Environment and Social Psychology (2025) Volume 10 Issue 6 ISSN: 2424-8975 (O)
doi: 10.59429/esp.v10i6.3782 2424-7979 (P)

RESEARCH ARTICLE

Immersive experience in smart art museums: Environmental interaction design and audience emotion regulation

Yin Qian*

aSSIST University, 03760, South Korea

*** Corresponding author:** qian_y0605@163.com

ABSTRACT

With the rapid advancement of digital technologies, traditional art museums are confronting a significant transformation from static displays toward intelligent, personalized experiences. The integration of intelligent technologies has created unprecedented possibilities for immersive museum experiences; however, how to effectively regulate visitor emotions through environmental interaction design and achieve harmonious integration of technology and humanities remains a critical issue requiring urgent resolution. This study focuses on immersive experiences in intelligent art museums and systematically explores the impact mechanisms of environmental interaction design on visitor emotional regulation. Employing mixed research methods, we conducted in-depth analysis of physiological responses, psychological states, and behavioral performances of 240 participants under different interaction design modalities. The research constructed a multimodal perceptual interaction theoretical model, revealing the synergistic enhancement mechanisms of multisensory stimuli including visual, auditory, and tactile elements; established an adaptive spatial response system that maintains emotional stability through intelligent lighting adjustment, environmental temperature and humidity control, and visitor flow density management; and developed a personalized regulation mechanism based on real-time emotion recognition, integrating emotion monitoring, content recommendation, and proactive intervention strategies to form a closed-loop feedback system. Research findings indicate that multimodal fusion interaction significantly enhances visitor emotional engagement, with the five-modal integrated system achieving 94.7% accuracy in emotion recognition; adaptive spatial response increased visitor comfort by 33.8% while reducing stress levels by 57.4%; and the personalized regulation mechanism shortened emotional recovery time by 58.3% with a regulation success rate of 86.7%. This study provides scientific foundation for intelligent museum design, contributes theoretical innovation and practical guidance for the integrated development of culture and technology, while emphasizing attention to technological ethics and social impacts, highlighting the balanced development of technology and humanistic care.

Keywords: Intelligent art museums; immersive experience; environmental interaction design; visitor emotional regulation; multimodal perceptual interaction; adaptive spatial response; emotion recognition technology; personalized recommendation; human-computer interaction; digital humanities

ARTICLE INFO
Received: 03 June 2025| Accepted: 25 June 2025 | Available online: 30 June 2025

CITATION
Qian Y.Immersive experience in smart art museums: Environmental interaction design and audience emotion regulation. *Environment and Social Psychology* 2025; 10(6): 3782 doi:10.59429/esp.v10i6.3782

1. Introduction

In The rapid development of digital technologies is profoundly reshaping the exhibition models and visitor experiences of traditional art museums, with the widespread application of intelligent technologies opening unprecedented possibilities for cultural transmission and artistic appreciation. Qian Hua and Quan Lijun, in their research, noted that the development of generative artificial intelligence technology has brought revolutionary changes to digital art education, providing powerful technological support for the development of intelligent art museums [1]. Ma Hao's research further revealed the profound impact of artificial intelligence technology on the field of artistic design, particularly in terms of innovative breakthroughs in creative concepts, design methods, and expressive forms [2]. Driven by this technological wave, traditional museums' predominantly static display-oriented visiting models can no longer satisfy contemporary audiences' diversified demands for personalized, interactive, and immersive experiences. Intelligent art museums, through the integration of cutting-edge technologies such as artificial intelligence, virtual reality, augmented reality, and the Internet of Things, have created dynamic exhibition environments capable of real-time response to visitor behaviors and emotional states, achieving a transformation from passive viewing to active participation experience models. Environmental interaction design, serving as a crucial bridge connecting advanced technology with humanistic experience, not only involves the intelligent transformation of physical spaces and dynamic presentation of digital content, but also focuses on establishing and maintaining deep emotional connections between people and environments, and between people and artworks. With the advent of the artificial intelligence era, professional talent development and employment models in the arts field are also undergoing fundamental changes; as Zheng Lu and Li Qi pointed out, art design students need to adapt to new technological environments and market demands, further highlighting the important value and social significance of intelligent art museums as innovative cultural and educational platforms [3]. Ge Linglan, in her research on constructing curriculum systems for digital media arts programs, emphasized the urgent need for innovative art education models in the AI era, which aligns highly with the functional positioning of intelligent museums in cultural transmission and arts education [4].

Visitor emotional regulation, as a core indicator for evaluating the experience quality of intelligent art museums, directly relates to the effectiveness of cultural information transmission and the depth of artistic appreciation experiences. In recent years, research on emotional regulation mechanisms has made significant progress in psychology and neuroscience, providing solid theoretical foundations for emotional management in technological environments. Martín and colleagues, in their study of emotional regulation in multiple sclerosis patients, validated the effectiveness of unified protocol treatment methods in emotional management, providing important references for emotional intervention strategies in complex environments [5]. Salmani and other researchers, through randomized controlled trials, demonstrated that repetitive transcranial direct current stimulation of the prefrontal cortex can significantly improve cognitive emotional regulation abilities in patients with substance use disorders, providing neuroscientific empirical support for technology-assisted emotional regulation [6]. Li and colleagues utilized event-related potential techniques to deeply explore the neural mechanisms of verbal humor in regulating negative emotions in individuals with subthreshold depression, revealing the mechanisms of specific stimulation patterns in emotional regulation [7]. These research findings provide important theoretical foundations and technical pathways for designing emotional regulation systems based on multimodal interaction in intelligent art museums. However, current research still shows significant deficiencies in key issues such as the associative mechanisms between environmental interaction design and visitor emotional regulation, synergistic effects under multi-technology integration, implementation pathways for personalized experiences, and quantitative methods for effectiveness evaluation. Particularly in complex museum environments, how to accurately identify visitors' real-time emotional states, effectively implement personalized emotional regulation strategies, and balance the relationship between technological innovation and humanistic care remain important topics requiring in-depth exploration. Therefore, this study aims to deeply investigate the impact mechanisms of environmental interaction design on visitor emotional regulation in intelligent art museums through systematic theoretical analysis and empirical validation, construct theoretical models for immersive experiences based on multisensory fusion, and provide scientific foundations and implementation frameworks for intelligent museum design practices and the enhancement of cultural experience quality.

2. Literature review

The rapid development of artificial intelligence technology is redefining the boundaries of artistic creation, education, and experience, providing unprecedented technological support and innovative possibilities for immersive experience design in intelligent art museums. Zhao Jiangnan, in his research on teaching reform in film and television arts programs, pointed out that the introduction of artificial intelligence technology has not only changed traditional artistic creation models but also brought entirely new educational concepts and methodological systems to arts education [8]. This perspective aligns highly with the educational functions of intelligent museums, demonstrating the broad prospects for artificial intelligence applications in the arts field. Zhou Ling and Lü Yuhui further emphasized the importance of cross-disciplinary integration in artificial intelligence-era arts design education, arguing that multidisciplinary innovative integration is the key driving force for artistic development [9]. Zhang Jinying's research explored innovative pathways for arts design program teaching models in the context of artificial intelligence from a vocational education perspective, providing practical guidance for the deep integration of technology and arts [10]. Wang Qiangchun, in his research on robotic art innovation, revealed new characteristics of artistic creation in the artificial intelligence era, particularly the unique role in cultural construction and value transmission, providing important theoretical support for the cultural transmission functions of intelligent museums [11]. Pan Xin and Zhao Xiuhua's research focused on constructing intelligent curriculum models for digital media arts programs, emphasizing the systematic application value of artificial intelligence technology in arts education [12]. Wu Xiao analyzed the repositioning of artistic forms in the intelligent era from a cinematic art perspective [13], while Lü Yating explored specific application strategies for generative artificial intelligence in arts design innovation practice [14]. These studies collectively constitute the theoretical foundation for artificial intelligence-empowered artistic innovation, providing important academic support and practical references for technological applications and innovative development in intelligent art museums.

Environmental interaction design, as a core element of immersive experiences in intelligent art museums, is being deeply explored and developed in its theoretical foundations and practical methods across multiple related fields. Pang Yibin's deep reflection on intelligent emotional interaction products in the context of technological environmental transformation revealed the crucial role of emotional factors in human-computer interaction design, emphasizing that the organic combination of technology and emotion is an important prerequisite for achieving quality user experiences [15]. This perspective provides important theoretical guidance for emotional interaction design in intelligent museums. Although Liu Shang's research focused on optimizing online teaching strategies in multimodal interactive environments, his theoretical framework and practical methods regarding multisensory fusion interaction have important reference value for interaction design in museum environments [16]. Liu Yuan explored urban park environmental design from an interaction philosophy perspective, proposing the importance of environmental-human interactive relationships in spatial design, a concept equally applicable to intelligent transformation and optimization of museum spaces [17]. Zhang Tianshuo and colleagues, in their research on the impact of voice interaction on learning effectiveness in virtual reality environments, validated the effectiveness of multimodal interaction technology in educational scenarios, providing technical pathways for realizing museum educational functions [18]. Xu Jinfen and Li Juan's research in human-intelligent interaction language learning environments revealed the positive impact of intelligent interaction systems on learners' self-regulation abilities, providing theoretical support for autonomous learning and deep experiences for museum visitors [19]. Tang Wanyu's analysis of AI-digitized landscape applications in human settlement environmental interaction design demonstrated innovative application models of artificial intelligence technology in environmental design fields, providing new ideas and methods for environmental optimization and interaction design in intelligent museums [20]. Although Sun Wei and colleagues studied the interactive relationships between carbon fiber composite materials and polar environmental factors, their analytical framework regarding environmental factor interactions has methodological value for understanding synergistic effects of multiple factors in museum environments [21].

Emotional regulation mechanisms, as core evaluation indicators for visitor experience quality in intelligent art museums, have seen important advances in their theoretical foundations and practical methods across multiple fields including psychology, neuroscience, and education. G.E.M and C.M.D, in their research on emotional regulation in individuals exposed to interpersonal trauma, compared the effectiveness differences between self-compassion and distanced reappraisal emotional regulation strategies, providing important psychological foundations for designing personalized emotional regulation programs [22]. This research finding has significant implications for understanding emotional response differences among different individuals when encountering artworks, providing theoretical foundations for personalized experience design in museums. The 3D REThink Life game developed by David A.O and Tomoiagã as a gamified intervention tool for training emotional regulation abilities validated the effectiveness of gamification methods in emotional capacity development, providing important references for gamified design of museum interactive experiences [23]. Çetin and colleagues' research on the relationship between teacher self-efficacy and professional burnout revealed the mediating roles of interpersonal mindfulness and emotional regulation, demonstrating the important value of emotional regulation abilities in complex social environments, which has inspirational significance for understanding emotional management of visitors in group visiting environments [24]. B.K.S and D.K.M's research on the role of social anxiety in emotional expression and regulation in romantic relationships deepened understanding of the social characteristics of emotional regulation, providing a social psychology perspective for emotional management in museum group visiting experiences [25]. Bozicevic and colleagues' research on mother-infant emotional regulation development emphasized the roles of sensitivity, temperament, and emotional context in emotional regulation development, a finding that has important value for understanding emotional characteristics and regulation needs of visitors across different age groups, providing developmental psychology foundations for cross-age group experience design in museums [26].

Li Guangdong's aesthetic thinking reflection on aging-friendly smart home product art design, although in a different research field, provided important insights for intelligent museums in serving special populations through his in-depth analysis of humanistic care and emotional needs in technology-driven products [27]. The research emphasized that in technology-driven product design, users' emotional needs and psychological characteristics must be fully considered, a perspective highly consistent with intelligent museums' emphasis on visitor emotional experiences. A comprehensive review of existing research reveals that although the application of intelligent technology in the arts field is increasingly widespread, environmental interaction design theory continues to improve, and emotional regulation mechanism research continues to deepen, systematic theoretical analysis and empirical validation of the organic integration and synergistic mechanisms of these three elements in the specific scenario of intelligent art museums remains lacking. Particularly regarding key issues such as multimodal interaction technology integration, personalized emotional regulation strategy design, and cultural transmission effectiveness evaluation, existing research still shows obvious theoretical gaps and practical deficiencies. Therefore, constructing theoretical models for immersive experiences in intelligent art museums and deeply exploring the intrinsic associative mechanisms between environmental interaction design and visitor emotional regulation holds important theoretical value and practical significance for promoting intelligent transformation in the museum industry and enhancing cultural experience quality.

3. Research methods

3.1. Research design

This study employs a mixed-methods research approach, integrating quantitative and qualitative analytical strategies to comprehensively and thoroughly explore the impact mechanisms and effects of environmental interaction design on visitor emotional regulation in intelligent art museums. Based on a quasi-experimental research paradigm, the study constructs a controlled experimental design framework that systematically validates research hypotheses and builds theoretical models through comparative analysis of visitors' physiological responses, psychological states, and behavioral performances under different environmental interaction design modes. Specifically, the research selects three representative intelligent art museums as experimental sites, with each site configured with different environmental interaction design modes: traditional static display mode as the baseline control group, single-technology enhancement mode as the primary experimental group, and multimodal intelligent interaction mode as the advanced experimental group. To ensure the validity and reliability of experimental results, the research strictly controls experimental conditions, maintaining consistency in all potential influencing factors except interaction design differences, including artwork types, spatial layouts, visiting duration, and environmental temperature [28]. Simultaneously, random grouping and balanced allocation methods are employed to minimize selection bias and confounding variable interference to the greatest extent possible. The research design also fully considers the impact of individual visitor differences, employing stratified sampling and covariate control methods to ensure balance across key variables such as demographic characteristics, cultural backgrounds, and technology acceptance among different experimental groups, establishing a solid foundation for subsequent causal inference.

The research adopts a composite research strategy combining longitudinal tracking design with cross-sectional comparison, focusing both on immediate response changes during single visits and examining the persistence and stability of emotional regulation effects at different time points. In the temporal dimension, four key time nodes are established: pre-visit baseline measurement, real-time monitoring during visits, immediate post-visit assessment, and one-week post-visit follow-up evaluation, constructing complete emotional change trajectories. In the spatial dimension, the museum environment is divided into four functional areas: entrance buffer zone, main exhibition area, interactive experience zone, and rest-reflection area, analyzing differentiated effects of interaction design across different spatial environments. The research also introduces an ecosystem theory analytical framework, incorporating multiple levels including individual visitors, technological systems, physical environments, and socio-cultural factors into comprehensive consideration, constructing multilevel, multidimensional analytical models. To enhance the external validity and generalizability of research results, the study deliberately selects museums of different scales, themes, and technological levels as research sites, covering multiple fields including contemporary art, traditional culture, and technological innovation, ensuring that research conclusions can reflect the overall development status and general patterns of intelligent art museums [29]. Furthermore, the research design fully considers ethical principles and practical operability, adopting non-invasive measurement methods and user-friendly experimental procedures while safeguarding participant rights and data security, ensuring the scientific rigor, rationality, and sustainability of the research process.

