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Effects of Visual Environment Under Different Thermal Conditions on Perceptual, Psychological, and Neural Responses in Patient Rooms: A Virtual Reality Study

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Abstract

Background/Objectives: Discrepancies between measured indoor temperature and perceived comfort in hospital settings raise concerns about the role of visual environment in shaping sensory perception and psychological well-being. This study examined the effects of wall finish, wall color, and color temperature on thermal perception, visual perception, affect, perceived restoration, and EEG responses in patient rooms using virtual reality. **Methods**: In total, 192 participants were assigned to either a 20 °C or 25 °C ambient-temperature condition and exposed to one of 12 virtual patient-room scenes in a between-subjects experiment. Pre- and post-experimental survey data and EEG data were analyzed. **Results**: Compared with those tested at 20 °C, participants tested at 25 °C underestimated room temperature more and rated wall finish, wall color, and color temperature as more visually comfortable. At 20 °C, participants exposed to the latex paint finish condition rated the wall finish as visually more comfortable and reported greater willingness to rest than those in the vinyl wallcovering condition; however, EEG regression showed higher occipital alpha/beta ratio index values for vinyl wallcovering, indicating a relaxation-related EEG response. Under both temperature conditions, yellow walls led to warmer temperature estimation than blue or white walls. At 20 °C, warm color temperature produced warmer thermal sensation, more visually comfortable color-temperature ratings, higher room pleasantness, and greater willingness to rest than cool color temperature. **Conclusions**: Differences in perceptual, psychological, and EEG responses to patient-room visual environment should be interpreted together with ambient-temperature conditions in healthcare settings.

Keywords: patient rooms; visual environment; thermal perception; visual perception; affect; perceived restoration; virtual reality

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1. Introduction

Patient satisfaction with healthcare services has become an important focus in healthcare-quality research, because service quality is closely related to whether patients' expectations and needs are met [1]. From the patient perspective, healthcare quality is shaped by multiple service-delivery factors, including provider–patient communication, access to care, waiting time, and physical environment [2]. Indoor environmental quality in healthcare facilities is also relevant to patient-related and staff-related outcomes, including comfort, stress, recovery-related experience, and work effectiveness [3]. Healthcare building performance, including room layout, air quality, and lighting, has also been discussed in relation to patient satisfaction, recovery-related outcomes, and safety [4]. Patient rooms deserve particular attention because patients spend much of their hospital stay in these rooms [5], where rest, observation, treatment, and daily care take place together. Unlike ordinary indoor spaces, patient rooms need to support clinical care while also shaping comfort, emotional response, activity, social connection, and sensory experience during hospitalization [6]. A practical problem remains because requirements for standard patient rooms are often omitted or limited to temperature and humidity, while patients may still feel uncomfortable and patient-room thermal conditions vary widely across settings [7]. Subjective evaluations in healthcare settings also indicate that perceived service environments are related to patient perceptions, service quality evaluation, and revisit intention, suggesting that patient appraisal is not limited to clinical care alone [8]. Recent patient-room studies combining objective environmental measurements with subjective evaluations further support the need to examine thermal perception and room appraisal under controlled ambient-temperature and visual-environment conditions [9,10].

The indoor visual environment is addressed in building-environment and lighting standards as an indoor environmental design domain concerned with daylighting, artificial lighting, visual task performance, safety, comfort, health, and well-being [11]. Within this broader indoor visual-environment scope, wall finish, wall color, and color temperature can be linked to visible material or surface appearance, room color, and lighting condition, which provides a basis for considering them as room-scale visual factors in patient-room evaluation [12,13]. Immersive virtual-environment research has reported associations between visible interior materials, such as wood and concrete, and thermal perception or tolerance [14]. Patient-room evidence involving color and art suggests that room-level color conditions may be related to recovery-related outcomes, as a randomized controlled trial after total hip or knee arthroplasty reported higher postoperative quality-of-life scores in colored patient rooms than in conventional patient rooms [15]. Color temperature is relevant to patient-room evaluation because participants in a simulated patient room rated higher color-temperature lighting conditions as less comfortable and less natural than lower color-temperature conditions [16]. Controlled laboratory evidence has also reported associations between color temperature and thermal sensation under specific temperature conditions [17]. Indoor-environment research has combined perceived restoration assessment with EEG indicators to examine restorative and cognitive responses to environmental exposure [18]. Existing studies therefore provide separate evidence for material appearance, room color, lighting condition, perceived restoration, and EEG responses, but they have not compared wall finish, wall color, and color temperature within the same patient-room context under different ambient-temperature conditions. To address this gap, this study used a virtual reality experiment to compare thermal perception, visual perception, affect, perceived restoration, and EEG responses across wall-finish, wall-color, and color-temperature conditions in patient rooms under two ambient-temperature background conditions, 20 °C and 25 °C.

2. Literature Review

2.1. Theoretical Foundations

Patient-room visual environment is continuously perceived during rest, observation, treatment, and care, and its role should be discussed beyond visual appearance alone. Cross-modal sensory perception provides a theoretical basis for explaining why visual characteristics may contribute to thermal judgment. People can form associations between

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sensory domains, including temperature and visual attributes such as color [19]. Indoor thermal–visual perception studies have also shown that visual conditions may interact with thermal perception under specific experimental conditions [20]. These findings support the examination of thermal perception and visual perception as perceptual responses to patient-room visual cues. Embodied accounts of architectural experience further argue that built environments are perceived through situated bodily experience rather than through visual appearance alone [21]. This perspective is relevant to patient rooms because wall surfaces, colors, and lighting are experienced during continuous room-scale exposure, which may involve physiological responses as well as conscious appraisal. Attention restoration theory explains how environmental settings can support restorative experience [22], while stress reduction theory and related embodied accounts suggest that environmental qualities may be linked with affective and cognitive responses [23]. These theories support the inclusion of affect and perceived restoration as psychological responses, and EEG responses as a neural indicator. Therefore, wall finish, wall color, and color temperature were selected as visible room-scale cues, and this study examined perceptual, psychological, and neural responses to these cues under two ambient-temperature backgrounds.

2.2. Visual Environment of Patient Rooms

Indoor environmental comfort is commonly divided into thermal, visual, acoustic, and respiratory comfort, placing visual comfort within the evaluation of indoor environments [24]. Healthcare environment research indicates that physical environmental factors are related to the well-being of patients, families, and healthcare staff [25]. In patient rooms, the visual environment can be understood as visible room-scale information perceived during rest, observation, treatment, and care. Wall finish, wall color, and color temperature correspond to surface appearance, color condition, and lighting condition at room scale. In a slightly cool environment, indoor finishing materials produced different visual warmth and thermal comfort evaluations. Wood was perceived as warmer than concrete, wallpaper, and brick, and wood-related impressions such as warmth and coziness contributed to thermal comfort [26]. Patient-room color has been examined more directly in clinical room studies. In simulated pediatric patient-room design, blue, yellow, and white have been examined as wall-color conditions, and color preferences were found to vary according to color type and participant characteristics [27]. Orange rooms were evaluated as eye-catching, inviting, pleasing, encouraging, and sincere, whereas blue rooms were evaluated as comforting and refreshing [28]. Colored patient rooms were also associated with higher postoperative quality of life after total hip or knee arthroplasty, although mood differences were not significant [15]. Simulated patient-room lighting research found that conditions of 5000 K and above were rated as less comfortable and less natural than lower color-temperature conditions [16]. Most of this literature treats material appearance, room color, and lighting condition as separate topics, and direct comparisons of these three patient-room visual factors within the same patient-room context remain limited.

2.3. Thermal Environment of Patient Rooms

Thermal environment in patient rooms involves physical conditions such as air temperature, mean radiant temperature, air movement, and humidity, while clothing insulation and activity level can further affect occupants' thermal sensation [29]. In a hospital patient study, patient-reported thermal sensation vote differed from predicted mean vote, and Griffith's method produced a neutral temperature range from 16.2 to 28.8 °C [30]. Although air temperature does not represent the whole thermal environment, it remains a practical parameter for patient-room environmental control because requirements for

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standard patient rooms are often omitted or limited to temperature and humidity, while patients may still report discomfort [7]. Visual conditions may also be relevant to thermal experience, as a structured review reported thermal perception differences after visual-environment manipulation in 80% of included experiments [31]. Color temperature provides a more specific visual cue, with recent evidence suggesting that higher color temperature is associated with cooler thermal sensation and that this relationship varies with thermal background, air temperature, and exposure duration [32]. Patient-room temperature also differs across clinical settings. In a longitudinal study of 18 patient rooms and 522 surveys, preferred temperature peaks ranged from 20.1 to 21.8 °C in cardiology rooms and from 25.3 to 26.8 °C in oncology rooms [33]. Patient type may further contribute to this variation, as orthopedic patients were more sensitive to thermal change than healthy individuals and had a lower neutral standard effective temperature of 17.7 °C compared with 21.7 °C [34]. These reported values suggest that patient-room thermal experience may cover cooler conditions close to 20 °C and warmer conditions close to 25 °C, making a single fixed comfort temperature insufficient for representing patient-room thermal backgrounds.

