INTERNATIONAL JOURNAL OF ACADEMIC RESEARCH IN PROGRESSIVE EDUCATION & DEVELOPMENT

OPEN ACCESS JOURNAL

Vol 14, Issue 3, (2025) E-ISSN: 2226-6348

The Role of Auditory Attention in Shaping Immersive Experiences in Augmented Reality Museum Settings

Piao Gui Cheng[a]*, Lee Jun Choi[b] and Rehman Ullah Khan[c]

[a]Faculty of Cognitive Sciences and Human Development, UNIMAS, Kota Samarahan, Sarawak, Malaysia, [b]Faculty of Cognitive Sciences and Human Development, UNIMAS, Kota Samarahan, Sarawak, Malaysia, [c] Faculty of Cognitive Sciences and Human Development, UNIMAS, Kota Samarahan, Sarawak, Malaysia

*Email: 20010062@siswa.unimas.my

DOI Link: http://dx.doi.org/10.6007/IJARPED/v14-i3/26129

Published Online: 26 August 2025

Abstract

This study examines how auditory attention shapes immersive experiences in AR-enhanced museum exhibitions. While sound is integral to multisensory engagement, its specific influence in curatorial environments remains underexplored. Based on empirical data from an AR exhibition at a provincial museum in China, the findings show a significant positive relationship between auditory attention and immersion. Auditory cues were found to deepen both cognitive and emotional engagement. Framed by the Stimulus–Attention–Organism–Response (S-A-O-R) model, the study highlights sound's role as an active agent in shaping immersive perception. These results contribute to emerging discussions on multisensory aesthetics and visitor-centered museum design. By bridging empirical analysis with a structuralist framework, this research offers new insights into how auditory elements can be strategically integrated into curatorial practices to enhance cultural experience.

Keywords: Auditory Attention, Immersive Museum Experience, Augmented Reality (AR), Visitor Engagement, Cognitive Immersion

Introduction

The integration of technology into museum experiences has fundamentally transformed how visitors engage with exhibits. Among recent innovations, augmented reality (AR) has emerged as a powerful tool to enhance multisensory engagement, allowing visitors to interact with cultural artifacts in more dynamic and immersive ways. While visual stimuli have traditionally dominated exhibit design, auditory elements are increasingly acknowledged as critical to creating a fully immersive experience. Auditory attention—defined as the selective focus on auditory stimuli—plays a distinct role in shaping both cognitive and emotional engagement, making it a key factor in understanding visitor immersion.

Previous research on sensory engagement in museums has primarily focused on visual attention, emphasizing its role in capturing interest and sustaining focus (Wu et al., 2021).

However, auditory attention complements visual input by shaping atmosphere, conveying narrative context, and eliciting emotional responses (Bitgood, 2010). For instance, ambient soundscapes can transport visitors to historical periods, while voiceovers can guide understanding of complex exhibits, thus enhancing both engagement and memory. Despite these benefits, the specific impact of auditory attention on museum immersion remains underexplored, especially within AR-enhanced environments.

This study addresses that gap by examining the relationship between auditory attention and immersion among visitors to AR-based exhibits. Unlike traditional displays, AR technology integrates auditory and visual stimuli, offering a unique opportunity to analyze the interaction between sensory modalities. Focusing specifically on auditory attention, the study aims to answer two research questions:

- How does auditory attention correlate with immersion in AR-enhanced museum exhibits?
- To what extent does auditory attention predict visitor immersion in such settings?

To frame this inquiry, the study draws on the Stimulus–Organism–Response (S-O-R) framework, expanding it into the Stimulus–Attention–Organism–Response (S-A-O-R) model. This theoretical extension positions attention as a mediating factor between external stimuli and internal cognitive-emotional responses. By incorporating auditory attention, the S-A-O-R model offers a more nuanced understanding of sensory engagement in immersive cultural contexts.

By investigating auditory attention within AR-enhanced museum settings, this study contributes both theoretically and practically. It underscores the significance of auditory cues in shaping visitor experiences and provides actionable insights for museum practitioners and exhibit designers. The findings also advance theoretical models of sensory engagement, highlighting the transformative role of auditory attention in fostering meaningful, immersive experiences.

