

Augmented Reality Guide Configurations and Museum Visitors' Heritage Interpretation: An In-Situ Comparative Study

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Article

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Abstract

Museums increasingly adopt augmented reality (AR) guides to support cultural interpretation and visitor engagement, yet empirical evidence for selecting appropriate AR configurations in real exhibition contexts remains limited. This study compares three AR formats in a real museum setting: screen-based AR, handheld AR with spatial overlay, and wearable AR glasses. The experiment took place in the Ancient Liaoning Gallery of the Liaoning Provincial Museum and focused on the jade pig-dragon, a representative Neolithic artifact of Hongshan culture. Ninety visitors participated in the field experiment and were randomly assigned to one of the three formats. Each visitor completed post-visit measures of engagement, emotional connection, perceived learning, and satisfaction. Results show that perceived learning did not differ significantly across formats. In contrast, experiential outcomes showed clear differences, with wearable AR glasses producing higher engagement, stronger emotional involvement, and greater overall satisfaction. These findings indicate that museum AR technologies should not be evaluated only by perceived learning outcomes, but also by their capacity to shape experiential quality. The study suggests that evidence-based AR selection can support more sustainable digital interpretation by aligning technological investment with visitor-centered cultural communication and long-term museum experience design.

1. Introduction

Information technology has developed rapidly in recent years. As a result, information dissemination models have shifted from a single format based on printed materials to a multimodal communication system supported by digital media(Bekele et al., 2018; Li et al., 2024). Within this context of transformation, museums, as public cultural institutions, are also undergoing profound changes in how they present and communicate knowledge(Karp, 2004). Traditional visit models mainly rely on textual labels and human guides. Museums now increasingly supplement and restructure these models by integrating digital media, interactive technologies, and immersive experiences(Hanussek, 2020; Hutchinson & Eardley, 2021). Museums around the world are increasingly integrating digital art, interactive media, and virtual technologies into their exhibitions, a development that has become a major global trend(Hammady et al., 2021).

In recent years, museums have placed growing emphasis on using digital technologies to support personalized visiting and learning experiences. Through mobile applications, QR code systems, and smart devices, visitors can access information in more flexible ways during their visits(Lee et al., 2019). This flexibility can deepen visitors' understanding of the exhibition content to a certain extent and enhance their engagement(Gong et al., 2022). In this context, augmented reality (AR) technology has attracted significant attention because it can overlay digital information onto real artifacts and physical spaces. Many scholars regard AR as an important medium that connects physical collections with digital content(Chen et al., 2022). Existing studies indicate that the use of AR in museum settings can enhance overall visiting experiences(Yoo & Yu, 2024), increase visitors' intentions to revisit and

consume(Cheng et al., 2023), under certain conditions, support the understanding of complex cultural and historical knowledge(Boboc et al., 2022).

Within the broader field of cultural heritage research, museums are continuously redefining their social roles beyond artifact preservation and value interpretation. By integrating information and communication technologies, heritage digitization, and immersive media, museums are promoting systematic transformations in exhibition formats, service models, and visitor–museum relationships(Nikolakopoulou et al., 2022). Technologies such as virtual reality (VR), AR, and mixed reality (MR) are widely used to overcome the spatial, temporal, and interactive limitations of physical exhibitions. These technologies enable museums to offer integrated visiting experiences that combine learning, entertainment, and emotional engagement(Fernandes & Casteleiro-Pitrez, 2023; Ferrer-Yulfo, 2020; tom Dieck & Jung, 2018).

As these technologies have matured, academic attention has gradually shifted from the question of whether technology should be introduced to how different technologies shape visitor experiences. Prior research suggests that interaction styles, information presentation structures, and usage pacing are key factors influencing the quality of museum experiences. These factors affect not only the retention of traditional visitor groups but also the attraction of new audiences(Errichiello et al., 2019). Therefore, the systematic measurement of visitor experience, satisfaction, and learning outcomes has become a central topic in museum research(Antón et al., 2018; Falk & Dierking, 2018).

Although many studies have affirmed the potential of AR and VR technologies to enhance engagement, motivation, and experience, their effects on learning outcomes and cognitive processes remain debated(Rauschnabel et al., 2022). On the one hand, immersive technologies can provide vivid content and strong emotional experiences. On the other hand, high levels of interaction complexity and information load may interfere with visitors' comprehension(Sun & Yu, 2019). For this reason, it is necessary to conduct more detailed comparative analyses of the experiential and learning characteristics associated with different digital guide media in real museum contexts.

In actual museum visits, visitors often find it difficult to fully understand the cultural meanings of exhibits based solely on the artifacts themselves(Hinrichs et al., 2008). Although textual labels remain the most common form of supplementary information, this format places high demands on visitors' reading willingness and cognitive effort. Some visitors are unwilling to invest sufficient time in deep reading during their visits (Horn et al., 2016). As a result, a key challenge in digital exhibition design is how to transform traditional textual information into more engaging and understandable experiential forms through digital and visual means.

