# Reading Emotion of Color Environments: Computer Simulations with Self-Reports and Physiological Signals

**So-Yeon Yoon and Kevin Wise**

**Abstract** The affective experience of a color environment has rarely been tested in actual physical settings. In addition to the challenges of manipulating and controlling colors in a real-world setting, an environment with multiple attributes and colors is more difficult to empirically study. Advanced computer graphic technology allows photorealistic representations of an environment, with the ability to control visual attributes and manipulate colors in the environment. Using Kobayashis color image scale (CIS) theory (Kobayashi in Color Res Appl 6:93–107, 1981) [1] and multimodal measures of user experience based on the interaction of emotion and cognition in processing visual messages, this study explores the feasibility of this framework for future research in color emotions. Ultimately, this study aims to support decision makers of commercial and health-care environments with a more reliable and empirical basis for user experience.

**Keywords** Emotion • Affective experience • User experience • Color • Environment • Bio-signal • Physiology

## 1 Introduction

Color is known to evoke emotional reactions and is thus a critical consideration for the planning and design of built environments. Although existing literature acknowledging the significance of color on people both emotionally and psychologically, little has been proven through empirical testing of what different color

S.-Y. Yoon (✉)
Cornell University, MVR Hall, Ithaca, NY, USA
e-mail: sy492@cornell.edu

K. Wise
University of Illinois, Gregory Hall, Urbana, IL, USA
e-mail: krwise@illinois.edu

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environments mean to people. The spectrum of research on color is very broad; however, a recent meta-analysis of more than 3,000 citations [2] displayed inconsistent views and few empirical findings regarding the emotional and psychological effects of color. The challenge in controlling and manipulating color variables (and potentially confounding variables such as light quality) is amplified when the target is a real-world environment.

Today's advanced computer-simulation techniques can shed light on empirical color studies. High-fidelity computer simulations offer great advantages in representing real objects and environments while controlling the variables of interest and the experimental settings, thus minimizing confounding elements. Bateson and Hui [3] claimed that such realistic images of settings can lead to results similar to what would be found in actual environments.

Although real-world testing is difficult, today's advanced computer graphics technology offers new possibilities for high-fidelity simulations. Over the last few years, applications of three-dimensional (3D) computer graphics have rapidly expanded in many areas such as psychological therapy, patient education, and health-care facility design. In a realistic simulation setting, the physical conditions of existing or potential physical spaces can be manipulated and tested for their impact on people. Therefore, design decision makers can predict the user's experience.

This study is part of a larger quest to gain evidence-based knowledge of the cross-cultural meaning of interior environments for global marketers and design decision makers of health-care facilities. This study experimentally tested color emotions in computer-simulated environments using high-fidelity graphics. Multimodal measures of emotional responses were explored using subjective self-reports for semantic and emotional responses, in addition to two physiological measures for emotional experiences: skin conductance and corrugator supercilii. With this study, we propose a new approach toward better understanding emotions in color environments using a proof of concept experiment. This study aims to develop an empirical research framework to explore the mind and body interaction to explain and further study the psychological and emotional effects of a color environment on people in the environment.

## 2 Affective Meaning of Color Environments

Color is one of the most important visual properties in every designed environment. Color researchers have investigated the association of color to many different variables including preference, meaning, and psychological effects. However, much effort has been on individual colors rather than combinations. Classic color-preference studies [4] suggested that people favor one color and tend to consistently choose it over other colors. Whitfield [5] studied wall color preferences for residential interiors. The results indicated that individual differences in gender, age, and social status were related to their color preference. Yoon et al. [6] demonstrated significant differences in interior color meanings represented in a series of adjectives between young and older adults in their experimental study. Ireland et al. [7] examined different preferences in color saturation levels among people with different anxiety levels. They found that participants with a high-anxiety level preferred less-saturated shades across six colors tested than did participants with a low-anxiety level.

Osgood et al. [8] suggested that meaning is a process linked to linguistic and situational variables of the individual. In other words, meaning is an individual's interpretation and expression of ideas rooted in his or her own prior experience, which is beyond the immediate experience. According to Butterfield [9], color meaning in interiors is defined as a subjective interpretation of the designed environment based on an individual's reaction to the colors or the color combinations.

Rapoport [10] stated people form their interpretation and meaning of an environment from the cultural norms for the appropriate use of design elements in his well-known book, The Meaning of the Built Environment. Therefore, different sociocultural groups have different meanings for the built environment, and similar meanings occur among the people who belong to the same sociocultural group and share similar experiences.