2.4. Patients' Perceptual, Psychological, and Neural Responses in Hospital Environments

Stroke patient-room research links room environmental features with emotional response, activity, social connection, environmental control, and sensory comfort [6]. Interior material studies also show that one scene may involve several response dimensions. Wood and red brick produced warm visual impressions, wood received the highest ratings for thermal comfort and pleasure, and white painted scenes received higher ratings for restoration and arousal [35]. This evidence suggests that room evaluation can involve thermal perception, visual perception, affect, and perceived restoration beyond a single overall preference judgment. Patient-room research on green visual elements reported different restorative utilities for indoor plants, nature window views, green nature views, plants, and green decor [36]. In room-based environmental studies, perceived restoration can be reflected in immediate subjective appraisal of the setting. EEG evidence provides a neural-response perspective for indoor-environment evaluation. A review of EEG studies on indoor thermal environments found mixed results and no accepted EEG index for thermal perception [37]. Indoor artwork research found that nature-themed artworks increased alpha activity in frontal, central, and occipital regions and produced higher restorative evaluation scores than blank walls [38]. Lighting research suggests that the alpha/beta ratio may reflect relaxation-related responses, as fatigue-based lighting increased this ratio at 17 of 19 electrodes [39]. These findings indicate that patient-room evaluation can involve perceptual, affective, restoration-related, and neural response dimensions, while evidence remains limited for examining these dimensions together with wall finish, wall color, and color temperature in the same patient-room context.

3. Methods

3.1. Study Design

This study used a between-subjects virtual reality factorial experiment to examine how the patient-room visual environment influenced thermal perception, visual perception, affect, perceived restoration, and EEG responses under two ambient-temperature conditions. As shown in Figure 1, the research route started from a real patient-room context, from which the main environmental factors were extracted. The visual environment included wall finish, wall color, and color temperature, while the thermal environment was represented by ambient temperature. These factors were organized into a factorial experimental design, in which 12 visual scene combinations were presented under two ambient-temperature conditions, resulting in 24 experimental conditions. A standardized virtual patient-room model was then developed in Unity (version 2021.2.17; Unity Technologies, San Francisco, CA, USA), and participants were assigned to one experimental condition for the formal VR and EEG experiment.

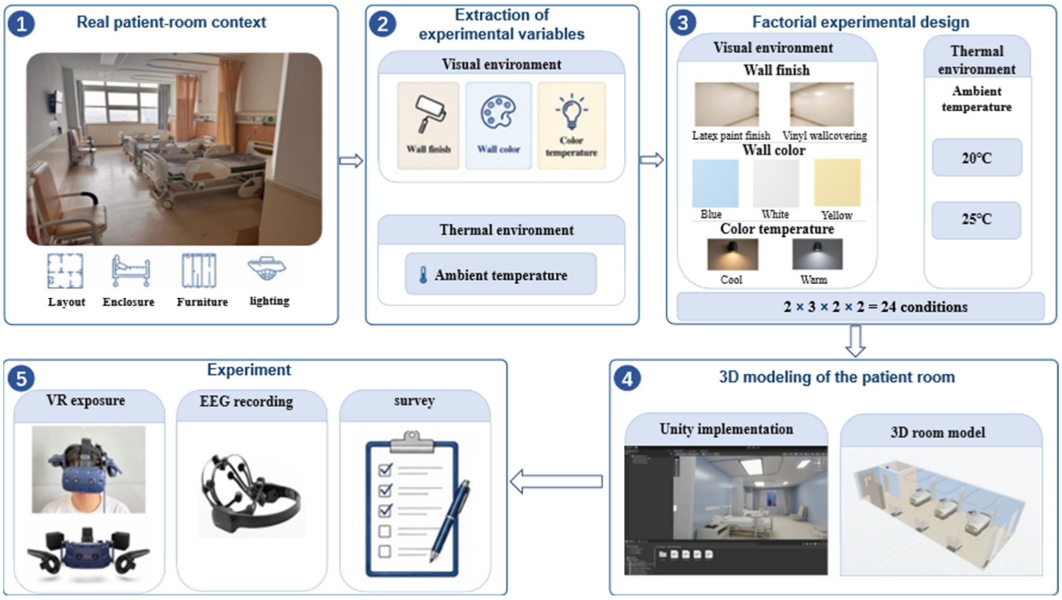

Figure 1. Study design and development process of the virtual patient-room experiment.

3.2. Development of Virtual Scenes

The virtual patient-room scene was developed based on a real hospital patient-room context. Before digital modeling, the research team conducted an on-site investigation of the reference patient room and documented its spatial layout, enclosure interfaces, bed arrangement, furniture configuration, wall surfaces, curtains, ceiling lighting, and participant-view direction. These elements were used to construct the initial patient-room model. The standardized model was then developed in Unity using a high-definition render pipeline and presented through SteamVR (version 2.3.2; Valve Corporation, Bellevue, WA, USA). The VR presentation provided an immersive first-person viewing condition, and participants observed the patient-room scenes from a fixed seated viewpoint consistent with the experimental procedure. Spatial geometry, room layout, major furniture, non-target room elements, and the participant viewpoint were kept constant across all experimental conditions. The patient-room layout and the corresponding three-dimensional digital model developed from the reference room are shown in Figure 2.

To improve scene consistency and visual realism, all virtual scenes were checked before the formal experiment to ensure that room scale, object position, viewing distance, participant viewpoint, and major non-target visual elements were consistent across conditions. The scenes were presented through the same VR system and software settings throughout the experiment to maintain a consistent visual-display environment. Because the study relied on a head-mounted display, color appearance and lighting impression were device-dependent. Therefore, wall color and color temperature were interpreted as controlled VR-rendered visual conditions rather than as exact physical colorimetric or spectral measurements.

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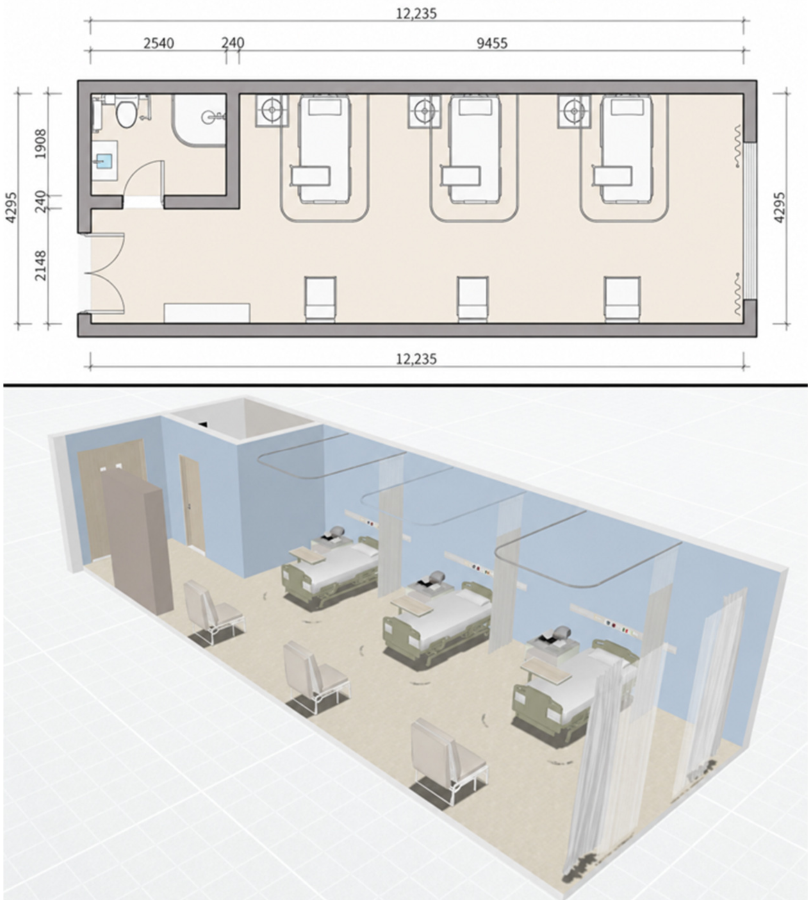

Figure 2. Patient-room model used in the VR experiment.