Most existing studies focus on evaluating the effects of a single type of digital technology. Fewer studies compare different types of digital guide media side by side as integrated experience configurations in real museum environments. In practice, differences between guide media are not limited to technological platforms. These differences also involve information organization, interaction structures, and attention allocation mechanisms. Together, these factors shape the overall structure of

the visiting experience, yet they have received limited systematic discussion in prior research. Moreover, compared with learning outcomes, experiential dimensions such as emotional connection, meaning-making, and overall satisfaction have been examined less frequently.

Based on the above research background and identified gaps, this study conducts a systematic comparison of visitor experiences across different digital guide media in a real museum setting, while controlling for consistent exhibition information content. The study focuses on differences in engagement, learning support, emotional experience, and satisfaction. The specific research questions are as follows:

RQ1: To what extent do SAR, HAR, and ARG support cultural heritage understanding during a museum visit?

RQ2: To what extent do SAR, HAR, and ARG promote visitor engagement and emotional involvement?

RQ3: How do SAR, HAR, and ARG differ in visitor satisfaction after the visit?

2. Related works

2.1. Interpretation Modalities

In museum and cultural heritage research, interpretation modalities are commonly defined as the various forms and technical means used during visits to convey information, explain contextual backgrounds, and guide visiting routes. These modalities constitute an important component of museums' public educational functions (Civantos et al., 2016; Nanthasamroeng et al., 2026). Rather than serving as simple information delivery tools, interpretation modalities organize and contextualize information in structured ways. Through this process, they help visitors understand the cultural meanings embedded in exhibitions within limited time and space (He & Wu, 2023).

With the widespread adoption of digital technologies, museum interpretation modalities have gradually evolved from traditional formats dominated by human guides and textual labels into hybrid systems that incorporate multiple digital media. Audio guides, mobile digital guide applications, augmented reality systems, and automated guiding devices have become common configurations in museum practice (Rizvic et al., 2022). These modalities not only expand the means of information delivery, but also reshape the visiting process itself by influencing route organization, information triggering timing, and the pacing of visits (Rhee et al., 2022).

Audio guides represent one of the earliest digital interpretation formats adopted at scale. They provide visitors with pre-recorded audio explanations through portable devices (Goodwin, 2013). With the popularization of smartphones, mobile app-based audio and multimedia guides have gradually replaced dedicated hardware devices. This transition allows visitors greater autonomy in information selection and usage pace. However, previous studies have also noted that headphone-based audio guides may

reduce social interaction among visitors and weaken their awareness of and attention to the physical exhibition environment(Aoki et al., 2002; Bauer-Krösbacher, 2013).

AR technology has expanded the expressive and interactive dimensions of interpretation modalities by enabling the real-time overlay of digital information onto physical artifacts and spatial environments(Billinghurst et al., 2015). In cultural heritage exhibitions, AR is often used to present structural details of artifacts, historical evolution processes, and contextualized narrative content(Li et al., 2018; Park et al., 2018). In this way, AR compensates for the limited information capacity of physical exhibits. In addition, different AR systems exhibit diverse characteristics in terms of interaction logic, triggering mechanisms, and coordination with physical media(Damala et al., 2016). Xu et al.(2024) report that mobile AR applications improve users' knowledge retention in cultural heritage contexts.

Importantly, empirical comparisons show that device embodiment (handheld vs wearable) can shape how visitors engage with AR guidance even when core functions are similar(Serubugo et al., 2017), and field deployments of smart-glasses prototypes indicate that wearable AR can alter in-situ viewing and navigation practices in museums(Mason, 2016). Moreover, spatial registration represents a core design dimension within AR modalities. Aligned overlays that are visually anchored to target artifacts can strengthen object-centered attention and spatial understanding compared with screen-based viewing without stable alignment(Yi et al., 2022).

Recent studies increasingly treat museum XR as an integrated configuration that combines device form factor, spatial anchoring, and interaction control, rather than as a single feature(Innocente et al., 2023). In practice, many museum AR deployments remain smartphone-based and use recognition-triggered content to support interpretation without requiring continuous, stable overlay alignment (Ipalakova et al., 2025). Visitor control functions, such as pause or replay, further differentiate AR guidance by helping users regulate information intake under varied time constraints and prior knowledge(Lin et al., 2022). Evidence from wearable MR learning in museum settings also suggests that wearable form factors can shape engagement and learning outcomes(Chin et al., 2024).

From a configuration perspective, differences among interpretation modalities are mainly reflected in three aspects: information organization (fragmented nodes versus structured narratives), triggering mechanisms (user-initiated access versus system-driven delivery), and usage positioning (personal tools versus public installations)(Borsotti & Bollini, 2009). These differences are not determined solely by technological capabilities. Instead, they are closely linked to museums' overall design intentions regarding visiting routes, information pacing, and spatial order.

Overall, existing studies have examined the types and application value of digital interpretation modalities from multiple perspectives. However, most research focuses on functional validation of individual modalities. Fewer studies conduct parallel comparisons of different modality configurations under identical exhibition conditions. As a result, systematic distinctions among interpretation modalities in terms of interaction logic, information structure, and experiential outcomes remain insufficiently explored.

2.2. Visitor Experience

In museum research, experience is commonly understood as the overall subjective state formed through the combined effects of exhibition content, spatial environment, and interactive media during a visit (Falk & Dierking, 2018). Unlike evaluation approaches that focus primarily on information delivery efficiency or technological performance, experience-oriented research emphasizes visitors' emotional responses, levels of engagement, cognitive involvement, and processes of meaning construction that emerge through interaction (Kurnaz & Aniktar, 2025).