Beyond the different backgrounds of users and individual differences, measuring color emotion in built environments is complicated because one color has multiple dimensions and an environment seldom consists of a single color. To conduct systematic research of color combinations, Kobayashi [11, 12], of Nippon Color & Design Research Institute developed the color image scale (CIS) to understand how a single color and combinations affect emotions. His research focuses on the association of colors and words (i.e., adjectives) describing feelings and psychological emotions. Kobayashi provides a 180-word Image Word Database of feelings such as cheerful, chic, clean, domestic, enjoyable, free, fresh, friendly, and graceful connected to more than 1,000 color combinations. The color combinations were suggested in four application fields: fashion, interior design, product design, and visual media.

The CIS was devised by the use of analysis of variance, cluster analysis, factor analysis, and the semantic differential method. Kobayashi claims that the associations of colors to image words are based on semantic axes (e.g., cool/warm and soft/hard) and can be used for universal application. His research methodology and practical application guidelines have been widely accepted by major industries in many countries in Asia as well as in Europe. Kobayashis theory has been examined through studies in a variety of contexts including interiors, e.g., [13]. In addition to the inherent complications in empirical research with color environments described here, known issues in accurate measures of emotional responses must be addressed in terms of the current study.

## 3 Measures of Emotion

Emotional response can be measured in at least three different ways affective reports, physiological reactivity, and overt behavioral acts [14]. In this study, we only considered self-reports and physiological measures to understand affective experiences.

### 3.1 Self-Reports

One of the most common methods to understand and evaluate emotional responses to designed objects has been adjective-based subjective self-reports. Many affect inventories have been developed specifically to measure people's reports of internal feeling states. Originally, Wundt [15] labeled the three basic dimensions of affective meaning among stimuli (i.e., words, objects, events) pleasure, tension, and inhabitation. Subsequent empirical work has confirmed Wundt's theoretical categories that pleasure, arousal, and dominance are pervasive in forming judgments for a broad range of symbolic and perceptual stimuli [16].

Despite the quest originally started by psychologists for affect inventories measuring emotion, it has been only in the last two decades or so that researchers in marketing looked at emotions combined with user experience. Among various approaches to emotions, it is consensual that emotions are a multifaceted phenomenon consisting of subjective feelings, physiological reactions, and behavioral intentions (approach/avoid). Mauss and Robinson [17] stated that a consensual, componential model conceptualizes emotions as experiential, physiological, and behavioral responses to personally meaningful stimuli (Fig. 1). Adjective-rating scales have been widely adopted in measuring human experience, both semantic and affective. Those self-reports can be valid and are likely to work where one is experiencing an emotion and he or she must be aware of and capable of reporting on momentary feelings. To address this problem, Lang [18] devised a picture-based instrument called the Self-Assessment Manikin (SAM) to measure the pleasure, arousal, and dominance associated in response to a stimulus.

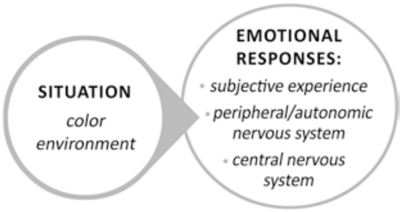
The SAM has been popularly used by subsequent researchers to measure emotional responses in a variety of contexts including reactions to images, sounds, pictures, and advertisements [16]. More recently, the Product Emotion Measurement instrument (PrEmo; http://www.premotool.com/), an online nonverbal method, was introduced and popularly used for quickly assessing peoples affective experience. Previous studies claimed that environmental stimuli can affect pleasure and arousal and also influence behaviors [19]. Arousal has been recognized as a significant dimension of human emotion [20]. As seen in Fig. 1, environmental psychologists Mehrabian and Russell [21] proposed the stimulus–organism–response (S-O-R) paradigm to explain the relationship among stimuli, environments, responses, and behavioral intention in the context of marketing and consumer behavior research.

### 3.2 Physiological Measures

Using self-reports (whether verbal or nonverbal), it is relatively simple to tell a particular emotion. However, scientific evidence of emotion remains one of the most challenging yet important issues in affective engineering. In order to account


**Fig. 1** Research framework based on the S-O-R model

**Fig. 2** A component model of emotions




for such a challenge, the application of psychophysiological measures to the study of cognitive and emotional processing of information is considered as one of the greatest methodological advances in the field of media psychology [22]. Psychophysiological measures of emotional processing of media include electromyography (EMG), galvanic skin conductance, heart rate variability, and electroencephalography (EEG).

