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Changes of Behavioral and Physiological Responses Caused by Color Temperature

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Abstract

LED lighting has an advantage of adjusting color temperature. This change of color temperature may derive change in behavioral and physiological responses of the visual perception for indoor environments. This research examined the changes of behavioral and physiological responses caused by the color temperature. The environment was configured that the indoor temperature was 20 degrees centigrade or less as the perceived uncomfortable environment in winter. Then, the comfortable sensation vote (CSV) and the results of 3-back working memory test were measured as behavioral responses. In addition, the Electrodermal Activity (EDA) and Electrocardiogram (ECG) were measured as the responses of autonomics nervous system (ANS) in the three conditions of color temperature (red: 3862K, white: 5052K, blue: 11,460K). As a result, behavioral responses were not significant by the condition of color temperature, but the tendency of occupants' physiological relaxation appeared in the blue color temperature condition compared with the white color temperature condition. Although the color temperature of LED lighting might be a small factor in terms of the characteristics of indoor environment, it suggests that the color temperature could have an impact on the physiological changes in the parasympathetic nervous system.

Key words: Color Temperature, Behavioral Responses, Physiological Responses, Indoor Environments

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1. Introduction

Indoor thermal environment which influences human activities is an important factor. In particular, during the winter season, the factors of the indoor thermal environment can be used as important indexes to predict or control human mind and behavior, because people live remain indoors for more than 80% of the day (Bae, Lee, &Lee, 1995; Gonzales, Nishi, &Gagge, 1974).

Numerous researches which are related to the relationship between thermal comfort and thermal environments has been conducted. Here, thermal comfort refers to the state of mind offeelingsatisfied with the thermal environment (Gagge, Fobelets, &Berglund, 1986; Tham &Willem, 2010). Generally, thermal environment is determined by the physical factors (indoor temperature, relative humidity, mean radiant temperature, air velocity), but thermal comfort is affected by the personal metabolism, the amount of personal clothing, and many psychological factors as well as the above physical factors (Ijzerman &Semin, 2009; Steinmetz &Mussweller, 2011; Zhong &Leonardelli, 2008).

In particular, the studies examined changes of the perceived temperature in a fixed environment which was controlled by physical factors. This research was reported that the change of the perceived temperature could affect the human behavior and emotion. For example, Williams and Bargh (2008) reported that if a person was primed with warmth, the perceived temperature of the person would be high, and he or she evaluated the emotionally neutral stimulus (e.g. human face) as positive. In addition, Patrica and Albert (1994) reported that the change of perceived temperature (subjective temperature) by the color temperature (it refers to the quantified degree of warmth exhibited by the light using the unit of absolute temperature, Kelvin) could affect the emotional state of the evaluator. It suggests that human behavior and emotion could be adjusted by the color temperature or the perceived temperature (Kim, 2013, 2014). Changes of subjective temperature can affect the performances of goal-oriented behavior (Min, Jung, &Kim, 2014). Research of Min et al. (2014) examined that the change of temperature-related comfort could affect the performances of visual search task which is related to selective attention.

These previous studies, however, used self-report scale or behavioral value as dependent measures. These measurements have a limitation which does not provide the information on the physical and physiological changes in the interactions of human and environment, and are final results only occurred by the interactions of human and environment. For this reason, self-reported basic physiological data and behavioral data should be collected for the interactions of human and environment. In other words, the integrative research on whether the perceived temperature causes the physiological changes as well as the subjective comfort and behavior performance is needed.

Therefore, this study examined both behavioral and physiological changes due to the perceived color temperatures using the LED lighting. To execute this study, the environment was configured so that the indoor temperature was 20 degrees centigrade or less as the perceived uncomfortable environment in winter.

2. Method

2.1. Participants

Thirty-three young adults (male: 16, female: 17) participated in the experiment. All participants did not have a mental disorder and experience of the heart and skin surgery. The average age of the participants was 21.18 (SD=1.59) years, and they had no problem in responding to the experimental stimuli.