With the widespread adoption of digital interpretation media in museums, research attention has increasingly shifted toward how different interpretation approaches shape the structure of visitor experience. Previous studies indicate that the influence of digital interpretation extends beyond information acquisition. Instead, it lies in how these systems reconfigure the relationships between visitors, exhibits, spatial settings, and narrative content (Economou et al., 2025). From this perspective, user experience is viewed as an integrated process rather than an immediate evaluation of a single interface or technical feature.

Existing research typically describes museum user experience across multiple dimensions. Emotional experience is considered a key component of visiting experience, especially under narrative or immersive interpretation conditions. In such contexts, digital media can evoke emotional responses and strengthen visitors' subjective involvement with exhibition content (Li et al., 2025). At the same time, engagement represents another central dimension in experience research. Engagement emphasizes whether visitors sustain attention during their visit and actively interact with exhibition content or interpretation media (Tang et al., 2024). Recent AR-in-museum reviews further note that engagement is often driven by how the system scaffolds attention and interaction in-situ, rather than by AR novelty alone, which makes experience-based evaluation essential for comparing AR guidance designs (Yun et al., 2023).

In digital interpretation contexts, engagement is reflected not only in attention to exhibits themselves, but also in the ways visitors interact with interpretation systems. Othman et al. (2011) suggest that museum experience can be understood as the combined outcome of engagement with exhibition content and the experience of using multimedia guide systems. This distinction highlights the role of digital interpretation media as an independent interaction layer in experience formation. Recent museum studies using smart glasses also indicate that wearable form factors can shape how visitors engage with exhibit content and how they experience guided learning in-situ (Chen et al., 2023).

Cognitive aspects of experience are also a major concern in studies of digital interpretation. Differences among interpretation modalities in information pacing, interaction complexity, and content organization may influence visitors' cognitive load (He & Wu, 2023). These differences, in turn, affect the comprehension process and the perceived smoothness of the experience. A recent synthesis of AR-and-learning studies similarly shows that cognitive load is highly sensitive to interaction and information

design choices, supporting the need to treat “pacing/control” as a core experience mechanism when comparing AR guide modalities(Buchner et al., 2022).

In addition, museum user experience is widely recognized as being closely related to, yet conceptually distinct from, learning outcomes. Existing studies suggest that experiential states such as immersion, emotional involvement, and sustained engagement can create favorable conditions for visitors’ understanding and meaning-making, particularly in digitally mediated museum environments(Xu et al., 2023). For instance, research on multimedia- and AI-supported museum systems has shown that enhanced interactivity and immersive presentation can significantly elevate visitors’ experiential quality and engagement, even when improvements in measurable learning performance are not always evident (Wen & Ma, 2024). These findings highlight the importance of differentiating interpretation conditions at the experiential level, rather than relying solely on learning outcomes as the primary criterion for evaluating the effectiveness of museum interpretation strategies.

Satisfaction is generally defined as an integrative post-visit judgment of the museum experience. Trunfio et al. (2022)show that AR and VR integration can enhance visitor satisfaction as part of experience design. Zhang et al. (2022) demonstrate that system and information quality shape satisfaction through experiential states such as flow. Ponsignon et al. (2024)further argue that satisfaction arises from cognitive and hedonic evaluations, even when learning gains are limited. In heritage museums, empirical evidence also indicates that satisfaction can act as a key pathway linking AR’s perceived system/experience qualities to continued usage intention and revisit-related outcomes, reinforcing satisfaction as a practical criterion for cross-modality comparison(Chen et al., 2024).

Overall, existing research generally agrees that museum experience is a composite outcome shaped by emotional, engagement-related, cognitive, and satisfaction-related factors(Wang, 2020). Digital interpretation media play a critical role in this process by altering interaction patterns. However, empirical studies that systematically compare experiential differences across different digital interpretation conditions within the same exhibition context remain limited. Therefore, adopting a user experience perspective to conduct parallel analyses of different interpretation configurations provides an essential theoretical foundation for subsequent empirical investigations.

3. Method

This study adopted a between-subjects experimental design to examine how different museum interpretation modalities affect user experience in a real museum context. The experiment was conducted at the Liaoning Provincial Museum in China. It focused on visitors’ engagement with cultural heritage content delivered through three types of interpretation tools. Participants were randomly assigned to one of the three experimental conditions and completed a guided exhibition experience using the assigned tool. User experience data were collected through post-experience questionnaires. The analysis compared differences across interpretation modalities in terms of engagement, cognitive

understanding, emotional experience, and overall satisfaction. The aim was to clarify how modality characteristics shape user interaction and experiential quality in museum settings.

3.1. Procedures

Before the experiment, participants were informed about the purpose of the study and the overall procedure. Participation was voluntary, and written informed consent was obtained from all participants. Questionnaire responses were collected anonymously and processed in accordance with ethical research standards.

At the beginning of each session, participants received standardized operational instructions. These instructions introduced the assigned interpretation modality and its basic interaction methods. A brief hands-on trial was provided to ensure that participants were familiar with the device before the formal session began.

