EFFECTS OF LED LIGHTING CHARACTERISTICS ON VISUAL PERFORMANCE OF ELDERLY PEOPLE

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Abstract— **Light-Emitting Diodes (LEDs) have been anticipated for use in home lighting. This study examines effects of planning of preferred LED lighting specifications on the visual performance of elderly people. This study is intended to examine the effects of Correlated Color Temperature (CCT), 2500 K, 5000 K and 8200 K, on the visual performance of elderly people using psychological and physiological measurements obtained under white LED lighting. Comparing results obtained from younger and elderly participants, visual performance and mood under experimental CCT conditions are discussed. Results suggest that 5000 K LED lighting is suitable for visual performance. Furthermore, LED lighting can present preferred LED characteristics as a visual environment for elderly people.**

I. INTRODUCTION

Light emitting diodes (LEDs) are gaining attention as a new lighting device, that will be increasingly available in many places. An assessment of LED lighting's support of legibility for elderly people was reported at a previous international conference (ISG2005). White LED lighting, is superior to that of fluorescent lamp and incandescent lamp to provide legibility for elderly people [1].

As a next stage of investigation of white LED lighting, this paper reports here preferred lighting characteristic for visual performance of elderly people. The result of this study will be important to propose effective house lighting to support the daily life of elderly people.

II. EXPERIMENT

A. Purpose of this study

Some studies which have addressed lighting and visual performance have revealed an effect of illuminance. For example, Boyce et al. found that visual searching can be done with higher performance and more accurately as the illuminance level increases [2]. Davis et al. examined task lighting for elderly people using visual performance task, showing similar effects of illuminance [3].

In addition, the correlated color temperature (CCT) level is a parameter that affects visual performance, but studies examining CCT effects have yielded inconsistent results. Therefore, the purpose of this study is to investigate the relationship between lighting and visual performance, particularly addressing CCT.

Boyce et al. and Davis et al. suggested that the effects of CCT only slightly affect visual performance, but Yasukouchi et al. described that the early component of contingent negative variation (CNV) is varied under different CCT conditions performing visual tasks: the arousal level is 7500 K, compared to 3000 K [4]. That result suggests that CCT conditions relate to psychological and physiological aspects to decreasing fatigue and workloads.

More importantly, visual functions degrade with age, along with reduced visual acuity and accommodation, with cataracts and lens yellowing. Therefore, the visual environment for elderly people must be considered with regard to specific visual characteristics. Performance of visual tasks would be expected to improve for elderly people if some CCT conditions were affected by psychological and physiological phenomena.

From these standpoints, this study examined the effect of CCT conditions on visual performance for elderly people using white LED lighting, and compared those effects to those of young people. This study is intended to identify preferred lighting characteristics of white LEDs for elderly people.

B. Subjects

In all, 12 elderly subjects (3 male and 10 female; mean =73.83 years, standard deviation (SD) =5.89) participated in this study. As an objective of comparison, 20 younger subjects (10 male and 10 female; mean=21.40 years, SD=2.68) also participated. All participants had normal vision, with no visual impairment. Some subjects wore their own glasses or contact lenses throughout this experiment.

C. Experimental lighting conditions

An integrated white LED (TG True White Hi®) unit (Toyoda Gosei Co., Ltd.) was used for this experiment. It was set to three CCT conditions: 2500 K, 5000 K and 8200 K. CCT conditions were produced using a conversion filter for CCT to control the color rendering property. The color rendering index (CRI) of these lightings were Ra=85 constant. Illuminance on the table was adjusted 470 ± 5 lx. Figure 1 shows the relative spectral distribution of each CCT condition.

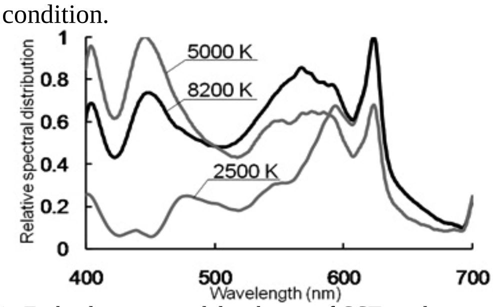

Fig. 1. Each relative spectral distribution of CCT condition

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D. Visual performance tasks

Task (a): Visual acuity test

Visual acuity was tested using a 30-cm visual acuity Landolt ring chart (Research Institute of Human Engineering for Quality Life; HQL). The chart was placed on the table 30 cm from the eyes to maintain illuminance on the chart surface.