Unlike language-based subjective self-reports, the key benefits of psychophysiological measures include the ability to index dynamic mental processes in real time (Fig. 2).

Abundant research has been conducted on the connection between emotion and peripheral nervous system activity, which is the interaction between mind and body. Media psychologists have used indices of peripheral nervous system activity to measure emotional processing of media content based on the concept that the mind is manifested by brain activity influenced by signals from the body. Psychophysiological measures of emotion focusing on central nervous system activity are developed to directly index specific brain activity (central nervous system) during emotional experiences. However, brain activities (EMG) are not considered within the scope of the current study.

### 3.2.1 Arousal and Valence

Among many discrete feeling states (i.e., emotion and affective experiences), researchers have identified the most widely superordinate dimensions as arousal and valence [16]. Learning from media psychologists interested in how the mind processes emotional content for many decades, psychophysiological measures reliably and validly index superordinate dimensions of emotion rather than discrete affective feeling states [23] such as anger, enjoyment, fear, and surprise.

The dimensional theoretical perspective on human emotion arousal and valence has been most widely adopted by media psychology researchers utilizing psychophysiology measures [22]. According to the dimensional approach, emotion as affective experience has two dimensions of motivation: Valence is the directional dimension of pleasant versus unpleasant emotional responses, and arousal is the intensity dimension of emotion [24]. Skin conductance and facial EMG are the two psychophysiological measures extensively used in research on emotional process in media.

#### 3.2.2 Skin Conductance: A Measure of Arousal

The peripheral nervous system comprises the autonomic and somatic branches. Skin conductance, also known as galvanic skin response (GSR), indexes sympathetic activation in the autonomic branch of the peripheral nervous system. Skin conductance is known to have a reliable correlation to arousal. Another advantage of skin conductance is that GSR provides continuous data and detects a very subtle level of arousal [22].

#### 3.2.3 Facial EMG: A Measure of Valence

Facial EMG, extensively used as a psychophysiological measure of the valence of emotional processing, consists of the somatic nervous system underlying facial muscle activity for emotional expression. A substantial body of psychophysiological research has identified that specific facial muscles are consistently activated responding to variance in the valence of emotion. The specific muscles are the corrugator supercilii, orbicularis oculi, and zygomaticus major. Researchers studying emotional processing of media have exclusively focused on measurement of activity within these specific facial muscles [25]. Previous work indicates that the zygomaticus major muscles and orbicularis oculi muscles measure pleasantness of emotional valence, and the activity of the corrugator supercilii muscles increases according to the unpleasant dimension of valence [26, 27].

## 4 Method

### *4.1 Participants*

Thirty-four undergraduates were recruited from an introductory communication class at a large Midwestern University to participate in this study. Students received course credit for their participation. Physiological and self-report data

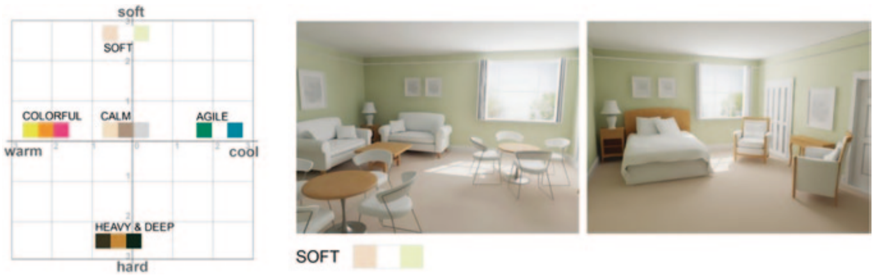



**Fig. 3** Five color combinations for the study and color simulation example

from two participants had to be discarded due to experimenter error, equipment malfunction, or excessive noise in the data, resulting in a significant number of missing values. Therefore, final analyses reflect data from 32 participants.

## *4.2 Stimuli*

For the study, five color palettes based on Kobayashis color image theory were developed, and they were applied to two different types of interiors one bedroom and one public dining space. Color stimuli were developed using 3D Studio Max with Vray (Autodesk, San Francisco, CA) photorealistic rendering engine and presented on the a computer screen.

Based on Kobayashis color theory [1, 11, 12] and the CIS, five of the most distinct color combinations were selected and simulated to represent five color schemes, i.e., soft, colorful, calm, heavy and deep and agile, using computer-generated 3D models. Color combinations selected for the experiment are considered suitable for interiors, and thus, the presented color environments are emotionally very subtle stimuli that might not stimulate individuals to process the color information in a distinct manner. Color Spyder (Datacolor, Lawrenceville, NJ) was used to calibrate colors on the screen. Figure 3 shows the five color combinations chosen for the study on the map of two main axes—soft/hard and cool/warm—and simulated interior shots of soft color combination.