Literature Review

Auditory Attention and Its Role in Immersive Experiences

Auditory attention, the capacity to selectively concentrate on relevant auditory stimuli while filtering out extraneous noise, is a critical component in the construction of immersive environments. Recent research has emphasized its role in enhancing both cognitive engagement and emotional resonance, particularly within augmented reality (AR) contexts (Kaghat et al., 2020). In museum settings, auditory elements such as ambient soundscapes and interactive audio cues have been shown to direct visitor attention and deepen interpretive understanding (Bitgood, 2010). However, despite growing interest in multisensory experience design, empirical studies that isolate and examine the unique contribution of auditory attention—especially within AR-enhanced exhibitions—remain scarce.

Privitera Multisensory Engagement in Museums

Museums are increasingly adopting multisensory strategies to enhance visitor engagement and improve learning outcomes. Multisensory engagement refers to the integration of visual, auditory, and tactile stimuli to create a cohesive and immersive experience (Luo et al., 2024). Emerging research highlights the critical role of auditory cues in several key areas:

- Directing attention through spatialized sound and interactive audio narratives (Kaghat et al., 2020).
- Enhancing memory retention by linking auditory elements with visual stimuli (Marian et al., 2021).
- Evoking emotional resonance that deepens the sense of immersion and connection to exhibits (Privitera et al., 2024; Bitgood, 2010).

Despite these findings, scholarly attention has largely focused on visual modalities, often overlooking the distinct contributions of auditory attention. This study aims to address this gap by examining the direct impact of auditory attention on visitor immersion within AR-enhanced museum environments.

Augmented Reality and Auditory Attention

Augmented reality (AR) technologies present distinctive opportunities for integrating auditory elements into museum exhibits, enhancing engagement by aligning sound with dynamic visual content (Yulifar et al., 2024; Kaghat et al., 2020). In AR environments, carefully designed soundscapes can simulate historical settings or natural habitats, thereby strengthening visitors' sense of presence and immersive experience (Cliffe, 2024). Despite these advantages, several challenges persist, including maintaining audio clarity, ensuring synchronization with visual stimuli, and addressing individual differences in auditory processing (Privitera et al., 2024). These issues underscore the need for further research to optimize auditory design within AR-enhanced cultural contexts.

Theoretical Framework: Extending the S-O-R Model

The Stimulus–Organism–Response (S-O-R) model has long served as a foundational framework for examining how environmental stimuli influence individual behavior (Mehrabian & Russell, 1974). Recent research suggests that attention functions as a critical mediating factor in this process, shaping how individuals perceive, interpret, and respond to external stimuli (Wu et al., 2021; Kaghat et al., 2020). Building on this premise, the present study extends the S-O-R model by incorporating auditory attention, resulting in the Stimulus–Attention–Organism–Response (S-A-O-R) framework. In this extended model:

- Stimulus (S): Represents auditory inputs such as ambient soundscapes and narrative audio.
- Attention (A): Captures the selective focus on auditory cues that direct and sustain engagement.
- Organism (O): Encompasses internal emotional and cognitive states, particularly levels of immersion.
- Response (R): Refers to observable behavioral outcomes, including increased satisfaction and prolonged exhibit interaction.

By employing the S-A-O-R framework, this study offers a nuanced theoretical lens through which to examine the role of auditory attention in shaping immersive experiences within museum environments.

Research Gaps

Although auditory attention is increasingly acknowledged as a vital component of multisensory engagement, its independent contribution to immersive experiences remains insufficiently examined (Yulifar et al., 2024). Much of the existing literature tends to conflate auditory and visual stimuli, thereby obscuring the distinct influence of each modality.

Moreover, research on augmented reality (AR) environments often prioritizes technological advancements over their effects on sensory engagement (Cliffe, 2024; Kaghat et al., 2020). To address these limitations, the present study seeks to:

- Examine the unique role of auditory attention in shaping visitor immersion.
- Explore how auditory attention interacts with AR technologies to influence engagement in museum contexts.

Methodology

This study adopted a quantitative research design to examine the relationship between auditory attention and immersion levels in augmented reality (AR)-enhanced museum exhibits. To enable a focused investigation, the study specifically assessed the direct contribution of auditory attention to the immersive experience, deliberately excluding other sensory modalities. Data were collected using structured questionnaires administered to museum visitors immediately following their interactions with AR exhibits.

Instrument Development

As Krosnick (2018) emphasizes, the core of any survey lies in its questionnaire, which serves as the primary interface between researchers and participants. The validity and reliability of survey results depend largely on the clarity, relevance, and conceptual alignment of the questionnaire items.

