Visual ergonomics, performance and the mediating role of eye discomfort: A structural equation modelling approach

Hamid Jahangiri[a], Reza Kazemi[b*], Hamidreza Mokarami[b], Andrew Smith[c]

[a]Student Research Committee, Shiraz University of Medical Sciences, Iran
[b]Department of Ergonomics, Shiraz University of Medical Sciences, Iran
[c]School of psychology, Cardiff University, UK

[*]Corresponding author:
Reza Kazemi:
- Department of Ergonomics, Shiraz University of Medical Sciences, Shiraz, Iran, E-mail address: reza_kazemi2007@yahoo.com

Abstract

This study aimed to model the visual ergonomic factors affecting the performance in human-computer interaction. A cross-sectional study using structural equation modelling was performed with a sample of 200 participants. The measuring instruments included the Office Lighting Survey Questionnaire, performance assessment questionnaires, visual ergonomics assessment, and an eye discomfort assessment. The hypothetical model evaluated workplace lighting status and visual ergonomics as precursors, performance as the output, and eye discomfort as a mediator. The results showed that eye discomfort directly affected performance. Visual ergonomics also had a significant direct effect on eye discomfort. The final model suggested a new path between lighting quality and visual ergonomics. Also, the lighting quality indirectly affected eye discomfort and performance, and the effect of visual ergonomics on performance was the same. Improving the lighting quality and visual ergonomics can reduce eye discomfort and increase performance.

Keywords: visual ergonomics; performance; office workers; eye discomfort

1. Introduction

Lighting is an essential and influential factor in human health and performance in the workplace. Bright lights from light sources or windows in the field of view can cause disabling and/or annoying glare [1, 2]. Furthermore, non-visual exposures such as flickering light sources may cause eye strain and headaches. The visual environment should allow natural light to enter but block out disturbing light [3]. Glare, when working with a computer, causes visual fatigue and can lead to diplopia [1], which is measured by the divergence of vision stabilization [2], which means a decrease in the ability of the eyes to concentrate [4]. The most common health problems associated with computer work are visual and ocular symptoms [5, 6, 7, 8, 9] and musculoskeletal symptoms in the neck and shoulders [10, 11], and there is evidence that shows a link between them [12, 13, 14]. Computer vision syndrome (CVS) is a complex eye and vision problem that results from prolonged computer use [15]. Symptoms of CVS include ocular strain, headache, blurred vision, eye fatigue and burning, back pain, neck pain, and muscle spasms. Many office workers experience visual symptoms, representing an occupational health problem [16]. Although computer work has not been shown to cause permanent damage to the eyes, it can cause temporary discomfort, leading to reduced productivity, lost work time, and reduced job satisfaction [17]. A systematic literature review by Jiang and Duffy showed a relationship between diseases, such as musculoskeletal disorders and computer vision syndrome, and productivity [18]. Therefore, establishing a proper visual environment to maximize visual comfort is vital to preventing musculoskeletal and visual symptoms and improving the job performance and efficiency of the workers [19, 20].

Previous studies in Environmental Ergonomics have usually focused on eye and neck health and improving visual displays' visual characteristics or lighting conditions [21, 22]. Although there is evidence that some factors such as brightness and visual attributes of screens affect performance [19, 20, 21, 22, 23], this evidence does not explain the effect of other lighting conditions such as brightness, light temperature, natural light and other underlying causes. Several studies have developed models to investigate the impact of environmental conditions on performance [24, 25], but the relationships are not fully defined in these models. Visual ergonomics is an integral part of modern office environments that need to be further explored to determine their relevance to the performance and health of employees, especially those whose work relies more on vision, such as computer operators. The hypothetical model presented in one study showed that if office workers work in a comfortable visual environment, they are expected to be symptom-free and perform their tasks quickly and effectively.

