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Subjective Judgments of Refrigerator Lighting by Altering Chromaticity and Placement across Age Groups

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Abstract

This study investigates an optimal chromaticity and placement of refrigerator lighting to meet users' preference. In the experiment, eighteen lighting stimuli were provided by combining six chromaticities and three placements. A total of 177 women aged 20 to 69 participated and assessed the lighting stimuli using ten affective scales. Based on the assessments, we derived four aspects to describe the characteristics of lighting styles: performance, aesthetics, visual comfort, and overall satisfaction. Specifically, cool white lighting placed in front appealed the well-functioning, performance support aspect. Further, when the shelves were lit in magenta-white, the refrigerator interior was evaluated to be the most attractive. When visual comfort matters more, shelf lighting in cyan-white would be optimal. An age effect was also discovered. Younger participants in their 20s and 30s preferred cool white when lit indirectly. Participants over 40, however, found magenta-white more attractive, especially when they viewed it directly. By expanding this study to diverse product categories, it could produce additional empirical findings for designers, so that they may choose and place lighting properties more efficiently and successfully.

Introduction

Light is increasingly considered a new type of design material [1] and a critical design element for consumer products. Light has been applied ornamentally to clothing [2], bicycle wheels [3], and shoes [4]. In addition to contemporary studies, it is easy to identify commercial movements that use light as a design element, mainly in objects that have interior space with a lighting system. For example, to offer different driving experiences, Kia automobiles collaborated with Pantone color to propose seven kinds of mood lighting for Kia's K9 passenger car. The Mercedes-Benz S-class series introduced six types of energizing light programs: freshness, warmth, vitality, joy, comfort, and a three-mode option. As described in the literature, ambient lighting harnesses the positive effects of light to affect passengers' well-being while on the road [5, 6]. There have also been efforts by airline companies to use mood lighting in their aircrafts. For example, Emirates' Boeing 777-300ER has embedded ambient lighting systems that change colors according to outside time. Lufthansa A350 has also applied mood lighting that considers passengers' biorhythms. In such circumstances, theory and research-based evidence about good lighting design is highly demanding. Earlier studies focused on finding optimal lighting conditions to achieve specific emotional effects. The optimal lighting conditions of various light properties, such as chromaticity and brightness, are currently being studied with products that have independent, interior space and illumination. For instance, consumer preferences for fluorescent lamps or LED lighting in commercial refrigerators was investigated by [7]. The effect of lighting placement on visual comfort in refrigerators was identified in [8]. They examined three lighting positions—ceiling, side, and front lighting—and determined that a range between ceiling and front lighting was visually more comfortable than other positions.

In parallel, some studies have asserted the necessity to define desired design style for product lighting. Researchers have attempted to determine how design styles affect emotional responses triggered by lighting properties, such as hue. For instance, interior lighting and emotional responses induced by chromaticity, brightness, and arrangement of the lighting was studied by [9]. Also, [10] investigated the appropriate luminance range of automobile lighting and analyzed the emotions that were felt in response to each lighting color. Previous studies have been conducted mostly within the automotive domain. Although lighting is regarded as an important factor in consumer purchase decisions, there are only a few studies that have considered emotions desired by customers [11].

Because lighting is an efficient tool for inducing targeted emotions, users' desired emotion should be identified first to optimize lighting conditions. For instance, desired light properties are different according to the context created by the space and the related activity in the residential space. According to [12], a light setup with bluish-purple color and low brightness was appropriate for watching chilling movies, whereas purple color and higher brightness was more suitable for watching dramatic or prestigious films. In kitchens, white (W) lighting with a 900 lux illuminance is considered food-centric lighting. In transportation, perceived safety, alertness, functionality, space perception, interior attractiveness, and interior quality are the main contexts that drive ambient interior lighting choices [9]. More recently, [13] supported this argument when they extracted desired design styles by collecting and analyzing refrigerator-related adjectives. The emotional categories from their study are different from other studies of different contexts.

This study aims to exploit the best lighting combination for the desired design style. An experiment was conducted with lighting stimuli created by manipulating chromaticity and lighting placement. In addition, we aimed to determine whether age influences lighting judgment.

