報　　告

LED読書灯による読書時の疲労と見やすさについて
―若年者と高齢者の比較―

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Fatigue and Readability when Reading with LED White Light
- Comparison between Young and Older Adults -

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要　　旨

読書灯を対象とした白色LEDの有用性を，白熱灯，蛍光灯，白色LED;（青色LED+黄色蛍光体）;WHITE Hi，白色LED;（パープルLED＋RGB蛍光体）;TRUE WHITE Hiタイプの4種類の光源を用いて，事象関連電位による疲労計測および読みやすさの心理的計測の観点から検討した．また，年齢要因を考慮して，若年者と高齢者で4種類の読書灯の有用性にどのような違いが見られるか対比した．

若年者では，2種類のLED読書灯よりも白熱灯と蛍光灯のほうが疲労の誘発量が少なく，読みやすさの心理評価結果では差がみられなかった．一方，高齢者では，2種類のLED読書灯のほうが白熱灯や蛍光灯よりも事象関連電位に基づく評価指標（読書前後のN1-P3振幅，N1潜時，P3潜時の変化量）と読みやすさの心理評価結果の両側面において優位で，さらに，白色LED;TRUE WHITE Hiタイプのほうが白色LED;WHITE Hiよりも優位であった．

これらの結果から，読書灯として白色LED;TRUE WHITE Hiタイプは，視・知覚機能が低下した高齢者にとって好ましいことを示唆していると判断される．

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Abstract

Using event-related brain potential (ERP) and psychological rating of readability, the fatigue and readability when reading with four types of individual reading lights was evaluated as a function of age. For each type of lights, the reading was continued for 30 minutes. Four types of individual reading lights were (1) incandescent light, (2) fluorescent light, (3) white LED(blue LED + yellow phosphor) ;WHITE Hi, and (4) white LED(purple LED + RGB phosphor);TRUE WHITE Hi type.

The participants were categorized into young (21-24 years old) and older adults (65-76 years old). As for the older adults, the rating of readability of texts was high for the white LED;TRUE WHITE Hi type. On the other hand, for the young group the rating was not different among four types of lights. Concerning the older adults, the evaluation of fatigue induced during a 30 minutes reading by means of ERP, especially P300 amplitude and latency, showed that the fatigue was less for the white LEDs than for the incandescent and fluorescent lights. On the other hand, as for the young adults, the fatigue did not differ significantly among four types of lights. The white LED;TRUE WHITE Hi type was found to be effective especially for the older adults from the viewpoint of readability and fatigue.

1.INTRODUCTION

The development of the light emitting diode (LED) has been advanced in recent years, and a LED with high brightness has been developed. LED has the advantage that the consumption of electric power is less than that of an incandescent lamp or a fluorescent lamp. As LED has very sharp spectral characteristics and the response speed in their radiation is high, the visibility afforded by LED to transmit a message or warning to users must be taken into account. The color types for LED have also increased. With such development efforts, LED has become applicable to many systems such as computers, printers, or duplicating machines in order to quickly and accurately transmit information or warnings to users.

Although the readability afforded by fluorescent lamps has been examined (Ohtani and Takanose, 1966), the readability afforded by white LED has not been examined fully and systematically. The readability of white LED has not been explored systematically. The spectral characteristics of white LED are different from that of fluorescent light or incandescent light. Therefore, the fatigue when reading might be different according to the type of reading light. Four types of individual reading lights (two types of white LED, incandescent light with dispersing film, and fluorescent light with ND film and dispersing film) were prepared for experiments.

In this study, the fatigue and readability when reading with four types of individual reading lights was investigated as a function of age. The experimental factors were type of individual reading lights(four levels) and age(young and older adults). The effectiveness of the four types of lights when reading documents under dark environment for one hour was evaluated from the viewpoints of mental fatigue measured using event related potential P300 and psychological rating on readability.

2.METHOD

Participants

Ten participants took part in the experiment. Five were older male adults from 65 to 76 years of age. Five were male undergraduate students from 21 to 24 years of age. None of the subjects had known neurological or psychiatric problems.