Four environmental attributes were manipulated or controlled in the virtual patient-room experiment: wall finish, wall color, color temperature, and ambient temperature. Wall finish had two levels: latex paint finish and vinyl wallcovering finish. These finishes were defined as rendered visual surface appearances rather than as claims about the physical performance of real construction materials. The latex paint finish was rendered as a relatively matte, low-gloss, and visually softer wall surface, whereas the vinyl wallcovering finish was rendered as a smoother, more reflective, and visually harder surface appearance. Wall color had three levels: blue, white, and yellow, which were selected to represent broad cool, neutral, and warm wall-color categories commonly used in studies of color-related thermal impressions, rather than exact colorimetric values. This manipulation was used to compare thermal perception, visual perception, affective response, perceived restoration, and EEG responses across different wall-color conditions in a controlled virtual patient-room setting. Color temperature had two levels: warm and cool. Because head-mounted displays have device-dependent colorimetric and spectral characteristics, color temperature was treated as a VR-rendered warm or cool lighting condition rather than as a directly calibrated physical light-source property. Ambient temperature had two levels, 20 °C and 25 °C, and was controlled in the physical laboratory rather than rendered in VR. These two temperature levels served as cooler and warmer ambient-temperature background conditions for examining responses to patient-room visual factors. The environmental attributes are summarized in Table 1.

Table 1. Virtual scenes with different visual and thermal environments.

Scenes	Visual Environment			Thermal Environment
	Wall Finish	**Wall Color**	**Color Temperature**	**Temperature**
Scene 1	Latex paint finish	Blue	Warm	20/25 °C
Scene 2	Latex paint finish	Blue	Cool	
Scene 3	Latex paint finish	White	Warm	
Scene 4	Latex paint finish	White	Cool	
Scene 5	Latex paint finish	Yellow	Warm	
Scene 6	Latex paint finish	Yellow	Cool	
Scene 7	Vinyl wallcovering	Blue	Warm	
Scene 8	Vinyl wallcovering	Blue	Cool	
Scene 9	Vinyl wallcovering	White	Warm	
Scene 10	Vinyl wallcovering	White	Cool	
Scene 11	Vinyl wallcovering	Yellow	Warm	
Scene 12	Vinyl wallcovering	Yellow	Cool	

Note: The 12 visual scenes were generated by crossing 2 wall finishes, 3 wall colors, and 2 color-temperature conditions. Each visual scene was tested under two ambient-temperature conditions, 20 °C and 25 °C. Therefore, the full experiment included 2 × 3 × 2 × 2 = 24 experimental conditions.

3.3. Experiment Procedure and Environmental Control

The experimental procedure and environmental control are shown in Figure 3. Before each session, the laboratory was preconditioned to the assigned ambient-temperature condition, either 20 °C or 25 °C, using the room air-conditioning system. Ambient temperature and relative humidity were checked before participant entry and monitored throughout the session using digital temperature–humidity meters (Fluke 971; Fluke Corporation, Everett, WA, USA) placed at three measurement points in the experimental area. The measurement points included one near the participant’s seated position and two on both sides of the experimental area. All measurement points were positioned at approximately the participant’s seated head height to better represent the temperature and relative humidity conditions at the actual exposure location. The meters were kept away from air outlets, direct airflow, and heat-generating equipment to reduce local measurement bias. Testing started only after the measured room temperature had reached the assigned ambient-temperature condition and remained stable within the preset tolerance range. During testing, temperature and relative humidity were recorded at regular intervals, and relative humidity was maintained at approximately 50% to 56%. Participants were required to wear lightweight indoor clothing and remain seated throughout the experiment to reduce clothing- and activity-related variation in thermal perception. After introduction and written informed consent, participants completed the pre-exposure survey, followed by HTC Vive Pro Eye (HTC Corporation, New Taipei City, Taiwan) fitting and EEG preparation. A two-minute eyes-open EEG baseline was then recorded while participants maintained resting fixation. During the formal exposure, each participant passively viewed one assigned virtual patient-room scene for three minutes while EEG was recorded. Immediately after exposure, participants completed the post-exposure survey. Each participant viewed only one virtual patient-room scene to maintain an independent-samples design and to avoid carryover or order effects.

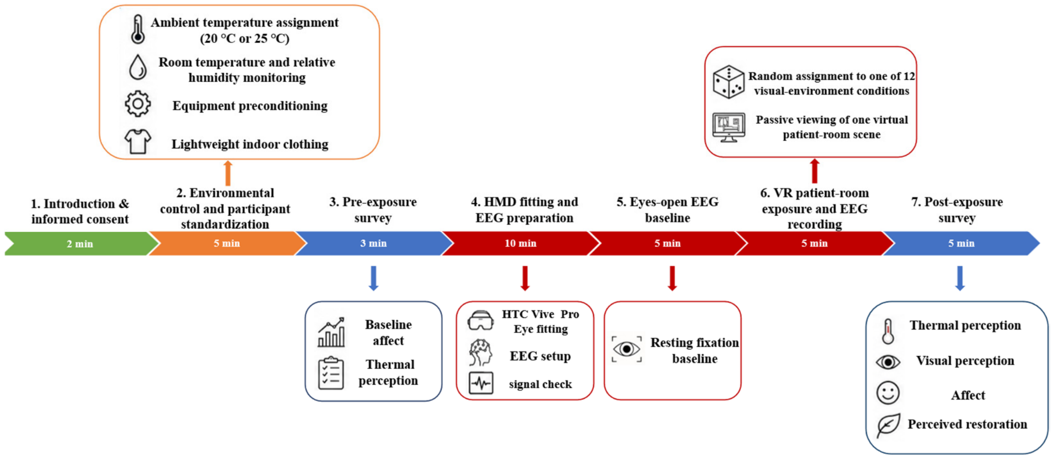

Figure 3. Experimental procedure and environmental control.

3.4. Pre- and Post-Experimental Survey Design

The experimental survey consisted of a pre-experimental survey and a post-experimental survey. The pre-experimental survey collected participant background information and pre-experimental affect. The post-experimental survey assessed thermal perception, visual perception, perceived restoration, and post-experimental affect after participants viewed the assigned virtual patient-room scene. Established standards or scales were used where available. Thermal sensation vote was used to assess thermal perception, and the Positive and Negative Affect Schedule (PANAS) was used to assess affect. The visual perception items were factor-specific survey items developed for the present virtual patient-room experiment and were not treated as a standardized visual comfort scale. Perceived restoration was operationalized using two immediate room-level indicators: room pleasantness and willingness to rest. These two indicators were analyzed separately and were used to represent participants' perceived restoration in the virtual patient-room scene. Thermal perception included temperature estimation and thermal sensation vote. Temperature estimation bias was computed as participant-estimated room temperature minus the actual ambient temperature, with positive values indicating overestimation and negative values indicating underestimation. Affect was assessed before and after virtual exposure using the Positive and Negative Affect Schedule. Positive affect and negative affect were calculated separately, and affect change scores were computed as post-experimental scores minus pre-experimental scores. The survey variables, item wording, answer options, and reference basis are summarized in Table 2.

Table 2. Experimental survey development.

Outcome Domain	Variable	Question	Measurements	Reference Basis
Thermal perception	Temperature estimation (°C)	What do you think the room temperature is in this virtual patient-room scene?	Numeric input (°C)	[14,31]
	Thermal sensation vote	Please rate your thermal sensation in this virtual patient-room scene.	−3 = Cold, 0 = Neutral, +3 = Hot	[40]
Visual perception	Visual perception of wall finish	How comfortable is the wall finish in this virtual patient-room scene?	1 = Uncomfortable 7 = Comfortable	[14,26,41]
	Visual perception of wall color	How visually comfortable is the wall color in this virtual patient-room scene?		[12,15,42]
	Visual perception of color temperature	How comfortable is the color temperature in this virtual patient-room scene?		[16,43]
Affect	Positive affect			[44]

	Negative affect	Please rate the extent to which you feel each affective state at this moment.	1 = Very slightly or not at all, 5 = Extremely	
Perceived restoration	Room pleasantness	How pleasant is this virtual patient-room scene?	1 =very unpleasant 7 =very pleasant	[14,36]
	Willingness to rest	I would be willing to rest in this virtual patient room.	1 = strongly disagree 7 = strongly agree	[45,46]