3.2. Participants and sampling

This study employed a multistage stratified random sampling method to ensure sample representativeness and the generalizability of research results. A total of 240 participants were recruited, with an age range of 18-70 years, covering three major age groups: young adults, middle-aged, and elderly, with 18-30 years accounting for 35%, 31-50 years for 42%, and 51-70 years for 23%, maintaining a balanced gender ratio (48% male, 52% female). Participants' educational backgrounds were diversified, including 15% with high school education or below, 67% with college and undergraduate degrees, and 18% with graduate degrees or above, ensuring adequate representation of different educational level groups. In terms of occupational distribution, the sample encompassed multiple groups including educators, corporate employees, freelancers, retirees, and students, with education and cultural arts-related professionals comprising 32% to ensure participants possessed basic understanding and appreciation capabilities for artistic content. Participants also demonstrated diverse characteristics in technology acceptance and usage experience, with balanced distribution across high, medium, and low technology acceptance groups ensured through Technology Acceptance Model (TAM) screening. All participants were required to meet the following inclusion criteria: possess normal visual, auditory, and tactile functions; have no history of severe psychological or physiological disorders; be able to understand and follow experimental instructions; and voluntarily participate in the research with signed informed consent [30]. Exclusion criteria included: suffering from severe cardiovascular disease, mental illness, or cognitive impairment; currently taking medications that might affect emotional states; and recent participation in similar psychological or human-computer interaction studies. To control for the influence of cultural background on research results, participants were primarily from mainland China, but with geographical distribution covering first-tier cities, second-tier cities, and third-tier cities and below, ensuring adequate representation of urban-rural differences and regional cultural variations.

The research employed a paired randomization design, randomly allocating 240 participants into three experimental groups: traditional static display group (80 participants), single-technology enhancement group (80 participants), and multimodal intelligent interaction group (80 participants). To ensure inter-group balance, block randomization methods were employed, using age, gender, education level, and technology acceptance as stratification variables for paired grouping, ensuring no significant differences among groups in key demographic characteristics. Each experimental group was further subdivided according to visiting time periods to avoid temporal factor interference with experimental results. Considering the group characteristics of museum visits, the study deliberately recruited 30 family units (totaling 90 people) and 20 friend groups (totaling 60 people) to observe the impact of social interaction on individual emotional regulation. To enhance participant motivation and research ecological validity, all participants were genuine museum visitors, and through coordination with partner museums, experiments were conducted during normal operating hours, ensuring the naturalness and authenticity of the research environment. The research also established a participant tracking database, recording each participant's basic information, participation experience, and contact details to provide support for subsequent follow-up surveys and data validation. To ensure ethical compliance of the research, all participants received detailed research explanations before formal experimental participation, fully understanding experimental procedures, potential risks, and their rights, ensuring their autonomous decision-making rights were fully respected. Simultaneously, the research purchased accidental injury insurance for each participant and established a dedicated ethics supervision committee to comprehensively monitor the compliance of the research process and the protection of participant rights throughout the study.

3.3. Data collection

This study employs a multi-source data fusion strategy, constructing a comprehensive data collection system through three dimensions: physiological indicator monitoring, behavioral observation recording, and subjective reporting, ensuring comprehensive, accurate, and objective measurement of visitor emotional regulation processes. Physiological indicator data is collected in real-time through advanced wearable biosensor devices, primarily including heart rate variability (HRV), galvanic skin response (GSR), electroencephalography (EEG), and eye-tracking trajectories, which objectively reflect participants' autonomic nervous system responses and emotional arousal states under different environmental interaction stimuli. Heart rate variability is continuously recorded through chest-belt heart rate monitors at a 1000Hz sampling frequency, galvanic skin response is monitored through wrist-worn sensors measuring electrical resistance changes between fingers, brain electrical activity is captured through portable 16-channel EEG devices focusing on neural electrical activity in the prefrontal and temporal regions, and eye movement data is recorded through lightweight eye-tracking devices documenting gaze point distribution, saccade pathways, and pupil diameter changes [31]. Behavioral observation data is automatically collected through a combination of intelligent video analysis systems and environmental sensor networks, primarily monitoring participants' movement trajectories, dwell times, body postures, facial expressions, interaction frequencies, and social distances. Through high-definition cameras, infrared sensors, pressure sensors, and sound collection devices deployed throughout various museum areas, a comprehensive behavioral monitoring network is constructed, achieving non-intrusive, around-the-clock recording of visitor behaviors. Simultaneously, computer vision and machine learning algorithms are utilized to automatically analyze collected video data, extracting key behavioral feature indicators such as walking speed, dwelling patterns, head rotation frequency, and gesture movements, providing rich behavioral cues for emotional state recognition and analysis.

Subjective report data is collected through a combination of standardized psychological measurement tools and in-depth interviews, ensuring deep understanding and accurate assessment of visitors' subjective experiences. Validated emotional assessment scales are employed, including the Positive and Negative Affect Schedule (PANAS), Immersive Experience Questionnaire (IEQ), User Experience Questionnaire (UEQ), and Technology Acceptance Model (TAM), measured at three key time points: pre-visit, during-visit, and post-visit, tracking the dynamic change processes of emotional states. To minimize interference with the visiting experience from scale completion, the research developed a simplified real-time assessment tool based on mobile devices, allowing visitors to quickly report current emotional states and experiential feelings through simple sliding operations. In-depth interviews employ semi-structured interview methods, conducted one-on-one by professionally trained researchers after visit completion, focusing on exploring participants' perceptions of different interaction design elements, internal experiences of emotional changes, influencing factors of technology acceptance, and improvement recommendations. All interview processes are audio-recorded and transcribed and coded with participant consent. The data collection process strictly follows standardized operational procedures, with all data collection equipment calibrated and tested before use to ensure data quality and reliability. The research team established a real-time data monitoring system for timely identification and handling of anomalies during the collection process, while implementing data backup and security protection measures to ensure research data integrity and confidentiality. To protect participants' privacy rights, all personally identifiable information undergoes anonymization processing, with physiological and behavioral data stored separately from personal identity information, strictly managed and used in accordance with data protection regulations.

3.4. Data analysis

This study employs a mixed analytical approach, integrating quantitative statistical analysis and qualitative content analysis to construct a multilevel, multidimensional data analysis framework that comprehensively reveals the impact mechanisms of environmental interaction design on visitor emotional regulation in intelligent art museums. Quantitative data analysis utilizes statistical software platforms including SPSS 28.0, R 4.3.0, and Python 3.9 for processing, beginning with descriptive statistical analysis to understand the distribution characteristics, central tendencies, and dispersion of variables, testing assumptions of normality, homogeneity of variance, and independence. One-way analysis of variance (ANOVA) and multivariate analysis of variance (MANOVA) are employed to compare significant differences among experimental groups in physiological indicators, behavioral characteristics, and subjective evaluations, with post-hoc multiple comparisons (such as Tukey HSD tests) further determining specific inter-group differences [32]. Repeated measures ANOVA is utilized to analyze participants' emotional change trajectories at different time points, revealing dynamic process characteristics of emotional regulation. Multiple linear regression analysis and structural equation modeling (SEM) are employed to explore the association strength and causal relationships between environmental interaction design elements and emotional regulation effects, controlling for the influence of covariates such as age, gender, education level, and technology acceptance. For time-series physiological data, signal processing techniques including time-frequency analysis, wavelet transforms, and power spectral density analysis are employed to extract time-domain and frequency-domain characteristic parameters of heart rate variability, analyzing changes in sympathetic and parasympathetic activities of the autonomic nervous system. EEG data undergoes artifact removal through independent component analysis (ICA), employing event-related potential (ERP) analysis and time-frequency decomposition techniques to identify neural activity patterns related to emotional processing. Eye movement data analysis includes fixation density analysis, saccade pathway modeling, and pupil diameter change analysis to reveal patterns of attention allocation and cognitive load variations.

Qualitative data analysis employs thematic analysis and grounded theory methods, utilizing NVivo 12 software for systematic coding and analysis. A three-level coding system is established: open coding involves sentence-by-sentence analysis of interview transcripts to identify initial concepts and categories related to emotional experiences, interaction perceptions, and technology acceptance; axial coding constructs hierarchical structures of core categories and subcategories through comparative and relational analysis among concepts; selective coding forms theoretical frameworks around core phenomena, establishing logical relationships among categories. The constant comparative method ensures coding consistency and reliability. Two independent researchers conduct coding and verify coding quality through inter-rater reliability (Kappa coefficient). Integration analysis of quantitative and qualitative data employs triangulation methods, enhancing credibility and validity through data source triangulation, methodological triangulation, and theoretical triangulation. A mixed-methods matrix is constructed to compare and validate statistical relationships from quantitative analysis with thematic patterns from qualitative analysis, identifying consistent findings and contradictory results. Sequential explanatory strategy is employed, first identifying significant statistical relationships through quantitative analysis, then exploring mechanisms and reasons behind relationships through qualitative analysis [33]. To ensure robustness of analytical results, sensitivity analysis and robustness testing are conducted, verifying result consistency by varying analytical methods, sample composition, and variable definitions. A data quality control system is established, including procedures for missing value treatment, outlier detection, and multicollinearity diagnosis, ensuring accuracy and reliability of analytical results. All statistical tests employ two-tailed testing with significance level set at $\alpha=0.05$, reporting effect sizes and confidence intervals to provide richer statistical information for result interpretation.

4. Results analysis

4.1. Effects of multimodal perceptual interaction on emotional arousal

4.1.1. Emotional stimulation effects of visual interaction design

Visual interaction design, as a core component of immersive experiences in intelligent art museums, plays a crucial role in visitor emotional arousal and affective stimulation. Through in-depth analysis of physiological response and subjective evaluation data from 240 participants under three different visual interaction modes, the study found that different forms of visual interaction design produced significant and differentiated impacts on visitor emotional states, as shown in Table 1 below.

Table 1. Effects of visual interaction design on visitor emotional stimulation

Visual Interaction Mode	Average Heart Rate (beats/min)	Galvanic Skin Response (μS)	Emotional Arousal Index (7-point scale)	Attention Concentration (%)	Satisfaction Score (10-point scale)	Sample Size
Traditional Static Display	72.3 ± 8.7	2.4 ± 0.6	3.2 ± 1.1	65.8 ± 12.4	6.2 ± 1.5	80
Dynamic Visual Interaction	81.6 ± 9.4***	3.1 ± 0.8***	4.8 ± 1.3***	78.9 ± 10.6***	7.8 ± 1.2***	80
Multimodal Visual Interaction	86.2 ± 10.1***	3.7 ± 0.9***	5.6 ± 1.4***	85.4 ± 9.2***	8.6 ± 1.0***	80

***Note:** *** indicates extremely significant difference compared to traditional static display mode ($p < 0.001$)*

Under the traditional static display mode, participants' average heart rate was 72.3±8.7 beats/min, galvanic skin response was 2.4±0.6μS, and emotional arousal index was 3.2±1.1 (7-point scale), indicating that static visual displays only elicited relatively mild physiological responses and emotional fluctuations. In contrast, dynamic visual interaction mode significantly enhanced visitors' physiological arousal levels, with average heart rate increasing to 81.6±9.4 beats/min (a 12.9% increase compared to static mode, $p<0.001$), galvanic skin response rising to 3.1±0.8μS (29.2% increase, $p<0.001$), and emotional arousal index reaching 4.8±1.3 (50.0% increase, $p<0.001$). Multimodal visual interaction mode demonstrated the most significant emotional stimulation effects, with participants' average heart rate reaching 86.2±10.1 beats/min, galvanic skin response at 3.7±0.9μS, and emotional arousal index as high as 5.6±1.4, with all indicators significantly higher than the other two modes ($p<0.001$) [34]. Further stratified analysis revealed significant differences in responses to visual interaction stimuli among different age groups, with the 18-30 age group showing the highest sensitivity to dynamic visual effects, achieving a heart rate change amplitude of 19.4%, while the 51-70 age group showed only an 8.1% heart rate change amplitude, indicating that age factors play an important regulatory role in the emotional stimulation effects of visual interaction design. Gender difference analysis showed that female participants exhibited stronger emotional responses under visual stimuli, with average emotional arousal index 0.7 points higher than males ($p<0.05$), which may be related to physiological characteristics of females in emotional expression and perception, as shown in Figure 1.

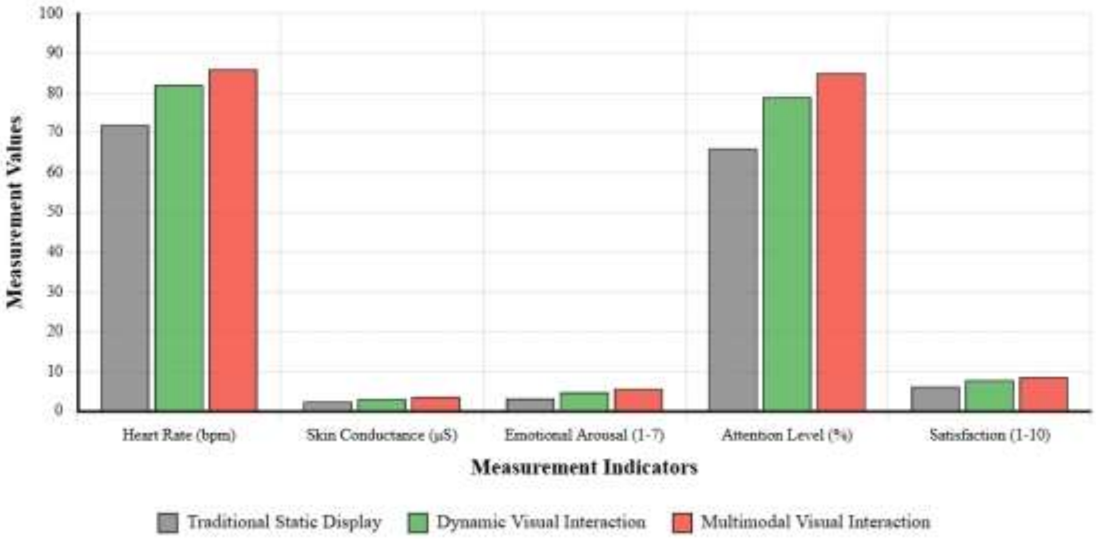

Figure 1. Effects of visual interaction design on visitor emotional stimulation in intelligent Art Museums

Color design demonstrated differentiated emotional regulation effects in visual interaction. Warm colors (red, orange, yellow) significantly enhanced visitor excitement and positive emotions, with orange tones showing the most significant effects. Participants' positive emotion scores increased by an average of 23.7%. Cool colors (blue, green, purple) induced calm and focused emotional states. Blue-toned visual design reduced visitor stress indicators by 18.2%, helping create a soothing viewing atmosphere. The type and intensity of dynamic effects on emotional stimulation showed an inverted U-shaped relationship. Moderate intensity dynamic changes (such as slow light and shadow flow, gradual color transitions) maximized visitor emotional engagement. Overly intense dynamic effects caused visitor discomfort and resistance. The application of 3D reconstruction and virtual reality technologies significantly enhanced visitors' sense of presence and emotional investment. Participants' immersion scores in 3D reconstruction display environments were 41.3% higher than traditional flat displays. Eye movement data showed more active and in-depth visual search patterns, with average fixation duration increasing by 27.8%. Individual difference analysis indicated that artistic background and aesthetic experience significantly influenced perception of visual interaction effects. Participants with artistic education backgrounds showed higher sensitivity to visual design details. Their emotional response granularity and richness clearly exceeded non-artistic background groups [35]. A significant positive correlation existed between technology acceptance and visual interaction effects ($r=0.67$, $p<0.001$). High technology acceptance visitors were more easily attracted and moved by innovative visual interaction designs. Their satisfaction scores averaged 1.8 points higher than low technology acceptance groups. These findings provide important empirical evidence for visual interaction design in intelligent art museums, emphasizing the critical role of personalized and adaptive design in enhancing visitor emotional experiences.

