Investigation of a real-time change of human eye pupil sizes for visual environmental controls in the workplace environment

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SUMMARY
This study adopted a series of human subject experiments to estimate each individual's visual sensations by analyzing pupil sizes and their change patterns based on the human body's autonomic nervous system. Various ranges of lighting parameters, including illuminance, contrast ratio, and unified glare rating, were generated and controlled while each test subject's pupil sizes were recorded. The experimental result data were statistically analyzed to identify a relationship between human visual sensations, lighting parameters, and pupil sizes as well. The research outcomes showed the potential use of pupil sizes for estimating an individual's visual sensation and confirmed the principle as an applicable technology to integrate with an environmental design and control system with the help of an advanced sensing device.

KEYWORDS
Visual comfort; Bio-signal; Machine learning; Unified glare rating; Indoor environmental quality

1 INTRODUCTION
Lighting is one of the most important key components in indoor environmental quality which impacts work productivity and environmental health of occupants in a building. However, a lot of existing design guidelines have been developed by empirical and experimental methods in monitored lab tests; while those recommended guidelines are mostly for the paper-based task instead of the computer-based. Also, visual discomfort resulting from contrast ratios in the user's vision field from the inappropriate placement of monitors can considerably impair on a person's productivity and general sense of well-being in the work-space. The human body has a physiological mechanism which minimizes the adverse effects of the surrounding environment on the body. Therefore, by utilizing this physiological mechanism, this research identified a relationship between human visual sensations, lighting parameters, and pupil sizes as a bio-signal which responds to the ambient lighting condition in real time.

2 METHODS
A series of human subject experiments with ten voluntary subjects were conducted in an environmental chamber located at the USC campus. The whole experiment took one hour and thirty minutes, all data, such as illuminance and pupil size were automatically recorded by multiple sensory devices, including a pupilometer. For every 30 minutes, a contrast ratio was updated while the horizontal illuminance level changed from 50 lux to 1400 lux with a 150 lux interval. Figure 1 illustrated each visual setting of contrast ratio. Each illuminance level was maintained for 3 minutes, including 2 minutes for visual stabilization and 1 minute for data collection and survey. The test subjects were asked to do a simple computer-based work during the test, and were requested to report his or her visual sensation, at the end of each illuminance condition by answering the questionnaire which consists of seven options ranging from "very dark (-3)" to "very bright (+3), with a "neutral" (0) mid-point.

Table 1: Demographic information about human subjects

	Gender		Age		Iris Color		Glass-worn	
	Male	Female	<25	≥25	Blue	Brown	Yes	No
Sample No.	4	6	7	3	2	8	5	5

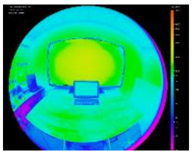
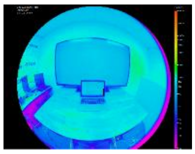
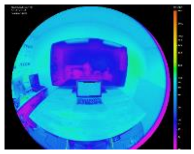
a)  b)  c) 

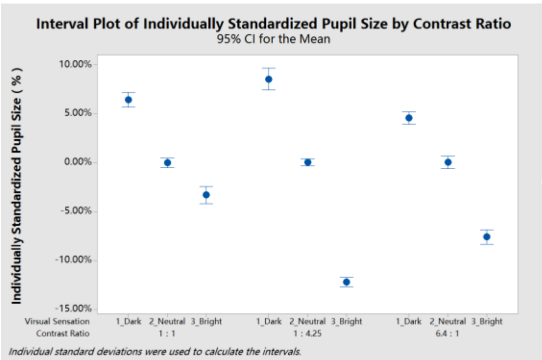
Figure 1: TV and computer screen luminance false color
(contrast ratio of computer screen to TV: a)1/4.25; b)1/1; c)6.4/1. UGR value: a)18.1; b)12.2; c)14.7)

3 RESULTS & DISCUSSION

Pupil sizes and shapes varied depending on individuals. Thus, standardized data for each individual were used for data analysis by using equation (1).

$$Standardized\_Pupil\_size(\%) = \left(\frac{Pupil\_size(i) - Pupil\_size(neutral\_sensation)}{Pupil\_size(neutral\_sensation)}\right) \times 100 \qquad (1)$$

Considering the practicality of data collection from eyes, this study selected pupil size with its gradient (i.e., changing rate per twenty seconds). The analysis of variance (ANOVA) showed significant differences of pupil size at each visual sensation in the contrast ratio groups, respectively. On average, the comparison of the changes in pupil size at the neutral sensation showed a -12.2% change rate for dark sensations and 8.6% for bright sensations in the 1/4.25 contrast ratio group, -3.2% and 6.4% in the 1/1 contrast ratio group, and -7.6% and 4.6% in the 6.4/1 contrast ratio group. These test results reported a p-value of 0.000 in all cases, which is within a 99% statistical significance. The contrast ratio 1/4.25 group revealed greater change rates than the other two groups at a bright sensation. These findings support that a common physical pattern could be generated across individual test subjects of each contrast ratio group. Similar characteristic patterns were also observed from the dataset grouped by unified glare rating (Figure 2 -b).

a) 

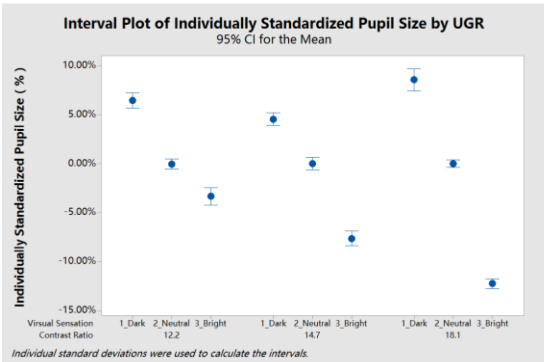
b) 

Figure 2. Interval plot of standardized pupil size, grouped by a) contrast ratio, b) UGR value.

4 CONCLUSIONS

This research investigated the relationship between human visual sensation and ambient lighting conditions, based on an occupants' physiological responses for detecting (im-)proper ambient lighting schemes. This study identified significant correlations between pupil size, contrast ratio, and UGR levels. The contrast ratio 1/4.25 group and 18.1 UGR group showed a greater change of pupil size rates than the other two groups did at a bright sensation, which may be one of the factors leading to eye fatigue. Therefore, the results of this study contribute to developing a potential application for indoor environmental quality control by integrating the investigated human physiological principle with the help of advanced sensing (i.e., wearable) device.

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