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Article

Ergonomic study of visitors in red cultural venues from a biomechanical perspective: A case study of students from Sichuan University of Arts and Science

Yang Gao

School of Marxism, Sichuan University of Arts and Science, Dazhou 635000, China; 20240108@sasu.edu.cn

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Abstract: Red cultural venues are pivotal in preserving China's revolutionary heritage and fostering national identity. However, these venues often encounter difficulties in engaging contemporary audiences, particularly younger visitors who seek more interactive and technologically enriched experiences. This study investigates the ergonomic and biomechanical challenges faced by young visitors, using students from the ideological and political education program and the cultural industry management program at Sichuan University of Arts and Science as a representative case study. Employing a mixed-methods approach, the research integrates quantitative surveys with 200 participants and qualitative interviews with 30 participants to assess physical discomfort and engagement levels. Statistical analysis reveals that prolonged standing significantly increases discomfort (β = 0.04, $p < 0.001$), while higher levels of interactive engagement ($\beta = -0.30$, $p = 0.002$) and overall satisfaction ($\beta = -0.20$, $p = 0.013$) are associated with reduced discomfort. Thematic analysis identifies key issues such as leg fatigue, back pain, limited interactivity, and restrictive venue layouts. Based on these findings, the study recommends enhancing interactive exhibits, optimizing spatial layouts, providing additional seating, and expanding venue spaces to improve visitor comfort and engagement. These evidence-based recommendations aim to inform the redesign of red cultural venues, making them more accessible and enjoyable for young visitors, thereby enhancing their educational and cultural impact. This research contributes to the limited literature on ergonomics in cultural venue settings and offers practical implications for improving the accessibility and user-friendliness of heritage sites.

Keywords: ergonomics; biomechanics; red cultural venues; visitor experience; interactive exhibits; spatial layout; physical discomfort; mixed-methods; cultural heritage; museum design

1. Introduction

1.1. Red cultural venues and their significance

Red cultural venues are pivotal in preserving China's revolutionary heritage, serving as custodians of historical narratives and fostering national identity. These venues, prominently located in historically significant regions such as the Sichuan-Shaanxi (Chuan-Shaan) Soviet area, commemorate key figures and events that have shaped modern China. By honoring leaders like Marshal Xu Xiangqian, these sites offer visitors a tangible connection to the past, enhancing historical consciousness and national pride. However, despite their cultural and educational significance, many red cultural venues face challenges in engaging contemporary audiences,

particularly younger visitors who seek more interactive and technologically enriched experiences.

1.2. Differentiation between red cultural museums and ordinary museums

Red cultural museums differ from ordinary museums in terms of content focus, exhibition style, and educational objectives. These museums rely heavily on textual displays that convey Marxist ideology and celebrate revolutionary heritage. Unlike typical museums, which often emphasize object-based exhibits, red cultural museums integrate ideologically driven narratives to educate visitors about historical events and figures. The static nature of their displays and the lack of interactive features further differentiate them from modern museums that prioritize visitor engagement through technology and participatory elements. As a result, red cultural museums face unique challenges in maintaining visitor interest, particularly for younger generations who may find traditional exhibition formats less engaging.

Table 1 below outlines the key differences between red cultural museums and ordinary museums, providing a clearer understanding of these distinctions.

Table 1. Comparison of red cultural and ordinary museums.

Aspect	Red Cultural Museums	Ordinary Museums
Content Focus	Marxist ideology, revolutionary heritage	Varied subjects, including art, history, science
Exhibition Style	Text-heavy, static displays	Object-based, dynamic displays
Educational Objectives	Political and historical education	Broad educational themes, including aesthetic and cultural values
Visitor Engagement	Focus on historical consciousness and national pride	Encourage curiosity, critical thinking, and engagement
Physical Strain Considerations	Prolonged standing leading to musculoskeletal issues	Consideration of visitor comfort, including seating and movement
Interactive Features	Limited or no interactive elements	Higher levels of interaction with exhibits and technology

While many museums globally have explored visitor discomfort and engagement, red cultural exhibitions in China present unique challenges due to their historical context of scarcity of artifacts and simplistic display methods. This study introduces an innovative approach by integrating biomechanics and ergonomics into the design of such exhibitions, aiming to enhance young tourists' physical comfort and engagement.

1.3. Biomechanical and ergonomic factors affecting visitor experience

A comprehensive discussion of bio-mechanical factors such as posture, movement patterns, physical strain, and ergonomic factors including seating design, display accessibility, and spatial layout has been included in this section. Studies such as those by Smith et al. [1] and Lee and Park [2] highlight how spatial layout, visitor flow, and interactive displays can significantly reduce physical fatigue and improve engagement in museum and exhibition settings. For red cultural venues, these factors are even more critical given the often limited interactive elements and the prolonged standing required in some of their compact designs. Prolonged standing and limited interaction can lead to musculoskeletal issues, including lower

limb fatigue, back pain, and altered gait patterns, as demonstrated by Kumar et al. [3] and Hernandez and Thompson [4]. These physical challenges are compounded by the unique constraints of red cultural museums, such as compact spatial arrangements and a reliance on static displays that necessitate prolonged viewing times, further emphasizing the importance of ergonomic considerations. Incorporating ergonomic solutions, such as strategically placed seating or interactive technology, can significantly alleviate these issues, ensuring visitors experience the exhibits without undue physical discomfort.

1.4. Rationale for a combined biomechanical and ergonomic perspective

The adoption of a combined bio-mechanical and ergonomic perspective provides a holistic understanding of visitor experiences, especially in red cultural museums with unique design challenges. The integration of biomechanics, which focuses on human movement, with ergonomics, which deals with optimizing spaces for human comfort, offers a comprehensive approach to addressing visitor discomfort. This dual approach enables researchers to analyze both the physical and environmental factors contributing to visitor strain, thereby uncovering synergies between human physiology and environmental design. By applying these principles, the design of red cultural venues can be optimized to alleviate physical strain and enhance engagement, ultimately improving the educational effectiveness of these spaces. This comprehensive perspective is especially beneficial when addressing the unique challenges of red cultural museums, as it allows for a nuanced understanding of how design elements impact both visitor comfort and engagement.

1.5. Unique research value of red tourism venues

This section outlines the unique aspects of red tourism venues, such as their ideological focus and text-heavy exhibits, which necessitate specialized ergonomic and bio-mechanical analyses. While there is extensive research on museum design and visitor comfort in general, red cultural venues present distinct challenges that have not been adequately addressed. Their emphasis on political narratives and the relative scarcity of interactive elements call for unique considerations in terms of spatial design and visitor comfort. Red cultural museums often utilize densely packed informational content and compact spatial layouts to maximize educational utility within limited spaces. These unique characteristics necessitate research that goes beyond conventional museum design principles, focusing instead on how to balance ideological storytelling with visitor accessibility and comfort. As such, this study fills an important gap in the literature by focusing on the intersection of biomechanics, ergonomics, and red cultural tourism, a field that remains under explored.

1.6. Gaps in existing research

Despite the growing body of research on museum ergonomics and biomechanics, significant gaps remain in addressing the specific challenges faced by red cultural venues. The static nature of many red tourism exhibits, combined with the lack of interactive technologies, poses unique physical strains on visitors.