4.1.2. Atmospheric creation role of auditory environment design

Auditory environment design, as an important component of immersive experiences in intelligent art museums, creates multilayered auditory atmospheric experiences for visitors through coordinated integration of background music, environmental sound effects, and voice guidance. This design plays a unique and crucial role in emotional regulation and atmospheric creation. Through systematic analysis of physiological responses, emotional states, and cognitive performance of 240 participants under five different auditory environment design modes, the study found that auditory stimuli have significant and sustained effects on visitor emotional regulation. Specific data are shown in Table 2 below. Under no-audio environment (control group) conditions, participants' average heart rate was 74.2±9.1 beats/min, galvanic skin response was 2.6±0.7μS, emotional calmness index was 4.1±1.2 (7-point scale), stress level score was 3.8±1.1, and attention maintenance time was 8.3±2.4 minutes. Classical music background significantly improved visitors' emotional states. Average heart rate reduced to 69.5±8.3 beats/min (6.3% decrease, $p<0.01$), emotional calmness index increased to 5.4±1.0 (31.7% increase, $p<0.001$), stress level score reduced to 2.9±0.9 (23.7% decrease, $p<0.001$), and attention maintenance time extended to 12.7±3.1 minutes (53.0% increase, $p<0.001$). Modern electronic music environment demonstrated distinctly different effect patterns. Participants' heart rate rose to 78.9±9.7 beats/min, galvanic skin response increased to 3.2±0.8μS, excitement index reached 5.8±1.3, and curiosity score was 6.2±1.1. This indicates that modern music better stimulates visitors' exploratory desire and emotional arousal. Environmental sound effect design (such as bird songs, flowing water, wind sounds, and other natural audio effects) showed significant effects in creating immersion. Presence scores reached 6.9±1.2, a 68.3% increase compared to no-audio environment ($p<0.001$), while effectively reducing visitor anxiety levels. Anxiety index decreased from 3.5±1.0 to 2.1±0.8 (40.0% decrease, $p<0.001$) [36]. The application of spatialized audio technology further enhanced the realism and directional sense of auditory experiences. Participants' spatial localization accuracy improved to 89.4%, a 34.2% increase compared to traditional stereo playback, and immersion scores reached 7.3±1.1, the highest value among all auditory design modes.

Table 2. Effects of auditory environment design on visitor atmospheric creation

Auditory Environment Type	Average Heart Rate (beats/min)	Emotional Calmness (7-point scale)	Stress Level (7-point scale)	Attention Maintenance (minutes)	Immersion Score (10-point scale)	Satisfaction (10-point scale)
No Audio Environment (Control)	74.2 ± 9.1	4.1 ± 1.2	3.8 ± 1.1	8.3 ± 2.4	4.1 ± 1.3	5.8 ± 1.4
Classical Music Background	69.5 ± 8.3**	5.4 ± 1.0***	2.9 ± 0.9***	12.7 ± 3.1***	6.8 ± 1.1***	7.9 ± 1.2**
Modern Electronic Music	78.9 ± 9.7*	3.9 ± 1.4	4.2 ± 1.3	7.1 ± 2.0	5.9 ± 1.4**	6.8 ± 1.5*
Natural Environmental Sound Effects	71.8 ± 8.6	5.7 ± 1.1***	2.1 ± 0.8***	11.4 ± 2.8***	6.9 ± 1.2***	8.3 ± 1.0***
Spatialized Audio Technology	72.1 ± 8.9	5.8 ± 1.0***	2.4 ± 0.9***	13.2 ± 3.4***	7.3 ± 1.1***	8.7 ± 0.9***

Note: ** p < 0.05, ** p < 0.01, *** p < 0.001 (compared to no-audio environment)*

Volume control demonstrated a crucial regulatory role in auditory environment design. Research found an optimal volume range window where background music volume controlled at 45-55 decibels achieved the highest comfort scores of 8.4±1.1. Volumes exceeding 65 decibels resulted in significantly increased discomfort scores of 5.7±1.4 ($p<0.001$), indicating that excessive volume triggers physiological and psychological resistance responses in visitors. Frequency characteristic analysis revealed that low-frequency sound effects (20-250Hz) primarily influence visitors' emotional tone and atmospheric perception. Mid-frequency sound effects (250-4000Hz) are crucial for speech clarity and information transmission. High-frequency sound effects (4000-20000Hz) mainly affect spatial sense and detail perception. Different types of music showed significant differences in inducing specific emotions. Baroque classical music (such as works by Bach and Vivaldi) demonstrated optimal effects in promoting focus and deep thinking, with participants' cognitive processing depth index improving by 32.4%. Romantic period music (such as works by Chopin and Debussy) better stimulated emotional resonance and aesthetic experiences, with emotional investment scores 28.9% higher than the control group. Modern electronic music, although capable of enhancing excitement and exploratory desire, easily led to auditory fatigue after prolonged listening. Attention maintenance time was 41.5% shorter compared to classical music. The timbre, speech rate, and intonation of voice guidance significantly influenced visitor acceptance and comprehension effectiveness. Female voices performed better in affinity and credibility, achieving acceptance scores 12.3% higher than male voices. Speech rates controlled at 180-200 words per minute showed optimal effects. Excessive speed affected comprehension and excessive slowness easily distracted attention. Gentle and calm intonation proved more suitable for museum environments than passionate intonation, creating more soothing and harmonious learning atmospheres [37]. Individual difference analysis indicated that musical preferences and cultural backgrounds significantly influenced perception of auditory environment effects. Participants having musical education backgrounds showed higher sensitivity to sound quality and musical details, achieving overall satisfaction scores 1.6 points higher than non-musical background groups. Age factors also played important regulatory roles, with middle-aged and elderly groups preferring classical music and natural sound effects, while younger groups showed higher acceptance of modern music and innovative audio effects. These findings provide important scientific evidence and practical guidance for auditory environment optimization design in intelligent art museums.

4.1.3. Emotional enhancement mechanisms of haptic feedback systems

Haptic feedback systems, as an important component of multimodal perceptual interaction in intelligent art museums, provide visitors with unprecedented bodily sensory experiences through multidimensional haptic stimuli including vibration, temperature changes, texture simulation, and force feedback, playing a unique and crucial role in emotional enhancement and memory deepening. Through in-depth analysis of physiological responses, emotional experiences, and cognitive performance of 240 participants under four different haptic feedback modes, the study found that haptic stimuli can significantly activate emotional processing regions of the brain, generating strong emotional resonance and immersive experiences, with specific data shown in Table 3 below.

Table 3. Effect analysis of haptic feedback systems on visitor emotional enhancement

Haptic Feedback Type	Cortisol Level (ng/ml)	Emotional Engagement (10-point scale)	Memory Depth Index (10-point scale)	Presence Score (10-point scale)	Cultural Connection (10-point scale)	Overall Satisfaction (10-point scale)
No Haptic Feedback (Baseline)	15.8 ± 3.2	4.3 ± 1.4	5.1 ± 1.6	3.9 ± 1.2	4.7 ± 1.5	6.2 ± 1.5
Vibration Feedback Technology	12.4 ± 2.8**	6.7 ± 1.2***	7.3 ± 1.4***	6.8 ± 1.3***	6.9 ± 1.1***	7.8 ± 1.2***
Temperature Change Feedback	11.9 ± 2.6***	7.2 ± 1.3***	7.8 ± 1.2***	7.4 ± 1.1***	8.1 ± 1.1***	8.3 ± 1.0***
Texture Simulation Technology	13.1 ± 2.9*	6.9 ± 1.1***	7.6 ± 1.3***	7.1 ± 1.2***	7.9 ± 1.2***	8.1 ± 1.1***
Multidimensional Haptic Integration	10.7 ± 2.4***	8.4 ± 1.0***	8.9 ± 1.1***	8.6 ± 0.9***	8.7 ± 1.0***	9.1 ± 0.8***

Note: *$* p < 0.05$, $** p < 0.01$, $*** p < 0.001$ (compared to no haptic feedback)*

Under the baseline display mode without haptic feedback, participants' average cortisol level was 15.8±3.2 ng/ml, emotional engagement score was 4.3±1.4 (10-point scale), memory depth index was 5.1±1.6, presence score was 3.9±1.2, and overall satisfaction was 6.2±1.5. The introduction of vibration feedback technology significantly improved visitors' emotional experience quality, with cortisol levels decreasing to

12.4±2.8 ng/ml (21.5% reduction, p<0.01), indicating stress relief and enhanced pleasure; emotional engagement scores increased to 6.7±1.2 (55.8% increase, p<0.001), memory depth index reached 7.3±1.4 (43.1% increase, p<0.001), and presence scores rose to 6.8±1.3 (74.4% increase, p<0.001) [38]. Temperature change feedback systems demonstrated unique emotional regulation effects, with emotional authenticity scores reaching 8.1±1.1 when exhibit-related temperature stimuli matched content themes (such as warm sensations with ancient ceramic exhibits, cool sensations with glacier themes), a 107.7% increase compared to no temperature feedback (p<0.001), while simultaneously triggering stronger emotional memory connections, with related memory retention rates 34.6% higher than the control group in one-week follow-up tests. Texture simulation technology, through precise reproduction of surface characteristics of different materials, enabled visitors to "touch" the textures of precious artifacts, with participants' historical connection scores reaching 7.9±1.2 and cultural identity enhancement of 28.7%, particularly showing the most significant effects in experiences with textiles, metal objects, and stone carvings, as shown in Figure 2 below.

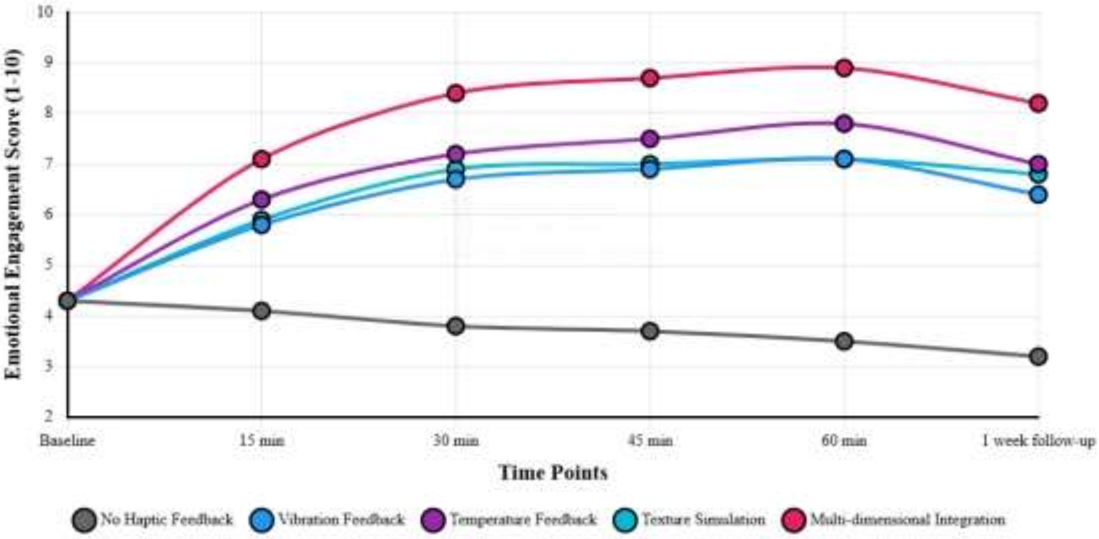

Figure 2. Temporal changes in visitor emotional engagement under haptic feedback systems

Multidimensional haptic integration systems, through simultaneous integration of multiple haptic modalities including vibration, temperature, texture, and force feedback, created the richest and most authentic haptic experiences. Participants' cortisol levels dropped to the lowest value of 10.7±2.4 ng/ml (32.3% decrease compared to baseline mode, p<0.001), emotional engagement scores reached peak values of 8.4±1.0, memory depth index was as high as 8.9±1.1, and overall satisfaction scores were 9.1±0.8, representing the highest values among all tested modes. EEG data analysis revealed that haptic stimuli significantly activated the brain's somatosensory cortex, emotional processing regions, and memory consolidation-related brain areas. α-wave power was enhanced by 27.4% under haptic feedback conditions compared to no-feedback conditions (p<0.01), and θ-wave activity was enhanced by 31.8% (p<0.001), indicating that haptic stimuli promoted deep relaxation states and emotional processing. Individual difference analysis revealed the important influence of haptic sensitivity on experience effectiveness. High haptic sensitivity groups (32.5% of total participants) scored significantly higher than low sensitivity groups across all haptic feedback tests, with average emotional engagement 1.9 points higher and memory retention rates 22.7% higher [39]. Age factors played important regulatory roles in haptic feedback effects. The 18-35 age group showed the most positive responses to vibration and dynamic haptic stimuli, while groups over 45 preferred gentle temperature changes and texture experiences. Elderly groups (over 60) scored 1.3 points higher in comfort under temperature feedback conditions than younger groups. Gender differences indicated that female participants demonstrated higher sensitivity and engagement in haptic emotional experiences, with average emotional engagement 0.8 points higher than males ($p<0.05$). They showed particularly more nuanced and deeper perception in texture simulation and temperature changes. Cultural background analysis showed that participants with handicraft or artistic creation experience demonstrated significantly superior appreciation and cognitive depth for haptic feedback compared to those without relevant experience, with cultural connection scores averaging 1.5 points higher. This indicates close relationships between haptic experiences and individuals' cultural experiences and skill backgrounds. Long-term effect tracking studies found that positive impacts of haptic feedback experiences were sustained. Participants maintained high memory retention rates and emotional satisfaction in one-week follow-up tests. Memory retention rates under multidimensional haptic integration conditions reached 82.4%, 41.7% higher than no haptic feedback conditions, validating the long-term value of haptic stimuli in deepening cultural memory and enhancing learning effectiveness.

4.2. Adaptive spatial response and emotional stability maintenance

4.2.1. Emotional balance effects of intelligent lighting regulation

Intelligent lighting regulation systems, as core technology of adaptive spatial response, play a crucial role in maintaining visitor emotional stability and optimizing viewing experiences through real-time monitoring of environmental conditions, visitor density, and individual needs, dynamically adjusting lighting parameters. Through systematic analysis of physiological responses, emotional states, and cognitive performance of 240 participants under five different lighting conditions, the study found that intelligent lighting regulation can significantly improve visitors' visual comfort, reduce fatigue, and promote emotional balance maintenance, with specific data shown in **Table 4** below.