Materials and Methods

Experimental Setup

A refrigerator equipped with LED lighting was prepared to provide lighting stimuli (see Fig. 1). The chromaticity of lighting was controlled by adjusting the pulse width modulation (PWM) values of red (R), green (G), blue (B), and W. Values were sent from a mobile application and then transmitted to an Arduino Nano with Bluetooth, which was connected to the lighting installations. To obtain sufficient brightness in the refrigerator, the surface lighting was additionally installed using Adafruit NeoPixel Digital RGBW strips and the light guide plate. For the side and ceiling lighting, multiple RGBW LED strips were arrayed and inclined toward the inside so as not to be easily visible from user view.

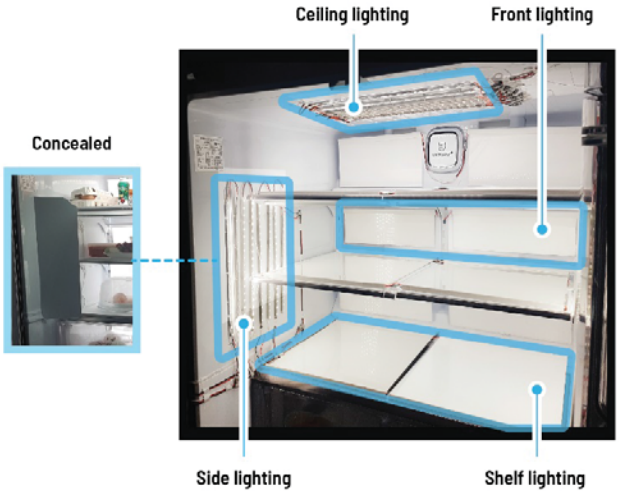
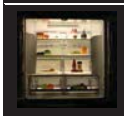
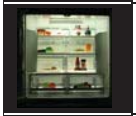


Figure 1. *The ceiling, front, side, and shelf lightings. Ceiling lighting was always turned on.*

Eighteen lightings were created for the lighting stimuli by manipulating chromaticity and placement. The six chromaticity values were selected within the W range of the 1931 Commission Internationale de l'Eclairage (CIE) chromaticity diagram (Table 1). Three correlated color temperatures (CCT) from the Planckian locus were chosen. The warm, neutral, and cool W had the CCT of 4000 Kelvin (K), 6000 K, and 8000 K, respectively. The other three were white as well but with special hue nuances of magenta, yellow-green, and cyan. Independent of the chromaticity, front, shelf, and side were considered as the lighting placements.

Table 1. Colorimetric values of six chromaticities.

Stimuli	Chromaticity	Measured colorimetric value	
		CCT (K)	Duv
	Warm white	4200	0.008
	Neutral white	6100	0.001
	Cool white	8300	-0.004
	Yellow-green	5600	0.038
	Cyan	7700	0.043
	Magenta	5300	-0.013

Ceiling lighting was always turned on to provide adequate brightness for the refrigerator. The illuminance level of stimuli was adjusted to 750 lux to confirm only the effects of chromaticity and placement of lighting. The colorimetric value and illuminance level were measured at the center of the second shelf. The colorimetric values of lighting stimuli were measured with an illuminance spectrometer TOPCON IM-1000.

The experiment was conducted in a room with an LED luminous ceiling. The room was configured at 6000 K, which corresponds to neutral W. To set the space brightness, eight Korean participants were recruited, and the illuminance around the refrigerator was measured at dining time, which is the time that the refrigerator is most heavily used. As a result, 300 lux was adopted as an average room illuminance.

Evaluation Criteria

The users' desired emotions for refrigerator lighting was explored by [13]. In their study, the desired emotions were analyzed through a brainstorming method, and almost 1,000 terms were collected. Terms were classified by the thesaurus relationship, and three emotion categories were suggested as desired design styles of a refrigerator: abstract quality, space perception, and visual comfort. In addition, some adjectives were introduced as being representative of these three emotion categories. Hence, these adjectives were adopted as evaluation criteria for this study, as shown in Table 2. In this study, the terms "novel" and "satisfied" were added to determine holistic reactions to lighting stimuli. Novel was added to gauge reactions to new kinds of lighting combinations that are not used in current refrigerator design. Satisfied represents the general preference of lighting stimuli. In sum, a total of ten adjectives were collected as evaluation criteria.

Table 2. Adjectives used as evaluation criteria in this study.