2.2. Experimental Environment and Apparatus

The main experiment was conducted in an enclosed test room consisting of a 3.5×5.4×2.1m (l×w×h) space. The temperature of test room was maintained at less than 20℃. LED lighting conditions were the three conditions (Red, White and Blue), and the color temperature values for each condition were measured by the CL-200A of the Opticom Incoporation in Korea (Red: 3862K, White: 5052K, Blue: 11,460K). In addition lights were given by the LX-101 of the Luxland Incorporation in Korea.

2.3. Behavioral Responses

The subjective comfort from the behavioral responses was composed of seven-point Likert scale with 1 indicating “very uncomfortable” and 7 indicating “very comfortable” (Kim, 2014; Kim &Min, 2014, Kim, Min, Shin, &Kim, 2013; Min et al., 2014). The participants were asked to rate the level of indoor thermal comfort twice, before and after the presentation of color temperature.

The 3-back working memory task as the experimental task was conducted with E-Prime 1.2 program. The stimulus of experimental task was presented on a 17-inch CRT monitor with a resolution of 1024×768 and a refresh rate of 75Hz. The 70cm distance between the participants and the screen was maintained, and all stimuli were presented with black color on a gray background. The stimulus was a two-syllable Korean word presented in the center of the monitor (visual angle: 0.04°×0.02°, totally 92 words used) (Kim, Min, &Yoon, 2006). The participants were asked to press the answer button if the currently presented word and the previously third trial presented word were the same (Lee et al., 2009). This task was also used as an activity-control task, because the activities of participants influence the thermal perception. Thus the activity of participant was set to 1.0 met. This value means that the participant sat in a chair watching the computer screen and simply pressed two keys as specified in the task (Kim, Kim, &Min, 2011; Kim, Min, Min, &Kim, 2011a, 2011b). Finally, accurate reaction time of 3-back working memory task was used.

2.4. Physiological Responses

The responses of the autonomic nervous system (ANS) were measured by the BiopacAmp of the Biopac System Incorporation of the USA. The AcqKnowledge (ver. 3.8.1) of MP100WS was used for input and analysis of physiological data. Electrocardiogram (ECG) was measured by Lead I inducing method regarding how to attach a reference electrode on the pulse of the right wrist, and a signal electrode on that of the left wrist. Electrodermal activity (EDA) was measured from the index- and middle-finger of the left hand.

For ANS response variables, the skin conductance level (SCL) which is the relatively long-lasting tonic activity was used for analysis as a detailed indicator of EDA. In addition, as detailed indicators of ECG, the heart-rate (HR) which is the number of heartbeats for a minute, and the respiration (RESP) which is the number of breaths taken in a minute, were used for analysis (Kim, Kang, Min, &Min, 2009; Kim, Min, Kim, &Min, 2011; Kim, Yi, Kim, Lim, Bak, Ji, Hong, Kang, Min, &Min, 2010; Lee, Lee, Hwang, Bae, Min, &Kim, 2013; Yi, Kim, Lim, Kim, Ji, Min, &Min, 2010).

2.5. Experimental Procedures

Before implementing the main experiment, the electrodes for measuring the response of the autonomic nervous system were attached to the participants, and they listened to a brief description of the experimental task and performed the practice for approximately 10 minutes. The main experiment was composed of two conditions, and the presented order of the conditions was counter balanced. One condition was base and task, another condition was with color temperature condition of the LED lighting. Participants participated in all conditions for 30 minutes as ANS responses were measured (See Figure 1).

2.6. Data Analysis

For the performance of the 3-back working memory task, repeated ANOVA was carried out for each color temperature condition (red, white and blue). For all dependent variables (subjective comfort and ANS responses) without the performance of the 3-back working memory task (base condition), the 2 (base and task) × 3 (color temperature condition: red, white and blue) repeated ANOVA was carried out with the SPSS program (ver. 16.0).

3. Data Results

3.1. Subjective Comfort

The subjective comfort was examined depending on two conditions (base/task and color temperature). As a result, the subjective comfort was not significant in accordance with two conditions (see Table 1).

Table 1. The results of subjective comfort from the behavioral responses depending on the experimental condition.