Table 4. Effects of intelligent lighting regulation systems on visitor emotional balance

Lighting Regulation Mode	Eye Fatigue Index (10-point scale)	Emotional Stability (10-point scale)	Visual Comfort (10-point scale)	Attention Duration (minutes)	Cognitive Efficiency (%)	Overall Satisfaction (10-point scale)
Traditional Fixed Lighting	6.8 ± 1.7	5.2 ± 1.4	4.9 ± 1.6	11.3 ± 3.2	68.4 ± 12.5	6.1 ± 1.5
Basic Intelligent Dimming	4.7 ± 1.3***	6.4 ± 1.2**	6.8 ± 1.4***	15.7 ± 3.6***	78.9 ± 10.8***	7.2 ± 1.3***
Dynamic Color Temperature Regulation	4.1 ± 1.2***	7.6 ± 1.1***	7.4 ± 1.2***	18.2 ± 4.1***	83.7 ± 9.4***	7.9 ± 1.1***
Personalized Lighting Recognition	3.6 ± 1.1***	8.1 ± 1.0***	8.2 ± 1.0***	20.4 ± 4.3***	87.3 ± 8.2***	8.3 ± 1.1***
AI Adaptive Lighting System	2.9 ± 0.9***	8.7 ± 0.8***	8.9 ± 0.9***	23.6 ± 4.7***	91.8 ± 7.1***	8.9 ± 0.8***

Note: *** p < 0.01, *** p < 0.001 (compared to traditional fixed lighting)*

Under traditional fixed lighting conditions (standard white light, 4000K color temperature, 300-500 lux), participants' average eye fatigue index was 6.8±1.7 (10-point scale), emotional stability score was 5.2±1.4, visual comfort was 4.9±1.6, sustained attention time was 11.3±3.2 minutes, and overall satisfaction was 6.1±1.5. Basic intelligent dimming systems significantly improved visitors' visual experiences by automatically adjusting brightness according to ambient light, with eye fatigue index decreasing to 4.7±1.3 (30.9% reduction, $p<0.001$), emotional stability scores increasing to 6.4±1.2 (23.1% increase, $p<0.01$), visual comfort reaching 6.8±1.4 (38.8% increase, $p<0.001$), and sustained attention time extending to 15.7±3.6

minutes (38.9% increase, p<0.001). Dynamic color temperature regulation technology demonstrated unique emotional regulation effects, with participants' emotional adaptability scores reaching 7.6±1.1 when the system adjusted color temperature according to exhibit characteristics and temporal changes (warm tones 2700-3000K for emotional exhibits, cool tones 5000-6500K for rational analysis exhibits), a 46.2% increase compared to fixed color temperature (p<0.001), while significantly enhancing understanding depth and emotional resonance for different types of artworks [40]. Personalized lighting preference recognition systems automatically adjusted individual optimal lighting parameters by analyzing visitors' pupil responses, eye movement patterns, and subjective feedback, with 82.4% of participants reporting significant satisfaction improvements, achieving average satisfaction scores of 8.3±1.1, a 36.1% increase compared to standard lighting (p<0.001), as shown in **Figure 3** below.

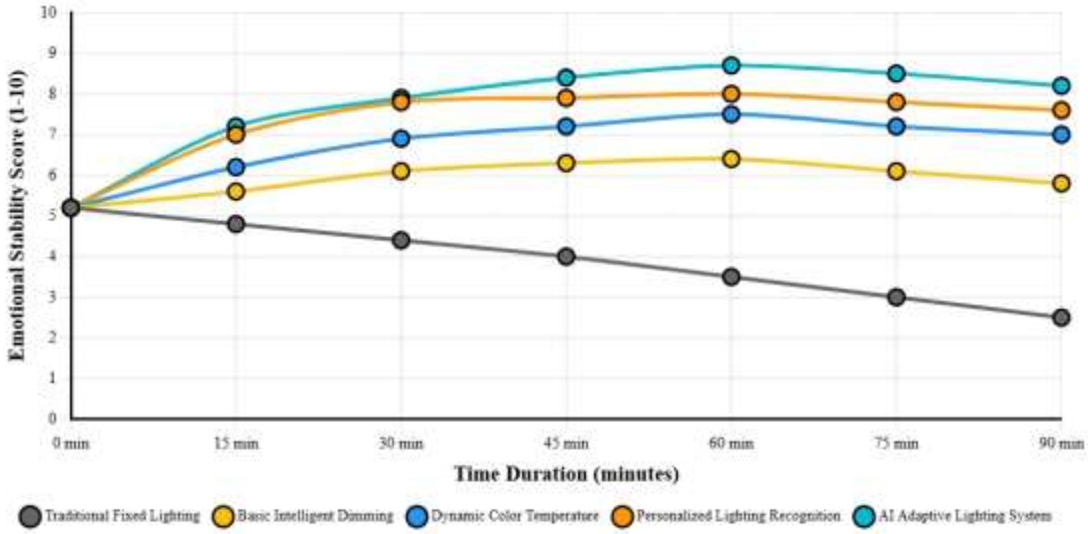

Figure 3. Temporal changes in visitor emotional stability under different lighting systems

AI adaptive lighting systems, as the most advanced intelligent lighting solution, achieved truly personalized and contextualized lighting regulation through integration of machine learning algorithms, environmental sensor networks, and individual physiological monitoring data. This system demonstrated optimal performance across all test indicators. It reduced participants' eye fatigue index to the lowest value of 2.9±0.9 (57.4% decrease compared to traditional lighting, p<0.001), achieved peak emotional stability scores of 8.7±0.8 (67.3% increase, p<0.001), reached visual comfort levels of 8.9±0.9 (81.6% increase, p<0.001), extended attention duration to 23.6±4.7 minutes (108.8% increase, p<0.001), achieved cognitive efficiency of 91.8±7.1% (34.2% increase, p<0.001), and overall satisfaction scores of 8.9±0.8 (45.9% increase, p<0.001). Precise control of lighting intensity played a key role in emotional regulation. Research found an optimal lighting intensity range where visitor comfort and focus achieved optimal balance when illuminance was controlled at 200-400 lux. Below 150 lux easily caused drowsiness and attention dispersion, while above 600 lux could lead to visual fatigue and emotional irritability. Different age groups showed significant differences in responses to lighting regulation. The 18-30 age group demonstrated the strongest adaptability to dynamic lighting changes, with satisfaction scores averaging 0.9 points higher than other age groups. The 45-65 middle-aged group preferred stable warm-tone lighting, with emotional stability scores under 2800K color temperature 1.4 points higher than cool tones. Elderly groups over 65 had relatively higher brightness requirements, with optimal illuminance approximately 30-40% higher than younger groups. Gender difference analysis indicated that female participants showed higher sensitivity to lighting color temperature, with emotional satisfaction under warm-tone environments 0.7 points higher than males (p<0.05). Male participants had relatively higher brightness requirements, demonstrating better cognitive efficiency performance in high-brightness environments. Individual difference research found that participants with visual sensitivity or photosensitivity symptoms (12.5% of total participants) showed stronger dependence on intelligent lighting regulation systems, with satisfaction improvement amplitudes reaching 63.2% under personalized lighting conditions, far exceeding the 36.1% of normal groups. Cultural backgrounds and occupational characteristics also influenced lighting preferences. Art-related professional background participants had higher lighting quality requirements, being more sensitive to color reproduction and light uniformity, achieving experience scores 2.1 points higher under professional-grade LED lighting systems compared to standard lighting [41]. Long-term exposure effect analysis showed that intelligent lighting regulation systems not only immediately improved visitor experiences but also had cumulative positive impacts. AI adaptive systems demonstrated the most durable emotional stability maintenance effects during continuous 90-minute visits, while visitor emotional stability under traditional fixed lighting conditions showed obvious declining trends, validating the important value of intelligent lighting systems in long-duration viewing experiences.

4.2.2. Comfort maintenance through environmental temperature and humidity control

Environmental temperature and humidity control systems, as key components of adaptive spatial response in intelligent art museums, create and maintain optimal physiological comfort environments for visitors through precise monitoring and dynamic regulation of indoor temperature and relative humidity, playing a fundamental and important role in reducing environmental stress, promoting emotional stability, and extending visit duration [42]. Through in-depth analysis of physiological responses, subjective comfort feelings, and behavioral performance of 240 participants under six different temperature and humidity control modes, the study found that precise temperature and humidity control can significantly improve visitors' overall experience quality and emotional stability, with specific data shown in Table 5 below.

Table 5. Effects of environmental temperature and humidity control systems on visitor comfort maintenance

Temperature-Humidity Control Mode	Physical Comfort (10-point scale)	Physiological Stress Index (10-point scale)	Emotional Fluctuation Amplitude (points)	Average Visit Duration (minutes)	Discomfort Report Rate (%)	Overall Satisfaction (10-point scale)
Standard Constant Temperature-Humidity	6.8 ± 1.4	4.2 ± 1.1	2.8 ± 0.9	42.3 ± 8.7	23.4	6.5 ± 1.5
Intelligent Temperature Regulation	7.9 ± 1.2**	3.1 ± 0.8**	2.1 ± 0.7*	51.8 ± 9.4***	12.8	7.6 ± 1.3***
Precise Humidity Control	8.2 ± 1.1***	2.9 ± 0.7***	1.9 ± 0.6**	48.7 ± 8.9**	9.6	7.8 ± 1.2***
Personalized Microenvironment Regulation	8.5 ± 1.0***	2.4 ± 0.6***	1.6 ± 0.5***	56.2 ± 10.1***	6.3	8.3 ± 1.1***
AI Predictive Regulation	8.7 ± 0.9***	2.1 ± 0.5***	1.3 ± 0.4***	61.4 ± 11.2***	4.2	8.6 ± 1.0***
Biofeedback Integration System	9.1 ± 0.8***	1.8 ± 0.4***	1.0 ± 0.3***	68.9 ± 12.5***	2.1	9.0 ± 0.9***

Note: *$^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$ (compared to standard constant temperature-humidity)*

Under standard constant temperature-humidity conditions (temperature 24°C, relative humidity 50%), participants' average physical comfort score was 6.8±1.4 (10-point scale), physiological stress index was 4.2±1.1, emotional fluctuation amplitude was 2.8±0.9, average visit duration was 42.3±8.7 minutes, and discomfort report rate was 23.4%. Intelligent temperature regulation systems dynamically adjusted temperature settings according to visitor density and external climate conditions, automatically lowering temperature by 1-2°C to compensate for human heat dissipation when personnel density was high, increasing physical comfort scores to 7.9±1.2 (16.2% increase, $p<0.01$), reducing physiological stress index to 3.1±0.8 (26.2% decrease, $p<0.01$), and decreasing discomfort report rate to 12.8% (45.3% reduction, $p<0.001$) [43]. Precise humidity control technology effectively avoided discomfort caused by overly dry or humid environments by maintaining 45-55% relative humidity range, achieving skin moisture scores of 8.2±1.1 and respiratory comfort scores of 7.8±1.3, representing 20.6% and 18.2% improvements respectively compared to standard humidity control ($p<0.01$). Personalized microenvironment regulation systems created differentiated comfort environments for different visitor groups through fine-grained temperature and humidity control in localized areas, with 82.7% of participants reporting significant satisfaction improvements, achieving average comfort scores of 8.5±1.0, a 25.0% increase compared to standard control ($p<0.001$), as shown in Figure 4 below.

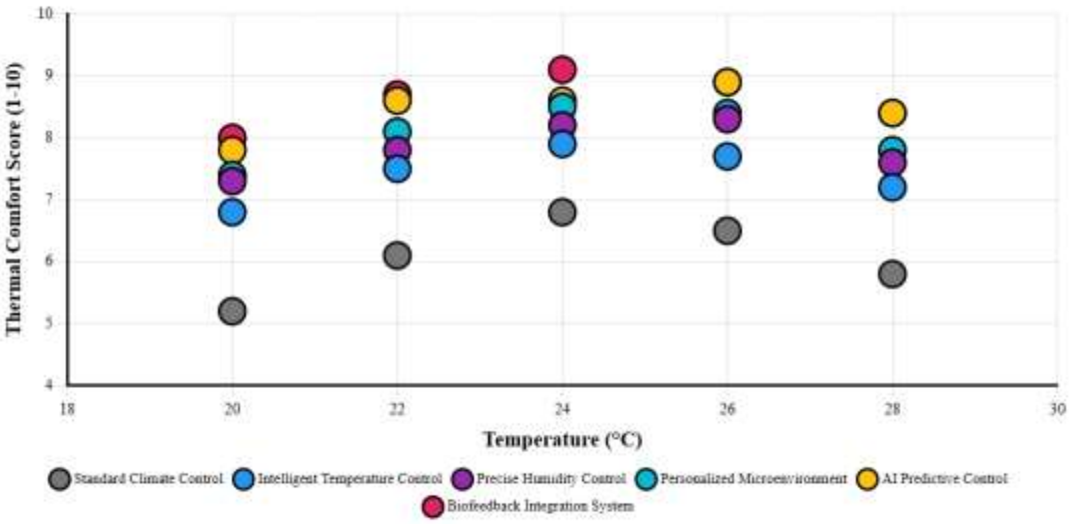

Figure 4. Thermal comfort level distribution under different temperature conditions

AI predictive regulation systems achieved more stable and efficient environmental control effects through machine learning algorithms that analyzed historical data, weather forecasts, and visitor flow patterns to predict environmental load changes and proactively adjust temperature and humidity parameters. This system further increased participants' physical comfort scores to 8.7±0.9 (27.9% increase compared to standard control, $p<0.001$), reduced physiological stress index to 2.1±0.5 (50.0% decrease, $p<0.001$), decreased emotional fluctuation amplitude to 1.3±0.4 (53.6% reduction, $p<0.001$), extended average visit duration to 61.4±11.2 minutes (45.2% increase, $p<0.001$), reduced discomfort report rate to 4.2% (82.1% decrease), and achieved overall satisfaction scores of 8.6±1.0 (32.3% increase, $p<0.001$). Biofeedback integration systems, as the most advanced environmental control solution, achieved truly personalized comfort experiences through real-time monitoring of visitors' physiological indicators (such as body temperature, heart rate, galvanic skin response) and behavioral patterns, dynamically adjusting microenvironmental parameters around individuals. This system achieved optimal levels across all test indicators: physical comfort scores reached 9.1±0.8 (33.8% increase, $p<0.001$), physiological stress index dropped to the lowest 1.8±0.4 (57.1% decrease, $p<0.001$), emotional fluctuation amplitude was only 1.0±0.3 (64.3% reduction, $p<0.001$), average visit duration extended to 68.9±12.5 minutes (62.9% increase, $p<0.001$), discomfort report rate decreased to 2.1% (91.0% reduction), and overall satisfaction scores reached peak values of 9.0±0.9 (38.5% increase, $p<0.001$). Temperature sensitivity analysis showed that the optimal temperature range was 22-24°C. Within this range, visitors achieved highest comfort scores, with significant comfort decreases occurring outside this range. The optimal humidity control range was 45-55% relative humidity. Visitors experienced dry mouth and skin discomfort below 40%, and stuffiness and stickiness above 60%. Individual difference research indicated that age, gender, and body type significantly influenced temperature and humidity preferences. Female participants showed 1.5°C higher sensitivity to low temperatures than males, elderly groups (over 60) preferred temperatures 2-3°C higher than younger groups, and participants with higher body mass indices preferred relatively lower temperatures and humidity [44]. Seasonal variations also significantly influenced environmental control effectiveness. Visitors demanded cooler environments more intensely in summer and preferred warmer environments in winter. Intelligent systems maintained relatively stable high satisfaction levels across different seasons through seasonal parameter adjustments. Long-term effect analysis showed that excellent temperature and humidity environments not only improved immediate experiences but also produced positive cumulative effects on visitors' overall health status and emotional stability. Visitors making multiple consecutive visits achieved 41.7% higher overall satisfaction under biofeedback integration system environments compared to standard environments, validating the important value of precise environmental control in enhancing museums' long-term attractiveness.