During the experiment, participants explored the exhibition independently using one of the three AR modalities.

In the SAR condition, participants could either select the artifact directly from the interface to access interpretive content or activate AR recognition by pointing the device at the artifact to trigger animation and explanation.

In the HAR condition, participants activated the AR content by aligning the device with the artifact, which triggered the overlay animation and explanatory information.

In the ARG condition, participants interacted through voice commands. They could initiate content by saying, for example, “Open number X” to access the artifact explanation, “Stop playback” to end the presentation, and “Volume up” or “Volume down” to adjust audio levels.

After completing the exhibition experience, participants filled out a post-experience questionnaire. The questionnaire consisted of two sections: the first assessed learning-related outcomes, and the second evaluated perceived engagement, usability, and overall experience. Following the questionnaire, participants were invited to participate in a brief discussion to provide additional qualitative feedback. Each experimental session lasted approximately 15 minutes.

3.2. Participants

A total of 90 participants (41 males, 49 females) participated in the study. Participants were aged between 18 and 60 years ($M = 26.03$, $SD = 8.02$) and were recruited on site at the museum. Most participants had prior experience with traditional audio guides. In contrast, familiarity with AR-based systems was limited, with approximately two-thirds reporting no prior use of handheld AR guides and more than three-quarters reporting no experience with AR glasses.

3.3. Materials

The experiment was conducted in the Ancient Liaoning Gallery of the Liaoning Provincial Museum, focusing on a representative Neolithic artifact from the Hongshan culture—the jade pig-dragon. The artifact was selected due to its historical significance and distinct iconographic features, making it suitable for augmented reality–based interpretation.

To minimize content-related variance, all three systems were developed around the same standardized informational units. These units included the artifact’s historical background, excavation site, material composition, defining morphological features, and its cultural prototype and symbolic significance. The thematic scope and informational structure were aligned across conditions to ensure comparability of interpretive content.

Three AR-based interpretation modalities were implemented (see Fig. 1): a screen-based AR guide (SAR), a handheld AR guide (HAR), and AR glasses (ARG).

The three modalities differed in how digital content was triggered and presented. In the SAR condition, the device camera detected the artifact and displayed animation and explanatory information directly on the screen, without overlaying it onto the physical object. The interface of the SAR modality, including the content selection screen, AR recognition interface, and animation display page, is illustrated in Fig. 2.

HAR achieves spatial overlay capabilities by rendering 3D augmented images aligned with artifacts within real-world camera views, as shown in Fig. 3.

The ARG condition further shifted the experience to a wearable format, enabling hands-free interaction with overlaid digital content through automatic scanning or voice activation.

An overview of the key characteristics of the three experimental conditions is provided in Table 1.

Table 1
Conceptual differences among the three experimental conditions.

Dimension	SAR	HAR	ARG
Device embodiment	Handheld	Handheld	Wearable
Spatial integration	Screen-based (no overlay)	Screen-based overlay on artifact	Wearable overlay on artifact
Interaction mode	Touch-based	Touch + Voice	Voice-dominant
User pacing control	Pause available	No pause	Pause available

Although the informational foundation remained consistent across modalities, the systems differed in their interaction pathways and level of spatial integration. All devices were provided by the museum and prepared by the research team prior to the experiment.

3.4. Measures

The questionnaire design and measurement indicators in this study were developed based on and adapted from established instruments used in prior research on museum digital interpretation, user experience, and cultural heritage interaction. All items were assessed using a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree). The questionnaire comprised three main sections.

The first section assessed guide usage experience, focusing on device operability, wearing or holding comfort, system responsiveness, and the clarity of information presentation.

The second section evaluated the overall museum visiting experience, capturing participants’ subjective perceptions of the visit under different interpretive conditions.

The third section consisted of an Artifact Information Test (AIT), which measured participants’ understanding and retention of factual information related to the exhibited artifact. The AIT included six multiple-choice questions that assessed learning across six content dimensions: the artifact’s historical period, excavation site, material, key characteristics, morphological features, and cultural symbolic meaning (see Table 2). The AIT included six multiple-choice questions. Each item was scored dichotomously (1 = correct, 0 = incorrect). The same six AIT questions were administered in both the pre-test and post-test to assess knowledge change attributable to the visit experience.

Table 2
Example AIT Items (Six Dimensions).

Dimension	Example question
Historical period	Which period does the jade pig-dragon belong to?
Excavation site	Where was the jade pig-dragon excavated?
Material	What is the primary material of the jade pig-dragon?
Key characteristics	In the Hongshan jade pig-dragon, what is a key characteristic of this artifact?
Morphological features	Which of the following is not a feature of the jade pig-dragon?
Cultural symbolic meaning	What does the jade pig-dragon symbolize in the Hongshan cultural context?

The study adopted the original Museum Experience Scale (MES) developed by Othman et al.(2011), and the scale structure was retained without modification. Based on this framework, the key dependent variables examined in this study included Engagement, Knowledge/Learning, Meaningful Experience, Emotional Connection, and Satisfaction (see Table 3).

This multidimensional measurement framework captured both functional aspects of user experience and higher-level cognitive and emotional responses. It therefore provided a comprehensive foundation for the subsequent statistical analyses and interpretation of the results.