Apparatus

Using Neuropack2200 (Nihonkoden), the EEG was recorded from three leads Fz, Cz, and Pz with a sampling frequency of 1 kHz (the time constant was 10 s). Silver-silver chloride electrodes were applied at Fz, Cz, and Pz according to the international 10-20 system. The reference electrode was linked to both ear lobes, and the difference of the potential between each EEG site and the reference electrode was recorded(mono-polar recording). The grand electrode was fixed to the forehead. The following four types of individual reading lights were used: (1) incandescent light, (2) fluorescent light, (3) white LED (blue LED + yellow phosphor);WHITE Hi(Toyoda Gosei), and (4) white LED(purple LED + RGB phosphor);TRUE WHITE Hi(Toyoda Gosei) type. Types (3) and (4) will be called WHITE Hi and TRUE WHITE Hi, respectively. The relative spectral sensitivity function of the four types of individual reading lights are shown in **Fig.1**.

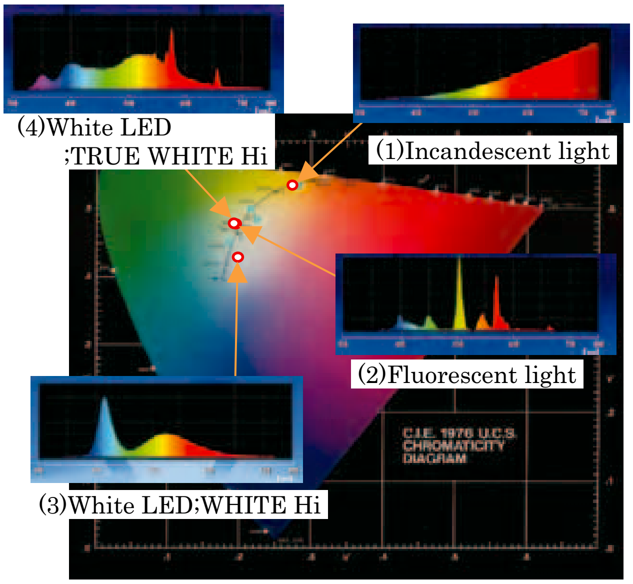

Fig.1 Spectral characteristics of four types of reading lights: incandescent light, fluorescent light, and two types of white LEDs.

Task

The experimental task was to read documents referenced from articles or columns related to politics, economics, sports and science for 30 min. These were collected from a few Web sites. The documents were written on white A4 paper. The number of words per one page was about 1000. The font and size of characters were MS gothic and 12 pt, respectively. Four types of documents were prepared.

Before and after the experimental task, ERP was measured as follows. The stimulus was presented as a flash stimulus using an LED goggle to obtain the P300 waveform. The subject was required to respond to count the number of LED flash stimulus when noticed it. The number of added EEGs to obtain an ERP waveform was 40. The analysis interval was from 160 ms before the stimulus onset and 900 ms after the stimulus onset.**Fig.2** shows example of ERP.

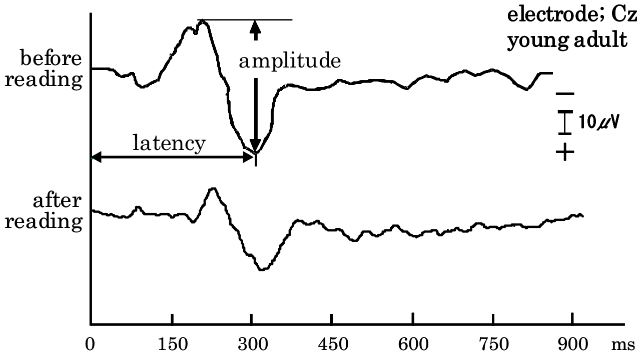

Fig.2 Example of ERP

Design

The experimental factors were lighting condition (four levels) and age (two levels). Lighting condition was a within-subject variable. Age was a between-subject variable.

Procedure

The four lighting conditions were randomly assigned to each of four documents. One lighting condition per day was conducted for each participant. A total of four days were necessary to exhaust all of four lighting conditions. For each lighting condition, the lighting environment was adjusted so that the illumination on the center of documents became about 102 lx. The illumination on the center of document was measured according to JIS 5-point measurement (10 cm × 10 cm). Before and after the reading task, ERP measurements were carried out. The P300 measurements were carried out two times with eyes closed for each subject. The participant was instructed to keep a mental count of the number of LED flashes. This number was reported immediately after the measurement. One measurement required about 15 min for each subject. Between two measurement sessions, the subject was allowed to take a rest for about 1 min. Using the grand-averaged ERP waveform, the latency and amplitude of N100, P200, N200, P300, and N400 components were obtained for each measurement. The EEG that included EOG was removed from the grand-averaged waveform.