Suppose employees are exposed to visually poor working conditions (such as insufficient illumination, glare, and difficult-to-read computer displays). In that case, they may experience CVS symptoms and difficulty performing their tasks [26]. Employees may also increase their visual effort to achieve the expected level of performance in visually impaired working conditions [27], and this can lead to a feeling of reduced visual performance and an unhealthy experience of stress [26, 28]. In addition, if the nature of the work is mentally challenging, the blink rate may decrease [29], which can be a risk factor for ocular symptoms [26]. The current study was conducted to bridge this research gap and specify the link between visually poor working conditions and experiencing CVS symptoms and performance impairment. Therefore, the present study was undertaken to model the effects of perceived visual ergonomic working conditions on self-rated visual performance and visual discomfort in an office environment. In the hypothetical model presented in this study, lighting quality and visual ergonomics were considered antecedent variables, eye discomfort as a mediating variable and performance as the output variable. It is assumed that the quality of lighting and visual ergonomics of the workplace can directly or indirectly affect employee performance by affecting eye discomfort. Given that no previous study has examined the effect of all visual characteristics of the workplace on performance and health, the results of this study will provide an overview of all the factors affecting the performance and health of office workers and the weight of each element.

The hypothetical model of the study is presented in Figure 1.

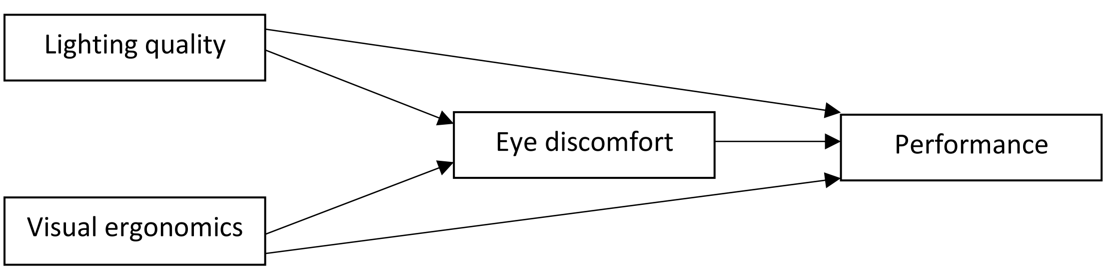

Figure 1. Hypothetical model.

2. Materials and methods

2.1. Participants

This cross-sectional study was conducted among the administrative staff of a university in Iran in 2020. A total of 312 office workers were employed. Inclusion criteria were complete mental and physical health, no history of eye surgery, uncorrected vision problems and age between 18 and

60 years. Two hundred forty-one employees met the inclusion criteria. The objectives of the research and the way it was performed were fully explained to the participants before distributing the questionnaire. A total of 219 employees were willing to participate in the study. The data of 19 people were deleted due to incompleteness and distorted data, and the final analysis was performed on 200 people.

It should be noted that the staff had no obligation to participate in the study and all received informed written consent to participate. In the present study, anonymous questionnaires were used, and the information was collected online. The ethics committee of Shiraz University of Medical Sciences approved this study (IR.SUMS.REC.1399.263).

2.2. Study materials

2.2.1. Demographic and visual characteristics

In this study, a researcher-made questionnaire was developed to collect demographic characteristics, including age, gender, job, hours of computer work during the day, use of glasses or medical lenses, daylight at work, physical activities, type of computer used, and screen size.

2.2.2. Lighting quality

A modified version of the Office Lighting Survey (OLS) [30] was used for the subjective assessment of lighting quality. This questionnaire consists of two parts. This study used the first part, which related to light quality assessment and included six questions. Answers were marked on a 4-point Likert scale (0 = *no*, 1 = *relatively no*, 2 = *relatively yes*, 3 = *yes*).

2.2.3. Visual ergonomics

A questionnaire used by Richter et al. [26] was used to assess visual ergonomics. The questions consisted of 3 items, including the ease of focusing on the letters and numbers when reading text on a computer screen, resolution and colour settings of the computer screen, and the person's assessment of visual comfort in the workplace. This questionnaire answered each question using a 5-point Likert scale (1 means minimal and five means very much). This questionnaire was translated into Persian, and its content validity and reliability were evaluated. The content validity index (CVI) was used to check the content validity. For this purpose, the opinions of 10 Occupational health and Ergonomics experts were used. The mean CVI score was 0.83. Also, the Cronbach's alpha coefficient of the questionnaire was 0.75.