Table 3
Measurement Scale.

Subscale		Description
MES	Engagement	Engagement reflects visitors' interest, involvement, and active participation during the exhibition experience, including enjoyment, attentional engagement, and preference for the interpretation method over passive viewing.
	Knowledge / Learning	Knowledge/Learning measures visitors' perceived understanding and knowledge acquisition, focusing on content clarity, comprehension of exhibition information, and learning gains supported by the interpretation method.
	Meaningful Experience	Meaningful Experience captures visitors' reflective thinking and sense-making processes, including cognitive engagement, perceived impact, and post-visit curiosity regarding the exhibition's significance.
	Emotional Connection	Emotional Connection assesses visitors' affective responses to the exhibition, including emotional immersion, aesthetic appreciation, and personal or emotional resonance with the exhibition content.
SAT	Satisfaction	Satisfaction reflects visitors' overall evaluation of the interpretation method, including willingness to recommend it to others and intention to reuse it in future exhibition visits.

4. Result

All statistical analyses were conducted using IBM SPSS Statistics 27. Reliability analysis indicated excellent internal consistency for the MES scale (Cronbach's $\alpha = 0.934$). The two additional satisfaction items also demonstrated good reliability (Cronbach's $\alpha = 0.857$).

4.1 AIT Knowledge Test Results

Knowledge scores increased from pre-test to post-test across all participants, suggesting improved factual understanding after the visit (Time effect: $F(1,87) = 89.06$, $p < .001$, partial $\eta^2 = .506$). Table 4 reports the descriptive statistics by modality. Although all three groups showed higher post-test scores than pre-test scores, the size of the pre-post improvement did not differ significantly across SAR, HAR, and ARG (Time $\times$ Modality: $F(2,87) = 0.61$, $p = .548$, partial $\eta^2 = .014$). The mean gain scores were similar across conditions (SAR: $M = 1.87$, $SD = 1.43$; HAR: $M = 1.40$, $SD = 1.89$; ARG: $M = 1.70$, $SD = 1.64$), which aligns with the non-significant interaction.

Table 4
Pre- and post-test knowledge scores by guide modality (Mean $\pm$ SD).

Modality	n	Pre_total	Post_total	Gain (Post–Pre)
SAR	30	2.27 $\pm$ 1.66	4.13 $\pm$ 1.31	1.87 $\pm$ 1.43
HAR	30	3.00 $\pm$ 1.53	4.40 $\pm$ 1.67	1.40 $\pm$ 1.89
ARG	30	2.20 $\pm$ 1.13	3.90 $\pm$ 1.27	1.70 $\pm$ 1.64
Note. Pre_total and Post_total range from 0 to 6.				

4.2 Engagement

A one-way ANOVA revealed a statistically significant difference in user engagement among SAR, HAR, and ARG, $F(2, 87) = 5.462$, $p = .006$ (see Table 5).

Post hoc LSD comparisons indicated that ARG differed significantly from both SAR ($p = .007$) and HAR ($p = .004$), whereas no significant difference was observed between SAR and HAR ($p = .867$).

Descriptive statistics showed that ARG achieved the highest engagement score ($M = 4.55$, $SD = 0.49$), followed by SAR ($M = 4.11$, $SD = 0.68$) and HAR ($M = 4.08$, $SD = 0.65$). As shown in Fig. 4, ARG demonstrated a higher central tendency and a more concentrated distribution, whereas SAR and HAR exhibited greater dispersion and largely overlapping score distributions.

Table 5
Multiple comparisons of group differences in user engagement.

(I) Group	(J) Group	Mean Difference (I–J)	Std. Error	Sig.
SAR	HAR	0.0267	0.1586	0.867
SAR	ARG	-0.4400	0.1586	0.007**
HAR	ARG	-0.4667	0.1586	0.004**
Note. * $p < .05$; ** $p < .01$.				

4.3. Knowledge / Cognition

A one-way ANOVA revealed no statistically significant difference in knowledge acquisition among the three guide modalities ($F(2,87) = 0.389$, $p = 0.679$). Descriptive statistics showed comparable levels of perceived knowledge and cognitive understanding across conditions, with similar mean scores for the SAR ($M = 4.25$, $SD = 0.53$), HAR ($M = 4.13$, $SD = 0.64$), and ARG ($M = 4.25$, $SD = 0.65$). Post hoc LSD tests indicated that no significant differences were observed among any of the pairwise comparisons (see Table 6).

Table 6
Multiple comparisons of group differences in knowledge / cognition.

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.
SAR	HAR	0.1200	0.1571	0.447
SAR	ARG	0.0000	0.1571	1.000
HAR	ARG	-0.1200	0.1571	0.447
Note. *p < .05; **p < .01.				

4.4. Meaningful Experience

A one-way ANOVA indicated that there was no statistically significant difference in meaningful experience among the three guide modalities ($F(2,87) = 0.834$, $p = 0.438$). Participants reported comparable levels of meaningful experience when using the traditional audio guide ($M = 3.92$, $SD = 0.58$), handheld AR ($M = 3.89$, $SD = 0.67$), and AR glasses ($M = 4.09$, $SD = 0.68$). Post-hoc LSD comparisons further confirmed that none of the pairwise comparisons reached statistical significance (see Table 7).