Prior to 2008, the construct of "immersion" had not been clearly operationalized for quantitative measurement. Most research in this area focused on video game experiences. However, Jennett et al. (2008) confirmed that immersion can be measured both subjectively—via questionnaires—and objectively—using indicators such as task completion time and eye tracking. They also noted that immersion involves not only positive experiences but can also include negative emotions such as anxiety.

Immersion is conceptually linked to several related constructs, including flow, cognitive absorption, and presence. Given the objectives and research questions of this study, the questionnaire was designed to integrate these constructs while focusing specifically on auditory and visual attention. The final instrument consisted of six sections:

Immersive Tendency – Assesses participants' innate predisposition to immersive experiences, adapted from the Immersive Tendencies Questionnaire (ITQ-Version 2) (Witmer & Singer, 1998). Items unrelated to audiovisual immersion (e.g., reading habits) were removed to fit the study context.

Museum Immersion – Measures immersion during the AR-enhanced museum experience. Items were adapted from the Immersive Experience Questionnaire for Film and Television (Film IEQ) (Rigby et al., 2019), with modifications to reflect museum scenarios. For instance, "To what extent did the movie, TV show, or clip hold your attention?" was revised to "To what extent did the immersive technology in museum displays hold your attention?"

Visual Attention – Developed specifically for this study to assess the extent of visual engagement during the museum experience.

Auditory Attention – Newly constructed items aimed at evaluating selective auditory engagement within the AR context.

Overall Experience – Captures general perceptions and satisfaction following the museum visit.

Demographics – Collects participant background information

Several items from the original Film IEQ were omitted due to their irrelevance to the museum context (e.g., questions about motivation for watching films or understanding film concepts). New items focusing on visual and auditory attention were added to support the specific research aims.

This adapted instrument ensures content validity by aligning with established theoretical frameworks while being tailored to the unique characteristics of immersive museum environments.

Translation of the Questionnaire

As the study was conducted in a museum context in eastern China, where the majority of visitors are Chinese speakers, it was essential to translate the original English questionnaire into Chinese prior to distribution. This study employed Brislin's (1976) back-translation model to ensure linguistic and conceptual equivalence between the source and target versions. The translation process followed these steps:

- Forward Translation: Two bilingual translators with high English proficiency independently translated the original English questionnaire into Chinese. They then collaborated to reconcile differences and produce a preliminary Chinese version, referred to as MIEQ (A).
- Back Translation: Two additional translators, who had no prior exposure to the original English questionnaire, independently translated MIEQ (A) back into English. The resulting English version was reviewed and finalized by the principal researcher.
- Reconciliation and Finalization: The back-translated English version was compared with the original questionnaire by the researcher and all translators. After careful discussion and refinement, necessary modifications were made to ensure conceptual and linguistic consistency. The finalized Chinese version, MIEQ (B), was then used for data collection.

This rigorous translation approach ensured that the questionnaire maintained both semantic accuracy and cultural appropriateness, thereby supporting the validity of cross-language measurement.

Cross-Cultural Adaptation

Literal translation alone is insufficient to ensure conceptual equivalence across cultures, as cultural nuances and contextual influences may lead to misinterpretations (Marzuki et al., 2018; Tsai et al., 2018; Epstein et al., 2015). To address this, cross-cultural adaptation was conducted in this study, incorporating expert review and a preliminary pilot test.

Four domain experts were invited to participate in the adaptation process, including two associate professors specializing in museum visitor research, one associate professor in attention and emotion studies, and one associate professor in cognitive psychology. The researcher collected their feedback during on-site evaluations.

Each expert independently assessed the translated items for linguistic clarity, conceptual accuracy, cultural appropriateness, and overall coherence. Specific attention was given to evaluating whether the items reflected the intended constructs in a culturally relevant manner. For suggestions or comments that required clarification, the researcher engaged in in-depth discussions with the experts and documented all feedback in detail.

Based on the consolidated expert input, necessary modifications were made to enhance the cultural and contextual suitability of the questionnaire, ensuring that it accurately captured the intended meaning while aligning with local language usage and visitor cognition.

Pre-Testing

The pre-testing phase of this study was conducted in two stages: the first aimed to assess the quality of the questionnaire translation, and the second to evaluate its reliability and validity. A preliminary survey was conducted with 20 museum visitors in eastern China using convenience sampling. The objective was to gauge respondents' comprehension of the questionnaire items and identify potential ambiguities or cultural misalignments. Participants were informed of the study's purpose and asked to complete the translated questionnaire. Following Zhao et al. (2022), three key questions were asked during the debrief:

- Do you understand the content of this item? Are there any ambiguous expressions?
- Do you know how to answer it? If not, what causes difficulty?
- Does the language reflect natural Chinese expression habits? If not, how would you suggest rephrasing it?

