration) and 3) safety. Thus, the major aspects of the luminous environment are illuminance, colour aspects, presence of daylight, glare and flicker [14].

Establishing objective criteria for good lighting may not be an easy task due to complexity involved in any lighting situation, and therefore it may be helpful to consider its qual-

itative aspects [15]. Consideration of various aspects of the physical environment such as lighting condition through subjective assessments can provide more specific and additional details about the lighting in a work environment. The subjective lighting assessments may also be useful, since objective measurements might be time consuming, complex or not available [15].

The present study was therefore conducted to: 1) evaluate the task illuminance level in indoor workplaces in three packing plants as an exemplar manufacturing environment, 2) examine the employees' subjective assessments of lighting conditions (including the light level, type of artificial light sources, use of daylight and light colour of artificial light sources) and their effects on employee satisfaction, job performance, safety and health, and to determine how these are related, and 3) compare the task area illuminance levels with the employees' subjective assessment of the light levels, satisfaction, job performance, and health and safety effects.

Methods

Subjects

One-hundred and thirty male employees aged between 20 and 44 years volunteered to participate in this field study. Being in good general health and not having any visual problems were considered as inclusion criteria for the study. Each subject signed a written informed consent form before participation in the study. They were familiarised with the study aims and any questions were answered by the investigators. The participation was strictly on a voluntary basis and the study subjects were not paid for their participation. The study protocol was reviewed and approved by Ethical Review Committee of Tabriz University of Medical Sciences.

Procedure

Three packing plants in Saveh (central Iran) were selected as research sites in this field study. Data were collected from different indoor working areas including services, paper production, paperboard conversion, pasting, cutting, printing and puncture sites. To compute sample size, basic information was obtained from a study by Dawal and Taha [2] on the primary endpoint of correlation between environmental factors and job satisfaction. To compute sample size, the minimum effect size (i.e. 0.2) was considered to obtain the maximum sample size. Considering a confidence level of 95%, a power of 80% and two tailed tests the minimum sample size required was computed as 134 by G-power software (version 3.1.2). The study period was between March and May 2013.

A questionnaire was developed by the authors to collect data about the lighting conditions in the working environment, and their influences on subjective assessments for employee satisfaction, job performance, health and safety. Demographic data including age, education level and marital status, as well as job details (including job category, job experience and daily working time) were recorded in the first part of the questionnaire. The employees' perception of the light level was assessed by the survey question: "How is the light level in your work area?" There were also similar items about the appropriateness of other lighting characteristics such as the type of artificial light sources ("How appropriate is the type of artificial light sources in your work area?"), use of daylight ("How appropriate is the use of daylight in your work area?"), and light colour ("How appropriate is the light colour in your work area?"). The response alternatives were: 1 = very low, 2 = low, 3 = moderate, 4 = high and 5 = very high. The next part of the questionnaire evaluated the effect of poor lighting conditions (i.e. low light levels, flickering lights, glare and unwanted shadows) on employee satisfaction (2 items; satisfaction with: (1) general lighting and (2) task visibility), job performance (2 items; decreased performance because of: (1) low light levels and (2) lighting disturbances), safety (2 items; falls or slips because of: (1) light levels and (2) lighting disturbances) and health (4 items; eye tiredness because of: (1) low light levels and (2) lighting disturbances as well as changing posture for better viewing of the work area because of: (1) low light levels and (2) lighting disturbances). The items of these constructs were based on the relevant literature [4, 7, 8, 16-18]. The same 5-point scale (from 1 = very low to 5 = very high) was also used to assess the influence of lighting condition on their satisfaction, job performance, safety and health.

The content and face validity of the measure were assessed by a panel of 5 experts in the fields of occupational health and ergonomics, and slight word modifications were made on some items in the questionnaire. Moreover, the internal consistency reliability of the constructs was evaluated by Cronbach's alpha in a pilot study by 30 subjects. The reliability coefficients for each of the constructs including satisfaction (alpha = 0.88); job performance (alpha = 0.76); safety (alpha = 0.68); and health (alpha = 0.71) demonstrated good internal consistency. The questionnaires were completed by one of the authors interviewing the employees. The whole questionnaire took approximately 10 minutes to complete.

Illuminance measurements were also taken throughout research sites during data collection. Immediately after completing the questionnaire, the illuminance levels were recorded at the horizontal task area of each of the employees. In the locations where the employees worked, horizontal illumination levels (in lx) were measured using a calibrated luxmeter (Hanger Digital Lux Meter, model EC1). The three packing plants operated only in one shift a day. All measurements were made between approximately 12.00 am and 14.00 pm for consistency. The measurements followed the procedures found in the literature [7,15]. In addition, the illuminance measurements were made for the artificial illumination that was usual for that time and work area and any desktop lamps were turned off during measurements. The illumination level of the task areas was measured at several places to represent, as closely as possible, the mean lighting level of that working area.