Base /Task	Color Temperature Condition (M±SD)			F value(df) (color temperature condition)
	Red	White	Blue	
Base	2.97±1.19	2.97±1.08	2.94±1.09	$0.27_{(2,64)}$
Task	2.91±1.23	3.03±1.16	2.97±1.05	
F value(df) (base/task)		$0.04_{(1,32)}$		(interaction) $0.49_{(2,64)}$

3.2. Performance of 3-back Working Memory Task

We examined the difference of the performance of 3-back working memory task depending on the color temperature condition. As a result, although there was no statisticalsignificance, the accurate reaction time was longer in white color temperature condition than other

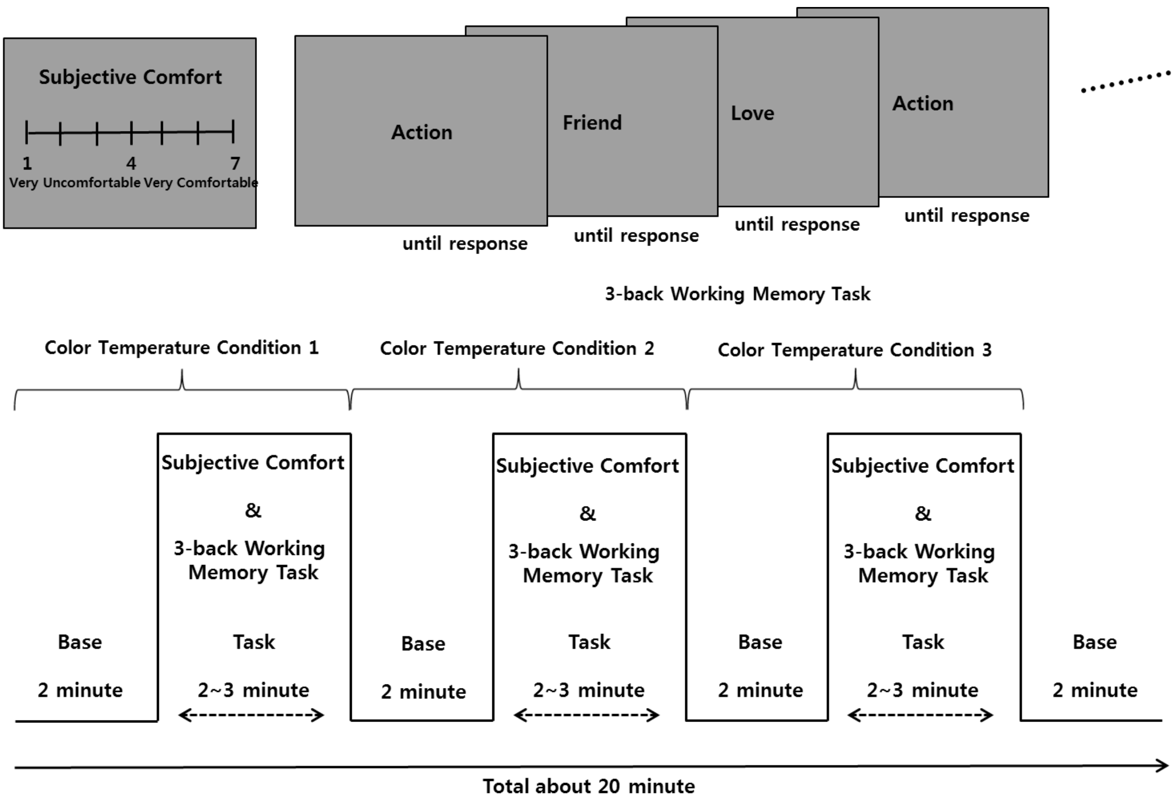

Figure 1. Experimental Procedures

color temperature conditions (see Table 2).

Table 2. The results of the performance of 3-back working memory task from the behavioral responses depending on the color temperature condition.

3-back Working Memory Task	Color Temperature Condition (M±SD)			F value(df)
	Red	White	Blue	
Accurate Reaction Times (ms)	921.52 ±259.13	994.87 ±310.79	912.41 ±292.20	$2.11_{(2,64)}$

3.3. EDA – SCL

The SCL was examineddepending on two conditions. As a result, the sweat production in a block of performing task was greater than that of the baseline (see Table 3). It means that the body is more awake when participants perform the task.

Table 3. The results of SCL from the physiological responses depending on the experimental condition.