Items identified as confusing or difficult were marked, and respondents' suggestions were documented. Based on this feedback and prior expert review, several revisions were made to form the final Chinese version of the MIEQ. Notable adjustments included:

- "How frequently" (**有多**频繁) in Item 6 was revised to "Do you often" (**您是否**经常) to reflect more natural Chinese phrasing.
- "Disagreeable tasks" (**不愉快的任**务) in Item 13 was changed to "Unsatisfactory tasks" (**不合心意的任**务) to reduce ambiguity.
- "Carnival or fairground rides" (**狂**欢节或游乐场的某些设施) in Item 17 was modified to "Fairground rides" (**游**乐场的某些设施), removing the culturally unfamiliar reference to "carnival."
- "Time dragged on" (时间拖得太久) in Item 25 was replaced with the idiom "Days wear on like years" (**度日如年**), more aligned with Chinese expression.

A pilot test was conducted in August 2023 during the summer vacation period at a major provincial museum in eastern China, focusing on a natural history exhibition enhanced by AR technology. AR glasses were rented at a dedicated counter, enabling the clear identification of visitors who had experienced the AR component. Participants were approached near the exhibit exit, and those who completed the questionnaire received a small monetary incentive. Initially, engagement was limited, likely due to privacy concerns. To address this, the research

team emphasized the anonymity of responses and clarified the purpose of the study, which led to a notable improvement in participation.

A total of 62 questionnaires were distributed. Data collection was conducted using both WeChat-based digital forms via "Questionnaire Star" and paper-based forms to accommodate varying levels of digital access. Six questionnaires were excluded due to uniform response patterns or inconsistencies in deception-detection items (Q34 and Q35), resulting in 56 valid responses (effective response rate: 90.32%).

Descriptive statistics showed that the valid sample included 33 males (58.93%) and 23 females (41.07%), with the majority aged between 18 and 30 years (57.14%). Table 1 provides further demographic details.

Table 1
Demographic Characteristics of Participants (n = 56)

Characteristic	Frequency	Percentage (%)	Accumulated percentage (%)
Gender			
Male	33	58.9	58.9
Female	23	41.1	100.0
Age (years old)			
0–17	3	5.4	5.4
18–30	32	57.1	62.5
31–40	13	23.2	85.7
41–50	4	7.1	92.9
51–60	2	3.6	96.4
60+	2	3.6	100.0
Occupation			
Student	23	41.1	41.1
Worker	5	8.9	50.0

Characteristic	Frequency	Percentage (%)	Accumulated percentage (%)
Salesperson	5	8.9	58.9
Administrative agent	2	3.6	62.5
Technician	4	7.1	73.2
Management	5	8.9	82.1
Teacher	2	3.6	85.7
Farmer	8	14.3	100.0
Others	0	0.0	100.0

Quantitative methods were applied to evaluate the instrument's reliability and validity. Cronbach's alpha was used to assess internal consistency, and exploratory factor analysis (EFA) with Bartlett's test of sphericity was conducted to examine construct validity. Following the Kaiser-Guttman rule (eigenvalues > 1), the number of factors in each section was determined. Reliability statistics were also calculated to identify and eliminate problematic items. A total of 7 items were removed due to negative impacts on reliability or construct validity: 2 from Section 1, 2 from Section 2, 1 from Section 3, and 2 from Section 4.

A second round of factor analysis was conducted on the revised instrument. Results indicated strong internal consistency across all subscales, with Cronbach's alpha coefficients ranging from 0.73 to 0.95, which falls within the "acceptable to excellent" range (George & Mallery, 2001). Factor loadings were as follows:

- Section 1 (Immersion Tendency): 0.61–0.75
- Section 2 (Museum Visitors' Immersion): 0.64–0.72
- Section 3 (Visual Attention): 0.65–0.80
- Section 4 (Auditory Attention): 0.70–0.75
- Section 5 (Overall Experience): 0.65–0.70

These findings demonstrate that each subscale effectively measures its intended construct. Consequently, the revised questionnaire was deemed to meet the standards of reliability and validity and was adopted for use in the formal survey phase.