The illuminance measurements were evaluated based on the lighting requirements for indoor working environments[14], which was used as a criterion to determine whether the illumination level in each working area met or not-met the standard. Each working area was scored as "met" if the illuminance was equal or higher than the recommended standard; otherwise it was scored as "not-met".

To determine if the perception of the illuminance can predict the actual illuminance levels in the workplace, the employees' perception of the light level was compared to the task area illumination levels. For this, the employees' perception of the light level in those working areas that the task area illumination levels met the standard was compared to those that did not meet this standard. The task area illumina-

tion levels were also compared with the subjective assessments of employee satisfaction, job performance, health and safety.

Statistical analysis

Statistical analysis of the data was performed using SPSS software version 11.5 (SPSS Inc., Chicago, IL, USA). Analyses included descriptive statistics, contingency coefficient test, Spearman's correlation analysis and non-parametric Friedman tests. With regard to ordinal measurement of the variables, contingency coefficient test was performed to evaluate the agreement between employees' perception of the light level and the actual illuminance measurements. Spearman's correlation coefficients were also computed to examine possible relationships between the study variables to fulfil the assumptions with regard to ordinal measurement of the variables[2,7,19,20]. In order to assess differences among the mean ranks of the different lighting characteristics, non-parametric Friedman tests were performed. This analysis was followed by Bonferroni method for multiple comparisons. A significance level of P <0.05 was considered statistically significant.

Results

Demographic and job details

Demographic and job characteristics of the study subjects are presented in Table 1. All subjects had a normal 8 h work shift. Their ages ranged from 20 to 44 years; about half of them (n = 66; 50.7%) aged 25–29 years. Their job experience ranged between 1 to 8 years (mean = 4.0 years; SD = 2.1 years). Most of the participants were married (n = 97; 74.6%). Twenty seven employees (20.8%) had primary school education, 81 (62.3%) had secondary education and 22 (16.9%) had university degrees.

Illuminance measurements

Table 2 shows the results of illuminance measurements (lx) in working areas. The illuminance levels were measured in 130 work areas. A considerable variation was found in the levels of illuminance for different workspaces surveyed. The illuminance levels ranged from 50 lx to 583 lx (Table 2). The levels were lower than the standard for 46.9% (n = 61) of the work areas.

Table 1: Demographic and job characteristics of workers (n = 130)

Variables	Number (%)
Age (yr)	
20-24	25 (19.2)
25-29	66 (50.7)
30-34	29 (22.3)
35-39	5 (3.9)
40-44	5 (3.9)
Education level	
Primary school (1-5 yr)	27 (20.8)
Secondary & High school (6-12 yr)	81 (62.3)
University graduate	22 (16.9)
Marital status	
Single	33 (25.4)
Married	97 (74.6)
Job experience (years)	
1–2	34 (26.1)
3–5	70 (53.8)
>5	26 (20.1)
Job category	
Services	21 (16.2)
Paper production	15 (11.5)
Paperboard conversion	17 (13.1)
Pasting	21 (16.2)
Cutting	26 (20.0)
Printing	19 (14.6)
Puncture	11 (8.4)

Table 2: The recommended (EN 12464-1 for industrial activities involving paper and paper goods) and measured illuminance (lx) levels as well as the number (%) of work areas that not met the standard in different departments

Research sites	Recommended illuminance (lx)	Measured illuminance (lx)		Non-standard work areas
		Mean	Min-Max	N (%)
Services	300	193	71-367	7 (33.3)
Paper production	300	267	102-455	7 (46.7)
Paperboard conversion	300	163	71-300	7 (41.2)
Pasting	300	182	55-583	14 (66.7)
Cutting	300	188	68-494	6 (32.1)
Printing	300	212	50-583	9 (74.3)
Puncture	300	140	52-236	11 (100)
Total	-	-	-	61 (46.9)

Employees' perception of the lighting characteristics

Table 3 illustrate the percentages and mean ratings (SD) of the lighting characteristics assessed by the employees. Ninety percent of the employees reported that at least one of the four lighting characteristics was not appropriate (i.e. very low to medium on the scale). The percentages of employees who indicated that the light level, type of artificial light sources, light colour, and use of daylight in their work environment was not appropriate were 68.5%, 65.7%, 64.3% and 56.3%, respectively. The results from non-parametric Friedman tests showed no statistically significant differences between the ratings.