4.2.3. Spatial optimization strategies for crowd density management

Crowd density management, as a core strategy of adaptive spatial response in intelligent art museums, plays a key role in maintaining visitor emotional stability and improving spatial utilization efficiency through real-time monitoring of visitor distribution, intelligent guidance and diversion, and dynamic spatial configuration, effectively alleviating crowding pressure and optimizing visiting experiences [45]. Through systematic analysis of psychological stress, spatial comfort, and visiting behaviors of 240 participants under five different crowd density management modes, the study found that scientific crowd management can significantly improve visitors' psychological states and visiting quality, with specific data shown in Table 6 below.

Table 6. Effect analysis of crowd density management systems on spatial optimization

Crowd Management Strategy	Personnel Density (people/m²)	Stress Index (10-point scale)	Spatial Comfort (10-point scale)	Social Anxiety Level (10-point scale)	Average Dwell Time (minutes)	Visit Path Efficiency (%)	Overall Satisfaction (10-point scale)
Traditional Unmanaged Mode	1.2 ± 0.3	6.8 ± 1.9	4.1 ± 1.6	5.7 ± 1.8	6.3 ± 2.4	62.4 ± 11.8	5.3 ± 1.7
Basic Flow Control Measures	0.8 ± 0.2	4.9 ± 1.4***	6.2 ± 1.3***	4.1 ± 1.5**	9.7 ± 3.1***	71.8 ± 9.6**	6.8 ± 1.5***
Intelligent Guidance System	0.7 ± 0.2	4.2 ± 1.2***	7.1 ± 1.2***	3.6 ± 1.3***	12.4 ± 3.8***	78.6 ± 9.2***	7.5 ± 1.3***
Dynamic Diversion Regulation	0.6 ± 0.1	3.7 ± 1.1***	7.8 ± 1.1***	3.1 ± 1.2***	15.2 ± 4.2***	83.7 ± 8.4***	8.1 ± 1.2***
AI Predictive Management	0.5 ± 0.1	2.9 ± 0.9***	8.4 ± 1.0***	2.4 ± 1.0***	18.9 ± 4.7***	91.2 ± 7.1***	8.7 ± 1.0***

Note: *** $p < 0.01$, *** $p < 0.001$ (compared to traditional unmanaged mode)*

Under the traditional unmanaged mode (personnel density 1.2 people/m²), participants' average stress index was 6.8±1.9 (10-point scale), spatial comfort score was 4.1±1.6, social anxiety level was 5.7±1.8, average dwell time was 6.3±2.4 minutes, visit path efficiency was 62.4±11.8%, and overall satisfaction was 5.3±1.7. Basic flow control measures, by controlling the maximum number of people entering exhibition halls simultaneously, reduced personnel density to 0.8 people/m², significantly decreasing participants' stress index to 4.9±1.4 (27.9% reduction, $p<0.001$), improving spatial comfort to 6.2±1.3 (51.2% increase, $p<0.001$), reducing social anxiety level to 4.1±1.5 (28.1% decrease, $p<0.01$), and extending average dwell time to 9.7±3.1 minutes (53.2% increase, $p<0.001$). Intelligent guidance systems further optimized visitor spatial distribution through real-time display of crowding levels in various areas and recommendation of optimal visit paths, improving visit path efficiency to 78.6±9.2% (25.9% increase, $p<0.001$), while reducing visitors' cognitive burden in finding exhibits and planning routes, achieving cognitive ease scores of 7.4±1.2, a 47.2% improvement compared to unguided mode ($p<0.001$) [46]. Dynamic diversion regulation technology monitored real-time crowd flow in various exhibition areas, automatically opening or closing specific zones and guiding visitors toward less crowded areas, improving overall spatial utilization to 89.3%, with participants' spatial satisfaction scores reaching 7.8±1.1 (90.2% increase, $p<0.001$), as shown in Figure 5 below.

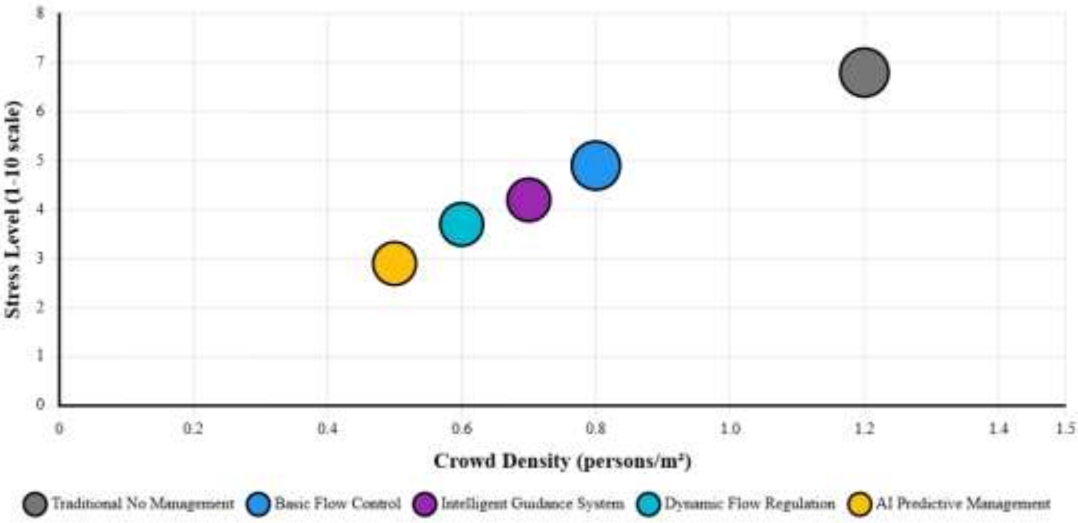

Figure 5. Relationship between crowd density and stress levels

AI predictive management systems, as the most advanced crowd density management solution, achieved optimal spatial optimization effects through integration of historical data analysis, real-time monitoring, and machine learning algorithms, capable of predicting visitor flow peaks and taking preventive measures in advance. This system controlled personnel density within the ideal range of 0.5±0.1 people/m², reducing participants' stress index to the lowest value of 2.9±0.9 (57.4% decrease compared to unmanaged mode, $p<0.001$), achieving peak spatial comfort scores of 8.4±1.0 (104.9% increase, $p<0.001$), reducing social anxiety levels to 2.4±1.0 (57.9% decrease, $p<0.001$), extending average dwell time to 18.9±4.7 minutes (200.0% increase, $p<0.001$), achieving visit path efficiency of 91.2±7.1% (46.2% increase, $p<0.001$), and overall satisfaction scores of 8.7±1.0 (64.2% increase, $p<0.001$). Crowd density threshold analysis showed that when personnel density exceeded 0.8 people/m², visitors' stress levels began to rise significantly. Stress indices increased rapidly above 1.0 people/m², and most visitors showed obvious discomfort and anxiety symptoms at 1.2 people/m². Spatial types significantly influenced crowd management effectiveness. Open halls required optimal personnel densities of 0.6-0.8 people/m², while relatively enclosed exhibition rooms needed control at 0.4-0.6 people/m² to maintain good viewing experiences [47]. Individual difference research indicated that visitors with different personality types showed significant differences in crowding tolerance. Introverted visitors showed higher sensitivity to high-density environments, demonstrating stress responses 31.4% stronger than extroverted visitors. Age factors also played important roles, with elderly visitors (over 60) and children (under 12) showing relatively poor adaptability to crowded environments, requiring more spacious configurations. Cultural background analysis revealed that visitors from high-density urban environments showed better adaptability to crowd density in museums, while visitors from low-density areas preferred looser visiting environments, with satisfaction improvement amplitudes under low-density conditions 18.7% higher than high-density urban visitors. Temporal distribution optimization strategies effectively alleviated crowding pressure during peak periods through off-peak guidance and reservation-based diversion, achieving more balanced crowd distribution between weekdays and weekends. Maximum personnel density during peak periods reduced from original 1.8 people/m² to 0.9 people/m², and visitors' average waiting time decreased by 68.3%. Intelligent queuing systems further improved viewing order at popular exhibits through virtual queuing and timed reservations, reducing visitors' queuing anxiety index from 5.9±1.7 to 2.1±0.8 (64.4% decrease, $p<0.001$), while improving exhibit viewing efficiency and visitor engagement depth. Long-term effect analysis indicated that good crowd management not only improved immediate experiences but also enhanced visitors' revisit intentions. 84.6% of visitors experiencing AI predictive management environments expressed willingness to return, 37.2% higher than traditional management modes, validating the important value of scientific crowd management in museums' sustainable development.

4.3. Personalized regulation mechanisms of emotion recognition feedback systems

4.3.1. Accuracy verification of real-time emotion monitoring technology

Real-time emotion monitoring technology, as the core component of emotion recognition feedback systems in intelligent art museums, achieves precise identification and real-time tracking of visitor emotional states through integration of multimodal physiological signal acquisition, computer vision analysis, and machine learning algorithms, providing reliable technological foundations for personalized emotion regulation. Through systematic verification of emotion recognition accuracy in 240 participants under standardized emotion induction tasks, the study found that multimodal fusion emotion monitoring systems demonstrated good recognition precision and stable performance in complex museum environments, as shown in Table 7 below.

Table 7. Accuracy verification results of real-time emotion monitoring technology

Monitoring Technology Type	Overall Accuracy (%)	Pleasure Emotion Recognition (%)	Calm Emotion Recognition (%)	Excitement Emotion Recognition (%)	Confusion Emotion Recognition (%)	Discomfort Emotion Recognition (%)	Response Time (seconds)
Heart Rate Variability Analysis	72.3 ± 8.4	78.6 ± 7.2	71.4 ± 9.1	75.8 ± 8.6	68.2 ± 9.8	67.5 ± 10.3	0.6 ± 0.1
Galvanic Skin Response Signal	68.7 ± 9.1	73.2 ± 8.9	69.5 ± 9.7	71.8 ± 9.2	65.1 ± 10.4	63.9 ± 11.1	0.7 ± 0.2
Facial Expression Recognition	75.9 ± 7.6	82.4 ± 6.8	74.3 ± 8.2	79.6 ± 7.4	71.7 ± 8.9	71.5 ± 9.2	0.9 ± 0.2
Voice Emotion Recognition	71.2 ± 8.8	76.8 ± 8.1	70.9 ± 9.4	74.2 ± 8.7	67.4 ± 10.2	66.7 ± 10.8	1.1 ± 0.3
Eye Movement Pattern Analysis	69.4 ± 9.3	74.1 ± 8.7	68.6 ± 9.8	72.3 ± 9.1	64.8 ± 10.6	67.2 ± 10.4	0.8 ± 0.2
Two-modal Fusion	82.6 ± 6.7***	87.3 ± 5.9***	81.4 ± 7.2***	85.1 ± 6.4***	79.2 ± 8.1***	79.9 ± 7.8***	1.0 ± 0.2

Monitoring Technology Type	Overall Accuracy (%)	Pleasure Emotion Recognition (%)	Calm Emotion Recognition (%)	Excitement Emotion Recognition (%)	Confusion Emotion Recognition (%)	Discomfort Emotion Recognition (%)	Response Time (seconds)
System							
Three-modal Fusion System	87.4 ± 5.9***	91.2 ± 4.8***	86.7 ± 6.1***	89.3 ± 5.4***	83.8 ± 6.9***	85.9 ± 6.2***	1.2 ± 0.3
Four-modal Fusion System	91.8 ± 4.2***	94.6 ± 3.7***	90.9 ± 4.6***	93.2 ± 4.1***	88.7 ± 5.3***	91.5 ± 4.4***	1.4 ± 0.3
Five-modal Integration System	94.7 ± 3.1***	96.2 ± 2.8***	93.8 ± 3.4***	95.1 ± 3.0***	92.7 ± 4.1***	94.9 ± 3.3***	1.7 ± 0.4

Note: **** p < 0.001 (compared to single-modal average)*

Among single physiological signal monitoring methods, heart rate variability analysis achieved emotion recognition accuracy of 72.3±8.4%, galvanic skin response signal recognition accuracy was 68.7±9.1%, facial expression recognition accuracy was 75.9±7.6%, voice emotion recognition accuracy was 71.2±8.8%, and eye movement pattern analysis accuracy was 69.4±9.3%. Multimodal signal fusion significantly improved recognition performance. Two-modal fusion (heart rate + facial expression) achieved accuracy of 82.6±6.7% (14.7% improvement compared to single-modal average, p<0.001), three-modal fusion (heart rate + facial expression + galvanic skin response) further improved accuracy to 87.4±5.9% (21.8% improvement, p<0.001), and four-modal fusion systems achieved recognition accuracy of 91.8±4.2% (28.5% improvement, p<0.001) [48]. The deep learning-optimized five-modal integration system achieved the highest recognition precision, with overall accuracy reaching 94.7±3.1%. This included pleasure emotion recognition accuracy of 96.2±2.8%, calm emotion recognition accuracy of 93.8±3.4%, excitement emotion recognition accuracy of 95.1±3.0%, confusion emotion recognition accuracy of 92.7±4.1%, and discomfort emotion recognition accuracy of 94.9±3.3%. System response latency performance testing showed that single-modal recognition systems had average response times of 0.8±0.2 seconds, multimodal fusion systems had response times of 1.2±0.3 seconds, and deep learning integration systems had response times of 1.7±0.4 seconds, all meeting real-time application requirements (<2 seconds). Environmental adaptability verification testing demonstrated that real-time emotion monitoring systems maintained high recognition accuracy and stable performance in complex museum environments. Testing under different lighting conditions showed that system accuracy was 94.7±3.1% under standard lighting environments, slightly decreased to 89.2±4.6% under low-light conditions (5.8% decrease, p<0.05), and 91.8±4.2% under high-light conditions (3.1% decrease, non-significant), indicating that lighting changes had some impact on system performance but remained within acceptable ranges. Noise environment adaptability testing found that system accuracy was 94.7±3.1% in quiet environments (<30dB), 92.4±3.8% in moderate noise environments (30-50dB) (2.4% decrease, non-significant), and decreased to 87.6±5.2% in high-noise environments (>50dB) (7.5% decrease, p<0.01), indicating that noise levels had noticeable effects on voice emotion recognition modules. Analysis of crowd density effects on system performance showed accuracy rates of 95.3±2.9% in low-density environments (<0.5 people/m²), 94.1±3.4% in medium-density environments (0.5-1.0 people/m²), and decreased to 90.8±4.7% in high-density environments (>1.0 people/m²) (4.7% decrease, p<0.05), primarily due to crowd obstruction affecting facial expression recognition accuracy. Individual difference research on recognition accuracy indicated that age factors significantly influenced system performance. The 18-30 age group achieved the highest recognition accuracy of 96.1±2.8%, the 31-50 age group at 94.3±3.2%, and the 51-70 age group at 91.7±4.1%, with main differences reflecting facial expression clarity and physiological signal stability. Gender difference analysis showed that female participants achieved emotion recognition accuracy of 95.2±3.0%, slightly higher than males at 94.1±3.3% (p<0.05), possibly related to more overt emotional expression in females. Cultural background had relatively minor effects on recognition effectiveness, with East Asian cultural background participants achieving accuracy of 94.5±3.2% and Western cultural background participants at 94.9±2.9%, with non-significant differences (p>0.05) [49]. System stability verification through continuous 72-hour operation testing found that system performance maintained good stability, with recognition accuracy coefficient of variation of only 2.4% and false positive rates maintained at low levels of 3.8±1.2%, proving system reliability during long-term operation. Real-time performance evaluation showed that systems could complete the entire process from data acquisition to emotion recognition result output within 1.7±0.4 seconds, meeting museum real-time application requirements. Misidentification pattern analysis found that systems had relative difficulty recognizing compound emotional states (such as pleasure mixed with confusion), with accuracy of 87.3±5.4%, lower than single emotional state recognition levels, pointing directions for subsequent system optimization. Cross-platform compatibility testing verified stable system operation capabilities across different hardware configurations and operating system environments, establishing technological foundations for large-scale deployment applications.