## *4.3 Procedure*

Participants spent 30 s on each of five color combinations. The order in which each color combination was viewed was randomized for each participant. There were no prior manipulations of any of these tasks. Participants were instructed to view each color combination. The only other instruction was not to look away from the color environment stimuli provided during the 30-s period.

### 4.4 Adjective Ratings

Nine adjectives from the CIS chart known to bring distinct feelings were used in the 7-point Likert scale adjective ratings to examine Kobayashis color image theory. The adjectives include pretty, wild, warm, neat, soft, cool, agile, calm, metallic, colorful, heavy and deep, and hard. Five professional interior designers selected the most agreeable color combination from each group representing the adjective.

In addition, the participants were asked to evaluate the color environments in terms of arousal and valence by using the SAM scale of Lang [18].

### 4.5 Dependent Variables

Adjective rating and the SAM scales were administered, and the data were collected using MediaLab (EmpiriSoft, New York, NY). Physiological signals were measured, amplified, and recorded using Coulbourn V-series modules (Coulbourn Instruments, Whitehall, PA) linked to a PC computer. The WinDaq software program (DATAQ Instruments, Akron, OH) coordinated the sampling and storage of physiology data. All physiological signals were sampled at 167 Hz.

#### 4.5.1 Skin Conductance

Skin conductance was measured by placing two 8 mm silver/silver chloride (Ag/AgCl sensors) (InVivo Metric, Healdsburg, CA) on the palm of each participant's non-dominant hand after the area was wiped down with distilled water to control for hydration. The skin conductance signal was sampled at 167 times per second and averaged off-line over each second of exposure.

#### 4.5.2 Corrugator Supercilii EMG Activity

Facial EMG activity was recorded by placing two 4-mm Ag/AgCl (InVivo Metric, Healdsburg, CA) electrodes over each participants left eyebrow (corrugator supercilii). Each signal was sampled at 167 Hz and averaged off-line over each second of exposure.

## 5 Results

### 5.1 Correspondence Between Self-Report and CIS

Figure 4 shows the position of the meanings on the profile graphs. The darker horizontal lines demonstrate how much participants agree with the meanings corresponding to the CIS.

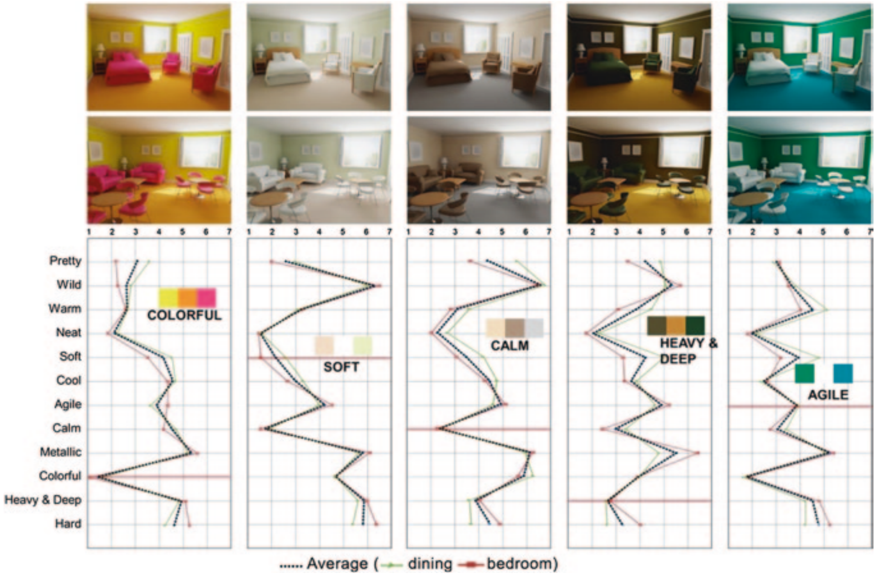



**Fig. 4** Profile analysis (1 = totally agree, 7 = totally disagree)

As shown in the profile graphs, the semantic ratings for two interior types (bedroom and public dining) were consistent throughout the five color combinations. Among the five, the agile combination was not perceived as agile. Except the agile combination, the other four combinations were rated as strongly agree with their CIS meanings. Throughout the five, it was found that neat feeling was rated as strongly agree. It is probably because the computer-simulated interiors do not display any additional items besides the main furniture. Ratings for soft and calm color combinations created very similar profiles; the two adjective items were rated consistently close to each other in all color combinations.