Table 3: Subjective ratings (from 1 = very low to 5 = very high) of lighting characteristics

Ratings	Lighting characteristics, N (%)				
	Light level	Type of artificial light sources	Use of daylight	Light colour	Total [a]
Very low	14 (10.8)	15 (11.8)	24 (18.0)	12 (9.3)	35 (26.9)
Low	10 (7.7)	10 (7.8)	11 (8.6)	11 (8.5)	26 (20.0)
Medium	65 (50.0)	60 (46.1)	38 (29.7)	61 (46.5)	94 (72.3)
High	30 (23.1)	31 (23.4)	40 (30.5)	36 (27.9)	63 (45.8)
Very high	11 (8.4)	14 (10.9)	17 (13.2)	10 (7.8)	29 (22.3)
Mean (SD)	3.12 (0.97)	3.14 (1.09)	3.12 (1.28)	3.16 (1.01)	

[a] Total percentage is greater than 100% because each participant rated four lighting characteristics

The mean ratings of the light levels assessed by the employees (i.e. employees' perception of the light level) are shown in Table 4. The employees' perception of the light level in working areas that the illuminance levels met the standard (mean rating = 3.4; SD = 0.97) was significantly different from those areas that did not meet this standard (mean rating = 2.7; SD = 0.98) (P<0.002). The contingency coefficient indicated a relatively good agreement (above 0.5) between the illuminance levels (lx) and the employees' perception of the light level.

Table 4: Employee's assessment of the light level as compared to the illuminance measurements in work areas that met vs. not-met the standard

Light level	Standard N (%)	Illuminance (lx) Mean (Min-Max)	Non- standard N (%)	Illuminance (lx) Mean (Min-Max)	Total N (%)	Illuminance (lx) Mean (Min-Max)
Very low	4 (3.1)	321 (300-367)	10 (7.7)	146 (71-236)	14 (10.8)	216 (71-367)
Low	2 (1.5)	379 (375-384)	8 (6.2)	83 (50-145)	10 (7.7)	145 (50-384)
Medium	33 (25.4)	445 (422-583)	32 (24.6)	113 (50-217)	65 (50.0)	264 (50-583)
High	20 (15.4)	382 (367-455)	10 (7.7)	107 (83-126)	30 (23.1)	302 (83-455)
Very high	10 (7.7)	378 (300-500)	1 (0.8)	133 (133-133)	11 (8.5)	321 (133-500)
All	69 (53.1)	349 (300-583)	61 (46.9)	114 (50-236)	130 (100)	271 (50-583)
Mean (SD)	3.4 (0.97)	-	2.7 (0.98) [a]	-	-	-

[a] Significant difference between the mean ratings assessed by contingency coefficient analysis (P < 0.01).

Lighting effects

Only 28.5% of the employees expressed their satisfaction (i.e. high or very high on the scale) with the lighting at their working environment. Sixty-four percent of employees believed that lighting had an adverse effect (i.e. moderate to very high on the scale) on their job performance. Adverse effects (i.e. moderate to very high on the scale) of lighting condition on changing posture for better viewing of the work area, eye tiredness, and falls or slips were reported by 33%, 31% and 13% of the employees, respectively. The results of Spearman correlation analyses indicated a significant correlation between the measured illuminance levels and employees' satisfaction with lighting (r = 0.204; P <0.020). The measured illuminance was not significantly correlated with other variables.

Correlations between variables

The results from Spearman's rank correlation indicated a number of significant correlations between the study variables. Some of the more interesting findings are reported here. It was found that satisfaction with lighting was negatively correlated with the age of respondents (r = -0.229; P<0.010). In addition, lighting characteristics including the light level (r = 0.779; P<0.001), type of artificial light sources (r = 0.591; P<0.001), light colour (r = 0.50; P<0.001) and use of daylight (r = 0.254; P <0.004) were found to be highly correlated with employee's satisfaction with lighting. The type of artificial light sources was also found to be correlated with job performance (r = 0.311, P<0.001) and eye tiredness (r = 0.273; P<0.002).

Discussion

The present study was conducted to evaluate the employees' perception of different aspects of lighting condition in manufacturing environments, and to compare these perceptions with the actual illumination levels to determine how they are related to one another. The main contributions of the study are that the illuminance varied considerably across different workplaces and the recommended illuminance level was not met in 46.9% of the work areas, which was in agreement with the employees' perception of the light level, and with low satisfaction with lighting in the work environment. The results indicated different effects of lighting characteristics and significant correlations among variables. The findings provide additional evidence and a useful support for the experimental findings on the lighting effects and the utility of its application to manufacturing work environments.