2.2.4. Performance assessment

A 4-item questionnaire previously used by Richter et al. [26] was used to assess performance. The questions in this section were related to the effect of eye comfort on the quality of computer work, the number of times computer users stop working due to eye discomfort, and their performance while working with the computer. The answers were designed using a 5-point Likert scale (1 means minimal and five means very much). This questionnaire was translated into Persian and validated. For this purpose, the opinions of 10 Occupational health and Ergonomics experts were used. The mean CVI score was 0.95. Also, Cronbach's alpha coefficient of the questionnaire was 0.78.

2.2.5. Evaluation of eye discomfort

A questionnaire designed by Habibi et al. [31] was used to assess eye discomfort. This questionnaire, developed in Persian, consisted of 15 questions, each evaluated using a 10-point visual analogue scale. The reliability of this questionnaire was 0.75, and its minimum CVI index was 0.75 (29). (0 means very little, and ten means very much).

2.3. Statistical analysis

The study model was investigated using structural equation modelling (SEM) and the maximum likelihood estimation methods at the variance matrix of covariance level. Model fit indices, including χ^2 / degree of freedom, root mean square error of approximation, the goodness of fit index and adjusted goodness of fit index, incremental fit index and the comparative fit index, was used to measure the goodness of fit of the final model. All statistical analyzes of the data were performed using SPSS version 23 and AMOS version 23.

3. Results

Ninety-one male and 109 female office workers participated in this study, and their mean age and length of work experience were 35.7 years and 11.4 years, respectively. The mean duration of the computer work was 4.7 hours a day. 40.2 per cent of the participants used corrective lenses. 85.5 per cent of the office workers used daylight in their workplace. 45.5 per cent of the participants reported having physical exercise during the week. 49.5 per cent of the participants used a computer, 26.5 per cent used a laptop, and 24 per cent reported using both a computer and laptop. Additionally, the size of most of the screens used was about 16 inches.

The mean, standard deviation and correlation matrix of the studied variables are presented in Table 1. As shown in Table 1, the quality of workplace lighting had a significant positive relationship with visual ergonomics ($r = 0.36$, $p <0.001$) and performance ($r = 0.24$, $p <0.001$). However, the relationship between this variable and eye discomfort was negative ($r = - 0.25$, $p <0.001$). Eye discomfort had a significant negative relationship with performance ($r = - 0.52$, $p <0.001$) and with increasing eye discomfort, performance decreased. The relationship between eye discomfort and visual ergonomics ($r = - 0.39$, $p <0.001$) was also negative. On the other hand, visual ergonomics had a significant positive relationship with staff performance ($r = 0.26$, $p <0.001$).

The hypothetical model of the study was not confirmed according to the fit indices (Table 2). In this hypothetical model, the quality of workplace lighting had no significant direct effect on eye discomfort ($\beta = - 0.12$, $p = 0.06$) and performance ($\beta = 0.11$, $p = 0.07$). Visual ergonomics also had no significant direct effect on performance ($\beta = 0.03$, $p = 0.65$), but had a significant direct effect on eye discomfort ($\beta = - 0.35$, $p <0.001$). On the other hand, eye discomfort had a significant direct effect on performance ($\beta = - 0.48$, $p <0.001$).

A posthoc modification model approach was implemented by removing non-significant paths (direct paths of lighting quality and visual ergonomics with performance) and adding a new path (path of lighting quality → visual ergonomics → eye discomfort). All the indices indicated that the final model had a good fit (Table 2). The final model of the studied variables is presented in Figure 2. The final model showed that the quality of workplace lighting had a significant direct effect on visual ergonomics (β = 0.36, p <0.001). Visual ergonomics had a significant direct effect on eye discomfort (β = - 0.38, p <0.001). Finally, eye discomfort greatly affected employee performance (β = - 0.52, p <0.001).