Formal Questionnaire Survey

This study investigates the impact of auditory attention on the immersion levels of museum visitors engaging with AR-enhanced exhibits. The formal data collection was conducted at a natural history exhibition featuring augmented reality content in a provincial museum in

eastern China. Using a random sampling approach, questionnaires were distributed on-site to address the research questions through empirical data.

Procedure

As in the pre-test phase, visitors could rent AR glasses at the distribution counter located at the museum's ground-floor entrance for a small fee. To identify participants who had experienced the AR-enhanced exhibition, the research team observed visitors exiting the relevant gallery space while wearing the glasses. Eligible individuals were then approached, informed of the study's purpose, and invited to complete a questionnaire. Participants were assured that the research was for academic purposes only, that their responses would remain strictly confidential, and that a small monetary incentive would be provided upon completion.

The data collection period lasted ten days, from June 29 to July 8, 2024. Surveys were administered via Questionnaire Star, which allowed participants to scan a QR code using their mobile phones for immediate access to the questionnaire. To ensure data quality, responses showing uniform answer patterns were excluded. Additionally, two validation items (Items 24 and 25) were embedded; contradictory responses to these items were treated as indicators of invalid questionnaires. Data analysis was performed using SPSS version 26.

Participants

This study initially collected survey data from 423 museum visitors. To ensure data integrity, specific criteria were applied to identify valid responses. Questionnaires displaying uniform response patterns were excluded, along with those in which participants provided contradictory answers to two validation items (Items 24 and 25). After this screening process, a total of 386 valid questionnaires were retained, yielding an effective response rate of 91.25%.

Of these, 187 respondents had used AR glasses during the exhibition (Questionnaire A), while 199 had not (Questionnaire B). As this study aims to investigate the impact of auditory attention on immersive experiences within AR-enhanced museum settings, all subsequent analyses focus exclusively on Questionnaire A.

Among the 187 respondents in Questionnaire A, 97 were male (51.87%) and 90 were female (48.13%). The majority of participants were aged between 18 and 30 (n = 72, 38.50%). The sample was relatively balanced by gender. Notably, a large proportion of participants were students, likely due to the timing of the study shortly after China's national college entrance examination period. Furthermore, young adults under the age of 30 made up 73.8% of the AR-user group, suggesting that younger visitors may be more inclined to engage with novel technologies such as AR. Additionally, two respondents identified their occupation as "other"; follow-up conversations revealed that both individuals were over 60 years old and retired.

Data Analysis

As several questionnaire items were removed following the pre-test and the formal survey involved a substantially larger sample, it was necessary to re-evaluate the instrument's reliability and validity. After confirming acceptable reliability and construct validity, a series of statistical analyses were conducted based on the research questions. These included

descriptive analyses by gender and occupation, as well as regression and correlation analyses using data from Questionnaire A.

Results

Reliability Analysis

The questionnaire consisted of five sections: Immersive Tendency, Museum Visitors' Immersion, Visual Attention, Auditory Attention, and Overall Experience. To evaluate internal consistency, Cronbach's alpha coefficients were calculated for each section. Table 2 summarizes the reliability scores across all dimensions.

Table 2
Reliability Analysis of Questionnaire Sections

Sections	Number of Items	Cronbach's α	Interpretation
Immersive Tendency	18	0.89	Good Internal Consistency
Museum Visitors' Immersion	8	0.85	Good Internal Consistency
Visual Attention	4	0.78	Acceptable Internal Consistency
Auditory Attention	3	0.81	Good Internal Consistency
Overall Experience	3	0.76	Acceptable Internal Consistency

The results indicate that all sections demonstrate acceptable to good internal consistency, suggesting that the items within each subscale reliably measure their intended constructs.

Validity Analysis-Factor Analysis

To evaluate the construct validity of the questionnaire, factor analysis was conducted for each of the five sections: Immersion Tendency, Museum Immersion, Visual Attention, Auditory Attention, and Overall Experience. The results are summarized below.

A factor analysis using a three-factor solution was applied to the Immersion Tendency section. As shown in Table 3, the factor loadings for items Q1 to Q18 suggest that this section captures multiple dimensions of immersion. However, since the objective of this study is not to explore the underlying structure of immersion tendency, but rather to consider it as a control variable, the entire section is treated as a unified construct representing participants' innate immersion tendency.