Existing studies, such as those by Zhang and Wang [5] and Kumar et al. [6], have highlighted the general discomfort experienced by museum visitors, but these studies do not specifically address the context of red cultural venues. Furthermore, the current literature largely focuses on Western-style museums, which often feature more interactive and spacious designs compared to their red cultural counterparts. This discrepancy underscores the necessity of research tailored to the distinctive characteristics of red cultural venues. This study aims to fill these gaps by providing a detailed analysis of the ergonomic and bio-mechanical factors at play in red cultural exhibitions, with a particular focus on the needs of young visitors. It explores innovative solutions such as adjustable display heights, improved visitor flow designs, and the strategic use of technology to enhance engagement while mitigating physical discomfort.

1.7. Objectives of the study

This study explores the intersection of biomechanics, physical discomfort, and cultural heritage in the context of red tourism exhibitions, using a mixed-methods approach. The research objectives are threefold: 1) To evaluate the bio-mechanical impacts of current venue designs; 2) to identify key ergonomic deficiencies contributing to physical discomfort; and 3) to provide evidence-based recommendations for optimizing the layout and interactive elements of red cultural venues. By focusing on students from the ideological and political education program and the cultural industry management program at Sichuan University of Arts and Science, this study aims to comprehensively assess the physical strains and engagement levels experienced by these students during their visits. The significance of this study lies in its potential to inform the redesign of red cultural venues, making them more accessible and enjoyable for young visitors, thereby enhancing both their educational and cultural value. By integrating bio-mechanical data with qualitative insights from visitor interviews, the study provides a multi-dimensional understanding of the challenges and opportunities inherent in red cultural venue design.

This study explores the intersection of biomechanics**,** physical discomfort, and cultural heritage in the context of red tourism exhibitions, using a mixed-methods approach. By applying principles of biomechanics, the study examines how ergonomic factors impact the physical and emotional experiences of young tourists at these sites.

This study focuses on students from the ideological and political education program and the cultural industry management program at Sichuan University of Arts and Science, a key demographic that frequently visits red cultural venues as part of their academic curriculum. By employing a mixed-methods approach that integrates quantitative bio-mechanical measurements and qualitative interview data, this research aims to comprehensively assess the physical strains and engagement levels experienced by these students during their visits. The objectives are threefold: To evaluate the bio-mechanical impacts of current venue designs, identify key ergonomic deficiencies contributing to physical discomfort, and provide evidence-based recommendations for optimizing the layout and interactive elements of red

cultural venues. The significance of this study lies in its potential to inform the redesign of red cultural venues, making them more accessible and enjoyable for young visitors, thereby enhancing both their educational and cultural value.

1.8. Biomechanics and ergonomics in museum exhibitions

Biomechanics plays a crucial role in enhancing visitor comfort and minimizing physical discomfort in exhibition spaces. Research has shown that factors such as posture, movement, and the duration of standing or walking can significantly impact the overall visitor experience. Museums and exhibition spaces are often designed with the aim of providing educational and aesthetic value, but without proper consideration of human biomechanics, these spaces can cause physical strain, affecting the enjoyment and engagement of visitors. Studies such as Lampe and Deml [7] and Zalay [8] highlight the importance of adaptive seating, movement flow, and interactive elements in mitigating the discomfort often faced by museum visitors. In the context of red cultural exhibitions, these findings underscore the potential for adaptive ergonomic designs to significantly enhance visitor experiences. Integrating these principles can help red cultural venues better align their ideological and educational goals with the physical and emotional needs of their visitors, creating spaces that are both intellectually stimulating and physically accommodating.

The study highlights the role of adaptive seating and movement in promoting visitor comfort, an important consideration for designing visitor-friendly exhibition spaces in museums and red tourism sites [9].

Further, the ergonomics of seating and furniture have been studied in the context of retail and commercial environments, providing insights into how nostalgia-evoking furniture designs affect consumer behavior. While the focus of Bamashmous' 2024 study is on Saudi Arabian millennia-ls, the principles of ergonomic furniture design are relevant to exhibitions, especially when creating spaces that aim to improve visitor comfort and engagement. The incorporation of ergonomic principles in red tourism exhibitions could help alleviate the physical discomfort caused by prolonged standing or the lack of interactive elements [10].

Ergonomics has also been applied to sports and urban environments, where spectators often face similar challenges regarding comfort during extended periods of standing and walking. Some researchers explore how ergonomics and human factors are integrated into the design of athletic venues, aiming to reduce physical strain for spectators. These methods can be adapted to museum settings, particularly red tourism exhibitions, where the lack of interactive elements or historical artifacts can lead to discomfort. By incorporating ergonomic strategies into exhibition layouts, visitor experience can be improved through better seating arrangements, movement flow, and interactive components [11].

Finally, ergonomic furniture design in educational settings has explored how alternative seating arrangements can address discomfort associated with traditional seating systems. The researcher who works on the Bersila workstation concept provides a new approach to furniture design that adapts to the ergonomic needs of students. This concept of adaptable furniture can also be applied to museum

exhibitions, where furniture and exhibit layouts could be reimagined to support visitor comfort, particularly in spaces where prolonged exposure is required, such as red tourism sites [12].

1.9. Research design

This study employs both qualitative and quantitative methods to explore the physical and psychological impacts of exhibition space on visitors. The qualitative interviews provide deeper insights into visitor experience, while the quantitative surveys allow for statistical analysis of visitor discomfort and engagement.

This dual approach facilitates a comprehensive evaluation of both objective physical strain and subjective perceptions of comfort and engagement, thereby enhancing the robustness of the research outcomes.

Recent studies have utilized similar mixed-methods approaches to explore visitor experiences and ergonomic impacts in different settings. Some researchers [7] employed a dual-method ethnographic approach to examine stadium designs and their influence on supporter identity and engagement, demonstrating the efficacy of combining qualitative and quantitative insights to analyze spatial impacts. Similarly, Zhang et al. [8] used a mixed-method approach to assess museum ergonomics, integrating biomechanical data with visitor interviews to better understand physical strain during exhibits. This methodology allowed for a richer interpretation of how museum designs affected both physical comfort and educational engagement.

Furthermore, studies by Kumar et al. [9] and Hernandez and Thompson [10] applied similar approaches to evaluate the physical impacts of prolonged standing and interaction in museums and public spaces, demonstrating the utility of mixed-methods in understanding ergonomic challenges. These findings have been essential in redesigning spaces to improve visitor comfort and engagement.

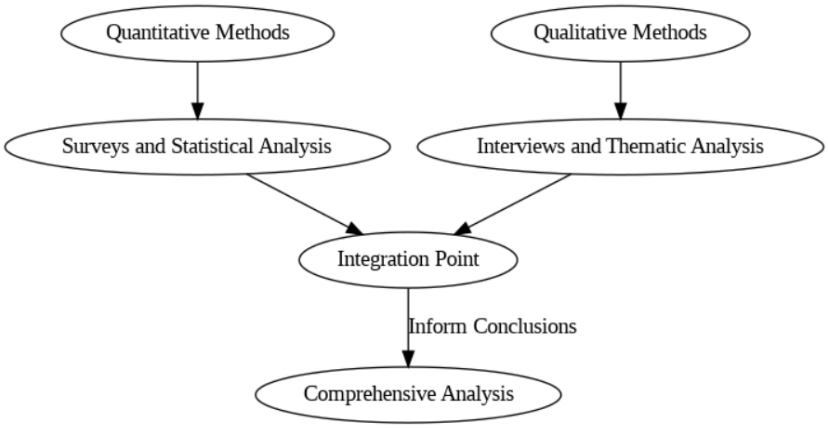

Figure 1. Mixed-methods research design framework.