The direct, indirect and total effects of all the studied paths in the final model are presented in Table 3. Workplace lighting quality had significant indirect effects on eye discomfort (β = - 0.14) and performance (β = 0.07). Visual ergonomics also indirectly affected performance (β = 0.20).

Table 1. Correlation matrix of variables.

Variable	Mean (SD)	1	2	3	4
1. Lighting quality	11.3 (2.79)	-			
2. Visual Ergonomics	10.47 (1.81)	0.361*	-		
3. Eye discomfort	3.4 (1.76)	-0.245*	-0.385*	-	
4. Performance	13.18 (2.26)	0.240*	0.255*	-0.523*	-

(*p< 0.001)

Table 2. Model fit indices.

Fit Index	Acceptable threshold	Hypothetical model	Final model
$\chi^2/_{df}$	<5 (p > 0.05)	27.76 (p < 0.001)	1.32 (p = 0.08)
GFI	> 0.8 or 0.9	0.94	0.98
AGFI	> 0.8 or 0.9	0.39	0.95
IFI	> 0.8 or 0.9	0.79	0.97
CFI	> 0.8 or 0.9	0.78	0.97
RMSEA	< 0.08	0.37	0.079

Note: df = degree of freedom; GFI = goodness of fit index; AGFI = adjusted goodness of fit index; IFI = incremental fit index; CFI = comparative fit index; RMSEA = root mean square error of approximation

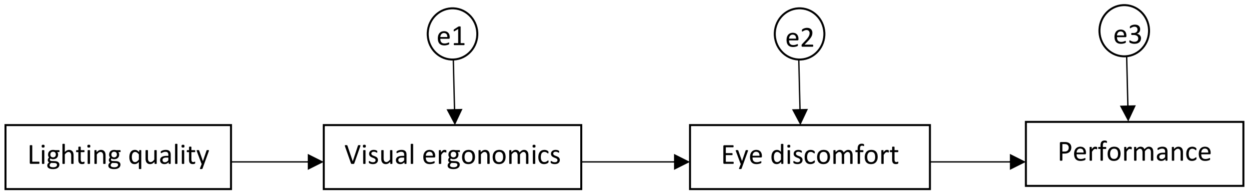

Figure 2. The final study model.

Table 3. Direct and indirect effects of the studied variables.

Predictive variable	Consequence variable	Direct effect	Indirect effect	Total effect
Lighting quality	Visual ergonomics	0.361	-	0.361
	Eye discomfort	-	-0.139	-0.139
	Performance	-	0.073	0.073
Visual ergonomics	Visual ergonomics	-	-	-
	Eye discomfort	-0.385	-	-0.385
	Performance	-	0.201	0.201
Eye discomfort	Visual ergonomics	-	-	-
	Eye discomfort	-	-	-
	Performance	-0.523	-	-0.523

4. Discussion

This study presents a model for combining the factors that affect the performance of office workers in their interaction with computers. In the final model, lighting quality was considered the first predictor variable, visual ergonomics and eye discomfort as the mediating variables, and performance as the output variable. Eye discomfort was the mediating variable between the preceding and output variables. Overall, all of these paths were significant.

The results of this study showed that eye discomfort has a direct effect on employee performance. So with increasing eye discomfort, performance decreases, which is consistent with the results of several studies. Ridder et al. (2011) showed that patients with dry eyes have difficulty performing tasks that elicit a reduced blink rate (such as reading, computer use, driving, etc.). Therefore, all patients with dry eye are prone to visual dysfunction under certain conditions [32]. Dry eye significantly reduces workplace and non-job-related performances [33]. Moreover, dry eye disease harms work productivity and impairs daily activities [34, 35].