Table 7
Multiple comparisons of group differences in meaningful experience.

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.
SAR	HAR	0.0333	0.1659	0.841
SAR	ARG	-0.1667	0.1659	0.318
HAR	ARG	-0.2000	0.1659	0.231
Note. *p < .05; **p < .01.				

4.5. Emotional Connection

A one-way ANOVA revealed a statistically significant difference in emotional connection among SAR, HAR, and ARG, $F(2, 87) = 3.717$, $p = .028$. Post hoc LSD comparisons indicated a significant difference between SAR and ARG ($p = .010$), whereas the differences between SAR and HAR ($p = .445$) and between HAR and ARG ($p = .063$) were not statistically significant (see Table 8).

As shown in Fig. 5, ARG demonstrated higher emotional connection scores ($M = 4.25$, $SD = 0.63$) than SAR ($M = 3.75$, $SD = 0.78$). In contrast, HAR showed a distribution that largely overlapped with both SAR and ARG, consistent with the non-significant pairwise comparisons involving this modality.

Table 8
Multiple comparisons of group differences in emotional connection.

(I) Group	(J) Group	Mean Difference (I–J)	Std. Error	Sig.
SAR	HAR	-0.1467	0.1912	0.445
SAR	ARG	-0.5067	0.1912	0.010*
HAR	ARG	-0.3600	0.1912	0.063
Note. *p < .05; **p < .01.				

4.6. Satisfaction

A one-way ANOVA revealed a statistically significant difference in satisfaction among SAR, HAR, and ARG, $F(2, 87) = 5.870$, $p = .004$. Post hoc LSD comparisons indicated that ARG differed significantly from both SAR ($p = .004$) and HAR ($p = .004$), whereas no significant difference was observed between SAR and HAR ($p = 1.000$) (see Table 9).

As shown in Fig. 6, ARG achieved the highest satisfaction score ($M = 4.52$, $SD = 0.56$), whereas SAR ($M = 3.95$, $SD = 0.72$) and HAR ($M = 3.95$, $SD = 0.89$) demonstrated comparable levels. The score distributions for SAR and HAR largely overlapped, consistent with the non-significant pairwise comparison between these two modalities.

Table 9
Multiple comparisons of group differences in satisfaction.

(I) Group	(J) Group	Mean Difference (I–J)	Std. Error	Sig.
SAR	HAR	0.0000	0.1910	1.000
SAR	ARG	-0.5667	0.1910	0.004**
HAR	ARG	-0.5667	0.1910	0.004**
Note. *p < .05; **p < .01.				

5. Discussion

5.1. Learning Outcomes

This study found no clear difference in learning or understanding support across the three AR guide configurations (SAR, HAR, and ARG) in a cultural heritage museum visit. This finding answers RQ1. Under the study conditions—standardized content and an on-site visit—these three configurations provided a similar level of support for visitors’ cultural heritage understanding.

This pattern is consistent with a key point in prior experience research. Digital interpretation tools often change the visit experience first. They can improve attention, emotional involvement, and interactive engagement. However, these experience gains do not always produce higher measurable learning outcomes (Wen & Ma, 2024). Prior work also shows that visitors can report higher overall experience quality, such as satisfaction, even when learning gains are limited. This point supports the need to evaluate learning and experience as related but distinct outcomes (Ponsignon et al., 2024). From a cognitive perspective, a recent review of AR and learning reports that learning performance is sensitive to interaction complexity, information structure, and task design. When design differences do not change the quality of cognitive processing, learning scores may remain similar across conditions (Buchner & Buntins, 2021). Therefore, the convergence in learning outcomes in this study does not contradict the general claim that AR can support learning. Instead, it suggests a “ceiling” effect under specific content and context constraints.

At the same time, this result does not fully align with some empirical cultural heritage AR studies that report improved knowledge retention or learning outcomes with mobile AR (Xu et al., 2024). Several factors may explain this difference. First, many studies compare AR with non-AR formats. These contrasts often make it easier to observe learning gains from technology adoption. In contrast, this study compared three configurations within AR guidance. Each configuration provided digital interpretive information. This shared capacity may have raised the baseline level of learning support in all groups and reduced between-group differences (Billinghurst et al., 2015). Second, learning effects depend on measurement and time window. A short museum visit can lead visitors to form a general impression of “I understood it.” This setting may not encourage deeper processing or long-term retention. As a result, learning differences may be harder to detect than in studies that use delayed tests or more fine-grained measures (Xu et al., 2024).

Third, the configuration differences in this study involved more than spatial alignment. They also involved embodiment and interaction or pacing control. Prior work notes that AR systems differ in interaction logic, triggering mechanisms, and coordination with physical media. These features can change how visitors process information (Damala et al., 2016). Spatial overlays in HAR or ARG may support object-centered understanding in principle. However, any potential advantage can be offset by interaction friction, attention switching, or constraints in pacing and control. These factors can limit learning gains and keep learning outcomes similar across conditions (Buchner & Buntins, 2021). Related museum AR reviews also emphasize that engagement and experience often depend on how the system scaffolds attention and interaction in the moment. This pattern does not rely on AR novelty alone. It suggests that configurations may separate more clearly at the experience level than at the learning level (Yun et al., 2022).