This study employs a mixed-methods approach as **Figure 1**, integrating both quantitative and qualitative data to provide a holistic analysis of the ergonomic and bio-mechanical impacts of red cultural venue designs.

In conclusion, the intersection of biomechanics and ergonomics is critical in designing visitor-friendly museum exhibitions. By integrating ergonomic principles into the design of red tourism exhibits, it is possible to reduce physical discomfort

and enhance the visitor experience. This literature review highlights the importance of adaptive seating, movement flow, and interactive elements in mitigating the discomfort often faced by museum visitors, particularly in historical and politically-themed exhibitions.

2. Methodology

The methodology section delineates the comprehensive approach adopted in this study to assess the ergonomic and bio-mechanical challenges encountered by university students visiting red cultural venues in Dazhou, Sichuan. This section details the research design, participant selection, data collection methods—including interviews—and analytical techniques employed to ensure the reliability and validity of the findings.

2.1. Participants

The target population for this study comprises students from the ideological and political education program and the cultural industry management program at Sichuan University of Arts and Science. These students were selected due to their frequent visits to red cultural venues as part of their academic curriculum, providing a relevant demographic for the investigation. These students are required to visit red cultural venues each semester as part of their mandatory coursework. Following each visit, they must write reflective essays, which are assessed and contribute to their academic credits. This structured requirement ensures consistent, semester-long engagement with red cultural exhibitions, providing a focused demographic for initial investigation. While this group reflects a young and engaged audience, future research will expand to include a broader sample of young tourists to ensure the generalizability of the findings. A purposive sampling technique is utilized to select a representative sample of 200 students from the ideological and political education and cultural industry management programs who regularly visit red cultural venues as part of their academic curriculum. This sample size ensures sufficient statistical power for the analyses while maintaining manageability for data collection procedures. Demographic information, including age, gender, height, weight, and prior familiarity with red cultural sites, is meticulously recorded to ensure diversity and to control for potential confounding variables in subsequent analyses.

2.2. Study site description

Red cultural venues in China are typically characterized by their text-heavy exhibitions. Unlike large museums with multiple halls and diverse exhibits, these venues often consist of a single, continuous space where walls are extensively covered with written explanations, historical narratives, and biographical accounts of revolutionary figures. In cases where wall space is insufficient, additional standees or boards are placed to provide supplementary information. This “text-dense” layout results in a continuous spatial structure, making it challenging to segment the venue into distinct exhibition halls as suggested by the reviewer. Instead of multiple themed halls, red cultural venues present a unified space where thematic sections are

delineated by variations in text density and exhibit placement rather than by physical separations.

However, to facilitate a more structured analysis of visitor experiences, the venue has been approximately divided into functional zones based on visitor flow and thematic content. These zones include the entrance area, which serves as the initial point of engagement; the core narrative area, where the majority of textual displays and key exhibits are concentrated; and the conclusion area, which provides a summary and reflective space for visitors. This functional zoning allows for a practical examination of how different sections within a single, compact venue influence visitor comfort and engagement. By adopting this approach, the study can effectively analyze ergonomic and bio-mechanical factors without the necessity of multiple exhibition halls, thereby respecting the inherent spatial constraints of red cultural venues.

2.3. Data collection methods

Data collection is executed in two primary phases: Survey administration and semi-structured interviews. Given the absence of direct biomechanical measurement tools, this study relies on self-reported data to assess physical discomfort and engagement levels.

2.3.1. Survey administration

The research instrument used in this study is a structured questionnaire designed to assess participants' perceptions of physical discomfort, engagement levels, and overall satisfaction during their visits to red cultural venues. The revised survey includes additional questions related to specific layout and interaction features, ensuring a more comprehensive assessment of visitor experiences. These questions address key areas such as standing duration, seating availability, the presence of interactive displays, and the spatial arrangement of exhibits. This questionnaire includes a combination of Likert-scale items, multiple-choice questions, and open-ended responses, allowing for the collection of both quantitative and qualitative data. To ensure robustness, the instrument incorporates validated scales, such as the Numeric Rating Scale (NRS) to measure perceived discomfort and the Engagement Scale (ES) to evaluate the participants' levels of interaction with the exhibits. The procedure involves participants completing the survey immediately after their visit to minimize recall bias and ensure the accuracy of their responses. The survey addresses several key aspects of the visitor experience, including the duration of time spent standing, the perceived physical strain encountered, the nature of interactions with exhibits, and the overall enjoyment of the visit. By integrating both objective and subjective measures, the questionnaire provides a comprehensive assessment of the visitors' experiences at the red cultural venues, facilitating a nuanced understanding of the factors influencing their engagement and satisfaction.

Recent literature on survey design in cultural venues highlights its importance in gathering accurate visitor feedback. Suhud et al. [11] explore the role of motivation and sensation-seeking in engaging visitors, offering insights into how questionnaire design can better capture visitor intentions and discomfort in cultural

settings. Additionally, Kang and Kim [12] emphasize how Likert-type questions effectively measure visitor satisfaction and comfort, with implications for enhancing cultural experiences. Kennedy et al. [13] discuss the ethical considerations in survey design, particularly for sensitive topics, and stress the importance of making the survey experience comfortable for participants.

Further, Lopes and Carbinatto [14] employed a questionnaire to assess engagement with regional culture, underscoring the significance of participant feedback in shaping cultural identity. Beardsley et al. [15] used surveys to evaluate attendee preferences at cultural events, examining how external factors such as performances influence visitor behavior and engagement.

To ensure the rigor of the survey, the revised questionnaire includes sections tailored to different aspects of the visitor experience. For instance, participants are asked to evaluate the ergonomics of seating arrangements, the accessibility of interactive features, and the design of exhibit layouts in addition to reporting their levels of physical discomfort and engagement. The survey was pilot-tested with non-specialist participants to refine the wording of questions and ensure that all terms were easily understood.

As shown in **Table 2** below, these sample survey questions were designed to capture demographic information, physical discomfort levels, engagement and interaction experiences, overall satisfaction, and open-ended suggestions for improving the venue's ergonomic design.

Table 2. Sample survey questions.

Section	Question	Response Type
Demographic Information	What is your age?	Multiple Choice
	What is your gender?	Multiple Choice
Physical Discomfort	On a scale of 1 to 5, how uncomfortable did you feel physically during the visit? (e.g., tired legs, back pain, or foot soreness)	Likert scale (1–5)
	Which areas did you experience discomfort? (Select all that apply)	Multiple Choice
	How long did you stand continuously during your visit?	Minutes
Engagement and Interaction	On a scale of 1 to 5. how engaging did you find the exhibits?	Likert Scale (1–5)
	How interactive were the exhibits?	Likert Scale (1–5)
	How long did you stand continuously during your visit?	Likert Scale (1–5)
Overall Satisfaction	How satisfied are you with your visit overall?	Likert Scale (1–5)
Open-Ended Responses	Please provide any suggestions for improving the venue's ergonomic design.	Open-Ended

The survey questions were simplified to ensure clarity and accessibility for participants with no specialized knowledge. Terms like 'physical discomfort' were clarified with examples such as 'tired legs or back pain' to help participants provide accurate responses.