Source	Category	Adjectives
Jeong & Suk (2018) [13]	Abstract quality	appetizing, luxurious, refined, refreshing
	Space perception	distinguishable, spacious, undistorted
	Visual comfort	visually comfortable
Added in this study		novel, satisfied

Procedure

A maximum of three participants took part in the experiment at one time to ensure sufficient viewing angles while looking at the same refrigerator. Participants were given detailed instructions at the beginning of the experiment. During the experiment, the 18 lighting stimuli were presented to the participants in random order. The refrigerator doors were closed while the next stimulus was prepared to minimize the impact of the previous lighting stimulus. For each stimulus, participants were asked to assess how well they matched to the given ten evaluation criteria with a 5-point scale Likert scale (1 = strongly disagree, 5 = strongly agree). Participants sat in chairs 50 cm from the refrigerator, and chair levels were adjusted so that participants were eye-level to the refrigerator's middle shelf. The experiment took about 30 minutes to complete (see Fig. 2).

Figure 2. Experimental process: Participants observed lighting stimulus at a 50-cm distance from the refrigerator.

Participants

The women is the majority user of refrigerator in Republic of Korea [14]. Studies of refrigerator held in Korea recruits mainly women as a participants [11, 15]. Hence, women aged 20 to 69 were recruited as participants in this study. As presented in Table 3, the average age was 45.38 with a standard deviation of 12.27 years. All participants were paid volunteers and had normal or corrected-to-normal vision. Ethical approval concerning human participants was obtained from the KAIST Institutional Review Board prior to the experiment (Approval No.: KH2017-92).

Table 4. Average age of each age group.

Age group	N	Age mean (SD)
20s	20	22.60 (2.21)
30s	36	35.53 (3.05)
40s	51	44.78 (2.58)
50s	45	54.31 (2.64)
60s	25	62.96 (3.16)
Total	177	45.38 (12.27)

Results and Analysis

Relative Importance of Attributes on Each Evaluation Criterion

Based on the subjective assessments, we performed conjoint analysis to identify relative importance and utility scores. These should indicate how relevant each attribute was and how impactful

Table 3. The spectral power distribution of six lighting stimuli.

Evaluation criterion	Attribute	Relative importance	Level	Utility
satisfied	chromaticity	73.21	magenta	0.25
	placement	26.79	front	0.08
novel	chromaticity	68.39	magenta	0.26
	placement	31.61	shelf	0.08
luxurious	chromaticity	72.43	magenta	0.22
	placement	27.57	front	0.04
			shelf	0.04
refined	chromaticity	75.20	magenta	0.23
	placement	24.80	front	0.05
spacious	chromaticity	63.15	cool white	0.31
	placement	36.85	front	0.21
undistorted	chromaticity	85.67	cool white	0.30
	placement	14.33	side	0.05
distinguishable	chromaticity	73.31	cool white	0.26
	placement	26.69	front	0.12
appetizing	chromaticity	91.77	cool white	0.24
	placement	8.23	shelf	0.02
refreshing	chromaticity	88.69	cool white	0.28
	placement	11.31	front	0.03
visually comfortable	chromaticity	31.76	cyan	0.06
			magenta	0.06
	placement	68.24	shelf	0.09

each level was within the attribute, respectively. As the eighteen lighting stimuli is the full-profile of chromaticity and placement, we selected the rating-based conjoint analysis method. The conjoint analysis was performed using the Statistical Package for the Social Sciences version 22 (SPSS). The method of data recording in SPSS is specified with the Sequence, Rank, or Score subcommands. The Score subcommand indicates that each data point is a preference score assigned to the lighting stimulus and a higher score implies greater preference. Hence, Score subcommand was selected since the user survey was proceeded using Likert scale.

Table 4 shows the results of conjoint analysis with regard to the entire ten evaluation criteria. For each criterion, the size of relative importance was compared, and the level with the highest utility score was matched. In general, chromaticity appeared more critical for assessing subjective qualities across criteria except for the visually comfortable criterion. Concerning this aspect, participants considered the placement of lighting more relevant. Among the six types of chromaticity, magenta-nuanced W was often the most preferred. Also, in terms of light placement, the front lighting was, in general, preferred across the criteria.

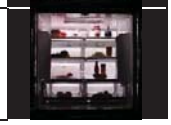
As the assessments were highly correlated among some criteria, we were able to cluster the ten criteria into several groups. For example, the assessments regarding luxurious, novel, and refined were positively correlated, indicating that these three criteria were related to similar aspects. After examined correlations among the assessments, we re-clustered them into four categories: general preference, performance, style, and visual comfort. Table 5 presents these categories and their respective criteria. We considered satisfied as an independent category, as it is a holistic measure.