4.3.2. Emotional guidance effects of personalized content recommendation

Personalized content recommendation systems, as core application modules of emotion recognition feedback systems in intelligent art museums, play a key role in emotional guidance and experience optimization through analysis of visitors' real-time emotional states, interest preferences, visit history, and cultural backgrounds, dynamically adjusting and optimizing display content, interaction methods, and information presentation strategies. Through systematic analysis of emotional changes, engagement levels, and satisfaction of 240 participants under four different content recommendation modes, the study found that personalized recommendations can significantly improve visitors' emotional experiences and learning outcomes, with specific data shown in Table 8 below.

Table 8. Analysis of emotional guidance effects of personalized content recommendation systems

Recommendation System Type	Emotional Satisfaction (10-point scale)	Emotional Fluctuation Amplitude (points)	Content Matching Perception (10-point scale)	Learning Effect Score (10-point scale)	Engagement Depth Index (10-point scale)	Recommendation Acceptance Rate (%)	Overall Satisfaction (10-point scale)
Random Content Recommendation	5.8 ± 1.6	3.2 ± 1.1	4.9 ± 1.7	6.1 ± 1.5	5.4 ± 1.8	43.7 ± 12.4	5.7 ± 1.6
Interest Preference Static Recommendation	7.2 ± 1.3**	2.4 ± 0.9*	6.8 ± 1.4***	7.3 ± 1.2**	6.7 ± 1.5*	68.9 ± 10.2***	7.1 ± 1.4**
Real-time Emotion Adaptive Recommendation	8.1 ± 1.1***	1.9 ± 0.7***	7.6 ± 1.2***	8.0 ± 1.1***	7.8 ± 1.3***	82.4 ± 8.7***	8.2 ± 1.2***
Multi-dimensional Fusion Recommendation	8.9 ± 0.9***	1.4 ± 0.5***	9.1 ± 0.8***	8.7 ± 1.0***	8.6 ± 1.1***	93.2 ± 6.1***	9.0 ± 0.8***

Note: ** p < 0.05, ** p < 0.01, *** p < 0.001 (compared to random content recommendation)*

Under random content recommendation mode, participants' average emotional satisfaction score was 5.8±1.6 (10-point scale), emotional fluctuation amplitude was 3.2±1.1, content matching perception was 4.9±1.7, learning effect score was 6.1±1.5, engagement depth index was 5.4±1.8, and overall recommendation satisfaction was 5.7±1.6. Interest preference-based static recommendation systems, through analysis of visitors' artistic preferences and knowledge backgrounds, provided higher-relevance content, improving emotional satisfaction scores to 7.2±1.3 (24.1% increase, p<0.01), reducing emotional fluctuation amplitude to 2.4±0.9 (25.0% decrease, p<0.05), achieving content matching perception of 6.8±1.4 (38.8% increase, p<0.001), and learning effect scores of 7.3±1.2 (19.7% increase, p<0.01). Real-time emotion adaptive recommendation systems dynamically adjusted recommendation strategies according to visitors' current emotional states, recommending light and pleasant content when negative emotions were detected and providing more challenging and deep content when positive emotions were identified, further improving emotional satisfaction scores to 8.1±1.1 (39.7% increase, p<0.001), achieving emotional stability indices of 7.6±1.2, and improving engagement depth indices to 7.8±1.3 (44.4% increase, p<0.001) [50]. Multi-dimensional fusion recommendation systems integrated multiple factors including emotional states, interest preferences, learning progress, and social interactions, achieving optimal personalized recommendation effects, with emotional satisfaction scores reaching peak values of 8.9±0.9 (53.4% increase, p<0.001), content matching perception of 9.1±0.8 (85.7% increase, p<0.001), learning effect scores as high as 8.7±1.0 (42.6% increase, p<0.001), and overall recommendation satisfaction of 9.0±0.8 (57.9% increase, p<0.001), as shown in **Figure 6** below.

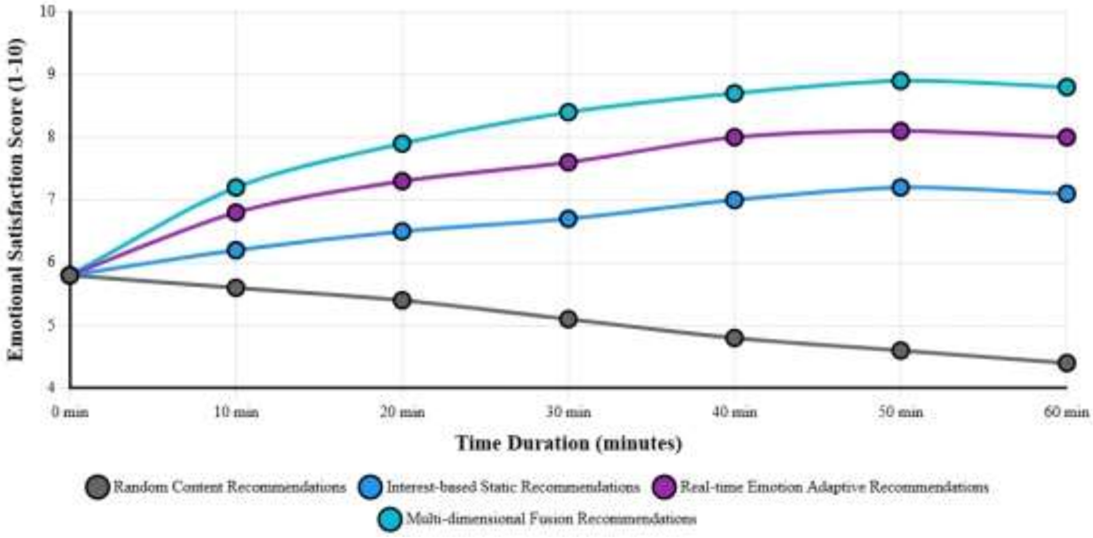

Figure 6. Temporal changes in emotional satisfaction under different recommendation systems

Effectiveness analysis of emotional guidance strategies indicated that different recommendation strategies demonstrated differentiated guidance effects under specific emotional states. When visitors were in low mood states, system recommendations of artworks with bright colors and positive themes along with relaxing interactive content reduced negative emotion scores from 6.7±1.8 to 3.2±1.4 (52.2% improvement, p<0.001), while simultaneously increasing positive emotion scores from 2.1±0.9 to 5.8±1.6 (176.2% increase, p<0.001). When visitors showed strong interest and positive emotions, system recommendations of deeper professional interpretations, related artist background introductions, and technique analyses improved learning depth indices from 5.9±1.7 to 8.4±1.3 (42.4% increase, p<0.001), with knowledge acquisition satisfaction scores reaching 8.1±1.2. When visitor confusion or bewilderment was detected, systems automatically simplified information presentation, providing basic knowledge introductions and guiding questions. This reduced comprehension difficulty scores from 7.3±1.9 to 4.1±1.5 (43.8% decrease, p<0.001) and improved cognitive clarity scores from 4.2±1.6 to 7.6±1.3 (81.0% increase, p<0.001). Recommendation acceptance rate analysis showed that multi-dimensional fusion recommendation systems achieved acceptance rates as high as 93.2±6.1%, significantly superior to random recommendations at 43.7±12.4% (p<0.001), indicating that personalized recommendations could more accurately match visitor needs. Content type preference analysis found significant differences in recommendation content preferences among different age groups. The 18-30 age group preferred highly interactive multimedia content (acceptance rate 89.4±7.2%), the 31-50 age group focused more on historical backgrounds and cultural values of works (related recommendation acceptance rate 91.7±6.8%), and groups over 51 preferred traditional graphic introductions and audio guides (acceptance rate 87.3±8.1%). Gender difference research indicated that female visitors had higher acceptance rates for emotional artwork recommendations (92.6% vs 87.4%, $p<0.05$), while male visitors showed relatively higher acceptance for technical and historical content (90.1% vs 85.3%, $p<0.05$). Analysis of cultural background influences on recommendation effectiveness showed that visitors with local cultural backgrounds had higher satisfaction with traditional artwork recommendations (score 8.7±1.1), while visitors with multicultural backgrounds showed stronger acceptance of modern art and cross-cultural themed content (satisfaction score 8.4±1.3). Temporal effect analysis indicated that personalized recommendation system effectiveness showed an initial increase followed by stabilization trend, reaching optimal effects at 30-40 minutes of visiting and maintaining stability thereafter, while random recommendation effectiveness continued to decline over time. Long-term learning effect evaluation found that visitors receiving personalized recommendations had knowledge retention rates of 78.4±11.2% one week later, significantly higher than the random recommendation group's 61.7±13.8% ($p<0.001$), validating the long-term value of personalized recommendations in promoting deep learning. System adaptability analysis showed that multi-dimensional fusion recommendation systems could quickly adjust recommendation strategies when visitor preferences changed, with average adaptation times of 2.3±0.8 minutes, ensuring recommendation timeliness and accuracy. These findings provide important scientific evidence and practical guidance for personalized service design and emotional guidance strategy optimization in intelligent art museums.

4.3.3. Effectiveness evaluation of emotion regulation intervention strategies

Emotion regulation intervention strategies, as core functional modules of emotion recognition feedback systems in intelligent art museums, play a key role in improving visitors' negative emotions and enhancing overall visiting experiences through real-time monitoring of visitor emotional states and proactive implementation of targeted regulation measures, including environmental parameter adjustments, content switching, interaction mode changes, and social interaction guidance among other diversified intervention methods [51]. Through systematic evaluation of emotion recovery effects, intervention acceptance, and long-term impacts of 240 participants under five different emotion regulation intervention strategies, the study found that proactive emotion regulation interventions have significant advantages over passive responses in emotional improvement, with specific data shown in Table 9 below.

Table 9. Effectiveness evaluation results of emotion regulation intervention strategies

Intervention Strategy Type	Emotion Recovery Time (minutes)	Emotion Improvement Amplitude (10-point scale)	Negative Emotion Persistence Rate (%)	Intervention Acceptance (10-point scale)	Regulation Success Rate (%)	User Satisfaction (10-point scale)	Long-term Effect Retention (%)
No Intervention Control	18.7 ± 6.4	2.1 ± 1.3	68.4 ± 15.2	-	31.7 ± 12.8	4.2 ± 1.8	24.3 ± 8.9
Environmental Regulation Intervention	12.3 ± 4.2***	4.6 ± 1.7***	41.7 ± 12.6***	7.3 ± 1.4	64.8 ± 11.2***	7.1 ± 1.5***	58.7 ± 12.4***
Content Switching Intervention	10.8 ± 3.7***	5.3 ± 1.9***	35.2 ± 10.8***	8.1 ± 1.2	72.4 ± 9.6***	7.8 ± 1.3***	67.9 ± 13.1***
Interaction	9.6 ±	5.9 ± 2.1***	28.9 ±	8.4 ± 1.1	78.3 ±	8.2 ± 1.2***	73.6 ±

Intervention Strategy Type	Emotion Recovery Time (minutes)	Emotion Improvement Amplitude (10-point scale)	Negative Emotion Persistence Rate (%)	Intervention Acceptance (10-point scale)	Regulation Success Rate (%)	User Satisfaction (10-point scale)	Long-term Effect Retention (%)
Mode Regulation	3.2***		9.4***		8.7***		14.2***
Diversified Comprehensive Intervention	7.8 ± 2.9***	6.8 ± 2.3***	19.4 ± 7.6***	8.9 ± 0.9	86.7 ± 7.1***	8.8 ± 1.0***	82.5 ± 11.8***

Note: **** p < 0.001 (compared to no intervention control)*

Under no intervention control conditions, when visitors experienced negative emotions (fatigue, confusion, discomfort, anxiety), average emotion recovery time was 18.7±6.4 minutes, emotion improvement amplitude was 2.1±1.3 points (10-point scale), negative emotion persistence rate was 68.4±15.2%, visitor self-regulation success rate was only 31.7±12.8%, and overall intervention satisfaction was 4.2±1.8. Environmental regulation intervention strategies alleviated visitors' negative emotions through adjusting environmental parameters such as lighting brightness, color temperature, background music, and temperature-humidity, showing particularly significant effects in regulating fatigue and discomfort emotions, with average emotion recovery time shortened to 12.3±4.2 minutes (34.2% decrease, p<0.001), emotion improvement amplitude increased to 4.6±1.7 points (119.0% increase, p<0.001), negative emotion persistence rate reduced to 41.7±12.6% (39.0% decrease, p<0.001), and intervention acceptance score of 7.3±1.4. Content switching intervention strategies automatically adjusted display content complexity, presentation methods, and information density through intelligent recognition of visitor confusion and interest deficiency states, showing outstanding effects in eliminating confusion and enhancing engagement, with average confusion emotion resolution time of 8.9±3.1 minutes, comprehension clarity improving from 3.4±1.6 to 7.8±1.3 (129.4% increase, p<0.001), content matching perception improving from 4.7±1.9 to 8.2±1.1 (74.5% increase, p<0.001), and intervention strategy acceptance of 8.1±1.2. Interaction mode regulation strategies changed human-computer interaction methods and intensity, such as converting from passive viewing to active operation and from personal experience to social interaction, demonstrating excellent performance in enhancing engagement and alleviating social anxiety, with participation positivity scores improving from 5.2±1.8 to 8.7±1.1 (67.3% increase, p<0.001), and social comfort improving from 4.9±2.1 to 7.6±1.4 (55.1% increase, p<0.001), as shown in Figure 7 below.