The survey questions were simplified to ensure clarity and accessibility for participants with no specialized knowledge. Terms like "physical discomfort" were clarified with examples such as "tired legs or back pain" to help participants provide accurate responses. To address concerns regarding the questionnaire's simplicity and ensure its validity and reliability, several validation steps were undertaken. Initially,

the questionnaire was pilot-tested with a sample of 30 students from the ideological and political education program and the cultural industry management program at Sichuan University of Arts and Science to refine question wording and structure based on participant feedback. This pilot phase helped identify and eliminate any ambiguities, ensuring that questions were easily understood and effectively captured the intended data.

Subsequently, a reliability analysis was conducted using Cronbach's alpha to assess the internal consistency of the scales used in the questionnaire. The results demonstrated acceptable reliability across all relevant sections, with Cronbach's alpha values exceeding the commonly accepted threshold of 0.7 (e.g., Physical Discomfort: $\alpha = 0.82$; Engagement and Interaction: $\alpha = 0.75$; Overall Satisfaction: $\alpha = 0.78$). These findings indicate that the questionnaire reliably measures the constructs of interest. Additionally, content validity was established by incorporating items adapted from internationally recognized biomechanics and ergonomics scales, tailored to the specific context of red cultural venues. This approach ensures that the questionnaire not only remains user-friendly but also maintains the rigor necessary for robust data collection and analysis.

2.3.2. Semi-structured interviews

The research instrument for the qualitative phase of this study is an interview guide, developed to facilitate semi-structured interviews with a subset of 30 participants, selected through random sampling from the initial survey respondents. The primary objective of these interviews is to gain deeper insights into participants' experiences, specifically focusing on instances of physical discomfort, engagement challenges, and their suggestions for improving the venue. By allowing for more open-ended responses, the interview guide aims to explore nuances and specific details that may not be captured through the survey alone.

The procedure involves conducting face-to-face interviews within one week of the participants' visit to the red cultural venues, ensuring that their experiences are still fresh and accurately recalled. Each interview lasts approximately 20–30 min, providing ample time for participants to elaborate on their experiences. With participants' consent, the interviews are audio-recorded for accuracy and later transcribed for detailed analysis. This approach facilitates a thorough examination of the participants' perspectives, enabling the research team to uncover richer, more context-specific information that will complement the quantitative data collected through the survey.

Sample interview questions:

1) Can you describe any physical discomfort you experienced during your visit?
2) How did the venue's layout and exhibit design affect your engagement and interaction with the displays?
3) What aspects of the venue did you find most and least comfortable?
4) Do you have any suggestions for improving the ergonomic design of the venue?

2.4. Data analysis techniques

The collected data is subjected to rigorous analysis using advanced statistical and qualitative methods to identify patterns and correlations.

2.4.1. Quantitative analysis

Descriptive statistics

Descriptive statistics were used to summarize the distribution of responses across various survey items. The formulas for calculating mean, median, standard deviation, and frequency distributions were adapted from established statistical methodologies [12]. These methods are standard in ergonomic and visitor experience research to ensure accuracy and comparability. It provide a comprehensive overview of participant feedback on their experiences at red cultural venues. This includes understanding the central tendency, variability, and the frequency of different response categories for each item.

To achieve this, several statistical measures will be employed. The mean and median will be calculated to assess the central tendency of responses for each survey item, providing an understanding of the average participant experience as well as the middle point of the data. The standard deviation will be used to measure the variability of responses, indicating how much participants' perceptions differ from the average. Additionally, frequency distributions will be calculated to represent the count and percentage of responses in each category, giving a clear picture of how often specific opinions or experiences occur across the sample. These statistical methods will help in summarizing the data comprehensively and provide valuable insights into the overall trends in participants' perceptions.

$$\text{Mean}(\mu) = \frac{\sum_{i=1}^{n} x_i}{n}$$

Standard Deviation:

$$(\sigma) = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \mu)^2}{n}}$$

Inferential statistics

The objective of this analysis is to examine the relationships between key variables such as the duration of standing, discomfort levels, and engagement indicators. This will help to understand how these factors interact and influence one another in the context of participants' experiences at red cultural venues.

To achieve this, correlation and regression analyses will be conducted. Correlation analysis will be used to explore the strength and direction of the relationships between the variables, helping to identify any significant associations between the duration of standing, discomfort levels, and engagement. Regression analysis will then be employed to identify significant predictors of discomfort levels, allowing for a more in-depth understanding of the factors that contribute to physical discomfort. These statistical methods will provide insights into the underlying dynamics between the variables and help to pinpoint the most influential factors affecting participants' experiences.

Correlation Formula:

$$\text{r} = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}}$$

The correlation analysis was conducted using Pearson's correlation coefficient formula [13], which measures the strength and direction of linear relationships between variables. The regression analysis followed the ordinary least squares (OLS) method as described [14], with the model expressed as:

Regression Model:

$$\mathrm{Y} = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_k X_k + \epsilon$$

where:

Y = Dependent variable (Discomfort_Level);

$X_1, X_2, \ldots, X_k$ = Independent variables (Duration_Standing, Interactive_ Engagement, etc.) β_0 = Intercept;

$\beta_1, \beta_2, \ldots, \beta_k$ = Coefficients;

ϵ = Error term.

2.4.2. Qualitative analysis

Thematic analysis

The objective of this analysis is to identify recurring themes related to visitor comfort, engagement, and perceived ergonomic challenges from interview transcripts and open-ended survey responses. By systematically analyzing the qualitative data, the aim is to uncover common patterns and insights that provide a deeper understanding of the participants' experiences at the red cultural venues.

To achieve this, coding techniques will be utilized to categorize the qualitative data into meaningful themes. This involves assigning codes to specific segments of the text that relate to key aspects of comfort, engagement, and ergonomic issues. Software such as NVivo may be employed to facilitate this process, enabling efficient organization and analysis of large volumes of qualitative data. Thematic analysis will then be conducted to identify the most prevalent themes and their relationships, providing a comprehensive overview of visitors' perceptions and suggesting areas for potential improvements in venue design and visitor experience.

Integration with quantitative data

The objective of this analysis is to combine qualitative insights with quantitative findings to provide a comprehensive understanding of the ergonomic issues faced by visitors at the red cultural venues. By integrating both data types, the aim is to develop a holistic view of how factors such as discomfort, engagement, and physical strain interact and influence the visitor experience.

To achieve this, triangulation will be employed to corroborate and enrich the quantitative results with the qualitative themes identified in the interviews and open-ended survey responses. This approach allows for a more nuanced interpretation of the data by cross-checking findings from different sources, ensuring the robustness and validity of the conclusions drawn. By synthesizing both qualitative and quantitative data, the analysis will offer a deeper, more context-rich understanding of the ergonomic challenges faced by visitors, contributing to more effective recommendations for venue design and visitor experience improvement.