After the experiment, the participant was required to rate the visibility of document under each lighting condition using a seven-point scale (1:very difficult to read, 7:very easy to read).

3.RESULTS

As a result of a two-way(age by lighting condition) analysis of variance conducted on the three psychophysiological measures, significant main effects of age were detected for the N100 latency(F(1,7)=6.242, p<0.05) and N1-P3 amplitude (F(1,7)=6.198, p<0.05) of Cz EEG site. As a result of Friedman non-parametric test conducted on the psychological rating on readability, a significant differences of rating score among four lighting conditions was detected only for the older adults(χ2=7.978, p<0.05).

In **Fig. 3** the change of N1-P3 amplitude (the difference between N1 and P3 amplitudes) before and after the task (the value after task minus the value before task) is plotted as a function of lighting condition (type of individual reading lights) and age. The negative value means that the fatigue is induced. If this value is nearly equal to zero, less fatigue is induced after the task.

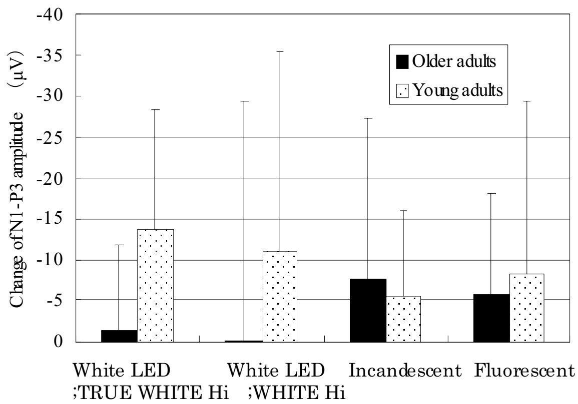

Fig.3 Change of N1-P3 amplitude before and after experiment (N1-P3 amplitude after experiment - N1-P3 amplitude before experiment) as a function of type of reading light and age.

In **Fig. 4**, the change of N100 latency before and after the task (the value after task minus the value before task) is shown as a function of lighting condition and age. The larger value means that the fatigue is induced. In **Fig. 5** the change of P300 latency before and after the task(the value after task minus the value before task) is shown as a function of lighting condition and age. The larger value means that the fatigue is induced.

In **Fig. 6**, the results of rating on readability of documents are shown as a function of lighting condition and age.

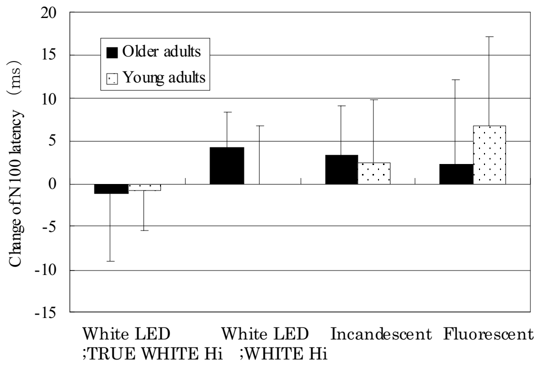

Fig.4 Change of N100 latency before and after experiment (N100 latency after experiment-N100 latency before experiment) as a function of type of reading light and age.

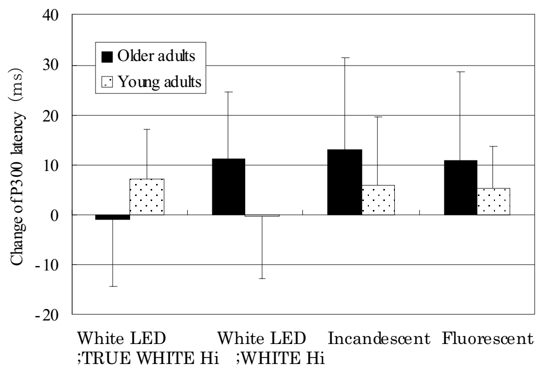

Fig.5 Change of P300 latency before and after experiment (P300 latency after experiment-P300 latency before experiment) as a function of type of reading light and age.