## 5.2 *Self-Report Arousal and Valence*

Figure 5 is average affective ratings of the five color combinations on the SAM scale plotted into a 2-dimensional affective space [20]. It was illustrated pleasant ratings for colorful, soft, and agile combinations while heavy and deep and calm combinations were rated neutral. Colorful was the only color combination rated as positive ratings in arousal. Compared to the other color combinations, the colorful consists of three colors with similar saturation (i.e., intensity or chroma) and value (i.e., lightness) levels. All five color combinations chosen for this study are considered analogous color schemes. For colorful and heavy and deep combinations, all three colors are next to each other on the color wheel; for soft, calm and agile, there are two adjacent colors and one neutral color in each combination.

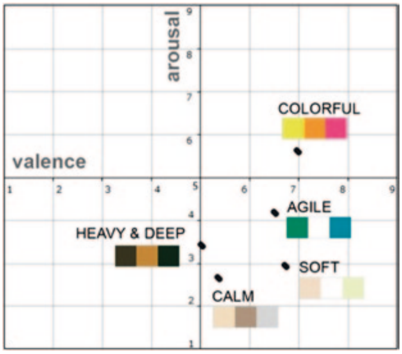



**Fig. 5** Five color combinations in a 2-dimensional affective space (SAM valence and arousal ratings)

Analogous color schemes are easily found in nature and color theories often characterize them as harmonious and pleasing to the eye. The colorful combination consisting of vivid colors was perceived the highest ratings in arousal and pleasant levels. Calm and soft color combinations with light grayish and pale tone colors received low arousal score. From the plot, no apparent correlation between arousal and valence scores was observed.

Participants reported soft and calm combinations similar in arousal rating, which is consistent with the profile analysis results. However, it was interesting to note that the soft combination was rated more pleasant than the calm combination. Calm and heavy and deep, the two least pleasant color combinations have more gray tones. While the two maps CIS and SAM do not present explainable associations, participants did rate the calm combination with the lowest scores in arousal.

## *5.3 Physiological Measures*

### 5.3.1 Arousal (Skin Conductance)

Figure 6 shows the second-by-second pattern of skin conductance level (SCL) (averaged across all participants) elicited by each color combination during the 30 s of exposure. There are two different features to consider when interpreting skin conductance data. The first feature to interpret is the skin conductance response (SCR) that occurs in the first few (1–4) seconds following stimulus onset. This is the electrodermal component of the orienting response (OR). The OR is most simply described as a What is it? response [28]. The purpose of the OR is to facilitate the encoding of unexpected or important information so that the organism can prepare an appropriate response. The relative magnitude of this phasic skin conductance reflects the level of novelty and/or importance of the stimulus. Because there is little important (from an evolutionary standpoint) information in the pictures that participants were exposed to, in this case the SCR likely reflects novelty.

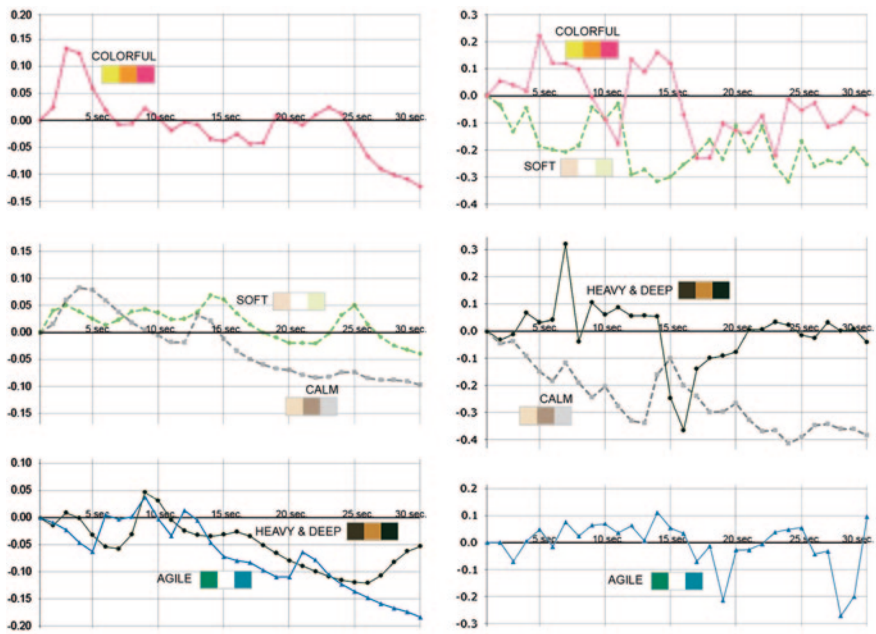



**Fig. 6** Change in skin conductance activation for 30 s (*left column*), change in corrugator supercilii activation for 30 s (*right column*)