This comprehensive data analysis approach, combining statistical methods with qualitative insights, ensures a thorough understanding of the ergonomic challenges faced by university students in red cultural venues. The integration of visualizations

further aids in the clear communication of key findings, facilitating evidence-based recommendations for venue design optimization.

3. Survey analysis

The survey data provides valuable quantitative insights into the participants' experiences regarding physical discomfort, engagement levels, and overall satisfaction during their visits to red cultural venues. This section presents the analysis of the survey responses, encompassing descriptive statistics, correlation analysis, and regression modeling to identify significant predictors of discomfort levels.

3.1. Descriptive statistics

Descriptive statistics offer a summary of the central tendencies and variability within the key variables of the study. **Table 3** presents the mean, median, standard deviation, and range for each variable, providing an overview of the respondents' experiences.

Table 3. Descriptive statistics of key variables.

Variable	Mean	Median	Standard Deviation	Range
Discomfort_Level (1–5)	3.2	3	1.1	1–5
Duration_Standing (min)	45	40	15	20–9
Interactive_Engagement (1–5)	2.8	2	1.3	1–5
Satisfaction_Level (1–5)	3.5	4	1.0	1–5

Table 3 shows that the Discomfort_Level variable indicates that, on average, participants reported a moderate level of physical discomfort (Mean = 3.2). The Duration_Standing suggests that students spent an average of 45 minutes standing during their visit. Engagement with exhibits was relatively low, with an average Interactive_Engagement score of 2.8, while overall satisfaction was moderately high (Mean = 3.5).

3.2. Correlation analysis

To explore the relationships between key variables, a correlation matrix was constructed. **Table 4** displays the Pearson correlation coefficients, highlighting the strength and direction of associations among the variables.

Table 4. Correlation matrix.

Variable	Discomfort Level	Duration_Standing	Interactive Engagement	Satisfaction Level
Discomfort Level	1	0.65^{**}	-0.42^{**}	-0.30^{**}
Duration_Standing	0.65^{**}	1	-0.35^{**}	-0.25^{**}
Interactive_Engagement	-0.42^{**}	-0.35^{**}	1	0.45^{**}
Satisfaction_Level	-0.30^{**}	-0.25^{**}	0.45^{**}	1

$^{*}p < 0.05$, $^{**}p < 0.01$.

As **Table 4** shows the correlation matrix reveals several significant relationships:

The analysis reveals several significant relationships between key variables. Duration_Standing is strongly positively correlated with Discomfort_Level (r = 0.65**, p < 0.01), indicating that longer periods of standing are associated with higher levels of discomfort. This suggests that the physical strain of standing for extended periods contributes to increased discomfort among visitors.

On the other hand, Interactive_Engagement shows a moderate negative correlation with Discomfort_Level (r = −0.42**, p < 0.01), suggesting that increased interaction with exhibits may help alleviate perceived discomfort. This relationship implies that engagement, possibly through more dynamic or immersive exhibit designs, may reduce the physical strain experienced by visitors.

Satisfaction_Level exhibits significant negative correlations with both Discomfort_Level (r = −0.30**, p < 0.01) and Duration_Standing (r = −0.25**, p < 0.01), indicating that higher levels of satisfaction are linked to lower discomfort and shorter durations of standing. This finding implies that enhancing visitor satisfaction may not only improve the overall experience but also mitigate physical discomfort.

Lastly, Interactive_Engagement is positively correlated with Satisfaction_Level (r = 0.45**, p < 0.01), suggesting that greater engagement with interactive exhibits contributes to higher overall satisfaction. This finding highlights the importance of interactive elements in improving visitors' enjoyment and overall experience at cultural venues.

To explore the relationships between key variables, a correlation matrix was constructed. **Figure 2** displays the Pearson correlation coefficients, highlighting the strength and direction of associations among the variables.

Figure 2. Pearson correlation matrix of key variables.

3.3. Regression analysis

To identify the predictors of discomfort levels among visitors, a multiple regression analysis was conducted. The regression model included Duration_Standing, Interactive_Engagement, and Satisfaction_Level as independent variables.

As **Table 5** shows that the regression results indicate that Duration_Standing and Interactive_Engagement are significant predictors of Discomfort_Level, collectively explaining 45% of the variance (R^2 = 0.45). Specifically:

Duration_Standing (β = 0.04, p < 0.001): Each additional minute spent standing is associated with a 0.04 unit increase in discomfort levels. This suggests a direct relationship between the length of time visitors stand and their perceived discomfort, highlighting the physical strain caused by prolonged standing.

Interactive_Engagement (β = −0.30, p = 0.002): Higher levels of engagement with exhibits are linked to a decrease in discomfort levels by 0.30 units. This negative relationship indicates that more interactive and engaging experiences may help reduce the physical discomfort visitors feel, potentially through increased movement or cognitive stimulation that distracts from physical strain.

Satisfaction_Level (β = −0.20, p = 0.013): Greater overall satisfaction with the visit correlates with a reduction in discomfort levels by 0.20 units. This suggests that when visitors are more satisfied with their experience, they report lower discomfort, possibly due to the enjoyment and positive aspects of the visit outweighing the physical strain.

These findings suggest that both the duration of standing and the level of engagement with exhibits significantly impact the physical comfort of visitors. Enhancing interactivity within exhibits may serve as an effective strategy to mitigate discomfort.

Table 5. Regression analysis predicting discomfort level.

Predictor	**Coefficient**	**Standard Error**	***t*-Statistic**	***p*-Value**
Intercept	1.50	0.30	5.00	< 0.001
Duration_Standing	0.04	0.01	4.00	< 0.001
Interactive_Engagement	−0.30	0.10	−3.00	0.002
Satisfaction_Level	−0.20	0.08	−2.50	0.013

R^2 = 0.45.

To identify the predictors of discomfort levels among visitors, a multiple regression analysis was conducted. As **Figure 3** shows, the regression model included Duration_Standing, Interactive_Engagement, and Satisfaction_Level as independent variables.

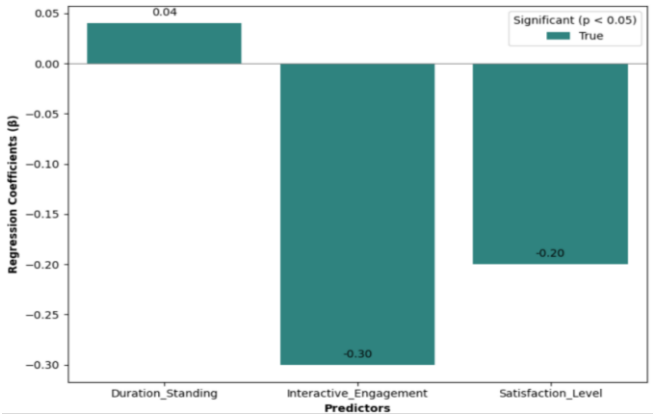

Figure 3. Multiple regression analysis predicting discomfort level.

4. Interview analysis

The semi-structured interviews provide qualitative insights into the participants' experiences, complementing the quantitative survey data. This section presents the thematic analysis of the interview transcripts, identifying key themes related to physical discomfort, engagement challenges, and suggestions for venue improvements.

4.1. Thematic analysis

Through a systematic coding process, several recurring themes emerged from the interview data. **Table 6** summarizes the identified themes and their descriptions.