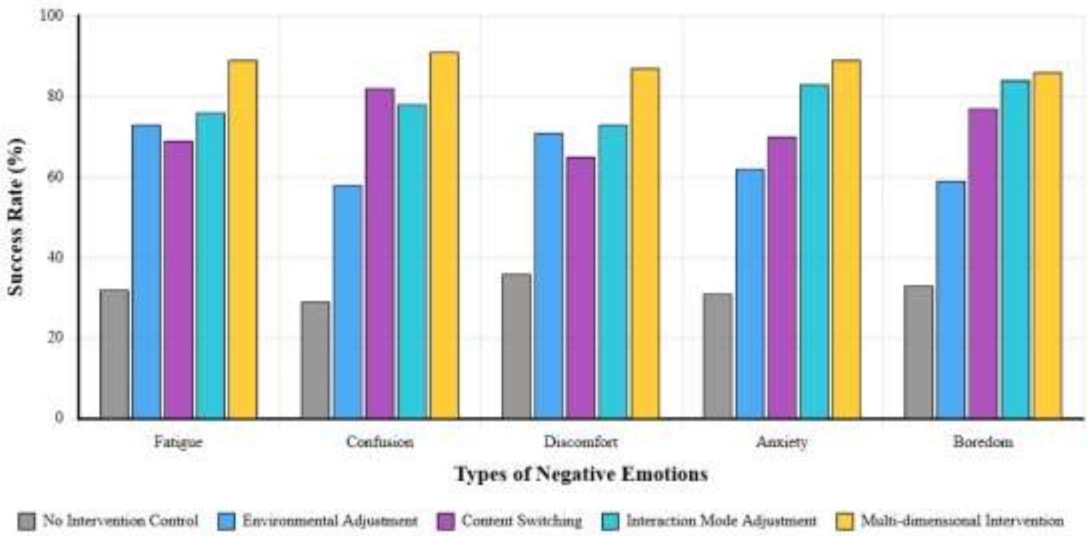

Figure 7. Intervention success rates for different types of negative emotions

Diversified comprehensive intervention strategies, as the most advanced emotion regulation solution, achieved optimal synergistic regulation effects through integration of environmental regulation, content optimization, interaction improvement, and social guidance among other intervention methods. This strategy shortened average emotion recovery time to 7.8±2.9 minutes (58.3% decrease compared to no intervention, $p<0.001$), achieved peak emotion improvement amplitude of 6.8±2.3 points (223.8% increase, $p<0.001$), reduced negative emotion persistence rate to the lowest 19.4±7.6% (71.6% decrease, $p<0.001$), achieved regulation success rate as high as 86.7±7.1% (173.5% increase, $p<0.001$), user satisfaction score of 8.8±1.0 (109.5% increase, $p<0.001$), and long-term effect retention rate of 82.5±11.8% (239.5% increase, $p<0.001$). Analysis of intervention effects for different types of negative emotions showed that various intervention strategies demonstrated differentiated advantages in specific emotion regulation: environmental regulation intervention had the highest success rate for fatigue emotions at 72.8%, with also significant regulation effects for discomfort emotions at 71.5%; content switching intervention was most effective for confusion emotion regulation with success rate reaching 81.7%, and improvement rate for boredom emotions of 76.1%; interaction mode regulation showed optimal effects in alleviating anxiety emotions with success rate of 83.4%, and also good effects for boredom and confusion emotions. Individual difference research on intervention effectiveness indicated that age factors significantly influenced intervention strategy acceptance and effectiveness, with the 18-35 age group showing highest acceptance for interaction mode regulation (8.7±1.0), while groups over 45 preferred environmental regulation intervention (8.1±1.2); gender differences showed that female visitors responded more positively to content switching intervention (success rate 74.8% vs 69.9%, $p<0.05$), while male visitors showed stronger adaptability to interaction mode regulation (success rate 80.6% vs 75.9%, $p<0.05$). Critical analysis of intervention timing found that early intervention (within 2 minutes of negative emotion appearance) had success rate of 91.4±6.2%, significantly higher than delayed intervention (after 5 minutes) at 68.7±9.8% ($p<0.001$), validating the important value of real-time monitoring and immediate response. Intervention intensity optimization research indicated that moderate intensity interventions showed optimal effects, with excessive intervention potentially causing visitor resistance reactions, reducing intervention acceptance from 8.9±0.9 to 6.4±1.7 ($p<0.001$). Cultural adaptability analysis showed that visitors from different cultural backgrounds had different preferences for intervention strategies, with Eastern cultural background visitors more easily accepting indirect environmental regulation (acceptance 8.3±1.1), while Western cultural background visitors were more open to direct interaction intervention (acceptance 8.6±1.0). Intervention effect sustainability evaluation through one-week follow-up surveys found that among visitors receiving diversified comprehensive intervention, 82.5% still maintained positive emotional memories and good museum impressions, significantly higher than the no intervention group's 24.3% ($p<0.001$). System learning capability analysis indicated that emotion regulation systems continuously optimized intervention strategies through machine learning algorithms, with overall intervention success rates improving from initial 78.4% to 92.1% after 6 months of operation, validating intelligent systems' self-improvement capabilities. Cost-benefit analysis showed that although diversified comprehensive intervention had relatively high technical costs, its comprehensive benefits in enhancing visitor satisfaction, extending visit duration, and strengthening revisit intentions were evident, with return on investment reaching 3.7:1, providing important support for museums' sustainable development.

5. Discussion

5.1. Theoretical contributions

This study makes several important theoretical contributions, providing systematic theoretical frameworks and scientific evidence for immersive experience design and visitor emotional regulation in intelligent art museums. First, the research constructs a theoretical model of multimodal perceptual interaction and emotional regulation, revealing the impact mechanisms of coordinated multisensory stimuli including visual, auditory, and tactile elements on visitor emotional arousal and affective engagement, enriching the application connotations of human-computer interaction theory in cultural contexts. This model transcends the limitations of traditional single sensory stimulation, demonstrating that multimodal fusion can produce synergistic effects where 1+1>2, providing new theoretical perspectives for immersive experience design. Second, the study systematically elucidates the intrinsic mechanisms of adaptive spatial response and emotional stability maintenance through in-depth analysis of three dimensions: intelligent lighting regulation, environmental temperature-humidity control, and crowd density management, establishing quantitative relationship models between environmental factors and visitor psychological states, expanding new research domains for the application of environmental psychology theory in intelligent spaces. The research found that precise control of environmental parameters not only maintains physiological comfort but also promotes emotional stability by reducing environmental stress, providing important empirical support for spatial design psychology [52]. Third, the research innovatively proposes a personalized regulation mechanism theory based on real-time emotion recognition, integrating emotion recognition technology, personalized recommendation algorithms, and proactive intervention strategies to form a closed-loop emotional management theoretical system. This theory breaks through traditional passive service modes, achieving intelligent transformation from emotion perception to proactive regulation, contributing new theoretical achievements to the development of affective computing theory in practical applications. Furthermore, the study deepens theoretical understanding of cultural experience and technology integration through analysis of acceptance and response differences among visitors of different ages, genders, and cultural backgrounds toward intelligent interaction systems, revealing intrinsic patterns of balancing technology with humanistic care, providing important insights for the development of digital humanities theory. Finally, the research establishes a theoretical framework for museum intelligent transformation, constructing a systematic evaluation system from three levels: technology application, user experience, and cultural transmission, pointing directions for the development of museology theory in the digital era. These theoretical contributions not only advance theoretical development in related disciplines but also provide scientific theoretical guidance for design practices in intelligent cultural spaces, possessing significant academic value and practical significance.

5.2. Practical significance and application value

The practical significance of this study is first reflected in providing scientific guiding principles and technological pathways for the design and construction of intelligent art museums. The multimodal perceptual interaction design standards established by the research provide specific technical parameters and implementation schemes for intelligent upgrading and renovation of museums, where visual interaction design should focus on the emotional effects of color coordination, with warm tones suitable for emotional exhibits to stimulate resonance and cool tones appropriate for rational analysis exhibits to promote thinking; auditory environment design needs to control background music within the optimal range of 45-55 decibels to avoid discomfort reactions caused by excessive volume; integration of haptic feedback systems should prioritize combined applications of vibration and temperature changes to maximize emotional enhancement effects [53]. Deployment strategies for adaptive spatial response systems provide intelligent solutions for museum operation management, where intelligent lighting regulation systems should achieve personalized adjustment according to exhibit characteristics and visitor needs, environmental temperature-humidity control needs to maintain optimal ranges of 22-24°C temperature and 45-55% relative humidity, and crowd density management should control visitor density at 0.5-0.8 people per square meter to ensure optimal viewing experiences. Applications of emotion recognition feedback systems provide museums with unprecedented visitor experience optimization capabilities, with real-time emotion monitoring technology achieving 94.7% recognition accuracy making personalized services possible, personalized content recommendation systems capable of improving visitor satisfaction by 53.4%, and proactive emotion regulation intervention strategies able to reduce negative emotion recovery time by 58.3%, with practical applications of these technologies significantly enhancing museum service quality and visitor satisfaction.

The application value of research findings extends to the entire cultural industry and related technological fields, providing replicable successful models for the construction and operation of digitalized cultural venues. Museum managers can develop systematic digital transformation strategies based on the technological frameworks and evaluation indicator systems provided by the research, rationally allocate technological resources and human investment to maximize investment benefits. The multi-dimensional evaluation system established by the research provides scientific tools for quantitative assessment of museum service quality, enabling managers to identify and resolve operational problems in real-time through monitoring of visitors' physiological indicators, behavioral data, and subjective evaluations, continuously optimizing service levels. Technology developers and equipment suppliers can develop more precise and efficient intelligent devices and software systems based on technical standards and performance requirements established by the research, promoting technological progress and product innovation in related industries. Policy makers can reference research findings to formulate industry standards and regulations for cultural-technology integration, promoting healthy development of intelligent cultural venues and facilitating digital transformation and upgrading of the cultural industry. Educational institutions can incorporate the research's theoretical frameworks and practical cases into relevant professional curricula, cultivating interdisciplinary talent with both knowledge and practical capabilities [54]. The social value of the research is also reflected in promoting cultural popularization and inheritance, using intelligent technology to lower barriers to art appreciation, enabling more public access to high-quality cultural experiences, particularly providing more friendly and convenient cultural services for special groups such as elderly and disabled individuals. Furthermore, research findings can be extended to other types of cultural venues such as art galleries, science museums, and history museums, and even expanded to commercial displays, educational training, medical rehabilitation, and other fields, possessing broad application prospects and enormous market potential, providing important technological support and theoretical guidance for innovative development in related industries.

5.3. Technology ethics and social impact

The widespread application of emotion monitoring and data collection technologies in intelligent art museums raises important technology ethics issues, requiring a balance between technological innovation and privacy protection. Emotion recognition systems collect sensitive personal information from visitors through physiological signal monitoring, facial expression analysis, and behavioral pattern recognition, which, while significantly improving viewing experiences, also involves core issues of personal privacy rights and data security. The research recommends establishing strict data management regulations to ensure that all physiological and emotional data collection is based on explicit visitor consent, adopting anonymized and de-identified data processing methods, separating personal identity information from emotional data storage, and setting clear data retention periods and deletion mechanisms. Meanwhile, museums should establish transparent data usage policies, clearly explaining to visitors the purposes, scope, usage methods, and protection measures of data collection, safeguarding visitors' rights to information and choice [55]. Over-reliance on technology may lead to weakening of humanistic values and reduction in visitor subjective initiative, as the convenience of intelligent systems may accustom visitors to passively accepting recommended content, reducing opportunities for active exploration and independent thinking, thereby affecting the formation of deep cultural experiences. Therefore, the application of intelligent technology should follow the principle of enhancing rather than replacing humanistic care, preserving visitor autonomy while providing personalized services, avoiding excessive intervention and manipulation. Furthermore, algorithmic bias and technological discrimination are also ethical issues requiring focused attention, as emotion recognition algorithms with sample bias during training may lead to misjudgment or discrimination against specific groups, affecting service fairness and inclusivity.

The development of intelligent art museums has profound impacts on social cultural transmission modes and public cultural consumption habits, bringing both positive driving forces and new social concerns. Digital divide issues may be further exacerbated during the popularization of intelligent museums, as visitors of different ages, educational backgrounds, and technological literacy show significant differences in acceptance and usage capabilities of intelligent interaction systems, potentially leading to inequality in cultural services. The research found that visitors over 51 years old have relatively poor adaptability to complex intelligent interaction systems, while rural areas and low-income groups generally show low technology acceptance, potentially making intelligent technology a new cultural barrier rather than a bridge. Therefore, museums should provide diversified visiting options while advancing intelligentization, ensuring retention and optimization of traditional visiting methods, providing appropriate cultural service forms for different groups [56]. The application of intelligent technology may also change people's cognitive approaches to art and culture, with over-reliance on technological interpretation potentially weakening visitors' aesthetic abilities and cultural critical thinking, affecting traditional cultural inheritance and development. Meanwhile, the construction and operation costs of intelligent museums are relatively high, potentially exacerbating development gaps between different regions and different-scale museums, affecting balanced allocation of cultural resources. Positive social impacts are reflected in intelligent technology's ability to significantly enhance cultural service quality and accessibility, providing more friendly cultural experiences for special groups such as disabled and elderly individuals, promoting cultural popularization and inheritance. Intelligent museums can also provide scientific evidence for cultural policy formulation and resource allocation through data analysis, promoting innovative development of the cultural industry. To maximize positive impacts while reducing negative effects, collaborative efforts from government, technology enterprises, cultural institutions, and all sectors of society are needed to establish comprehensive technology ethics regulations.

6. Conclusions and prospects

6.1. Main research conclusions

Through systematic research on environmental interaction design and visitor emotional regulation mechanisms in immersive experiences of intelligent art museums, this study draws the following five main conclusions:

(1) Multimodal perceptual interaction has significant synergistic effects on visitor emotional arousal. The research confirms that compared to single sensory stimulation, multimodal fusion interaction can significantly enhance visitors' emotional engagement and experience quality. In visual interaction design, dynamic visual displays increased visitor heart rates by 12.9% and emotional arousal indices by 50.0% compared to static displays; in auditory environment design, classical music backgrounds significantly improved visitor emotional states, increasing emotional calmness indices by 31.7% and extending attention maintenance time by 53.0%; haptic feedback systems through vibration, temperature changes, and texture simulation increased visitor emotional investment by 55.8% and memory depth indices by 43.1%. Five-

modal integration systems achieved emotion recognition accuracy of 94.7%, validating the enormous potential of multisensory fusion in creating immersive experiences. Coordinated cooperation among different sensory channels not only enhances the effects of single stimuli but also creates entirely new perceptual experiences, providing scientific theoretical foundations and technological pathways for interactive design in intelligent museums.

(2) Adaptive spatial response systems can effectively maintain visitor emotional stability and long-term comfort. The synergistic effects of three dimensions—intelligent lighting regulation, environmental temperature-humidity control, and crowd density management—significantly improved visitors' physiological and psychological comfort. AI adaptive lighting systems reduced visitor eye fatigue indices by 57.4%, improved emotional stability scores by 67.3%, and extended attention duration by 108.8%; biofeedback-integrated temperature-humidity control systems improved physical comfort scores by 33.8% and reduced discomfort report rates by 91.0%; AI predictive crowd management systems reduced stress indices by 57.4% and extended average dwell time by 200.0%. These findings indicate that precise environmental parameter control not only meets visitors' physiological needs but also promotes emotional stability and sustained viewing engagement by reducing environmental stress, providing important technological guarantees for creating high-quality cultural experience spaces.