3.5. Electroencephalography Acquisition and Processing

Electroencephalography was recorded using a 14-channel Emotiv EPOC (EPOC X; EMOTIV Inc., San Francisco, CA, USA) system arranged according to the international 10–20 system. A two-minute eyes-open resting baseline was collected before virtual patient-room exposure to support within-participant normalization. EEG recording and VR presentation were synchronized under the same experimental computer configuration. Before recording, electrode contact quality was checked, and conductive medium was applied as needed. The continuous EEG signal was processed to reduce non-neural contamination, including eye-movement, muscle, and motion-related artifacts. Wavelet-enhanced independent component analysis was used as the main artifact-reduction procedure. After preprocessing, the continuous signal was segmented into two-second non-overlapping epochs, and power spectral density was estimated using Welch's method. Mean band power was calculated for alpha activity from 8 to 13 Hz and beta activity from 13 to 30 Hz. Task-related band power during virtual patient-room exposure was normalized to the eyes-open baseline and expressed in decibels using Equation (1):

$$\Delta P\alpha = 10\log10((P_{\alpha,task})/(P_{\alpha,base})),\ \Delta P\beta = 10\log10((P_{\beta,task})/(P_{\beta,base})) \quad (1)$$

The occipital region of interest was defined a priori as O1 and O2 because the experimental manipulations were room-scale visual-environment factors. The two occipital channels were averaged for subsequent analysis. The occipital alpha/beta ratio index was calculated as the difference between baseline-normalized alpha and beta power in the occipital region, as shown in Equation (2):

$$\text{Occipital alpha/beta ratio index} = \Delta P\alpha - \Delta P\beta \quad (2)$$

where $P_{\alpha,task}$ and $P_{\beta,task}$ denote alpha and beta power during virtual patient-room exposure, and $P_{\alpha,base}$ and $P_{\beta,base}$ denote alpha and beta power during the eyes-open baseline. A higher occipital alpha/beta ratio index value indicates that, relative to baseline, alpha modulation was greater than beta modulation in the occipital region during scene exposure. The baseline-normalized decibel transformation follows the common EEG time-frequency normalization procedure, in which task-related power is expressed relative to baseline power using $10\log_{10}(P_{task}/P_{baseline})$ [47]. Alpha/beta ratio indicators have been used in VR–EEG architectural research to examine relaxation–arousal responses to changes in spatial elements [48]. Lighting-related EEG research has also interpreted higher alpha/beta ratio values as relaxation-related responses [39]. Therefore, the occipital alpha/beta ratio index was used as a relaxation-related EEG response indicator during virtual patient-room exposure.

3.6. Participants

Participants were recruited from undergraduate and postgraduate student populations. The final sample comprised 192 healthy participants, with 96 participants tested under the 20 °C ambient-temperature condition and 96 participants tested under the 25 °C ambient-temperature condition. Within each ambient-temperature condition, participants were randomly assigned to one of the 12 virtual patient-room scenes, with eight

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participants in each scene. Demographic information, including education level, age, and sex, was collected for sample description, but demographic variables were not treated as primary analytical factors in this study. Participants were screened according to the following criteria: (1) normal or corrected-to-normal vision; (2) no self-reported neurological disorders; (3) no severe sleep disorders; (4) no major cardiovascular, metabolic, or other health conditions that could substantially affect thermoregulation; (5) no strong susceptibility to VR sickness or history of poor tolerance to head-mounted displays; (6) no caffeine intake or strenuous exercise before the experiment on the test day; (7) lightweight indoor clothing during the test session; (8) seated posture maintained throughout the experiment.

4. Results

4.1. Perceptual, Psychological, and Neural Responses Under Two Temperature Conditions

This section compares the 20 °C and 25 °C groups without further dividing participants by wall finish, wall color, or color temperature. Because each participant was assigned to only one ambient-temperature condition, independent-samples comparisons were used. As shown in Table 3, participants in the 25 °C condition had a more negative temperature estimation bias than those in the 20 °C condition, indicating that they tended to estimate the room temperature further below the actual setpoint at 25 °C. Participants in the 25 °C condition also gave higher visual perception ratings for the three visual factors, meaning that they perceived these visual factors as more visually comfortable under the 25 °C condition. No significant differences were found for thermal sensation vote, positive affect change, negative affect change, room pleasantness, willingness to rest, or the occipital alpha/beta ratio index. These results indicate that the differences between the two ambient-temperature groups were concentrated in temperature estimation and comfort-related visual perception.

Table 3. Comparisons of perceptual, psychological, and EEG responses under two ambient-temperature conditions.

Perceptual, Psychological, and Neural Responses		**20 °C (96)**	**25 °C (96)**	***p***	**Cohen's d**
Thermal perception	Temperature estimation bias (°C)	0.53 ± 4.49	−1.71 ± 4.02	<0.001 *	0.525
	Thermal sensation vote	0.71 ± 1.41	1.02 ± 1.24	0.105	−0.235
Visual perception	Visual perception of wall finish	4.78 ± 1.50	5.24 ± 1.35	0.027 *	−0.322
	Visual perception of wall color	4.80 ± 1.56	5.27 ± 1.40	0.030 *	−0.316
	Visual perception of color temperature	4.71 ± 1.46	5.25 ± 1.30	0.007 *	−0.393
Affect	Positive affect change score	−0.21 ± 0.65	−0.17 ± 0.65	0.650	−0.066
	Negative affect change score	−0.34 ± 0.65	−0.15 ± 0.85	0.075	−0.258
Perceived Restoration	Room pleasantness	4.73 ± 1.48	4.94 ± 1.49	0.331	−0.141
	Willingness to rest	4.80 ± 1.56	5.00 ± 1.58	0.384	−0.126
EEG responses	Occipital alpha/beta ratio index	1.03 ± 2.52	1.28 ± 2.07	0.446	−0.110

Note: Values are presented as mean ± SD. * $p < 0.05$.

4.2. Perceptual, Psychological, and EEG Responses Under Different Wall Finishes and Wall Colors

Because wall finish and wall color both involved wall-related visual conditions, their results are reported in the same subsection. Since each participant viewed only one virtual scene, wall-finish differences were examined using independent-samples comparisons, whereas wall-color differences were examined using Kruskal–Wallis tests followed by pairwise comparisons when the overall test was significant. Full statistical results are given in Tables 4 and 5. Figure 4 further presents the violin plots of the significant differences identified between two types of wall finish, and Figure 5 further presents box plots of differences between three types of wall colors for temperature estimation bias. For wall finish, visual perception of wall finish and willingness to rest differed significantly under the 20 °C condition (see Figure 4a,b). The occipital alpha/beta ratio index differed between latex paint finish and vinyl wallcovering under both 20 °C and 25 °C (see Figure 4c,f). Participants in the latex paint finish condition rated the wall finish as visually more comfortable and reported greater willingness to rest than those in the vinyl wallcovering condition. In contrast, participants in the vinyl wallcovering condition showed higher occipital alpha/beta ratio index values than those in the latex paint finish condition under both 20 °C and 25 °C. Other wall-finish comparisons, including temperature estimation bias, thermal sensation vote, positive affect change, negative affect change, and room pleasantness, were not significant.

For wall color, temperature estimation bias was the only outcome that differed significantly among the blue, white, and yellow wall-color conditions (see Figure 5a,b). Under the 20 °C condition, participants in the yellow wall condition estimated the room as warmer than those in the blue and white wall conditions, while the blue and white wall conditions did not differ significantly from each other. The same result was found under the 25 °C condition. Although temperature estimation bias in the yellow wall condition was lower at 25 °C than at 20 °C, it remained higher than that in the blue and white wall conditions. The wall-color groups did not differ in visual perception of wall color, affect, perceived restoration, or the occipital alpha/beta ratio index. Thus, wall-finish comparisons showed differences in willingness to rest and the occipital alpha/beta ratio index, whereas wall-color comparisons showed differences mainly in temperature estimation bias.

Table 4. Comparisons of wall finish on perceptual, psychological, and EEG responses.

Perceptual, Psychological, and Neural Responses		**Latex Paint (48)**	**Vinyl Wallcovering (48)**	***p***	**Cohen's d**
Ambient temperature—20 °C					
Thermal perception	Temperature estimation bias (°C)	0.82 ± 4.38	0.24 ± 4.64	0.528	0.129
	Thermal sensation vote	0.98 ± 1.28	0.44 ± 1.50	0.060	0.388
Visual perception	Visual perception of wall finish	5.15 ± 1.29	4.42 ± 1.61	0.016 *	0.500
Affect	Positive affect change score	−0.17 ± 0.67	−0.25 ± 0.63	0.555	0.121
	Negative affect change score	−0.34 ± 0.62	−0.35 ± 0.67	0.950	0.013
Perceived Restoration	Room pleasantness	5.00 ± 1.44	4.46 ± 1.47	0.072	0.371
	Willingness to rest	5.19 ± 1.57	4.42 ± 1.47	0.015 *	0.507
EEG responses	Occipital alpha/beta ratio index	0.24 ± 2.23	1.81 ± 2.56	0.002 *	−0.655
Ambient temperature—25 °C					
Thermal perception	Temperature estimation bias (°C)	−1.50 ± 3.90	−1.92 ± 4.17	0.614	0.103
	Thermal sensation vote	1.10 ± 1.13	0.94 ± 1.34	0.513	0.134
Visual perception	Visual perception of wall finish	5.29 ± 1.30	5.19 ± 1.41	0.708	0.077
Affect	Positive affect change score	−0.17 ± 0.65	−0.17 ± 0.66	0.963	0.010
	Negative affect change score	−0.13 ± 0.87	−0.17 ± 0.84	0.840	0.041
Perceived Restoration	Room pleasantness	5.02 ± 1.54	4.85 ± 1.44	0.585	0.112
	Willingness to rest	4.94 ± 1.66	5.06 ± 1.52	0.701	−0.079
EEG responses	Occipital alpha/beta ratio index	0.70 ± 2.10	1.86 ± 1.89	0.006 *	−0.575

Note: Values are presented as mean ± SD.* $p < 0.05$.