Table 3
Factor Loadings Subscale

Item	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Factor 8
Q1	0.68	0.23	0.12					
Q2	0.71	0.19	0.15					
Q3	0.65	0.25	0.22					
Q4	0.63	0.3	0.18					
Q5	0.6	0.28	0.17					
Q6	0.55	0.31	0.24					
Q7	0.7	0.2	0.19					
Q8	0.65	0.25	0.23					
Q9	0.68	0.21	0.22					
Q10	0.62	0.3	0.2					
Q11	0.64	0.27	0.18					
Q12	0.66	0.24	0.17					
Q13	0.61	0.29	0.2					
Q14	0.63	0.28	0.18					
Q15	0.67	0.22	0.21					
Q16	0.59	0.3	0.22					
Q17	0.64	0.25	0.19					
Q18	0.62	0.28	0.18					
Q19				0.6	0.35			
Q20				0.65	0.32			
Q21				0.68	0.28			
Q22				0.64	0.27			
Q23				0.62	0.3			
Q24				0.67	0.26			
Q25				0.59	0.34			
Q26				0.61	0.31			
Q27						0.78		
Q28						0.81		
Q29						0.75		
Q30						0.77		
Q31							0.8	
Q32							0.84	
Q33							0.79	
Q34								0.85
Q35								0.88
Q36								0.82

Note: Factor loadings above 0.60 are considered high and support the dimensionality of each section.

For Section 2 (Museum Immersion), a factor analysis with a two-factor solution was performed. Items Q19 to Q26 aligned well with two underlying factors, suggesting multidimensionality. Nevertheless, because museum immersion serves as the dependent variable in this study, it is treated as a single, composite construct regardless of its sub-dimensions.

For Sections 3 to 5—Visual Attention, Auditory Attention, and Overall Experience—a single-factor solution was used for each. All items within these sections demonstrated strong loadings on a single factor, indicating that each section reliably measured a distinct and coherent construct.

Collectively, the factor analysis results provide robust evidence for the construct validity of the questionnaire. The items in each section loaded clearly onto their respective factors, supporting the instrument's effectiveness in capturing key dimensions of visitor experiences in immersive museum environments.

Confirmatory Factor Analysis and Construct Validity

Cronbach's alpha coefficients were calculated to assess the internal consistency of each subscale. The results indicated acceptable to excellent reliability, with values ranging from 0.76 (Overall Experience) to 0.89 (Immersive Tendency; see Table 2). All values exceeded the recommended threshold of 0.70 (Nunnally & Bernstein, 1994), demonstrating strong internal consistency.

Confirmatory Factor Analysis (CFA) was conducted to verify the structural validity of the constructs. The single-factor model for Visual Attention exhibited excellent fit indices (CFI = 0.97, TLI = 0.96, RMSEA = 0.07, SRMR = 0.03), with standardized factor loadings ranging from 0.80 to 0.85 ($p < 0.001$). Table 4 summarizes the CFA fit indices for both Visual and Auditory Attention, supporting the adequacy of their single-factor structures.

Table 4
Confirmatory Factor Analysis (CFA) Fit Indices

Fit Index	Visual Attention	Auditory Attention
CFI	0.97	0.98
TLI	0.96	0.96
RMSEA	0.07	0.05
SRMR	0.03	0.03

Convergent validity was established using Average Variance Extracted (AVE) and Composite Reliability (CR). Auditory Attention yielded an AVE of 0.68 and CR of 0.87, while Visual Attention achieved an AVE of 0.62 and CR of 0.85. All values exceeded the recommended thresholds (AVE ≥ 0.50, CR ≥ 0.70; Hair et al., 2010), confirming convergent validity.

Discriminant validity was also supported, as the square roots of AVE for Auditory Attention (0.81) and Visual Attention (0.78) were greater than their inter-factor correlation, consistent with the criteria proposed by Fornell and Larcker (1981).

Analysis of the Impact of Immersion Tendency on Museum Visitors' Immersion

To assess whether immersion tendency (Section 1) significantly predicts museum visitors' immersion (Section 2), a linear regression analysis was conducted. Total scores were computed for each participant by summing their responses to Section 1 (Q1–Q18) and Section 2 (Q19–Q26), with reverse scoring applied to Q19 and Q25 to ensure consistent directionality of the scale.

The regression results indicated that the model was not statistically significant (p = 0.733). The coefficient for immersion tendency was negative and non-significant (t = -0.342, p = 0.733), suggesting no meaningful relationship between general immersion tendency and the level of immersion reported during the museum experience.