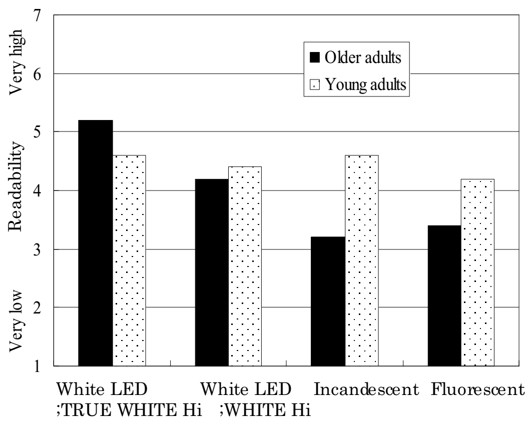

Fig.6 Psychological rating of visibility as a function of type of reading lights and age.

4.DISCUSSION

The event-related brain potential (ERP) is a transient series of voltage oscillations in the brain that can be recorded on the scalp following a discrete event. The ERP has been traditionally partitioned into a number of separate components. The component labels, such as N100 and P300, indicate both the polarity and approximate latency of the peak. The N100 component represents a negative peak occurring approximately 100 ms after the stimulus onset. The P300 component is a positive peak that appears approximately 300 ms after a stimulus onset. The amplitude and latency of the components occurring within 100 ms of a stimulus onset are labeled as exogenous and are influenced by the physical attributes of a stimulus, such as intensity, modality, and presentation rate. Later (endogenous) components, such as P300, are nonobligatory responses to stimuli that vary in amplitude, latency, and scalp distribution with strategies, expectancies, and other mental activities triggered by the event eliciting the ERP. These components are not influenced by the physical attributes of the stimuli.

The P300 components are useful to identify the depth of cognitive information processing. It has been reported that the P300 amplitude elicited by mental task loading decreases with the increase in the perceptual/cognitive difficulty of the task (Ullsperger, Mets, and Gille, 1988;Kramer, Wickens, and Donchin, 1983;Isreal, Chesney, Wickens, and Donchin, 1980;Isreal, Wickens, Chesney, and Donchin,1980;Donchin,1979;Wickens,1979; Ullsperger, Neumann,andGille,1986;Johnson and Donchin, 1980; Neumann, Ullsperger, and Gille,1986;Mangun, Hillyard,1987;Magliero, bashore, Coles, and Donchin, 1984;Kramer, Wickens, and Donchin, 1985). The P300 amplitude or the difference between N100 and P300 amplitudes, that is, N1-P3 amplitude reflects the depth or degree of cognitively processing the stimulus. In other words, it is strongly related to the level of attention. In the studies cited above, the relationship between the P300 latency and the perceptual/cognitive difficulty of the task was also discussed. The P300 latency was found to reflect the temporal aspect when cognitively processing the stimulus. When the stimulus was cognitively difficult to process, the P300 latency was prolonged. The smaller the difference of N1-P3 amplitude, N100 latency, and P300 latency before and after the task, the less the fatigue induced during the experimental task is.

From **Fig. 3, 4**, and **5**, it is clear that the degree of fatigued induced differs between young and older adults and among four types of lighting condition. As for the older adults, two LED individual reading lights ((3)WHITE Hi,(4)TRUE WHITE Hi) induced less fatigue than (1)incandescent light, and (2) fluorescent light. On the other hand, as for the young adults, it tended that (1)incandescent light and (2)fluorescent light induced less fatigue than two LED individual reading lights. Psychological rating also showed that the readability for the older adults is higher than that of incandescent light and fluorescent light. As for the young adults, the psychological rating on readability did not differ among four types of lighting conditions. Such differences between young and older adults must be due to the difference of relative spectral function among four lighting conditions. As shown in **Fig. 1**, the types (3) and (4) reading lights include more relative luminous efficiency with low wavelength than the types (1) and (2). Such characteristics of relative spectral sensitivity function must be proper for older adults whose visual or perceptual function degrades as compared with young adults. Comparing the types (3) and (4), the type (4) was more desirable than the type (3). This must be because the type (4) includes more relative luminous efficiency with broad wavelength than the type (3).