Task (b): Color sorting using the Macbeth ColorChecker®

The ColorChecker was placed on the table. Subjects were instructed to name each color in the checker using 11 color names according to Berlin and Kay [4] (red, green, yellow, blue, brown, orange, purple, pink, white, black and gray), which are used consistently among observers and occasions.

Task (c): Numerical Verification (NV) task [3]

For this task, participants compared juxtaposed lists (30-digit numbers) of numbers (Fig.2) and found discrepancies. The numbers are nearly identical, except for random single-digit errors. Subjects compared the lists from top to bottom, found the errors, and marked them with a pen stroke. Figure 2 portrays an example of the NV task.

Furthermore, this task used four contrast levels: black ink 100 %, 55 %, 35 % and 15 %, on white background [6]. Respective luminance ratios were 0.91, 0.71, 0.44 and 0.16.

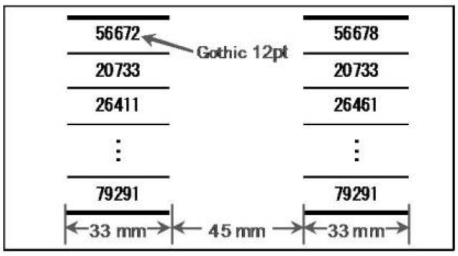

Fig. 2. Example of NV task

E. Psychological ratings

Measurement of psychological aspects was done by administering a psychological arousal and rating questionnaire for lighting conditions. Psychological arousal was measured using a Two-Dimensional Mood Scale (TDMS) [7]. This scale is used to rate mood changes (arousal/pleasant) easily and rapidly. Figure 3 depicts the relationship between each arousal (positive / negative) and pleasant stimulus on the TDMS.

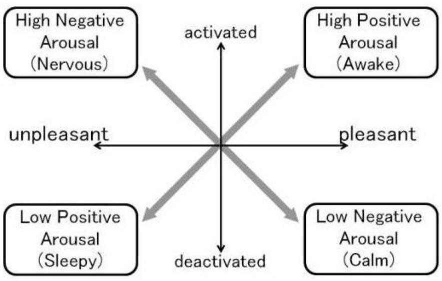

Fig. 3. Relationship between each arousal and pleasant stimulus.

Ratings for lighting conditions were made using a seven-point scale with seven bipolar adjectives: dark - bright, dislike - like, unpleasant - pleasant, cool - warm, hazy - clear, subduing - stimulating, and non-uniform - uniform.

F. Experimental method

Firstly, during this experiment, only the experimental white LED lighting was turned on in the dark room. The experimental procedure was explained to subjects in advance. In this step, four electrodes were placed on subjects to record the ECG.

Secondly, subjects were instructed to rest for 5 min (pre-rest). Then subjects were provided the tasks sequentially. After completing the tasks, subjects are asked to rest again (post-rest). During this procedure, measurements of physiological aspects were made using an electrocardiogram (ECG; Polymate, TEAC Corp.). For the experiment, measurements were carried out based on the precordial leads.

Finally, participants were given the lighting-rating questionnaire. Figure 4 shows the lighting conditions.

Fig. 4. Lighting condition process

For other conditions, the experiment was conducted as portrayed in Fig. 4. The procedure was repeated at each CCT condition. The lighting order was randomized among subjects. Figure 5 depicts this experimental environment.