These findings imply that visitors' predisposition to immersive experiences does not significantly influence their actual immersion within the context of AR-enhanced museum exhibits.

Auditory Attention and Museum Visitors' Immersion

This section presents the results of a regression analysis conducted to examine the relationship between auditory attention and museum visitors' immersion. A simple linear regression was performed, with the total score of Section 2 (museum visitors' immersion) as the dependent variable and the total score of Section 4 (auditory attention) as the independent variable. Table 5 summarizes the regression results.

Table 5
Regression Analysis of Auditory Attention on Museum Immersion

Variable	Coefficient	Std. Error	t-value	p-value
Intercept	2.2917	0.567	4.041	0.000
Auditory Attention Mean	0.6206	0.093	6.707	0.000
R-squared	0.198			

The analysis revealed an R-squared value of 0.198, indicating that auditory attention accounts for 19.8% of the variance in immersion scores. The regression coefficient for auditory attention was 0.6206 and statistically significant ($p < 0.001$), suggesting that greater auditory attention is positively associated with higher levels of museum immersion.

Discussion

Reliability and Validity of the Questionnaire

The reliability analysis indicated acceptable to strong internal consistency across all questionnaire sections, with Cronbach's alpha values ranging from 0.76 (Overall Experience) to 0.89 (Immersive Tendency). These results confirm that the items within each section reliably measure their respective constructs. In particular, the high reliability coefficients for Immersive Tendency ($\alpha = 0.89$) and Museum Immersion ($\alpha = 0.85$) demonstrate the questionnaire's robustness in capturing these core dimensions.

Factor analysis further supported the construct validity of the instrument. The Visual Attention, Auditory Attention, and Overall Experience sections each loaded strongly onto a single factor, indicating unidimensionality and consistent construct measurement. Although Immersive Tendency and Museum Immersion sections revealed multiple dimensions, these were treated as unified constructs in this study, in line with the study's focus on their overall contribution to the immersive experience.

The Confirmatory Factor Analysis (CFA) provided additional support for the theoretical model. For instance, the Auditory Attention construct showed excellent fit (CFI = 0.98, RMSEA = 0.05), reinforcing its unidimensional structure. Convergent and discriminant validity were

also established, with AVE and CR values exceeding recommended thresholds (Hair et al., 2010; Fornell & Larcker, 1981).

Although the reliability coefficients for Visual Attention (0.78) and Overall Experience (0.76) were near the acceptable threshold, their validity metrics (AVE ≥ 0.62; CR ≥ 0.84) remained strong, indicating that scale brevity did not compromise construct validity. Overall, these findings confirm the questionnaire's reliability and validity in evaluating sensory engagement in AR-enhanced museum contexts.

The Impact of Immersion Tendency on Museum Visitors' Immersion

The regression analysis revealed that immersion tendency (Section 1) did not significantly predict museum visitors' immersion (Section 2). The regression coefficient was not statistically significant ($t = -0.34$, $p = 0.73$), indicating that individuals' predisposition to become immersed in general activities had no meaningful influence on their actual level of immersion during the AR-enhanced museum experience.

This finding suggests that immersion during museum visits is shaped more by situational or contextual factors—such as exhibit design and sensory stimuli—rather than by visitors' inherent tendency to become immersed. In other words, the immersive experience appears to be primarily driven by the immediate environment and content of the museum rather than by stable personality traits.

Auditory Attention and Museum Visitors' Immersion

The findings of this study demonstrate a significant positive relationship between auditory attention and the level of immersion experienced by museum visitors engaging with AR-enhanced exhibits. This result supports existing literature indicating that auditory elements are instrumental in shaping both cognitive and emotional engagement within immersive environments (Cliffe, 2024; Kaghat et al., 2020). Specifically, soundscapes and narrative voiceovers appear to guide visitor focus, enrich contextual understanding, and foster a more coherent and engaging museum experience.

Correlation analyses revealed that higher auditory attention scores were associated with greater reported immersion, reinforcing the mediating role of attention as posited in the Stimulus-Attention-Organism-Response (S-A-O-R) framework. Rather than acting in isolation, auditory cues are likely to complement visual stimuli by enhancing interpretive depth and emotional resonance, thus facilitating a heightened sense of presence and absorption within the exhibition space.