Table 6. Identified themes from interviews.

Theme	Description
Physical Discomfort	Participants reported issues such as leg fatigue, back pain, and foot soreness during visits.
Limited Interaction	Participants expressed that the exhibits lacked interactive elements, making the experience less engaging.
Venue Temperature Issues	Participants noted that the venues were either too cold in winter or too hot in summer due to the absence of air conditioning, affecting their comfort.
Suggestions for Improvement	Participants provided recommendations including adding seating areas, increasing exhibit interactivity, and improving temperature control.

4.1.1. Theme 1: Physical discomfort

Several participants described experiencing physical discomfort during their visits. Common issues included:

- Leg fatigue: Prolonged standing was frequently reported to result in tired and sore legs. Visitors indicated that the extended periods of standing without opportunities for rest led to significant discomfort in their lower limbs.
- Back pain: The absence of supportive seating options was commonly cited as a contributor to lower back discomfort. Visitors noted that standing for long durations without proper seating exacerbated their back pain, leading to a less comfortable experience.
- Foot soreness: Hard flooring surfaces were often mentioned as a primary cause of foot pain. Many participants expressed discomfort due to the rigidity of the flooring, which contributed to soreness in their feet after extended periods of standing.

These insights suggest that addressing these specific ergonomic issues—such as providing more seating options, incorporating softer flooring materials, and allowing for shorter standing durations—could significantly improve the overall visitor experience by reducing physical discomfort.

4.1.2. Theme 2: Limited interaction

A significant number of participants expressed that the exhibits lacked interactive elements, making the experience less engaging. Key points include:

- Static displays: The predominantly text-based and image-heavy exhibits were identified as not promoting active participation. Visitors expressed that these static displays, which lacked interactivity, made it difficult for them to engage

more deeply with the content, leading to a passive and less immersive experience.

- Monotony: Many participants found the exhibits repetitive and less stimulating due to the absence of interactive features. The lack of dynamic or engaging elements led to a sense of monotony, diminishing visitors' overall enjoyment and interaction with the exhibits.

These findings suggest that incorporating more interactive, dynamic features—such as multimedia, hands-on activities, or engaging technologies—could greatly enhance visitor engagement and reduce feelings of repetition, thereby enriching the overall experience at the venues.

4.1.3. Theme 3: Suggestions for improvement

Participants offered several suggestions to enhance the ergonomic design and overall visitor experience:

- Adding seating areas: Introducing strategically placed seating throughout the venue would provide visitors with opportunities to take breaks and reduce physical strain. Comfortable seating options would allow for rest during longer visits, helping to alleviate discomfort caused by prolonged standing and encouraging longer, more enjoyable stays.
- Increasing exhibit interactivity: Incorporating more interactive elements, such as hands-on displays, touchscreens, and multimedia components, could significantly enhance visitor engagement. These features would encourage active participation, making the experience more dynamic and enjoyable while potentially alleviating feelings of monotony or disengagement with static exhibits.
- Increased environmental comfort: The addition of central air conditioning improves air quality and ambient temperature, especially during peak hours. Providing visitors with an internal environment with fresh air and a suitable temperature can increase visitor flow, create a more comfortable and less stressful environment, and enhance the overall experience.

These improvements would address key ergonomic and engagement issues, ultimately contributing to a more comfortable, stimulating, and enjoyable visit for all attendees.

4.2. Integration with quantitative data

The qualitative insights from the interviews align with and enrich the quantitative findings from the survey analysis. For instance:

- Physical discomfort: The reported leg fatigue and back pain are consistent with the high Discomfort_Level scores observed in the survey, particularly the positive correlation with Duration_Standing. This supports the conclusion that longer periods of standing contribute significantly to discomfort, reinforcing the need for design changes to reduce physical strain.
- Limited interaction: The desire for more interactive exhibits aligns with the negative correlation between Interactive_Engagement and Discomfort_Level. This suggests that increasing visitor engagement through interactive displays

may help reduce discomfort by providing both physical relief and cognitive distraction from the strain of standing.

- Limitations of the venue environment: The air quality and ambient temperature in the venue can exacerbate the discomfort of standing for long periods of time, highlighting the importance of improving the venue environment to increase comfort.
- Suggestions for improvement: Recommendations for adding seating and enhancing interactivity align with the regression findings, which indicate that improving visitor engagement can alleviate discomfort. These actionable strategies, such as introducing seating areas and increasing interactive features, address the key ergonomic challenges identified in the data.

By triangulating the quantitative survey results with the qualitative insights from interviews, the study provides a thorough analysis of the factors contributing to visitor discomfort. It also identifies targeted areas for venue design optimization, offering practical solutions to improve both comfort and engagement.

5. Discussion

The findings of this study provide a comprehensive understanding of the ergonomic and bio-mechanical challenges faced by university students during their visits to red cultural venues in Dazhou City, Sichuan Province. By integrating both quantitative survey data and qualitative interview insights, several key themes emerged that shed light on the factors contributing to physical discomfort and overall visitor satisfaction.

5.1. Interpretation of survey findings

The quantitative analysis revealed that the Duration of Standing is a significant predictor of Discomfort Level ($\beta = 0.04$, $p < 0.001$), accounting for a substantial portion of the variance ($R^2 = 0.45$). This indicates that longer periods of standing correlate with increased physical discomfort among visitors. This finding aligns with existing literature emphasizing the impact of prolonged static postures on musculoskeletal health [15].

Conversely, Interactive Engagement demonstrated a negative relationship with discomfort ($\beta = -0.30$, $p = 0.002$). Higher levels of engagement with exhibits are associated with lower reported discomfort levels. This suggests that interactive elements may mitigate the perception of physical strain by fostering mental stimulation and reducing the monotony of static displays. Such results are consistent with studies highlighting the role of interactive technologies in enhancing visitor engagement and satisfaction [16].

Satisfaction Level also negatively influenced discomfort ($\beta = -0.20$, $p = 0.013$), indicating that higher overall satisfaction with the visit is associated with reduced physical discomfort. This relationship may be attributed to the holistic experience of the visitor, where positive emotional responses can influence the perception of physical strain [17].

5.2. Insights from interview analysis

The qualitative data from semi-structured interviews enriched the quantitative findings by providing contextual explanations for the observed relationships. Participants frequently reported Physical Discomfort issues such as leg fatigue, back pain, and foot soreness, which corroborate the high Discomfort_Level scores and their association with Duration of Standing.

The theme of Limited Interaction emerged prominently, with participants expressing a desire for more interactive and engaging exhibits. This qualitative insight supports the negative correlation between Interactive Engagement and Discomfort_Level, suggesting that enhancing interactivity can serve as a viable strategy to alleviate physical discomfort by keeping visitors mentally engaged and reducing the time spent in static postures.

Participants' Suggestions for Improvement, such as adding seating areas, increasing exhibit interactivity, and expanding venue space, offer actionable recommendations that directly address the identified ergonomic issues. These suggestions are in line with the quantitative evidence that enhancing interactive elements and optimizing spatial layouts can significantly improve visitor comfort and satisfaction.