In conclusion, this study indicates that the LED individual reading light the relative spectral function of which includes more low wavelength relative luminous efficiency is more proper for older adults. When designing individual reading lights in vehicles and airplanes, the types (4)TRUE WHITE Hi is recommended especially for older adults. Future research should verify the results of this study by collecting more samples.

REFERENCES

1)Boyce, P.R. 2003.Human Factors in Lighting (Taylor & Francis, London), 2nd edition, 428-457.

2)Bullough, J. and Rea, M.S. 2000. Simulated driving performance and peripheral detection at mesopic and low photopic light levels, Lighting Research Technology, 32, 194-198.

3)Donchin, E. (1979). Event-related brain potentials: a tool in the study of human information processing, In Evoked Brain Potentials and Behavior (Ed. by H.Begleite), Plunum Press :New York, 13-88.

4)Eklund, N.H. 1999. Exit sign recognition for color normal and color deficient observers, Journal of Illumination Engineering Society, 28, 71-81.

5)Gottingin, N.L., Stelmach, G.E., and Amrhein, P.C. 1989. Effects of age on motor preparation and restructuring, Bulletin of the Psychonomic Society, 27, 199-202.

6)Isreal, J.B., Chesney, G.L., Wickens, C.D., and Donchin, E. (1980). P300 and tracking difficulty: Evidence for multiple resources in dual-task performance, Psychology, 17, 259-273.

7)Isreal, J.B., Wickens, C.D., Chesney, G.L., and Donchin, E. (1980). The event-related brain potential as an index of display monitoring workload, Human Factors, 22, 211-224.

8)Johnson, D.E. (1998). Applied Multivariate Methods for Data Analysis, Duxbury Press, and Pcific Grove:CA, pp.93-146, 1998.

9)Johnson, R. and Donchin, E. (1980). P300 ans stimulus categorization : Two plus one is not so different from one plus one, Psychophysiology, 17, 167-178.

10)Kramer, A.F., Wickens, C.D., and Donchin, E. (1983). An analysis of the processing demands of a complex perceptual-motor task, Human Factors, 25, 597-622.

11)Kramer, A.F., Wickens, C.D., and Donchin, E. (1985). Processing of stimulus properties : evidence for dual-task integrality, Journal of Experimental Psychology : Human Perception and Performance, 11, 393-408.

12)Magliero, A., Bashore, R.B., Coles, M.G.H., and Donchin, E. (1984). On dependence of P300 latency on stimulus evaluation processes, Psychophysiology, 21, 171-186.

13)Mangun, G.R.R., and Hillyard, S.A. (1987). The spatial allocation of visual attention as indexed by event-related brain potentials, Human Factors, 29, 195-211.

14)Neuman, U., Ullsperger, P., Gille, H.-G., and Erdman, U. (1986). Effects of graduated processing difficulty on P300 component of the event-related potential, Z.Psychology, 194, 25-37.

15)Park, D.C. and Schwartz, N. 2000. Cognitive Aging: A Primer(Psychology Press, Philadelphia:PA).

16)Squires, S. and Hillyard, S. (1975). Two varieties of long-latency positive waves evoked by unpredictable auditory stimuli in man, Electroencephalography and Clinical Neurophysiology, 38, 387-401.

17)Uetake, A. and Murata, A. (2000). Assessment of mental fatigue during VDT task using event-related potential (P300), Proc. of the 2000 IEEE International Workshop on Robot and Human Interactive Communication, 235-240.
18)Ullsperger, P., Neumann, U., Gille,H.-G., and Pietschann, M. (1986). P300 component of the ERP as an index of processing difficulty. In Human Memory and Cognitive Capabilities (Eds. by F.Flix and H.Hagendorf), North-Holland, Amsterdam, 723-731.
19)Ullsperger, P., Metz, A.-M., and Gille, H.-G. (1988). The P300 component of the event-related brain potential and mental effort, Ergonomics, 31, 1127-1137.
20)Wickens, C.D. (1979). Measures of workload, stress and secondary tasks, In Mental Workload : Its Theory and Measurement (Ed. by N.Moray), Plunum Press: New York, 79-99.