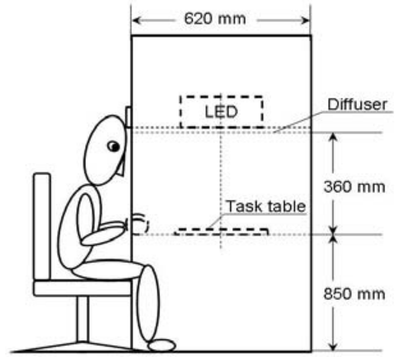

Fig. 5. Experimental environment

III. RESULTS

A. Visual performance tasks

Task (a): Test for visual acuity

Visual acuity showed an equal level among CCT conditions for elderly and younger subjects (mean=0.45, SD=0.17; mean=1.0, SD=0.21, respectively). This result is inferred to be attributable to the same luminance contrast level across CCT conditions, because it would appear that the visual acuity is affected by the luminance contrast more than CCT.

Task (b): Color sorting under the Macbeth ColorChecker ®

Each color on the ColorChecker containing 24 colors was tested for color names reported by participants among CCT conditions. For elderly participants, the answer to each of 24 colors was similar to the color names reported in different CCT conditions.

For younger participants, answers to 23 colors of 24 colors on the ColorChecker were similar color names to those reported in different CCT conditions.

Consequently, the color appearance using the Macbeth ColorChecker® is almost consistent across CCT conditions for both age groups. This result is shown to be caused by the same color rendering index (Ra) of lightings. This means that color appearance is affected color rendering more than CCT.

Task (c): The NV task

Elderly subjects showed equal visual acuity among CCT conditions according to Task (a), some subjects were able to recognize and perform the NV task produced by contrast level 15 %; others were unable to see it. Therefore, participants were divided to three groups as follows.

- The “more than 15 %” is a group that was able to see the 15 % task under all CCT conditions (four subjects).
- The “value from CCT” is a group that was able to see the 15 % task depending on CCT conditions (four subjects).
- The “less than 15 %” is a group that was unable to see the 15 % task under any CCT conditions (four subjects).

Figure 6 shows these results among CCT conditions.

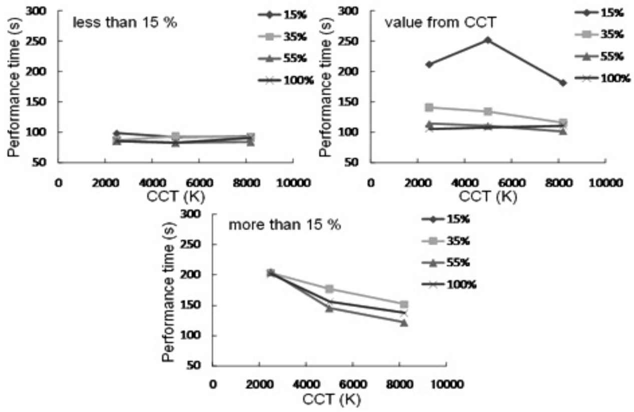

Fig. 6. Performance time performed task for elderly subjects among CCT.

Each of group is investigated for differences of the NV task performance speed, which is designated as the performance time (s). The “less than 15%” panel shows the result of similar performance times among CCT conditions and is shorter than the other groups.

The “value from CCT” clarifies that only time performed 15 % task (mean time=205.44 s, SD=66.47) is the longest of four contrast levels across all CCT conditions. The contrast levels of 35 %, 55 % and 100 % show similar performance times: 35 %; mean=127.88, SD=28.45, 55 %; mean=107.23, SD=14.39 and 100 %; mean=108.45, SD=13.41, respectively. This result raises the possibility that participants of this group might perform the task in a short time under 8200 K.

The “more than 15 %” shows that performance time of the NV task is shorter for higher CCT.

These results show that the higher CCT, the more rapidly elderly participants were able to perform. It is especially important that the 15 % task was done by five participants at 2500 K and eight participants at 8200 K (Fig. 7). Consequently, these results suggest that when elderly people must recognize lower-contrast objects, 8200 K is a suitable lighting condition.

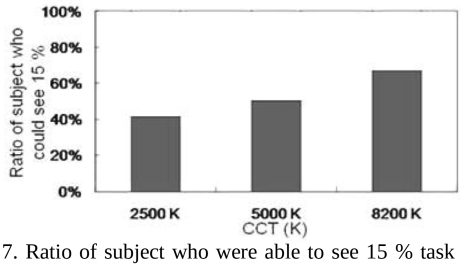

Fig. 7. Ratio of subject who were able to see 15 % task in different CCT conditions.