Table 5. The 10 criteria were clustered into four and labeled as performance, style, visual comfort, and satisfactory (N = 177).

Criteria category	Included evaluation criteria
Performance	appetizing, distinguishable, refreshing, spacious, undistorted
Style	luxurious, novel, refined
Visual Comfort	visually comfortable
Satisfactory	satisfied

Next, we integrated the conjoint analysis (Table 4) and criteria category (Table 5) to identify the optimized lighting that best serves each category of criteria. For example, to enhance the performance aspect, a cool W light placed toward the front should be the best among the combinations. However, this would not be as successful in achieving a more stylish aspect. To express luxurious, novel, and refined styles through lighting design, we propose a W light with a magenta nuance that is placed on the shelves of the refrigerator. In this way, depending on desired product concerns, designers can alter the chromaticity and placement of light, just like any other design activity to visualize forms and shapes. Table 6 shows the best matches of chromaticity and placement of light to each of the four criteria categories.

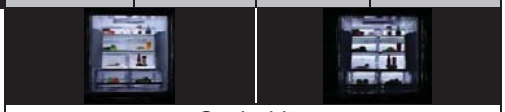
Table 6. The best combination of chromaticity and placement attributes for the four criteria categories. The illuminance level was fixed to 750 lux in all combinations.

Criteria category	Best combination (CCT, Duv)	Image
Performance	cool white, front (8300 K, -0.004)	
Style	magenta, front (5300 K, -0.013)	
Visual Comfort	cyan, shelf (7700 K, 0.043)	
Satisfactory	magenta, front (5300 K, -0.013)	

Age Effect on Refrigerator Light Preference

As we recruited female participants aged between 20 and 69, we were able to analyze variabilities across age groups. We replicated the analyzing procedure and we obtained an overview of tendencies across the five age groups (Table 7).

Table 7. The combination of two attributes to best serve the each criteria category along age groups. The illuminance level was fixed to 750 lux in all combinations.

Criteria category	Best lighting combination for each age group			
	20s	30s	40–50s	60s
Perfor-mance				
	Cool white			
	Side		Front	
Style				
	Magenta			
	Front	Shelf		Front
Visual Comfort				
	Warm W	Neutral W	Cyan	Magenta
	Side	Shelf		
Satis-factory				
	Cool W	Magenta		
	Side	Shelf	Front	

Although best combinations for each age group was derived slightly different, lighting placement was found as more critical to Visual Comfort while chromaticity was more influential to other three criteria categories. This means unified placement or chromaticity was derived across the age. Cool W was derived as the best chromaticity condition for the Performance category regardless of age difference. Cool W could give the impression that refrigerator is working its basic role, helping food stay fresh. Unified chromaticity condition, magenta-nuanced W, for all age group was also identified to increase elegant feeling irrespective of the age. Visual comfort could be acquired by installing indirect lighting.

In general satisfactory aspect, younger age groups favored cool W while older age groups preferred magenta-nuanced W. With regard to light placement, younger participants preferred the side; older participants showed a higher preference for front lighting. In other words, the younger participant liked indirect lighting, whereas the older participants preferred direct lighting.

Discussion and Conclusion

This study examined user preferences of refrigerator lighting design based on chromaticity and placement of lighting. We configured six chromaticities and three placements to generate a total of 18 lighting variations. Within the given combination, we collected participant's subjective judgments on ten criteria. Based on the assessments, we performed a conjoint analysis, thereby quantifying the impact of lighting attributes between chromaticity and placement. Specifically, we identified combinations of these two attributes that best serve the concepts. In this study, the ten criteria were clustered into four categories, and we employed them as four refrigerator concept alternatives. In Fig. 3, we summarize the optimal combinations.

Furthermore, as we recruited women aged 20 to 69, we determined that age affected their refrigerator lighting preferences. Limited to the optimal brightness of lighting, a previous study found that older people prefer higher luminosity due to the normal aging of their vision [16]. More specifically, as the pupil size decreases with age, less illuminance reaches the retina [17]. This explains why older people require higher illuminance levels. A similar tendency has been revealed in other studies that showed higher illuminance levels are expected by older users, which suggests adaptive illuminance is relative to age group [18, 19]. In fact, we observed that older participants preferred the front placement of lighting, while younger ones complained about its glare. In terms of the chromaticity of lighting, older groups showed stronger preferences for the magenta-nuanced lighting, which they evaluated to be more luxurious. In this way, this study provides evidence that designers should consider lighting just as they do other types of visual elements.