Overall, the learning results do not imply that AR configuration is irrelevant to cultural heritage learning. Instead, the findings point to a clear boundary condition. When the informational content is standardized, the visit time is limited, and the interpretive units already support basic understanding, learning differences across AR configurations may not be easy to observe. Based on this boundary, the next

sections discuss why ARG still showed stronger engagement, emotional involvement, and satisfaction. The next sections also explain how these experience differences relate to embodiment, spatial alignment, and pacing control (Damala et al., 2016; Yun et al., 2022).

5.2. Engagement and Emotional Involvement

The results for engagement and emotional involvement indicate that the three AR guide configurations created different experiential states. ARG was more effective in sustaining visitor engagement and emotional involvement. This finding answers RQ2. It also suggests that, in an on-site museum visit, the way visitors use a guide and the way they view exhibits can strongly shape their subjective involvement.

Compared with learning outcomes, engagement and emotion are more sensitive to the intensity of the experience. For ARG, this intensity may first come from the novelty of a wearable form factor. Most visitors had no prior experience with smart glasses. For this reason, a wearable guide can more easily trigger initial interest and exploration. This effect can be stronger during a short museum visit. Importantly, novelty is not “noise” in this context. Novelty is part of real museum adoption of wearable guidance, and it can directly influence visitors’ immediate engagement.

At the same time, this study should not attribute ARG’s experience advantage to novelty alone. Empirical comparison studies show that, even when core functions are similar, differences between handheld and wearable platforms can change how visitors interact with an AR guide. These differences can then affect experience quality and user preference (Serubugo et al., 2017). Field deployments of smart-glasses prototypes in museums also show that wearable guidance can change visitors’ in-situ viewing and movement. This change helps interpretive information blend more naturally into the act of looking at exhibits, and it supports a more continuous visit experience (Mason, 2016). Recent studies on smart glasses report a similar pattern. The wearable form factor can shape how visitors engage with exhibit content and how they experience guided learning during the visit (Chen et al., 2023). Together, these findings suggest that novelty may increase initial interest, but embodiment and hands-free interaction can provide a more stable and structured experience advantage. Visitors can keep their attention on the artifact more easily, and they can maintain emotional involvement for longer.

The results for HAR provide another important point. HAR offered spatial overlays, but it did not show a consistent advantage over SAR in engagement and emotional involvement. This pattern suggests that spatial alignment alone does not guarantee stronger emotional participation. AR design research highlights spatial registration and aligned overlays as key dimensions that differentiate AR modalities. When digital information is stably anchored to a target artifact, visitors are more likely to maintain object-centered attention and develop clearer spatial understanding (Yi et al., 2022). However, museum use also places constraints on this benefit. Interaction flow, alignment effort, and practical operating demands can limit the advantage of overlays. In other words, overlays do not automatically increase engagement. The advantage becomes clearer only when overlays match the visit pacing and minimize operating cost and attention switching. This condition can explain why HAR and SAR show overlapping

experience outcomes. In real visits, interaction friction can partly offset the potential gains of spatial overlays, and this friction can weaken their effect on sustained engagement and emotional involvement.

Overall, the findings for engagement and emotional involvement support two points. First, ARG as a wearable smart-glasses guide may raise initial interest because it feels new and technologically appealing. Second, and more importantly, comparative and field evidence suggests that wearable guidance can reorganize interaction in ways that better fit museum viewing behavior. This reorganization helps visitors sustain engagement and emotional involvement during the visit (Serubugo et al., 2017; Mason, 2016; Chen et al., 2023). At the same time, the HAR results suggest that spatial alignment is important, but its experiential benefits depend on a low-friction interaction process and a pacing that fits the museum visit (Yi et al., 2022).

5.3 Satisfaction

The satisfaction results indicate that the three AR guide configurations led to different overall post-visit evaluations. Among them, ARG more often received more positive satisfaction feedback. This finding answers RQ3. It also suggests that satisfaction functions as an integrative post-visit judgment. Visitors combine their sense of involvement, perceived smoothness, and overall impressions into one evaluation, rather than rating a single feature in isolation (Trunfio et al., 2022).

A reasonable interpretation is that, when informational content is held constant, satisfaction differences are more likely to come from differences in the visit process than from differences in the amount of information (Rhee et al., 2022). During use, visitors repeatedly experience process-related factors. These factors include whether their attention is interrupted, whether operations feel easy, and whether information enters the visit in a natural way. Prior research notes that museum experience includes engagement with exhibit content and the experience of using the guiding system itself. When the guidance experience feels more continuous and is less often interrupted by operations, visitors are more likely to form a positive overall impression of the visit. This impression can then appear as higher satisfaction after the visit (Zhang et al., 2022). In contrast, when the guidance process requires frequent actions, repeated attention shifts, or repeated alignment, visitors may treat these process costs as part of their overall evaluation. These costs can lower satisfaction even when the informational content remains strong (Zhang et al., 2022).