Base /Task	Color Temperature Condition (M±SD)			F value(df) (color temperature condition)
	Red	White	Blue	
Base	9.38±5.22	9.42±5.01	9.53±5.12	$0.23_{(2,64)}$
Task	9.67±5.57	9.53±5.14	9.69±5.29	
F value(df) (base/task)		$8.11^{**}_{(1,32)}$		(interaction) $2.50_{(2,64)}$

$^{**}p<.01$

3.4. ECG – HR

Changes of the HR depending on two conditions was examined. As a result, the HR increased when participants perform the task compared to that of the baseline (see Table 4). It also means that the body is more awake when participants perform the task.

Table 4. The results of HR from the physiological responses depending on the experimental condition.

Base /Task	Color Temperature Condition (M±SD)			F value(df) (color temperature condition)
	Red	White	Blue	
Base	83.21 ±9.19	82.52 ±9.98	82.19 ±11.49	0.94 (2,64)
Task	86.23 ±10.65	85.93 ±11.33	84.78 ±10.70	
F value(df) (base/task)		$8.98^{**}_{(1,32)}$		(interaction) $0.29_{(2,64)}$

$^{**}p<.01$

3.5. ECG – RESP

Changes of the HR depending on two conditions was examined. As a result, the RESP increased when participants perform the task compared to that of the baseline (see Table 5).

Table 5. The results of RESP from the physiological responses depending on the experimental conditions.

Base /Task	Color Temperature Condition(M±SD)			F value(df) (color temperature condition)
	Red	White	Blue	
Base	17.70 ±4.07	19.09 ±5.05	17.88 ±3.53	$3.35^{*}_{(2,64)}$
Task	21.82 ±4.78	21.70 ±5.92	20.30 ±4.22	
F value(df) (base/task)		$24.95^{**}_{(1,32)}$		(interaction) $2.50_{(2,64)}$

$^{*}p<.05$, $^{**}p<.01$

It means that the body is more awake when the participants perform the task. In addition, the RESP changed according to the color temperatures. As a result of post-hoc test, the RESP in the white-color temperature condition was greater than in the blue-color temperature condition (see Figure 2). It means that the body is more awake in the white-color temperature condition than in the blue-color temperature condition.

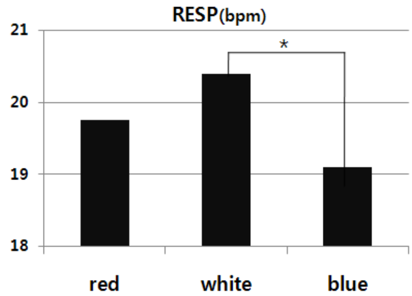

Figure 2. The differences of RESP between color temperature conditions (*p<.05)

4. Discussion

This study examined the changes of behavioral and physiological responses depending on the color temperature in the environment which was configured with less than 20 degrees centigrade indoor temperature as the perceiveddiscomfort in the winter.

In terms of the results, first, there was no statistical significancefor both subjective comfort and the performance of the 3-back working memory task as behavioral responses for all conditions. These results suggest that the color temperature is not a strong factor in inducing a discomforting situation, and that it is not likely that changes of the color temperature may even induce the behavioral performance.

Second, the SCL, the HR, and the RESP was greater when participants performed the task than during baseline (not perform the task). It means that both SCL and HR occurred as a result of the activation of the sympathetic nervous system responses, and that RESP occurred as a result of the activation of the parasympathetic nervous system responses (Blosh, Lemeignan, &Aguilera, 1991; McManis, Bradley, Berg, Cuthbert, &Lang, 2001). In addition, the RESP was greater in the white-color temperature condition compared with the blue-color temperature condition. The tendency of interactions of the base/task and the color temperature in the SCL and the RESP results. These results are consistent with the earlier research which examined that the cognitive processing and the physiological change are not matched equally depending on the color temperature or the color (Grandner, Kripke, &Langer, 2006; Knez, 2001). It suggests that changes of the color temperature induce physiological change in theparasympathetic nervous system.