Table 5. Comparisons of wall color on perceptual, psychological, and EEG responses.

Perceptual, Psychological, and Neural Responses		Blue Median (IQR)	White Median (IQR)	Yellow Median (IQR)	H	df	*p*	ε²
Ambient temperature—20 °C								
Thermal perception	Temperature estimation bias (°C)	−2.00 (4.50)	0.00 (3.90)	3.00 (5.00)	14.528	2	0.001 *	0.135
	Thermal sensation vote	1.00 (2.00)	1.00 (1.00)	1.00 (3.00)	2.022	2	0.364	0.000
Visual perception	Visual perception of wall color	5.00 (2.00)	5.00 (3.00)	5.00 (3.00)	1.790	2	0.409	0.000
Affect	Positive affect change score	−0.38 (1.19)	−0.20 (1.05)	−0.25 (0.60)	1.433	2	0.489	0.000
	Negative affect change score	−0.15 (0.98)	−0.20 (0.50)	−0.30 (1.00)	0.222	2	0.895	0.000
Perceived Restoration	Room pleasantness	4.00 (2.00)	5.00 (3.00)	5.00 (3.00)	2.630	2	0.268	0.007
	Willingness to rest	5.00 (3.00)	5.00 (2.00)	5.00 (3.00)	1.028	2	0.598	0.000
EEG responses	Occipital alpha/beta ratio index	0.00 (2.68)	1.12 (2.88)	1.59 (3.59)	5.864	2	0.053	0.042
Ambient temperature—25 °C								
Thermal perception	Temperature estimation bias (°C)	−2.00 (5.00)	−2.00 (6.00)	0.00 (3.00)	13.446	2	0.001 *	0.123
	Thermal sensation vote	1.00 (2.00)	1.00 (2.00)	1.00 (1.00)	2.276	2	0.320	0.003
Visual perception	Visual perception of wall color	5.00 (1.00)	5.00 (2.00)	5.00 (2.00)	0.237	2	0.888	0.000
Affect	Positive affect change score	−0.05 (0.68)	−0.20 (0.90)	0.00 (0.70)	5.666	2	0.059	0.039
	Negative affect change score	0.00 (0.50)	0.00 (0.40)	−0.20 (0.75)	4.259	2	0.119	0.024
Perceived Restoration	Room pleasantness	5.00 (2.00)	5.00 (3.00)	5.00 (2.00)	0.906		0.636	0.000
	Willingness to rest	5.00 (2.00)	5.00 (4.00)	5.00 (3.00)	0.952	2	0.621	0.000
EEG responses	Occipital alpha/beta ratio index	0.754 (2.321)	1.098 (2.787)	2.525 (1.919)	5.894	2	0.054	0.041

Note: Values are presented as median (IQR). ε² is reported as the effect size. * $p < 0.05$.

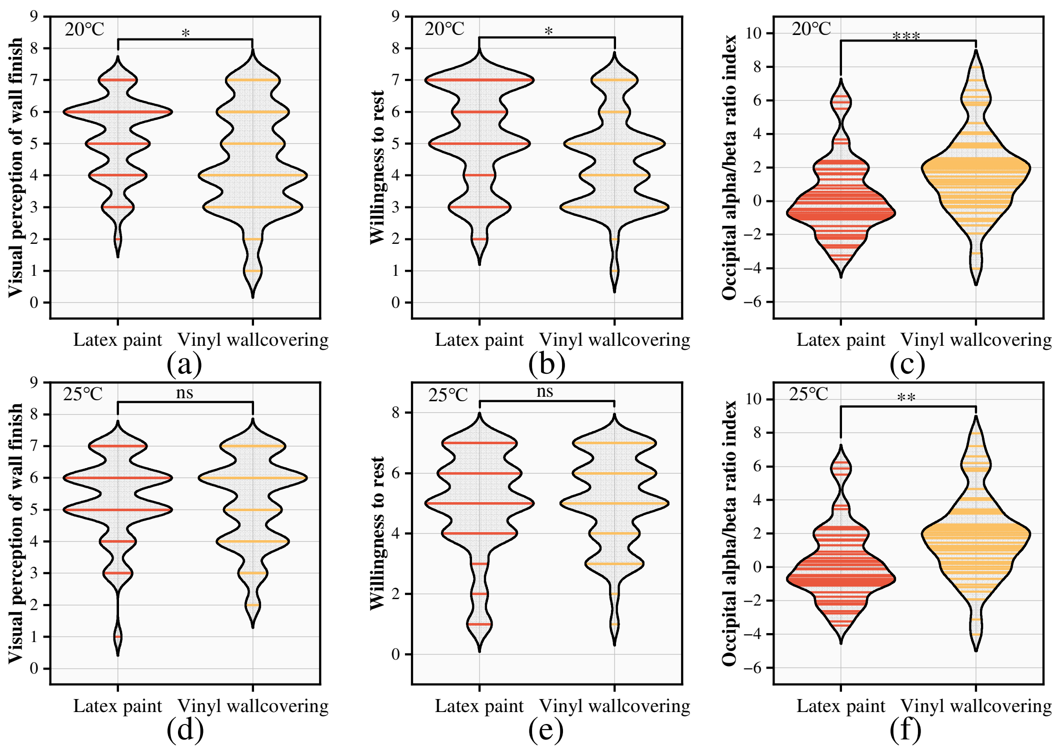

Figure 4. Violin plots comparing outcomes with significant differences between latex paint finish and vinyl wallcovering. (**a**) Visual perception of wall finish under the 20 °C condition; (**b**) willingness to rest under the 20 °C condition; (**c**) occipital alpha/beta ratio index under the 20 °C condition; (**d**) visual perception of wall finish under the 25 °C condition; (**e**) willingness to rest under the 25 °C

condition; (**f**) occipital alpha/beta ratio index under the 25 °C condition. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.005$.

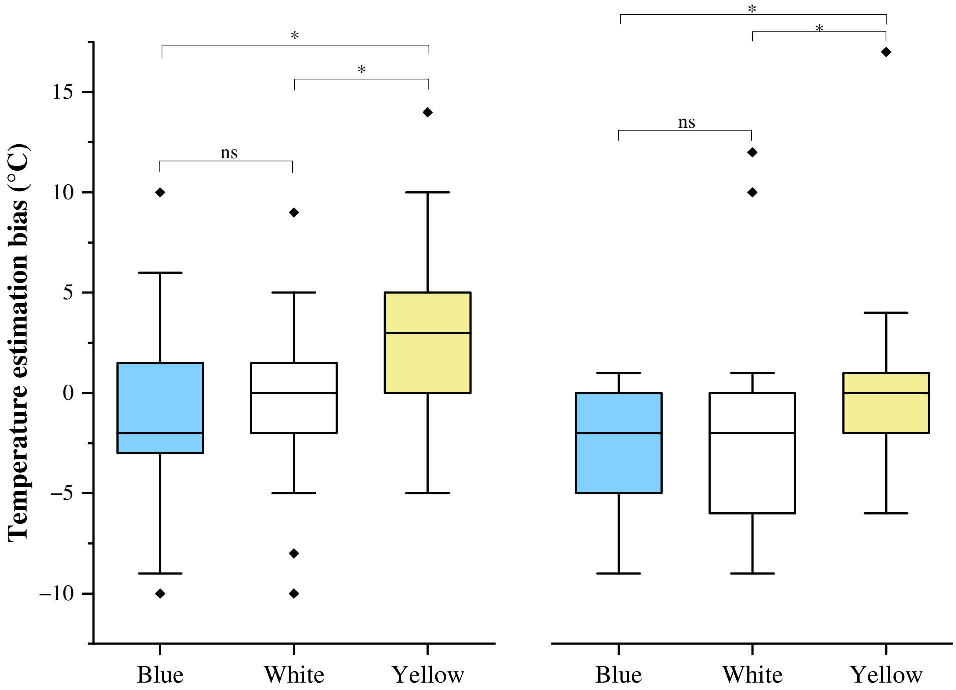

Figure 5. Box plots comparing temperature estimation bias among blue, white, and yellow wall-color conditions. (**a**) Temperature estimation bias among the three wall-color conditions under the 20 °C condition; (**b**) Temperature estimation bias among the three wall-color conditions under the 25 °C condition. * $p < 0.05$.