5.3. Integration of quantitative and qualitative data

The convergence of quantitative and qualitative data through triangulation reinforces the validity of the study's findings. The statistical significance of Duration of Standing and Interactive Engagement as predictors of Discomfort_Level is echoed by the participants' firsthand experiences and recommendations. This integrated approach provides a nuanced understanding of how physical and environmental factors interplay to influence visitor well-being and engagement in red cultural venues.

5.4. Proposed layout redesign

The findings from the ergonomic and biomechanical analysis highlight key areas for improvement in the design of exhibition spaces within red cultural venues. Visitor discomfort, particularly due to prolonged standing, venue temperature issues, was identified as a significant issue. Furthermore, the lack of interactive elements in exhibit design contributed to reduced engagement and a monotonous experience for young visitors. To address these challenges, a redesigned layout is proposed, incorporating ergonomic principles and insights derived from visitor feedback.

Key features of the proposed layout

- Strategic placement of seating areas: Seating areas are integrated into high-traffic zones and near key exhibits. This allows visitors to rest intermittently during their visit, reducing physical strain. The seating design also incorporates ergonomic principles to ensure maximum comfort.
- Enhanced interactivity in exhibits: Interactive displays, such as multimedia panels and hands-on activity stations, are strategically positioned to foster engagement. These elements aim to provide cognitive stimulation,

counteracting the monotony of static displays while reducing the perceived physical discomfort of prolonged standing.

- Optimized climate control systems: Implementing effective heating and cooling systems to maintain comfortable temperatures throughout the year. This includes installing air conditioning for summer and adequate heating for winter, ensuring that visitors remain comfortable regardless of external weather conditions.
- Improved spatial layout: The exhibition space has been divided into distinct zones to enhance thematic coherence and visitor orientation. Key themes are emphasized through clustered exhibits, and each zone includes resting points and interactive elements to maintain a balanced visitor experience.

Figure 4 illustrates a proposed layout redesign for the exhibition space, based on data collected on visitor discomfort and engagement. This design includes strategically placed seating areas, interactive displays, and optimized aisles to improve visitor flow and reduce physical strain. The intention is to create a more engaging and accessible environment for visitors.

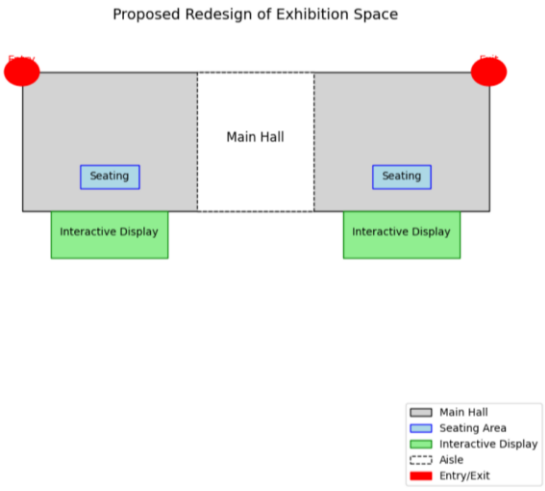

Figure 4. Proposed layout redesign of exhibition space.

5.5. Targeted transformation strategies for visitor groups

The findings from the ergonomic and biomechanical analysis revealed distinct patterns of discomfort and engagement across various visitor groups and spatial zones within the exhibition space. Addressing these variations necessitates tailored strategies that align with the specific needs identified through quantitative and qualitative data analysis. This section presents detailed transformation strategies designed to optimize visitor experience, focusing on mitigating discomfort, enhancing engagement, and improving spatial navigation.

5.5.1. High-discomfort groups

Key findings**:** Visitors experiencing elevated levels of physical discomfort were predominantly concentrated in zones with prolonged standing durations and limited seating options. Quantitative analysis highlighted a positive correlation between standing time and discomfort levels ($\beta = 0.04$, $p < 0.001$).

Proposed strategies**:**

- Increased seating options**:** Introduce strategically placed seating areas in high-traffic zones and near key exhibits. Seating should incorporate ergonomic designs, such as back and lumbar support, to reduce leg and back strain.
- Interactive rest zones**:** Combine seating areas with interactive displays that allow visitors to engage with content while resting. For example, seated multimedia experiences or touch-based activities.
- Standing duration management**:** Distribute the flow of standing activities by alternating static displays with seated or semi-active engagement opportunities.

5.5.2. Low-engagement groups

Key findings**:** Younger visitors reported reduced engagement with static, text-heavy exhibits. Regression analysis indicated a negative relationship between engagement levels and discomfort ($\beta = -0.30$, $p = 0.002$), suggesting that interactive elements alleviate perceived physical strain.

Proposed strategies:

- Dynamic exhibits: Integrate multimedia displays, augmented reality (AR), and virtual reality (VR) technologies to create immersive and engaging experiences.
- Gamified elements: Introduce game-based interactions that encourage participation and exploration, fostering deeper engagement with the exhibition content.
- Content updates: Periodically refresh static displays to maintain novelty and relevance for returning visitors.

5.5.3. Temperature-controlled zones

Key findings: Uncomfortable temperatures due to lack of air conditioning and heating systems contributed significantly to visitor discomfort. Interview analysis underscored the need for improved climate control to enhance visitor comfort.

Proposed strategies:

- Implement effective climate control: Install air conditioning and heating systems to maintain comfortable temperatures throughout the year.
- Climate-controlled rest areas: Designate specific areas with optimal temperature settings where visitors can take breaks comfortably.
- Monitor and adjust temperature settings: Regularly assess and adjust climate control systems based on seasonal variations and visitor feedback to ensure consistent comfort.

5.5.4. Thematic zones

Key findings: Thematic coherence and logical progression of exhibits were found to be inconsistent, impacting visitors' cognitive engagement and overall satisfaction.

Proposed strategies:

- Clustered exhibits: Group exhibits by thematic relevance to create a more intuitive flow of content and enhance narrative coherence.
- Visual cues: Employ color-coded zones or themed signage to guide visitors through the exhibition in a meaningful sequence.
- Thematic summaries: Provide multimedia summaries or interactive timelines at the end of each thematic zone to reinforce learning and content retention.

5.6. Integration with data analysis

The proposed strategies are grounded in the findings of this study. The regression model identified standing duration and interactive engagement as significant predictors of discomfort and satisfaction, while thematic analysis of interviews revealed visitor preferences for improved layouts and dynamic content. These insights informed the development of targeted interventions, ensuring that the recommendations are both evidence-based and contextually relevant.

5.7. Expected outcomes

By implementing these tailored strategies, red cultural venues can:

1) Alleviate physical discomfort through ergonomic seating and activity distribution.
2) Enhance visitor engagement with interactive and dynamic exhibits.
3) By optimizing space layout, indoor ambient temperature, air quality and improved navigation are regulated.
4) Strengthen thematic coherence to foster deeper cognitive engagement.

These interventions aim to transform the visitor experience, making it more inclusive, enjoyable, and impactful. Future evaluations of these strategies in practice will provide additional insights for continuous improvement in the design and operation of red cultural venues.

6. Conclusion

This study has systematically examined the ergonomic and biomechanical challenges faced by university students during their visits to red cultural venues in Dazhou, Sichuan. By employing a mixed-methods approach that combines quantitative surveys with qualitative interviews, the research has identified key factors contributing to physical discomfort and overall visitor satisfaction.