Although the lighting requirement in different working areas was not generally high (i.e. 300 lx), but in about half of the work areas the measured illuminance levels were lower than the recommended standard. On the other hand, more than two-third of the employees (68.5%) believed that the light level on their working area was not appropriate. Interestingly the contingency coefficient analysis indicated a relatively good agreement between the measured illuminance levels and the employees' perception of the light level. In most cases, the employees' perceptions of the illuminance reflected the actual illuminance levels in such a way that the subjective rating was likely to be more appropriate if that work area met the standard. This means that the employees' assessment generally reflected the actual situation so that no over- or underestimation was found between subjective and objective illuminance assessments. These findings suggest that there is a potential that the employees' assessment may reflect the actual circumstances of the working environment.

As shown in this study, less than one-third of the employees were satisfied with the lighting condition at their working environment. On the other hand, the results of Spearman correlation analysis indicated that the employees' perception of the light level and of other lighting characteristics (including the type of artificial light sources, use of daylight and light colour) were highly correlated with employees' satisfaction with lighting in the work environment. Therefore, it seems that the employees' satisfaction with the lighting condition tended to reflect the actual circumstances of the work environment. The results also indicated that satisfaction with lighting was negatively correlated with the age of respondents. This is perhaps not surprising as previous research has shown that environmental conditions of the workplace may affect older worker more than younger workers [21]. Finally, the finding that the measured illuminance levels was correlated with the employees' satisfaction is in agreement with the findings of Räsänen [1] et al. and Dawal and Taha [2], who found similar results among industrial workers. Altogether, these findings suggest that the workers' satisfaction is one of factors that need to be taken into account when evaluating the lighting condition in working environments.

Approximately two-third of the respondents indicated that lighting in their work environment had an adverse effect on their job performance. This is perhaps not surprising in view of evidence that improving lighting in the work environment can increase the job performance [12]. Juslén [12] et al. reported an approximately 3% increase in the speed of production of electronic assembly workers when the illumina-

tion level was increased from 800 lx to 1200 lx. These findings highlight the importance of adequate lighting in working areas to improve employees' performance.

Adverse health and safety consequences of poor lighting conditions in working environments have been well documented in the literature [8-9,11,13]. About one-third of the employees in the present study reported that lighting condition at their working environment could cause eye tiredness to them, which is in line with previous observations [8]. Nevertheless, lighting condition was less a problem in terms of falls/slips because few employees believed that lighting conditions could cause such problems. However, compared to the above mentioned effects, the effect of poor lighting conditions on working postures is an important issue that has not been adequately addressed in most previous studies. This may be important from the ergonomics point of view because awkward working postures have been reported to be a significant risk factor contributing to the development of musculoskeletal problems among workers in different occupations [22,23]. About one-third of the employees in the present study reported that they needed to change their posture for better viewing of the work area due to low illuminance levels or lighting disturbances such as flickering lights, glare sources and unwanted shadows.

The study has limitations that need to be taken into account when interpreting the findings and that should be addressed in future studies. The first limitation is that the findings regarding job performance, and health and safety (i.e. falls or slips and working postures) were based on subjective reports, and therefore it is recommended for future studies to consider these effects in a more objective manner (i.e. objective performance measures, actual falls or slips data, posture analysis, etc.). The generalisability of the findings to other task environments should also be taken into account when applying the findings. For instance, the findings of the present study were obtained from three packing plants, where the lighting requirements were generally at intermediate level. In those jobs that the complexity of the tasks are different and require a greater or lower level of lighting requirements, lighting conditions may have different effects on job performance and safety and health of employees. Moreover, the illuminance levels were measured during one working shift. Therefore, further studies to be conducted in other working environments and during different times of the day, would strengthen the generalization of the findings of this study. Despite these limitations, these findings highlight the potential usefulness of subjective assessments to supplement objective measures and provide a more holistic approach to lighting design and planning.

Conclusions

The findings of the present study provide an insight into the employees' perception of the lighting conditions together with illuminance levels in an exemplar manufacturing environment, and of how these are related. The findings have practical implications for employees and organizations. It is suggested that quantitative lighting measurements should be supplemented by qualitative subjective assessments to attain a deeper understanding and give more specific and additional details about the lighting conditions in each working environment. The findings also highlight the areas that need further attention through more appropriate design of the workplace to improve employees' satisfaction, performance, health and safety.

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Conflict of interest statement

The authors declare that there is no conflict of interest.

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