Figure 6 (left column) suggests that the colorful combination elicited the greatest initial SCR across all participants. The soft and calm combinations elicited smaller initial peaks in skin conductance, and the agile and heavy deep combinations failed to elicit an initial response.

The second feature of the skin conductance data to consider is the pattern of activity over the entire period of exposure. Because these pictures are static and, in terms of threat or reward, does not contain a great deal of important information, one would expect SCL to gradually decrease over the duration of exposure. As seen by looking at the entire 30 s responses in Fig. 6, this was generally the case. The greatest sustained arousal was elicited by the soft combination, followed by the colorful combination.

### 5.3.2 Unpleasantness (Corrugator Supercili)

Figure 6 (right column) shows the second-by-second pattern of corrugator activation (averaged across all participants) elicited by each color combination during the 30 s of exposure. The magnitude of responses is grouped loosely by darkness of combination, with agile, colorful, and heavy deep eliciting more activity than calm and soft.

## 6 Conclusion

The affective or emotional quality of environments is becoming more important in today's highly competitive marketplace. Emotional dimensions often lead to different behavioral decisions, and a delightful environmental experience belongs to the affective rather than to the rational domain. In health-care environments, understanding emotional and psychological effects is a critical user experience for both patients and caregivers. Considering the direct and indirect influence on recovery and workplace performance and satisfaction, design decision makers are learning the role of emotional satisfaction beyond efficiency and effectiveness in design.

Color is one of the fundamental design elements in every environment. Despite numerous efforts to understand the effect of color environments in such fields as design and marketing, little empirical evidence exists due to the inherent challenges in studying the topic in the real-world environment with language-based self-reporting.

This study proposes a new approach for examining this long-lasting area of research, with computer-simulations and multimodal measures of emotion learning from clinical psychology and media studies. High-fidelity simulations have the freedom of representing photorealistic views of built or virtual environments while controlling every environmental element, including color and lighting.

Previous studies noted critical drawbacks in verbal instruments to study affective experiences for various constituents, including the elderly, the cognitively impaired and subjects from different language backgrounds [6]. Psychophysiological measures are used in addition to self-reporting to better capture the emotional responses of users to different color environments for this study. Physiological measures help indicate peoples emotional and cognitive states while interacting with represented environments by understanding their physiological states.

In this study, we administered both self-reports and physiological measures to better examine color emotions in two types of the same-sized environments, a bedroom and a public dining room. Adjective-rating scales [1], the SAM pleasant-valence arousal scale and psychophysiology measures skin conductance and facial EMG were used to test five color combinations known to draw distinct images from the CIS [1].

Self-reporting data showed that participants' assessments of the characteristics of each color combination accurately reflected the names of each combination in the CIS. The SAM ratings showed that these combinations were generally perceived as calm and pleasant. Physiological data showed that brighter combinations tended to elicit both greater arousal and greater unpleasantness.

The limitations of this study, and any study using computer simulations and psychophysiology measures, include validity issues the extent to which the simulation-based experimental situations resemble real-life experiences. The simulation certainly provides a filtered experience through the screen, even when the computer-generated content is completely life-like. In addition, the procedures of psychophysiological data collection, with electrical sensors and the preparation process, may introduce anxiety.

As an attempt to more systematically simulate color environments, we borrowed interior color schemes from Kobayashis color theory. To better investigate the link between environmental color properties and physiological signals, simpler and more intense color stimuli can help establish the knowledge base at the exploratory research phase. While the adjective ratings on the color images were somewhat consistent with the CIS, these verbal concepts may or may not relevant to the purpose of designing more emotionally satisfying environments, beyond understanding different meanings. Future work should further explore the impact of color saturation and value levels, based on our findings that show more effects on emotions than hues and focusing on emotions by using skin conductance, facial EMG, and heart rate. Although heart rates were not considered for this study, the cardiac signal is known to be a good indicator of cognitive resources when encoding information from the environment.

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