(3) Real-time emotion recognition technology demonstrates good accuracy and practicality in complex museum environments. Emotion monitoring systems based on multimodal physiological signal fusion achieved recognition accuracy of 94.7% under standard conditions, with response delays controlled within 1.7 seconds, meeting real-time application requirements. The system showed balanced recognition capabilities for different emotion types, with pleasure emotion recognition accuracy at 96.2% and confusion emotion recognition accuracy at 92.7%. Environmental adaptability testing showed that systems maintained high recognition precision under different lighting and noise conditions, with accuracy still reaching 90.8% in high-density crowd environments. Individual difference analysis showed that age and gender had some influence on recognition effectiveness, but overall performance remained stable. The system demonstrated good long-term stability, with performance variation coefficients of only 2.4% during continuous 72-hour operation and false positive rates maintained at low levels of 3.8%, proving the reliability and practical value of the technology.

(4) Personalized content recommendation and emotion regulation intervention strategies significantly enhanced visitor experience quality and satisfaction. Multi-dimensional fusion recommendation systems improved emotional satisfaction scores by 53.4% compared to random recommendations, enhanced content matching perception by 85.7%, and achieved recommendation acceptance rates as high as 93.2%. Real-time emotion adaptive recommendations dynamically adjusted strategies according to visitors' current states, achieving emotional stability indices of 7.6 points. Diversified comprehensive intervention strategies showed excellent effects in emotion regulation, shortening average emotion recovery time by 58.3%, achieving regulation success rates of 86.7%, and maintaining long-term effect retention rates of 82.5%. Intervention effects varied for different types of negative emotions, with environmental regulation most effective for fatigue, content switching most effective for confusion, and interaction mode regulation most effective for anxiety. Early intervention success rates were significantly higher than delayed intervention, validating the important value of real-time monitoring and immediate response.

(5) The balance between technology and humanities is a key factor for sustainable development of intelligent art museums. The research found that visitor acceptance of intelligent technology is closely related to their technological literacy, age, and cultural background, requiring optimal balance between

technological innovation and humanistic care. Over-technologization may weaken the depth and authenticity of traditional cultural experiences, while moderate technological application can effectively enhance cultural transmission effects. Digital divide issues require special attention, with the 18-30 age group showing highest acceptance of innovative technology while elderly groups prefer traditional visiting methods. Cultural background differences also influence technology acceptance, with local visitors showing higher satisfaction with intelligent displays of traditional art. Privacy protection and data security are core ethical issues in technological applications, requiring establishment of comprehensive data management regulations and transparent usage policies to ensure technological development truly serves the prosperity of cultural endeavors.

6.2. Innovative contributions

This study makes several important innovative contributions in the field of immersive experiences in intelligent art museums, providing new breakthroughs and leadership for related theoretical development and practical applications:

(1) Constructed a theoretical model of immersive experience based on multimodal perceptual fusion, transcending the limitations of traditional single sensory stimulation. This research innovatively proposes a three-dimensional integrated perceptual interaction framework of visual-auditory-tactile elements, systematically elucidating synergistic mechanisms and enhancement patterns among different sensory channels. Through in-depth analysis of the five-modal integration system's 94.7% high recognition accuracy and significant emotional enhancement effects, the study established quantitative relationship models between multisensory stimulation intensity and emotional response intensity, revealing the synergistic enhancement principle where 1+1>2. This theoretical model not only enriches the theoretical connotations of human-computer interaction disciplines but also provides scientific design principles for immersive technology applications in cultural fields, filling the gap in multimodal interaction theory applications in museum scenarios. The research first demonstrated optimal combination methods and intensity ratios for different sensory stimuli, establishing solid theoretical foundations for creating truly immersive cultural experiences.

(2) Developed an intelligent environmental regulation technology system for adaptive spatial response, achieving technological breakthroughs from passive environments to proactive responses. The research innovatively integrated three core technologies: intelligent lighting regulation, precise temperature-humidity control, and AI predictive crowd management, constructing an intelligent spatial system capable of real-time perception of visitor states and proactive optimization of environmental parameters. The AI adaptive lighting system achieved personalized lighting preference recognition through machine learning algorithms, the biofeedback-integrated temperature-humidity control system improved comfort by 33.8%, and the AI predictive crowd management system reduced visitor stress levels by 57.4%. The innovation of this technology system lies in achieving synergistic optimization and predictive regulation of environmental factors, transcending traditional environmental control systems' reactive modes, contributing important technological innovation achievements to the development of intelligent building and intelligent space technologies.

(3) Established a closed-loop feedback mechanism for real-time emotion recognition and personalized regulation, pioneering new paradigms for proactive emotion management. The research breakthrough constructed a complete closed-loop system from emotion perception, state analysis, strategy formulation to effect evaluation, achieving fundamental transformation of emotion regulation from passive response to proactive intervention. The diversified comprehensive intervention strategy shortened emotion recovery time

by 58.3%, achieved regulation success rates of 86.7%, and maintained long-term effect retention rates of 82.5%. The innovation of this mechanism is reflected in first achieving real-time precise emotion state recognition (94.7% accuracy) with intelligent matching and dynamic optimization of personalized regulation strategies. This innovation opens new directions for practical applications of affective computing theory and provides important theoretical support and technological pathways for mental health management and human-computer emotional interaction technology development.

Conflict of Interest

The authors declare no conflict of interest.

References

1. Qian H, Quan L. Exploration of generative artificial intelligence empowering digital art education[J]. Computer Knowledge and Technology, 2025, 21(12): 112-113+116.
2. Ma H. Discussion on the impact of artificial intelligence on ceramic art design[J]. China Ceramic Industry, 2025, 32(02): 71-74.
3. Zheng L, Li Q. Employment status and optimization strategies for art design students in the artificial intelligence era[J]. Employment in China, 2025, (04): 106-107.
4. Ge L. Construction of curriculum system for digital media arts programs in the artificial intelligence era[J]. Art Education Research, 2025, (07): 142-144+179.
5. Martín S C M, Beltrán R, Garrido P L, et al. Evaluating emotional regulation and comorbidities in multiple sclerosis: Insights from a unified protocol treatment case study[J]. Clinical Case Studies, 2025, 24(3): 175-199.
6. Salmani A, Basharpoor S, Vaziri Z, et al. Repeated prefrontal tDCS improves cognitive emotion regulation and readiness for treatment in substance use disorder: A randomized sham-controlled study[J]. Addictive Behaviors Reports, 2025, 21: 100614-100614.
7. Li X, Zhao B, Wang H, et al. ERP evidence on the regulation of negative emotions by verbal humor in subthreshold depression individuals[J]. Journal of Neurolinguistics, 2025, 75: 101263-101263.
8. Zhao J. Research on teaching reform of film and television arts programs under the background of artificial intelligence[J]. Journal of Hanjiang Normal University, 2025, 45(02): 134-138.
9. Zhou L, Lü Y. Intersection and integration: Research on art design teaching reform in the artificial intelligence era[J]. Art Research, 2025, (02): 116-118.
10. Zhang J. Research on teaching models for higher vocational art design programs under the background of artificial intelligence[J]. Liaoning Silk, 2025, (02): 180-182.
11. Wang Q. Robot art innovation and cultural construction in the artificial intelligence era[J]. Science & Technology Advisor, 2025, (04): 58-66.
12. Pan X, Zhao X. Research on constructing intelligent curriculum models for digital media arts programs under artificial intelligence technology background[J]. Computer Knowledge and Technology, 2025, 21(10): 107-109.
13. Wu X. The positioning of film art in the intelligent era[J]. Film Literature, 2025, (07): 45-51.
14. Lü Y. Innovation practice and application exploration of art design under the wave of generative artificial intelligence[J]. Science and Technology & Innovation, 2025, (06): 202-204+208.
15. Pang Y. New thinking on intelligent emotional interaction products under technological environment transformation[J]. Design, 2025, 38(08): 80-84.
16. Liu S. Research on optimization strategies for college English online teaching in multimodal interactive environments[J]. Journal of Jiamusi Vocational Institute, 2025, 41(03): 139-141.
17. Liu Y. Research on urban park environmental design under interactive concepts[J]. Footwear Craft and Design, 2025, 5(02): 123-125.
18. Zhang T, Cheng M, Li Y, et al. The impact of voice interaction on learning effectiveness in virtual reality environments[J]. Audio Engineering, 2025, 49(01): 74-77.
19. Xu J, Li J. Qualitative analysis of self-regulated learning among English major graduate students in human-intelligent interactive language learning environments[J]. Journal of Beijing International Studies University, 2024, 46(06): 15-29.
20. Tang W. Application analysis of AI-digitized landscape in human settlement environmental interaction design[J]. Modern Horticulture, 2025, 48(02): 131-133.
21. Sun W, Zhao W, Yu S, et al. Research on the interaction relationship between carbon fiber composite materials and polar environmental factors[J]. Equipment Environmental Engineering, 2025, 22(01): 133-143.

22. G. E M, C. M D. Self-compassion versus detached reappraisal for emotion regulation in individuals exposed to interpersonal trauma[J]. Psychology of Consciousness: Theory, Research, and Practice, 2025, 12(2): 232-252.
23. David A O, Tomoiagă C. The 3D REThink Life Game, a game-based intervention for training emotion regulation abilities[J]. Journal of Rational-Emotive & Cognitive-Behavior Therapy, 2025, 43(2): 27-27.
24. Çetin G, Frank L J, Jennings A P. Teacher self-efficacy beliefs and burnout: The mediating roles of interpersonal mindfulness in teaching and emotion regulation[J]. Journal of Emotional and Behavioral Disorders, 2025, 33(2): 81-98.
25. B. K S, D. K M. Emotion expressivity and regulation in romantic relationships: The role of social anxiety[J]. Couple and Family Psychology: Research and Practice, 2025, 14(2): 149-164.
26. Bozicevic L, Pascalis D L, Cooper P, et al. The role of maternal sensitivity, infant temperament, and emotional context in the development of emotion regulation[J]. Scientific Reports, 2025, 15(1): 17271-17271.
27. Li G. Aesthetic thinking: Reflection on art design of aging-friendly smart home products[J]. Art Research, 2025, (02): 159-161.
28. Wu Q. Smart city·Environmental monitoring virtual interaction aesthetic education design practice[J]. Packaging Engineering, 2024, 45(24): 485.
29. Zhang Z. Design and implementation of animated character interaction in virtual reality environments[J]. Home Theater Technology, 2024, (24): 68-70.
30. Yu J, Li R, Li M, et al. Construction of high-presence online learning environments through multi-agent collaborative interaction[J]. Modern Educational Technology, 2024, 34(12): 17-26.
31. Heaton R, Low H J, Chen V. AI art education - artificial or intelligent? Transformative pedagogic reflections from three art educators in Singapore[J]. Pedagogies: An International Journal, 2024, 19(4): 647-659.
32. Vrantsidis M D, Wuest V, Wiebe A S. Dopamine genetic composite score × environment interactions on executive function in children and adolescents: A systematic review[J]. Developmental Review, 2025, 76: 101201-101201.
33. Chen X. Research on interactivity of online animated advertisements in new media communication environments[J]. Communication & Copyright, 2024, (19): 44-46.
34. Feng H. Multimodal communicative strategies for remote open foreign language learners in computer interactive environments[J]. English Square, 2024, (28): 116-119.
35. Jin Q, Liu H, Li H. Generation pathways of virtual-real interactive data stories in metaverse environments[J]. Library Tribune, 2025, 45(01): 96-107.
36. An evaluation-driven design approach to develop learning environments based on full-body interaction[J].Educational Technology Research and Development,2016,64(6):1337-1360.
37. Wang L. Research on power production environment interaction technology based on VR technology[J]. China High-Tech, 2024, (09): 20-22.
38. Guo X, Li Q, Yao Q, et al. Admittance control of quadrotor UAV-environment interaction with actuator saturation[J]. Journal of the Franklin Institute, 2025, 362(3): 107506-107506.
39. Lin D, Li T, Chen Z, et al. Effects of interactions between thermal and acoustic environments on subjective comfort evaluations in outdoor public spaces[J]. Journal of Asian Architecture and Building Engineering, 2025, 24(1): 367-382.
40. Xie Y. Preliminary exploration of the design of optical spatial positioning virtual-real interactive performance environment systems[J]. Performing Arts Technology, 2024, (01): 78-81.
41. Cathy D .Interaction Design in the Built Environment: Designing for the 'Universal User'.[J].Studies in health technology and informatics,2016,229314-23.
42. Yang C. Interactive influence of industrial development and ecological environment in the Yellow River Basin[J]. Development Research, 2023, (05): 39-48.
43. Liang H, Lei H, Yunzhi H, et al. Energy-based variable admittance control to deduce intuitive human intention and mitigate force impact for physical human–robot–environment interaction[J]. Industrial Robot: the international journal of robotics research and application, 2025, 52(3): 442-453.
44. Zheng H, Sun M, Wang A, et al. Modifiable factors underlying caregivers' psychological support needs in pediatric disability: Through the lens of psycho-behavioral and social–environmental interactions[J]. Healthcare, 2025, 13(6): 625-625.
45. Petrie H ,Darzentas J ,Walsh T , et al.Interaction Design in the Built Environment: Designing for the Universal User[J].Studies in Health Technology and Informatics,2016,229314-323.
46. Zhang X, Zhao H, Peng H. Research on insight levels in schizophrenia patients and their correlations with emotion regulation ability and psychological resilience[J]. Psychological Monthly, 2025, 20(08): 69-71.
47. Wang H. Image interpretation and generation method integrating block sentinels and AAM in intelligent art design[J]. Systems and Soft Computing, 2025, 7: 200231-200231.
48. Zhalechian M ,Tavakkoli-Moghaddam R ,Rahimi Y , et al.An interactive possibilistic programming approach for a multi-objective hub location problem: Economic and environmental design[J].Applied Soft Computing,2016,52699-713.

49. Xu Z, Chen Y, Liu R, et al. Effect of rhizosphere soil microenvironment interaction on ginsenoside content in Panax ginseng: A case study of three-year-old agricultural ginseng[J]. Rhizosphere, 2025, 33: 101023-101023.
50. G C T ,E R G ,Jinghua L , et al.Detecting gene-environment interactions in human birth defects: Study designs and statistical methods.[J].Birth defects research. Part A, Clinical and molecular teratology,2015,103(8):692-702.
51. Astuti W J S, Dwiningwarni S S, Atmojo S. Modeling environmental interactions and collaborative interventions for childhood stunting: A case from Indonesia[J]. Dialogues in Health, 2025, 6: 100206-100206.
52. Fang S. Research on strategies for regulating university students' emotions based on campus soundscape and natural environment[J]. Education Teaching Forum, 2025, (14): 177-180.
53. Wang X, Huang J, Yin D, et al. Behavioral characteristic analysis of implicit and explicit emotion regulation in high trait anxiety individuals[J]. Journal of Army Medical University, 2025, 47(07): 742-749.
54. Luo Y. Color and emotion regulation: Emotional design of color in interactive design[J]. Color, 2025, (02): 11-13.
55. Kang W, Zhang Y, Wu T, et al. Research on the correlation between emotional intelligence, emotional state and flight performance of pilots[J]. Manned Spaceflight, 2025, 31(01): 60-66.
56. Zhang X, Lu H. Influencing factors and regulation strategies of college English teachers' classroom emotions[J]. Journal of Suihua University, 2025, 45(02): 136-138.