For younger subjects, results of performance times show that, at 5000 K, the time is shorter than that at 2500 K. Accordingly, this result suggests that 5000 K can be applied to younger people for adequate visual performance. Figure 8 shows the results.

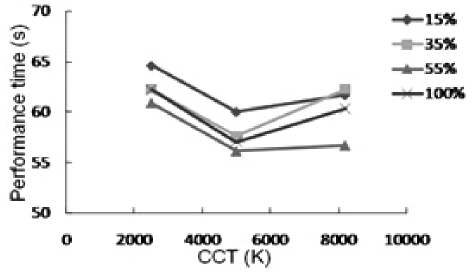

Fig. 8. Performance time for younger subjects among CCT

B. *Measurement of physiological response*

The results of physiological response were investigated for 6 elderly subjects and 13 younger subjects. Intervals between each R-wave peak are detected (R-R interval) to analyze data. The mean heart rate (HR) per minute was calculated from each R-R interval. Based on the mean of HR, the ratio of post-rest to pre-rest is calculated to investigate the variance in HR using the following formula: the ratio = post-rest / pre-rest. Figure 9 presents the results in different CCT conditions.

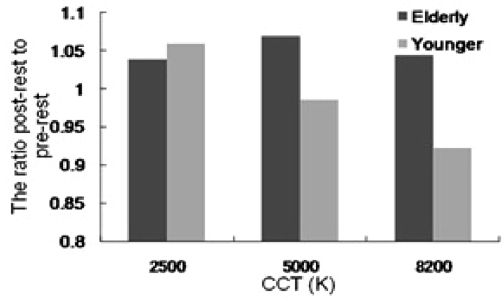

Fig. 9. Ratio of post -rest HR to pre -rest HR among CCT conditions.

For elderly participants, results show that post-rest HR is modestly increased compared to pre-rest HR across all CCT conditions, which suggests that elderly participants were in a tense state during performing tasks.

For younger subjects, Fig. 9 shows that the higher the CCT, the lower the ratio of pre-rest HR to post-rest HR is, which suggests that 2500 K is a lighting condition as leave task load. Both 5000 K and 8200 K produced a relaxed state during task achievement.

C. *Measurement of psychological aspect (TDMS)*

The psychological score on the TDMS was calculated using Sakairi's method [7] as the positive arousal score (P score), the negative arousal score (N score) and the pleasant score. Figure 10 presents the arousal score (longitudinal axis) and pleasant score (horizontal axis) of each subject. As portrayed in Fig. 10, this corresponds to the model of Fig. 3.

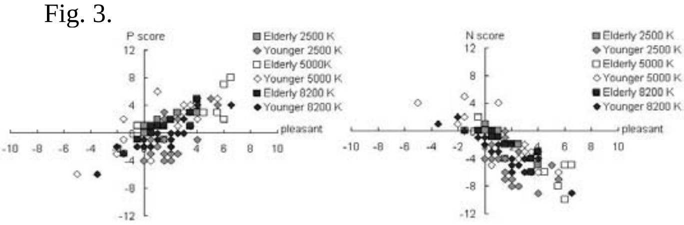

Fig. 10. Correspondence between arousal (positive and negative) and pleasant among CCT conditions for elderly and younger subjects.

Figure 11 shows the difference in each score for elderly and younger subjects among CCT conditions.

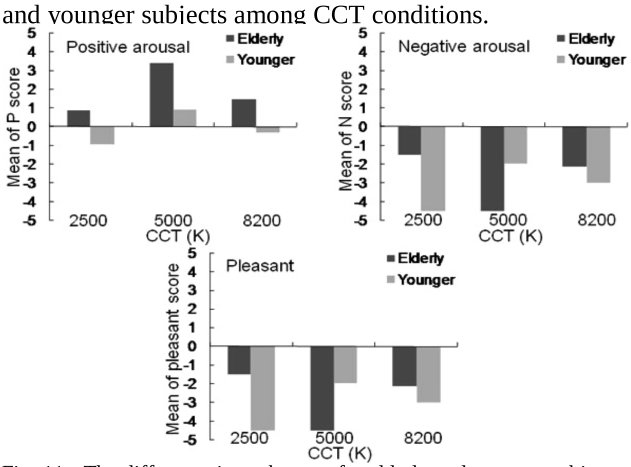

Fig. 11. The difference in each score for elderly and younger subjects among CCT conditions.