In spite of these results, this study has a limitation that the study had been executed in only less than 20 degrees centigrade environments as the perceived uncomfortable environment. These environments may induce arousal state regardless of the color temperatures. For this reason, effect of the color temperature on the behavioral and physiological responses could have been reduced in this study. Therefore, for future studies, it is necessary to overcome this limitation, and to further examine the changes in the central nervous system responses which is the direct indicator of the psychological and behavioral responses.

REFERENCES

Bae, G. N., Lee, C. H., &Lee, C. S. (1995). Evaluation of Korean thermal sensation in office building during the summer season (여름철 사무실 내 한국인의 온열감 평가),*Korea Journal of Air-Conditioning and Refrigeration Engineering, 7(2)*, 341-352.

Blosh, S., Lemeignan, M., &Aguilera, N. (1991). Specific respiratory patterns distinguish among human basic emotions. *International Journal of Psychophysiology, 11(2)*, 141-154.

Gagge, A. P., Fobelets, A. P., &Berglund, L. G. (1986). A standard predictive index of human response to the thermal environment, *American Society of Heating Refrigerating and Air-Conditioning Engineers Transaction, 92(2)*, 709-731.

Gonzales, R. R., Nishi, Y., &Gagge, A. P. (1974). Experimental evaluation of standard effective temperature: A new biometeorologica index of man's thermal discomfort, *International Journal of Biometeorolog, 8(1)*, 1-15.

Grandner, M. A., Kripke, D. F., &Langer, R. D. (2006). Light exposure is related to social and emotional functioning and to quality of life in older women, *Psychiatry Research, 143*, 35-42.

Ijzerman, H. &Semin, G. (2009). The thermometer of social relations mapping social proximity on temperature, *Psychological Science, 20(10)*, 1214-1220.

Kim, B. (2013). The characteristics of the learning performance according to the indoor temperature of the learning environment and the color of the learning materials (학습 환경의 실내 온도와 학습 재료의 색채에 따른 학습수행의 특성), *Journal of the Korea Academia-Industrial cooperation Society, 14(2)*, 681-687.

Kim, B. (2014). Effect of the cold-warm color contrast of the learning-item on the learner's performance (학습항목의 한난 색채대비가 학습자의 학습수행에 미치는 영향), *Journal of the Korea Academia-Industrial cooperation Society, 15(3)*, 1442-1447.

Kim, B., Kang, J. K., Min, B. C., &Min, Y. K. (2009). The changes of the cognitive load's level and the heart-rate due to driving road condition complexity (운전 도로조건 복잡성에 따른 인지적 부하수준과 심박율의 변화), *Journal of the Korean Data Analysis Society, 11(1)*, 241-251.

Kim, B., Kim, J. H., &Min, Y. K. (2011). Effects of the perceived thermal sensitivity on performances of learning task according to the level of difficulty (온열 지각 민감도가 난이도별 학습과제 수행에 미치는 영향), *Journal of the Korean Data Analysis Society, 13(5)*, 2513-2522.

Kim, B., Min, B. C., Kim, J. H., &Min, Y. K. (2011). Driving performance and heart-rate change of middle-aged drivers in left-turn situation (교차로 환경에서 좌회전 시 중년 운전자들의 운전수행 및 심박율의 변화 특성),*Journal of the Ergonomics Society of Korea, 30(1)*, 213-220.

Kim, B. &Min, Y. K. (2014). Exploring the possibility of utilizing facial skin temperature for reflection of subjective thermal comfort sensation on the composition of learner-centered comfort learning environment (학습자 중심의 쾌적 학습환경 조성에 있어 주관적 온열 쾌적감 반영을 위한 안면 피부온도의 활용 가능성 탐색), *Journal of Social Science (Institute of Social Science Chungnam National University), 25(1)*, 3-13.

Kim, B., Min, Y. K., &Yoon, J. (2006). Differences of Stroop effects due to modalities of stimulus and response (자극과 반응의 감각양상에 따른 스트룹 효과의 차이),*Journal of the Korean Data Analysis Society, 8(6)*, 2473-2481.

Kim, B., Min, Y. K., Min, E., &Kim, J. H. (2011a). The changes of psychological and physiological emotional responses according to change of the index of predicted mean vote (PMV) due to air conditioning types (공조방식에 의한 예상 온열감 반응(PMV) 변화에 따른 심리/생리적 감성반응의 변화),*Korean Journal of the Science of Emotion &Sensibility, 14(4)*, 645-652.