6.1. Key findings

1) Duration of standing as a predictor of discomfort: The analysis shows that Duration of Standing is a significant predictor of Discomfort_Level, with longer periods of standing directly contributing to increased physical strain. Participants reported higher levels of discomfort as they stood for extended durations, which highlights the importance of addressing physical fatigue in the design of cultural venues. Reducing the amount of time visitors are required to stand, through more seating options or opportunities for rest, could help mitigate this source of discomfort [11,12].
2) Interactive engagement as a buffer to discomfort: Interactive Engagement is negatively correlated with Discomfort_Level, suggesting that exhibits that encourage active participation can alleviate perceived physical discomfort. Visitors who interacted with hands-on displays or multimedia elements reported lower discomfort levels compared to those who engaged with static, text-based exhibits. This finding underscores the value of incorporating more dynamic and engaging exhibit features to reduce the physical strain associated with passive viewing and prolonged standing [13,14].

3) Satisfaction_Level and its role in comfort: Satisfaction_Level plays an important role in reducing discomfort, highlighting the broader impact of overall visitor experience on physical comfort. Participants who expressed higher satisfaction with their visit also reported lower discomfort levels. This suggests that factors beyond just physical comfort, such as the quality of the exhibits, the atmosphere, and the overall enjoyment of the visit, contribute to a more positive experience, which in turn may reduce the perception of physical strain [15].
4) Venue temperature issues: Including the lack of air conditioning leading to excessively cold conditions in winter and overheating in summer, exacerbate physical discomfort and restrict visitor mobility. Participants noted that the uncomfortable temperatures made it difficult to enjoy the exhibits, leading to increased feelings of physical strain and frustration. These temperature-related limitations not only contribute to physical discomfort but also hinder the overall visitor experience, underscoring the importance of implementing effective climate control measures to ensure a comfortable environment year-round [18,19].
5) Participant Suggestions for Ergonomic Improvements: Participants provided valuable suggestions for improving the ergonomic aspects of the venue, with a focus on seating areas, enhanced interactivity, and expanded venue spaces. The addition of strategically placed seating would provide visitors with opportunities to rest and reduce fatigue. Increasing interactivity in exhibits would engage visitors more actively, reducing feelings of monotony and discomfort associated with passive observation. Expanding venue spaces, particularly in areas with high traffic, would alleviate congestion and make the environment more comfortable for visitors, enhancing overall mobility and comfort [20,21].

By integrating these findings, it is clear that addressing both physical and experiential factors is key to improving the comfort and satisfaction of visitors at red cultural venues. The study highlights the importance of combining thoughtful design with engaging content to create a more comfortable and enjoyable experience for all attendees.

6.2. Implications

The findings underscore the critical need for ergonomic considerations in the design and operation of red cultural venues. Enhancing interactive elements not only fosters greater engagement but also serves as an effective strategy to mitigate physical discomfort. Additionally, optimizing spatial layouts to reduce congestion and provide adequate resting areas can significantly improve visitor comfort and satisfaction.

6.3. Recommendations

1) Enhance interactive exhibits: To increase visitor engagement and reduce physical strain, it is essential to incorporate more hands-on displays, multimedia elements, and interactive technologies into the exhibits. These features not only

foster active participation but also provide visitors with opportunities to move and engage, which can counteract the discomfort associated with prolonged static postures. By making exhibits more dynamic, visitors are likely to feel more immersed and less fatigued.

2) Optimize spatial layouts: Priority should be given to designing wider passageways and more open Spaces, regulating indoor ambient temperature and air quality to facilitate the flow of tourists. Especially in high-traffic areas, the site can create a more comfortable environment, allow easier movement, reduce physical discomfort due to air quality and indoor ambient temperatures that are too high or too low, and enhance the overall visitor experience.
3) Provide resting areas: Strategically placing seating throughout the venue will allow visitors to take breaks, reducing physical strain and fatigue, especially during extended visits. Resting areas should be integrated in areas with high standing duration or popular exhibits, offering visitors a chance to relax and recover. This will contribute to both comfort and satisfaction, encouraging visitors to engage more deeply with the venue without feeling physically overwhelmed.
4) Implement feedback mechanisms: Establishing real-time and post-visit feedback systems will help monitor visitor comfort and engagement continuously. This could include digital surveys, interactive kiosks, or mobile app-based feedback tools. By gathering insights from visitors during and after their visit, the venue can identify areas that need improvement and make ongoing adjustments to enhance the visitor experience. This feedback-driven approach ensures that the venue remains responsive to visitor needs and can adapt quickly to address any emerging issues related to comfort or engagement.

Together, these strategies will not only improve the physical comfort of visitors but also enhance their overall experience, making the venue more inviting, engaging, and user-friendly.

6.4. Limitations

While this study provides valuable insights, it is limited by its reliance on self-reported data, which may be subject to bias. Additionally, the absence of direct bio-mechanical measurements restricts the ability to objectively quantify physical strain. Future research could incorporate wearable technology to obtain precise bio-mechanical data and explore longitudinal effects of venue design on visitor well-being.

6.5. Future research directions

1) Objective bio-mechanical measurements: Future research could utilize wearable sensors to collect objective data on posture, movement, and muscle activity during visits to red cultural venues. These sensors would provide real-time, accurate measurements of physical strain, helping to quantify the impact of standing, walking, and interacting with exhibits. By capturing detailed bio-mechanical data, this approach can offer valuable insights into the specific areas

of the body most affected by prolonged visits and contribute to more targeted ergonomic interventions.

2) Longitudinal studies: Investigating the long-term health impacts of frequent visits to red cultural venues would provide a deeper understanding of the cumulative effects of repetitive physical strain. By following participants over an extended period, researchers could assess whether sustained exposure to discomfort (e.g., prolonged standing or limited movement) leads to chronic musculoskeletal issues, fatigue, or other health problems. These findings would be crucial for designing venues that promote not only immediate comfort but also long-term well-being for visitors.
3) Diverse demographics: Expanding the study to include a more diverse participant pool would enhance the generality of the findings. Including participants from various age groups, physical conditions, and cultural backgrounds would allow for a broader understanding of how different demographics experience and cope with physical discomfort and engagement. This expansion could uncover age- or ability-related differences in discomfort levels, engagement preferences, and the effectiveness of ergonomic interventions, leading to more inclusive venue design recommendations.
4) Intervention studies: Conducting intervention studies would allow researchers to assess the effectiveness of implemented ergonomic improvements on reducing discomfort and enhancing engagement. For example, after making design changes such as adding seating areas, improving exhibit interactivity, or optimizing spatial layouts, researchers could compare visitor feedback and bio-mechanical measurements before and after the interventions. This approach would provide empirical evidence of the benefits of specific changes, guiding future venue modifications and ensuring that the improvements lead to measurable gains in visitor comfort and satisfaction.

By exploring these additional research directions, future studies can offer a more holistic and evidence-based approach to improving the visitor experience at red cultural venues, addressing both short-term comfort and long-term health considerations.

In conclusion, this research highlights the pivotal role of ergonomic and bio-mechanical considerations in enhancing the visitor experience in red cultural venues. By addressing the identified challenges and implementing the recommended improvements, these venues can become more accessible, comfortable, and engaging for university students, thereby fulfilling their educational and cultural missions more effectively.

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