Analyses of the relationship between arousal and CCT revealed the following. For elderly participants, positive arousal was higher at 5000 K than at either 2500 K or 8200 K. Although the P score of younger participants is generally high compared to that of elderly participants, the score shows a similar tendency to that of elderly subjects. Apparently, 5000 K is a lighting condition that engenders an activated state in both age groups.

Negative arousal of elderly subjects demonstrates that 5000 K is a lower score than that of either 2500 K or 8200 K. The N score of younger participants shows that 5000 K is a higher score than that of either 2500 K or 8200 K. In particular, N score under 2500 K differs between age groups. Younger participants show lower scores than elderly participants: at less 2500 K, younger subjects are likely to report a “calm” state.

Regarding pleasant scores, elderly subjects had higher scores at 5000 K than for either 2500 K or 8000 K. Elderly participants feel “pleasant” in a 5000 K lighting condition. Pleasant scores of younger subjects show similar scores among CCT conditions.

D. Subjective rating for lighting conditions

Figure 12 shows the mean of each of subjective rating scale on CCT conditions according to age group.

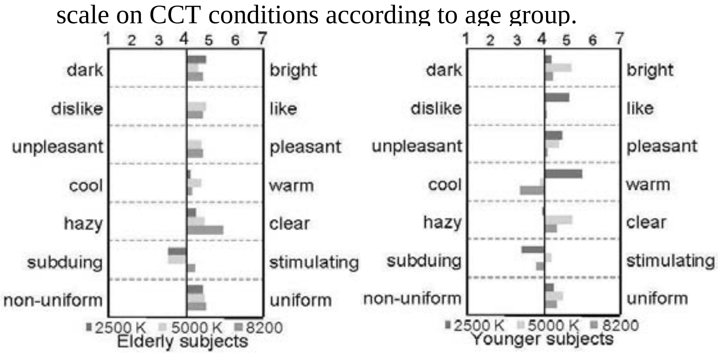

Fig. 12. The subjective rating among CCT conditions for elderly and younger subjects.

As shown Fig. 12, elderly subjects are likely to provide similar ratings among CCT conditions on each scale.

Younger subjects show significant differences in “like-dislike” and “warm-cool” among CCT conditions. Additionally, they tend to report a difference between “clear-hazy” among CCT conditions. Therefore, 2500 K is more preferred than 5000 K and 8000K despite task performance. On “warm-cool”, 2500 K is rated the warmest lighting of the three, and 8200 K is rated the coolest lighting of others. This result corresponds to the light color based on CCT. Moreover, 5000 K is likely to provide a high rating score to “clear” others. Considering that younger subjects performed the NV task for a short time at 5000 K, the possibility exists that the rating of “clear-hazy” is related to task performance.

IV. Conclusion

Using white LED lighting, this study examined the influence of CCT conditions on visual performance.

Elderly participants were able to perform the visual task for a short time at 8200 K. P score and pleasant score from psychological arousal show that 5000 K is a lighting condition that engenders an activated state and pleasant, although the result of physiological response is relative constant on CCT conditions. According to these results, elderly participants report a satisfactory arousal state at 5000 K. These results suggest that, for elderly people, CCT greater than 5000 K is a suitable mode of lighting for visual performance.

Moreover, elderly subjects could be divided three groups whether they could recognize low contrast task or not. Three groups have different tendency for performance times performed the NV task. Results for elderly people suggest that conditions of objects as contrasts should be examined in future studies.

For younger people, the 5000 K lighting condition is shown to be preferred task lighting.

Future studies must examine CCT for elderly people to assess features of visual objects.

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