4.3. Perceptual, Psychological, and EEG Responses to Color Temperature

Significant differences between warm and cool color-temperature conditions were found only under the 20 °C condition, as shown in Table 6. Figure 6 further presents violin plots of the significant differences identified between warm and cool color-temperature. Because each participant viewed only one virtual scene, warm and cool color-temperature conditions were compared separately within each ambient-temperature condition using independent-samples comparisons. At 20 °C, participants in the warm color-temperature condition showed higher temperature estimation bias and reported warmer thermal sensation than those in the cool color-temperature condition, indicating that they estimated and experienced the room as warmer under warm color temperature (see Figure 6a,b). The warm color-temperature condition was also rated as visually more comfortable, and participants in this condition reported higher room pleasantness and willingness to rest (see Figure 6c–e). Positive affect change, negative affect change, and the occipital alpha/beta ratio index did not differ significantly between the two color-temperature conditions. At 25 °C, no significant warm–cool differences were found for any outcome variable (see Figure 6f–j). Therefore, the warm–cool differences were found at 20 °C and were limited to thermal perception, visual perception of color temperature, and perceived restoration.

Table 6. Comparisons of color temperature on perceptual, psychological, and EEG responses.

Perceptual, Psychological, and Neural Responses		Warm (48)	Cool (48)	p	Cohen's d
Ambient temperature—20 °C					
Thermal perception	Temperature estimation bias (°C)	2.41 ± 4.27	−1.34 ± 3.93	<0.001 *	0.914
	Thermal sensation vote	1.00 ± 1.22	0.42 ± 1.54	0.043 *	0.420

Visual perception	Visual perception of color temperature	5.08 ± 1.27	4.33 ± 1.55	0.011 *	0.530
Affect	Positive affect change score	−0.14 ± 0.68	−0.29 ± 0.63	0.276	0.224
	Negative affect change score	−0.47 ± 0.80	−0.22 ± 0.42	0.058	−0.393
Perceived Restoration	Room pleasantness	5.15 ± 1.34	4.31 ± 1.50	0.005 *	0.586
	Willingness to rest	5.13 ± 1.35	4.48 ± 1.70	0.042 *	0.421
EEG responses	Occipital alpha/beta ratio index	0.68 ± 2.21	1.37 ± 2.78	0.185	−0.272
Ambient temperature—25 °C					
Thermal perception	Temperature estimation bias (°C)	−1.21 ± 4.42	−2.21 ± 3.55	0.225	0.249
	Thermal sensation vote	0.96 ± 1.34	1.08 ± 1.15	0.624	−0.100
Visual perception	Visual perception of color temperature	5.19 ± 1.48	5.31 ± 1.10	0.639	−0.096
Affect	Positive affect change score	−0.11 ± 0.67	−0.23 ± 0.63	0.357	0.189
	Negative affect change score	−0.09 ± 0.86	−0.21 ± 0.84	0.512	0.134
Perceived Restoration	Room pleasantness	4.79 ± 1.57	5.08 ± 1.40	0.339	−0.196
	Willingness to rest	4.88 ± 1.75	5.13 ± 1.41	0.442	−0.158
EEG responses	Occipital alpha/beta ratio index	1.04 ± 2.17	1.52 ± 1.97	0.260	−0.232

Note: Values are presented as mean ± SD. * $p < 0.05$.

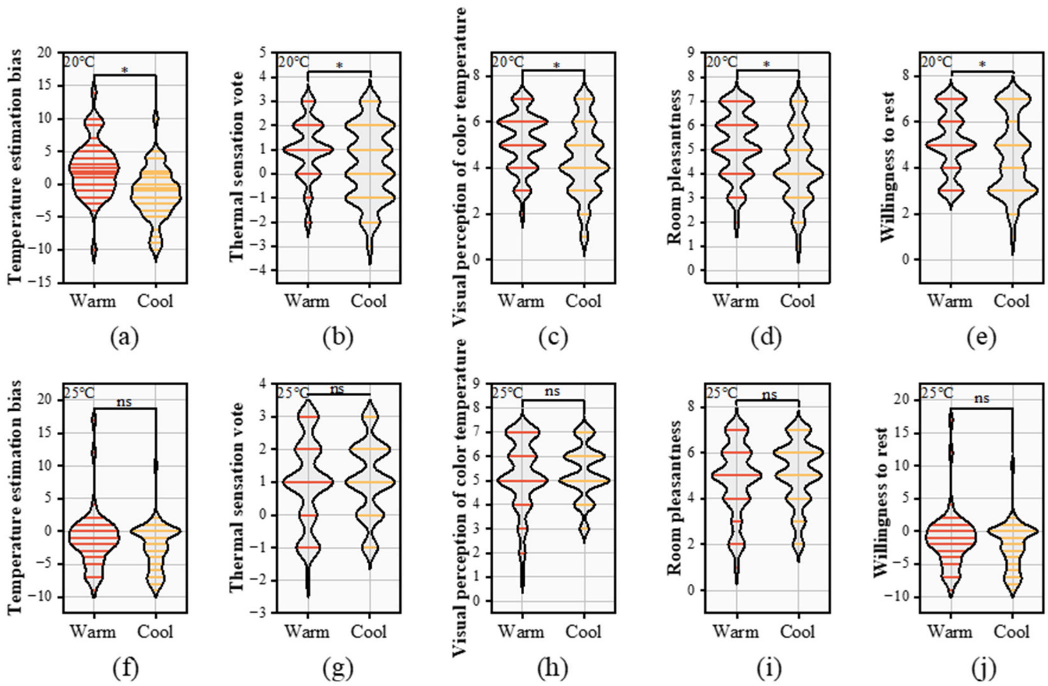

Figure 6. Violin plots comparing warm and cool color-temperature conditions under 20 °C and 25 °C ambient-temperature backgrounds. (**a**) Temperature estimation bias under the 20 °C condition; (**b**) thermal sensation vote under the 20 °C condition; (**c**) visual perception of color temperature under the 20 °C condition; (**d**) room pleasantness under the 20 °C condition; (**e**) willingness to rest under the 20 °C condition; (**f**) temperature estimation bias under the 25 °C condition; (**g**) thermal sensation vote under the 25 °C condition; (**h**) visual perception of color temperature under the 25 °C condition; (**i**) room pleasantness under the 25 °C condition; (**j**) willingness to rest under the 25 °C condition. * $p < 0.05$.

4.4. Regression Analysis for Affect, Perceived Restoration, and EEG Response

The regression analysis tested whether ambient temperature, wall finish, wall color, and color temperature predicted affect, perceived restoration, and EEG responses when entered into the models together, as shown in Table 7. The regression models for positive affect change, negative affect change, room pleasantness, and willingness to rest were not statistically significant. For EEG responses, wall finish and wall color significantly predicted the occipital alpha/beta ratio index. Compared with latex paint finish, vinyl wallcovering was associated with higher occipital alpha/beta ratio index values, indicating a more relaxation-related EEG response during virtual patient-room exposure. Wall color also significantly predicted this EEG indicator, with values increasing along the coded order from blue through white to yellow. This result suggests a possible relaxation-related EEG tendency along the wall-color order.

Table 7. Regression models for affect, perceived restoration, and EEG responses.