The present study showed that visual ergonomics have a significant direct effect on eye discomfort; with an improvement in visual ergonomics, eye discomfort decreases, consistent with the results of several studies [36, 37]. According to the results of a study by Zalat et al. (2021), visual ergonomics and preventive measures such as the proper height of the monitor, regular screen cleaning, adequate lighting, and eye drops are significantly associated with a reduction in the symptoms of computer vision syndrome [37]. Computer visual effects such as brightness, screen resolution, glare and light quality are all the factors that cause computer vision syndrome. As the resolution decreases, the image quality decreases and the visual demand to understand the image or text increases. The contrast between words and the background, the glare of the computer screen, and the reflection of light from the screen are essential factors determining computer users' visual needs required to understand the image. Bright lights, windows, and fluorescent ceilings often cause annoying glare. Light filters should control bright light sources or changes in the room layout to provide adequate lighting for minimizing eye strain [36].

The final model in the present study showed that workplace lighting quality could affect employee performance by affecting visual ergonomics and eye discomfort. A study by Dianat et al. (2016) found that 43% of employees in a manufacturing plant reported a negative effect on their job performance due to poor lighting conditions [38], which is consistent with the present study results. Also, the study of Dianat et al. (2013) showed a relationship between lighting and employee satisfaction in a hospital [39]. The research results by Richter et al. (2019) indicated a positive relationship between visual performance and perceived visual ergonomics [26], which is consistent with the results from the present study. For example, suppose the resolution or brightness of a computer screen is not optimal. In that case, it is reasonable to expect people to have difficulty doing their job; therefore, more time and visual effort are needed to complete the tasks.

In the Richter et al. (2019) study, visual discomfort was not recognized as a mediating factor between visual ergonomic conditions and visual performance. Visual discomfort was not considered a cause of performance impairment (32). In contrast, our study identified visual discomfort as a mediating factor between visual ergonomic conditions and performance. However, the impact of visual performance on the job is not always clear. Visual performance is of different importance in different job tasks. A study showed a link between cognition and high-quality vision, so the tolerance to vergence/accommodation conflict was lower in the more cognitively demanding tasks [40], which means that visual performance is essential in cognitive tasks.

Additionally, apart from job tasks, there may be numerous other factors that can affect job performance. For example, workers' lack of motivation to continue to perform well because of poor visual ergonomic work conditions, thereby not straining their eyes (and not reporting any CVS symptoms), can be a reason for the zero correlation between visual and job performance. Also, a worker's motivation to continue to perform well despite poor visual ergonomic work conditions and related fatigue / CVS symptoms, by eliciting compensatory effort to counteract the fatigue, may also have something to do with why the mentioned zero correlation may arise. If motivation exists (monetary incentives, deadlines, etc.), the individual worker may try to perform at a high level, despite visual discomfort.

The present study was conducted among office workers who spend most of their daily time using computers. Most of their tasks are visual, so their performance can positively affect the job. Their overall individual performance, and as mentioned earlier, visual performance is affected by the lighting quality, and the lighting quality in the workplace influences eye discomfort. Therefore, as the results of the present study showed, it can be concluded that improving the quality of lighting can affect employee performance by improving visual ergonomics and reducing eye discomfort.

5. Study Limitations

This study has limitations that should be considered in future studies. Visual disturbance, performance and visual ergonomics parameters were evaluated subjectively. Objective evaluations have a higher validity, and it is vital to pay attention to this issue in future studies. On the other hand, the present study was conducted only on day workers and office workers whose job is mainly based on good vision. Studying other occupations and during night shifts could produce different results.

6. Conclusion

Today, office workers do most of their work using computers. Therefore, job-related lighting and visual ergonomics can significantly affect eye comfort and job performance. The findings of this study showed that eye discomfort has a significant effect on reducing employee performance. Office lighting and visual ergonomics problems can often be overlooked in the workplace. Still, it should be noted that correcting these problems can have a long-term impact on increasing organizational productivity and employee satisfaction. Poor lighting conditions can lead to myriad hidden costs for employers and employees. It is noteworthy that a positive trade-off is often presented between the costs associated with improving visual ergonomic work conditions versus the costs associated with performance limitations due to poor visual ergonomics. Therefore, to reduce the visual problems of employees and increase their performance and productivity, it is necessary to pay special attention to the workplace's lighting conditions and improve the visual ergonomics of the computer.

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Disclosure statement

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