Nonetheless, the findings in this study are limited to the given experimental settings. For example, identical lighting could look different depending on ambient lighting. In our experiment, we set an ambient lighting of neutral W with CCT of 6000 K, which will appear as a cool W when the kitchen is lit with lower CCT. Future study should consider properties of ambient lighting to draw conclusions with higher practical implications. Additionally, this study focused on a single product and a single-sex user population. The gender dependent preference might be reflected in the result. Future study should recruit male participants to confirm the research result. Methods and theories should be customized to optimally fit to given items and contexts.

Nevertheless, this study is one of few practical approaches that has involved actual lighting stimuli and explored aesthetic quality judged by people. Although more advanced experiments should follow, this study provides data designers can articulate for their

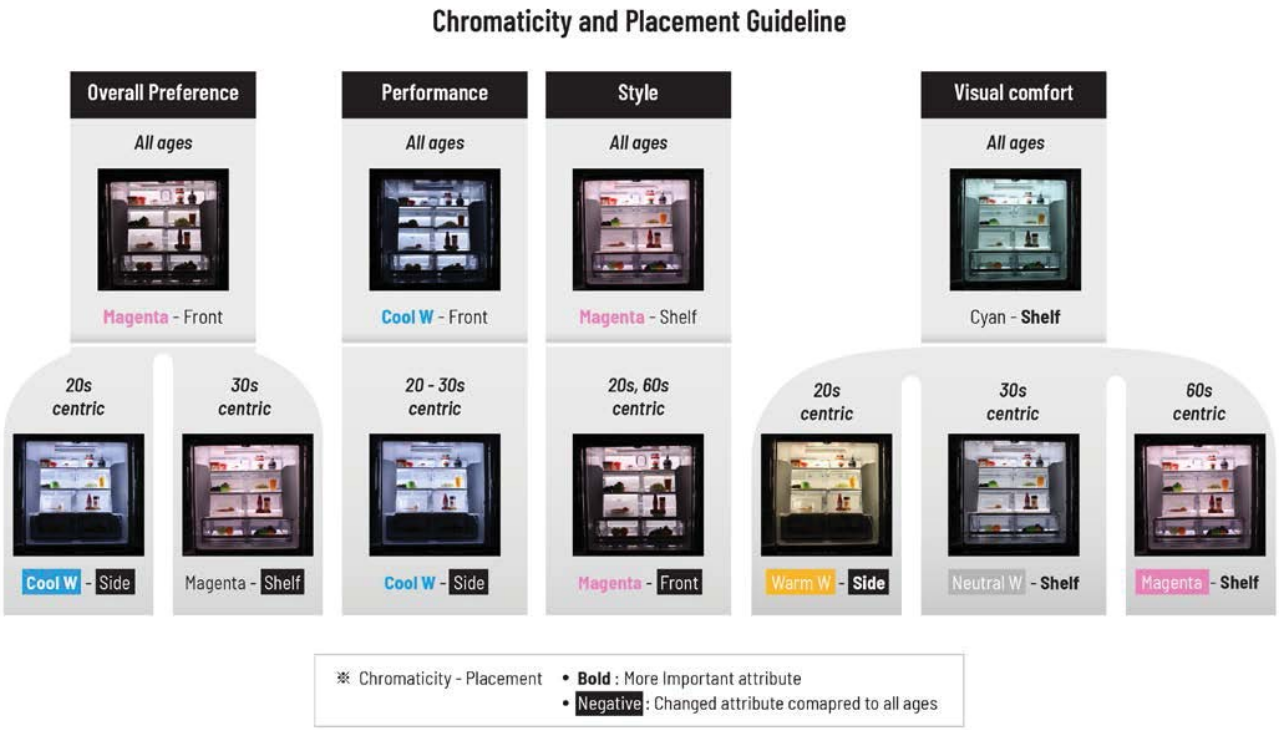


Figure 3. *Guidance of selecting chromaticity and placement according to the target group. Bold text implies more critical attribute on target criteria category. The negative-colored text illustrates the different attribute condition for particular age group, compared to the best lighting conditions for all ages.*

design practice. In addition, this study included consumer characteristics, such as age, so that our findings may have greater practical value. We expect this study will encourage further human-centered lighting studies to contribute to a reliable database that designers can easily use to develop new ideas in design practice.

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