Model	B	S.E.	Sig.	95% CI	VIF	R	R²	AR²	ANOVA	
									F	Sig.
1. Positive affect change score ⟵							**Affect**			
Constant	−0.333	0.110	0.003 *			0.148	0.022	0.001	1.051	0.382
Ambient temperature	0.043	0.094	0.649	[−0.142, 0.228]	1.000					
Wall finish	−0.046	0.094	0.628	[−0.231, 0.139]	1.000					
Wall color	0.074	0.057	0.193	[−0.038, 0.187]	1.000					
Color temperature	0.137	0.094	0.146	[−0.048, 0.322]	1.001					
2. Negative affect change score ⟵							**Affect**			
Constant	−0.201	0.128	0.118			0.173	0.030	0.009	1.434	0.224
Ambient temperature	0.195	0.109	0.076	[−0.020, 0.410]	1.000					
Wall finish	−0.020	0.109	0.852	[−0.236, 0.195]	1.000					
Wall color	−0.097	0.066	0.146	[−0.228, 0.034]	1.000					
Color temperature	−0.069	0.109	0.526	[−0.285, 0.146]	1.001					
3. Room pleasantness ⟵							**Perceived Restoration**			
Constant	4.561	0.248	<0.001 *			0.203	0.041	0.021	2.011	0.095
Ambient temperature	0.208	0.211	0.326	[−0.209, 0.626]	1.000					
Wall finish	−0.360	0.212	0.090	[−0.777, 0.057]	1.000					
Wall color	0.205	0.129	0.113	[−0.049, 0.458]	1.000					
Color temperature	0.283	0.212	0.183	[−0.135, 0.700]	1.001					
4. Willingness to rest ⟵							**Perceived Restoration**			
Constant	4.719	0.265	<0.001 *			0.156	0.024	0.004	1.170	0.325
Ambient temperature	0.198	0.226	0.383	[−0.248, 0.644]	1.000					
Wall finish	−0.327	0.226	0.150	[−0.774, 0.119]	1.000					
Wall color	0.142	0.138	0.304	[−0.130, 0.413]	1.000					
Color temperature	0.208	0.226	0.360	[−0.239, 0.654]	1.001					
5. Occipital alpha/beta ratio index ⟵							**EEG response**			
Constant	−0.079	0.358	0.825			0.416	0.173	0.155	9.769	<0.001 *
Ambient temperature	0.254	0.306	0.406	[−0.348, 0.857]	1.000					
Wall finish	1.375	0.306	<0.001 *	[0.772, 1.978]	1.000					
Wall color	0.708	0.186	<0.001 *	[0.341, 1.074]	1.000					
Color temperature	−0.595	0.306	0.053	[−1.198, 0.008]	1.001					

Note: Five enter-method multiple linear regression models were conducted for positive affect change score, negative affect change score, room pleasantness, willingness to rest, and EEG responses. Room pleasantness and willingness to rest were analyzed as two separate indicators of perceived restoration. Predictors were ambient temperature, wall finish, wall color, and color temperature. Coding: ambient temperature, 0 = 20 °C, 1 = 25 °C; wall finish, 0 = latex paint finish, 1 = vinyl wallcovering; wall color, 0 = blue, 1 = white, 2 = yellow; color temperature, 0 = cool, 1 = warm. B = unstandardized coefficient; S.E. = standard error; CI = confidence interval; VIF = variance inflation factor. * $p < 0.05$.

5. Discussion

5.1. Temperature Estimation and Visual Perception Across the 20 °C and 25 °C Conditions

The comparison between the 20 °C and 25 °C conditions showed that the main differences were in temperature estimation bias and comfort-related visual perception ratings. Compared with the 20 °C group, participants at 25 °C underestimated the room temperature more strongly but rated wall finish, wall color, and color temperature as visually more comfortable. Comparable evidence has been reported in controlled indoor-environment research, where visual-perception differences were found under different temperature conditions [49]. Previous lighting–thermal research has shown that thermal-perception differences related to visual conditions may become more evident under warmer ambient-temperature conditions [17]. Broader thermal–visual perception research further suggests that visual and thermal domains may interact under specific indoor conditions [20]. In patient rooms, this matters because environmental control is usually based on measured or set temperatures, whereas occupants may evaluate the room through a combined thermal and visual experience. The stronger underestimation in the 25 °C condition further suggests that participants' perceived room temperature may not have closely aligned with the physical ambient temperature. The higher visual perception ratings may also indicate that a warmer ambient-temperature background made visible room features easier to accept. Therefore, ambient temperature should be treated as a background condition for interpreting patient-room visual evaluation, rather than as an isolated physical parameter. The lack of broader differences in affect, perceived restoration, and EEG responses further suggests that these responses were more closely related to specific visual factors than to ambient temperature alone.

5.2. Perceived Restoration and EEG Responses in Wall-Finish Comparisons

The wall-finish comparison did not identify one finish as better across all outcomes. At 20 °C, participants in the latex paint finish condition rated the wall finish as visually more comfortable and reported greater willingness to rest than those in the vinyl wallcovering condition. This result may be related to the rendered surface appearance of the latex paint finish, which was designed as a matte, low-gloss, and visually softer wall surface. Previous material-perception research has shown that visual evaluation of indoor wall materials is related to surface properties such as gloss, hue, and saturation [41]. Research on visual and tactile assessment of building materials has also reported that vision can dominate overall material assessment, although visual assessment does not always accurately anticipate tactile experience [50]. This evidence is relevant to the present VR experiment because participants did not touch the wall surfaces, and their responses were mainly based on rendered visual surface cues. Similar evidence from immersive VR research shows that visible interior materials can influence perceived warmth and thermal perception [14]. In a patient room, where occupants may spend long periods facing nearby wall surfaces, a low-reflectance surface may reduce visual harshness and appear more suitable for rest. By contrast, participants in the vinyl wallcovering condition showed higher occipital alpha/beta ratio index values under both 20 °C and 25 °C, and the regression analysis also linked vinyl wallcovering with higher values of this EEG indicator. This result may be related to the smoother, more reflective, and visually harder surface appearance of the vinyl wallcovering finish, which may have produced a different form of visual processing from the matte latex paint finish. Because this index was used as a relaxation-related EEG response indicator, the higher values in the vinyl wallcovering condition can be interpreted as a stronger relaxed environment in patient rooms.

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5.3. Thermal Perception and EEG Responses in Wall-Color Comparisons

The wall-color result was concentrated mainly in temperature estimation bias. Under both 20 °C and 25 °C, participants in the yellow wall condition estimated the room as warmer than those in the blue and white wall conditions. This result is partly consistent with color and thermal research showing that warm-colored walls can increase thermal sensation votes and cool-colored walls can reduce them relative to neutral colors [42], although the present difference was found in temperature estimation rather than thermal sensation vote. Research on temperature-based cross-modal correspondences also shows that people often associate visual attributes such as color with temperature experience [19]. Color psychology research also indicates that color is not only a visual property, because it may evoke learned associations and influence cognitive, affective, and behavioral responses [51]. Based on these studies, yellow wall color may have activated a warm-color association and made the room appear warmer at the level of cognitive estimation. Participants in the yellow wall condition did not report higher room pleasantness, willingness to rest, or affective improvement, and the group comparisons did not show a significant EEG difference for wall color. Therefore, yellow wall color should be discussed mainly as a temperature-estimation cue, rather than as a main strategy for improving perceived restoration or affect. The regression tendency along the wall-color order may still provide supplementary EEG evidence, because the increasing occipital alpha/beta ratio index from blue through white to yellow was consistent with a relaxation-related or lower-arousal response tendency. However, this EEG pattern should be interpreted cautiously and used to support, rather than replace, the main temperature-estimation interpretation. From a design perspective, yellow wall color may be useful when the aim is to support warmer thermal impressions, but it should not be treated as a general comfort strategy.

5.4. Thermal Perception, Visual Perception, and Perceived Restoration in Color-Temperature Comparisons

Color temperature showed the clearest condition-specific result. In the present virtual patient room, participants in the warm color-temperature condition showed warmer thermal judgment, higher comfort-related visual perception ratings for color temperature, and higher perceived-restoration ratings only at 20 °C. Under the cooler ambient-temperature background, warm color temperature may have acted as a visual warmth cue and reduced the mismatch between the relatively cool physical condition and the desired feeling of a restful patient room. This visual warmth may have made the room easier to judge as warm, visually comfortable, and suitable for rest. This finding is in line with lighting research showing that color temperature can be related to indoor thermal perception under controlled conditions [43]. Similar evidence has also shown that color temperature can influence thermal perception and comfort, although the effect may depend on the thermal condition [17]. It is also consistent with simulated patient-room lighting research showing that lower color-temperature conditions were rated as more comfortable and more natural than higher color-temperature conditions [16]. At 25 °C, the warm–cool differences were not found, possibly because the warmer ambient-temperature background weakened the contrast between the warm and cool color-temperature conditions. Therefore, the color-temperature result should be interpreted as a patient-room appraisal difference under the cooler condition, rather than as a general advantage of warm color temperature under all thermal backgrounds.