Kim, B., Min, Y. K., Min, E., &Kim, J. H. (2011b). Effects of thermal environmental factors on behavioral responses of the selective attention mechanism (물리적 온열환경 요소들이 선택적 주의 기제의 행동 반응에 미치는 영향), *Journal of the Korean Data Analysis Society, 13(5)*, 2523-2533.

Kim, B., Min, Y. K., Shin, E., &Kim, J. H. (2013). The validation study of shaping comfortable environments based on the PMV index using facial skin temperature (안면 피부온도를 활용한 PMV 지표 기반 쾌적환경 조성의 타당성 연구), *Korean Journal of the Science of Emotion &Sensibility, 16(3)*, 311-318.

Kim, B., Yi, Y. C., Kim, H. W., Lim, D. H., Bak, M. S., Ji, D. H., Hong, S. H., Kang, J. K., Min, B. C., &Min, Y. K. (2010). The characteristics of elderly drivers' driving behavior on intersection using graphic driving simulator. *Journal of the Ergonomics Society of Korea, 29(4)*, 611-617.

Knez, I. (2001). Effects of colour of light on nonvisual psychological processes, *Journal of Environmental Psychology, 21(2)*, 201-208.

Lee, S. J., Min, Y. K., Kim, B., Choi, M. H., Yang, J. W., Choi, J.S., Jun, J. H., Tack, G. R., Min, B.

C., &Chung, S. C. (2009). Difference of 3-back task performance ability due to levels of arousal (각성 수준에 따른 3-back 과제 수행 능력의 차이), *Korean Journal of the Science of Emotion &Sensibility, 12(4)*, 373-380.

Lee, Y. C., Lee, H. J., Hwang, E. J., Bae, J. W., Min, Y. K., &Kim, B. (2013). ANS and CNS responses according to thermal comfort based on the PMV (예상 온열감 반응 기반 온열 쾌적감에 따른 자율신경계 및 중추신경계 반응), *Journal of the Korean Data Analysis Society, 15(1)*, 349-358.

Lee, Y. C., Min, Y. K., Lee, H. J., Jeon, Y. W., Kim, S. H., Kim, Y. K., Min, B. C., Seo, S. H., &Kim, B. (2014). The changes of ANS responses due to the color temperature of LED lighting, *In Proceedings of 1st Asian Conference on Ergonomics and Design (ACED 2014)*, 57.

McManis, M. H., Bradley, M. M., Berg, W. K., Cuthbert, B. N., &Lang P. J. (2001). Emotional reactions in children: Verbal, physiological, and behavioral responses to affective pictures, *Psychophysiology, 38*, 222-231.

Min, Y. K., Jung, W. H., &Kim, B. (2014). The effect of indoor thermal comfort on visual search task performances in a personal learning environment, *Psychology and Behavioral Sciences, 3(6)*, 185-191.

Patrica, V. &Albert, M. (1994). Effects of color on emotions, *Journal of Experimental Psychology: General, 123(4)*, 394-409.

Steinmetz, J. &Mussweller, T. (2011). Breaking the ice: How physical warmth shapes social comparison consequences, *Journal of Experimental Social Psychology, 47(5)*, 1025-1028.

Tham, K. W., &Willem, H. C. (2010). Room air temperature affects occupants' physiology, perceptions and mental alertness, *Building and Environments, 45*, 40-44.

Williams, L. E., &Bargh, J. A. (2008). Experiencing physical warmth promotes interpersonal warmth, *Science, 322*, 606-607.

Yi, Y. C., Kim, B., Lim, D. H., Kim, H. W., Ji, D. H., Min, B. C., &Min, Y. K. (2010). Autonomic nervous systems in yellow interval dilemma situation (황색신호 딜레마 상황에서의 자율신경계 반응),*Journal of the Korean Data Analysis Society, 12(1)*, 185-194.

Zhong, C. B., &Leonardelli, G. F. (2008). Cold and lonely: Does social exclusion literally feel cold? *Psychological Science, 19(9)*, 838-842.

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