However, prior qualitative research suggests that the effectiveness of auditory attention is contingent upon the design, clarity, and synchronization of auditory components. Auditory stimuli that are poorly integrated or excessively complex may result in sensory overload, ultimately diminishing the immersive experience (Privitera et al., 2024). In AR-enhanced museum settings, particular attention must be paid to sound quality, contextual alignment, and volume balance to ensure a seamless and supportive sensory environment.

Theoretically, these findings extend the applicability of the S-A-O-R model by illustrating how auditory attention functions as a critical intermediary between external

stimuli and internal experiential states. While traditional models such as the S-O-R framework emphasize the direct influence of environmental stimuli, this study highlights the importance of attentional mechanisms in shaping immersive responses.

From a practical standpoint, the results offer valuable implications for museum professionals and exhibit designers. Effective strategies may include the development of contextually relevant soundscapes, the incorporation of well-timed audio narratives, and the use of spatialized or directional audio to guide visitor attention. Such practices can significantly enhance the immersive quality of exhibits and contribute to more impactful visitor experiences.

In conclusion, auditory attention emerges as a key driver of visitor immersion in AR-enhanced museum contexts. This study contributes to the growing body of knowledge on sensory engagement and offers actionable insights for optimizing exhibition design. Future research could expand on these findings by investigating the combined effects of auditory attention with other sensory modalities, such as tactile or olfactory stimuli, to construct a more holistic model of multisensory immersion.

Conclusion

This study underscores the pivotal role of auditory attention in shaping immersive experiences for museum visitors interacting with AR-enhanced exhibits. By establishing a significant positive relationship between auditory attention and immersion levels, the findings highlight the importance of designing exhibition environments that effectively capture and sustain auditory engagement. Elements such as ambient soundscapes, interactive audio, and narrative voiceovers emerge as powerful tools for enhancing cognitive processing and emotional resonance, thereby deepening visitor connection with the exhibition content.

The study contributes to existing scholarship by extending the Stimulus-Attention-Organism-Response (S-A-O-R) framework, emphasizing attention—specifically auditory attention—as a key mediating factor that translates sensory stimuli into meaningful engagement. While prior research has predominantly emphasized visual attention, this study shifts the focus to auditory dimensions, offering a more comprehensive and balanced perspective on sensory engagement within immersive settings.

From a practical standpoint, the findings provide valuable insights for museum practitioners and exhibition designers. Strategic integration of auditory elements into AR-enhanced exhibits can substantially enhance visitor experience, promoting deeper learning, emotional involvement, and overall satisfaction. The study also highlights the need for synchronization between auditory and visual components to ensure a cohesive and compelling narrative throughout the exhibition.

Despite its contributions, the study acknowledges several limitations. These include the reliance on self-reported data and the specific focus on AR-enhanced environments, which may limit generalizability. Future research could explore the role of auditory attention in other immersive settings, such as virtual reality (VR) or fully multisensory exhibitions, and investigate the interplay between auditory attention and other modalities such as tactile and

olfactory stimuli. Additionally, longitudinal studies could examine the sustained impact of auditory engagement on memory retention and long-term visitor connection to museum content.

In conclusion, auditory attention plays a vital and often underexplored role in immersive museum experiences. By leveraging auditory cues effectively, museums have the potential to create more inclusive, emotionally resonant, and memorable environments—ultimately redefining how visitors engage with cultural and educational content.

Theoretical and Contextual Contributions

This study offers several key contributions to both theory and practice. Theoretically, it extends the traditional Stimulus–Organism–Response (S-O-R) framework by incorporating the mediating role of auditory attention, resulting in the Stimulus–Attention–Organism–Response (S-A-O-R) model. This enriched model provides a more granular understanding of how specific sensory modalities shape immersive experiences in museum contexts, particularly emphasizing the underexplored auditory dimension. This advancement deepens theoretical discourse on multisensory engagement and positions attention as a critical bridge between external stimuli and internal cognitive-emotional responses.

Contextually, the research is situated within a provincial museum in eastern China, thereby addressing the geographic and cultural gaps in existing literature, which has largely focused on western museum settings. By capturing visitor responses in a localized AR-enhanced environment, the study contributes culturally grounded empirical insights into how auditory attention operates within immersive technologies. It highlights how auditory cues, when effectively integrated into AR systems, can enhance visitor engagement across diverse sociocultural contexts.

Together, these contributions respond to an evident gap in both theory and application. The findings not only enrich scholarly understanding of sensory immersion but also provide practical strategies for museum professionals seeking to create more inclusive, engaging, and cognitively stimulating exhibition experiences in technologically mediated environments.

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