5.5. Integrated Interpretation of Multisource Responses and Theoretical Implications

Patient-room visual cues can be understood as part of a multisensory appraisal process rather than as purely visual features. In a patient room, wall finish, wall color, and color temperature are seen together with the ambient-temperature background while occupants rest, wait, receive care, or observe the surrounding room. This helps explain why the responses in this study appeared across thermal judgment, visual perception, rest-related appraisal, affect, and EEG responses. Cross-modal perception and multisensory integration provide one explanation for these results. Wall color mainly acted as a thermal-estimation cue; yellow walls may have evoked learned associations with warmth and supported warmer room-temperature estimates in the present patient-room scenes [19,51]. Color temperature showed a broader effect under the 20 °C condition, suggesting that warm lighting appearance may be combined with the cooler thermal background when occupants judge room warmth, visual comfort, and rest suitability [20]. Wall finish involved material-related visual appraisal, because gloss, reflectance, visual brightness, and perceived softness or hardness can affect whether a patient-room surface appears suitable for rest even without tactile contact [41,50]. The EEG findings add another level of evidence. The occipital alpha/beta ratio index reflected relaxation-related neural responses, whereas the subjective measures captured conscious judgments of comfort, warmth, pleasantness, and willingness to rest. These two response levels did not always follow the same pattern, which is consistent with embodied accounts of architectural experience [21]. The findings are also relevant to attention restoration theory and stress reduction theory, because several visual conditions were linked with rest-related appraisal, affective response, and relaxation-related EEG patterns [22,23]. For patient-room design practice, color temperature is more suitable for adjustable thermal and rest-related appraisal, wall finish for stable surface design, and wall color for supplementary thermal-impression cues.

6. Recommendations

6.1. Practical Recommendations

Patient-room visual design should be matched to the ambient-temperature condition and the intended response, instead of relying on one generally warm or comfortable scheme. The most direct recommendation concerns color-temperature-adjustable luminaires around the bed and resting zone, because color temperature showed the clearest practical importance among the three visual variables and can be adjusted more easily during building operation than wall finish or wall color. Under the 20 °C condition, participants in the warm color-temperature condition showed higher temperature estimation bias, thermal sensation vote, visual perception of color temperature, room pleasantness, and willingness to rest than the cool color-temperature group, whereas these warm–cool differences were not found under the 25 °C condition. Warm color temperature is therefore more appropriate when the room is operated near the lower ambient-temperature condition or when the design aim is to support warmer thermal judgment, more pleasant room appraisal and stronger willingness to rest. From a healthcare-building perspective, adjustable color temperature is also efficient because it can be modified during daily operation without changing fixed finishes or wall colors. Wall finish should also be selected by response target. For rooms intended to support subjective rest under the cooler ambient-temperature condition, matte or low-reflectance finishes visually close to latex paint are preferable, because participants in the latex paint finish condition perceived the wall finish as visually more comfortable and reported greater willingness to rest at 20 °C. If vinyl wallcovering is required for hygiene, durability, or maintenance, its surface sheen should be carefully controlled, since material category alone does not describe the visual surface quality experienced by occupants. Wall color should serve a more specific design purpose. Yellow wall color may be useful when the aim is to support warmer room-temperature estimates, because the yellow wall group showed higher temperature estimation bias than the blue and white wall groups under both ambient-temperature conditions. The regression results also suggested a possible relaxation-related EEG tendency along the wall-color order. For patient-room design, adjustable color temperature and low-reflectance wall finish may provide more direct options for supporting visual comfort and willingness to rest, while warm wall colors may be used selectively when the design aim is to support warmer thermal impressions. These recommendations are intended to support patient-room environmental experience and healthcare-building design decisions, rather than to claim direct evidence of clinical recovery outcomes.

6.2. Research Limitations and Future Study

This study was conducted in a VR-based patient-room setting rather than in a real patient room, so the findings should be interpreted as immediate responses to a controlled simulated environment. The thermal environment was represented by two ambient-temperature conditions, 20 °C and 25 °C, which allowed comparison between cooler and warmer backgrounds but did not capture intermediate thermal states or the wider range of thermal conditions that may occur in hospital settings. The visual manipulations were limited to representative levels of wall finish, wall color, and color temperature, so the results cannot cover the wider range of surface materials, chromatic conditions, and lighting settings used in practice. In addition, EEG responses were represented by the occipital alpha/beta ratio index, while other EEG indicators, brain regions, and physiological measures were not examined. The sample consisted of healthy university participants rather than patients, which may limit the external validity and direct transfer of the findings to occupied clinical settings. Healthy university students were selected for ethical, practical, and experimental-control reasons, because they were able to complete the VR exposure and EEG recording procedures under stable laboratory conditions and helped reduce potential confounding effects related to illness, pain, medication use, fatigue, and clinical stress. Hospitalized patients may differ from healthy participants in physical discomfort, emotional state, medication use, fatigue, sensory sensitivity, and thermal perception; therefore, the findings should be applied to real healthcare settings with caution. Neurodiversity and individual differences in sensory sensitivity were not systematically assessed in the present study and should be considered in future patient-room environmental research.

Although the experiment used a factorial design, interaction effects among ambient temperature, wall finish, wall color, and color temperature were not further examined because each complete four-factor condition included a limited number of participants, and adding multiple interaction terms across several outcome variables would increase model complexity and the risk of statistical overinterpretation. The use of multiple planned comparisons across several environmental variables and outcome measures may also have increased the risk of Type I error. No single correction procedure was applied across all outcome domains, because the study aimed to identify exploratory response patterns rather than to test one single omnibus hypothesis. Therefore, significant findings should be interpreted cautiously together with effect sizes and response-pattern consistency. Future studies should test these patterns in real patient rooms, include patient groups where possible, examine a broader range of ambient-temperature conditions, and use larger-sample factorial or confirmatory models.

7. Conclusions

Patient-room visual environment is not only a decorative issue, because patients may spend long periods viewing the same walls, colors, and lighting during rest, observation, treatment, and care. This study used a VR-based patient-room experiment to compare wall finish, wall color, and color temperature under 20 °C and 25 °C ambient-temperature conditions. The outcomes included thermal perception, visual perception, affect, perceived restoration, and EEG responses. Four main conclusions were obtained. (1) The

20 °C and 25 °C comparison showed differences mainly in temperature estimation bias and visual perception ratings. Participants in the 25 °C condition underestimated the room temperature more strongly and perceived wall finish, wall color, and color temperature as more visually comfortable. This suggests that ambient temperature should be considered as a background condition when interpreting visual perception in patient rooms. (2) Wall finish showed different subjective and EEG results. Under 20 °C, participants in the latex paint finish condition gave higher visual perception ratings for wall finish, indicating that they perceived the latex paint finish as visually more comfortable, and they also reported greater willingness to rest. Participants in the vinyl wallcovering condition showed higher occipital alpha/beta ratio index values under both temperature conditions, and the regression result also linked vinyl wallcovering with higher values of this EEG indicator. For patient rooms intended to support willingness to rest under lower temperature conditions, matte or low-reflectance finishes visually close to latex paint may be considered. (3) Wall color mainly affected temperature estimation. Yellow walls were estimated as warmer than blue and white walls under both temperature conditions. The regression results further suggested a relaxation-related EEG tendency along the coded order from blue through white to yellow. Yellow wall color may therefore be used as a supplementary thermal-perception cue, but it should not be treated as the main strategy for improving perceived restoration or affect. (4) Color temperature showed the clearest condition-specific result. Under 20 °C, participants in the warm color-temperature condition estimated the room as warmer, reported warmer thermal sensation, perceived the color temperature as more visually comfortable, and reported higher room pleasantness and greater willingness to rest than those in the cool color-temperature condition. Color-temperature-adjustable luminaires near the bed and resting zone may therefore be useful when the room is operated under a lower ambient-temperature background.

Overall, wall finish, wall color, and color temperature should be selected according to the target response and the thermal background of the patient room. Among the three visual factors, color temperature has the greatest practical importance because it affected thermal perception, visual perception, room pleasantness, and willingness to rest under the 20 °C condition, and it can be adjusted more easily in real patient-room operation. Wall finish is more relevant to stable surface design and rest-related visual comfort, while wall color should be used mainly as a supplementary cue for warmer thermal impressions. Although the visual scenes were presented in VR, the experiment included physically controlled 20 °C and 25 °C ambient-temperature conditions. Therefore, the findings still provide controlled evidence for patient-room environmental improvement under different thermal backgrounds. The study also adds to cross-modal, embodied, and restoration-related discussions by showing that patient-room visual cues may be interpreted together with ambient-temperature background when examining thermal perception, rest-related appraisal, and EEG responses.

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Abbreviations

The following abbreviations are used in this manuscript:

VR	Virtual reality
EEG	Electroencephalography
PANAS	Positive and Negative Affect Schedule
HMD	Head-mounted display
ISO	International Organization for Standardization
SD	Standard deviation
IQR	Interquartile range
CI	Confidence interval
VIF	Variance inflation factor
ANOVA	Analysis of variance
S.E.	Standard error
Sig.	Significance
df	Degrees of freedom

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