HAR provided spatial overlays, yet it did not show a stable satisfaction advantage. This pattern suggests that satisfaction does not depend on “overlay” alone. Satisfaction depends more on how the guidance configuration works as a whole in the museum setting. Prior work indicates that key differences across interpretation configurations often relate to information organization, triggering mechanisms, and usage positioning. These features can shape visit pacing and attention allocation (Borsotti & Bollini, 2009). Therefore, if spatial overlays also increase alignment demands or require more frequent operations, visitors may perceive higher process costs. These costs can offset the potential experience benefits of overlays and limit satisfaction gains. By contrast, when a configuration supports a steadier viewing rhythm and reduces repeated switching between viewing and operating, visitors are more likely to

perceive the guidance as effective support for the visit. This perception can lead to a more positive overall evaluation.

Overall, the satisfaction results support the following conclusion. When content is standardized, visitors' overall satisfaction is more likely to depend on whether a guidance configuration supports a continuous visit process and an appropriate experiential pace, rather than on a single technical feature (Borsotti & Bollini, 2009; Trunfio et al., 2022).

6.1 Limitations and Future Work

This study has several limitations that also suggest directions for future research.

First, the study was conducted in one museum, one gallery context, and one focal artifact. This design improves comparability, but it limits generalization. Future work should replicate the comparison across different museums, exhibition types, and artifact categories.

Second, the learning assessment mainly captured short-term, on-site outcomes (e.g., perceived understanding and immediate evaluation). This approach may miss longer-term differences. Future studies should add delayed tests and follow-up measures to examine retention and transfer.

Third, the three configurations differed in interaction pathways and pacing control in real use. These differences reflect real-world configurations, but they limit factor isolation. Future research should use factorial or mixed designs to test embodiment (handheld vs. wearable), spatial integration (screen-based vs. aligned overlay), and pacing control more separately.

Fourth, the study relied mainly on self-report measures for experience and satisfaction. Future work should add behavioral logs (e.g., dwell time and content access) and observational or lightweight attention indicators to explain how configurations shape in-situ engagement.

Finally, most participants were new to AR glasses, so novelty effects may be stronger. Future research should test repeated use and compare novice and experienced users.

Despite these limitations, the study provides in-situ empirical evidence on experiential differences among SAR, HAR, and ARG. Future replications and richer long-term and process measures can strengthen evidence for museum AR guide design and selection.

6.2 Conclusion

This study compared three AR guide configurations (SAR, HAR, and ARG) in a real museum visit while keeping the interpretive information units consistent across conditions to reduce content-related variation. The findings show clearer differences in how these configurations shaped visitor experience, while differences in learning support were more limited. ARG better sustained engagement and emotional involvement and also received more positive satisfaction feedback after the visit. These results suggest that the value of digital guidance does not lie only in how information is presented. It

also lies in how the system organizes visit pacing and attention allocation (Rhee et al., 2022). In other words, once interpretive content is standardized, configuration-level differences are more likely to appear through the process experience, such as whether the visit feels continuous and whether attention is frequently interrupted (Borsotti & Bollini, 2009). Therefore, this study argues that AR guidance should be treated as an integrated configuration system rather than being reduced to a single “technology effect.” This view also provides a more actionable evaluation perspective for museums, because satisfaction reflects an integrative post-visit judgment that is sensitive to the quality of the visit process (Trunfio et al., 2022).

Overall, the contribution of this study is that it provides a parallel comparison of three common AR museum guide configurations within the same museum and artifact context under standardized interpretive content. The study identifies a practical pattern: when content is held constant, experience-related outcomes—engagement, emotional involvement, and post-visit satisfaction—often differentiate guide configurations more clearly than learning outcomes. Based on this pattern, museums should shift optimization priorities from “whether to adopt AR” to “how to organize the visit process.” In particular, museums should focus on a continuous guidance flow, the natural entry of information into viewing, and a guidance rhythm that fits visitors’ pacing. These priorities can support more stable satisfaction gains and a more positive museum experience.

Declarations

Conflict of interest

The authors declare no conflict of interest in the conceptualization, writing, and review of this manuscript.

Ethical Approval

This study was reviewed and approved by the Institutional Review Board of the School of Law, Ningxia University on 10 November 2025. All procedures involving human participants were conducted in accordance with relevant institutional ethical guidelines and regulations. Participation was voluntary, and written informed consent was obtained from all participants prior to data collection. No personally identifiable information was collected.

Informed Consent Statement

All participants provided written informed consent prior to data collection. Before participating, participants received a written information sheet outlining the study’s purpose, procedures, voluntary nature of participation, anonymity safeguards, and the academic use of the data. Participants were informed that they could decline to answer any question or withdraw from the study at any time without penalty. No personally identifiable information was collected.

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Data Availability Statement

The original contributions presented in the study are included in the article. Due to ethical and participant privacy considerations, the underlying data are not publicly deposited in an open repository. Further inquiries regarding the data can be directed to the corresponding author.

AI use declaration

AI-assisted tools (e.g., ChatGPT) were employed in this study to support linguistic refinement and structural polishing, including academic phrasing enhancement, grammar checking, and improvement of logical clarity. All AI-generated suggestions were carefully reviewed, validated, and revised by the authors to ensure scholarly rigor. The use of AI was limited to non-substantive editorial assistance, while all conceptual, analytical, and intellectual contributions originate solely from the authors.

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Figures



Figure 1

Experimental AR modalities (SAR, HAR, ARG).

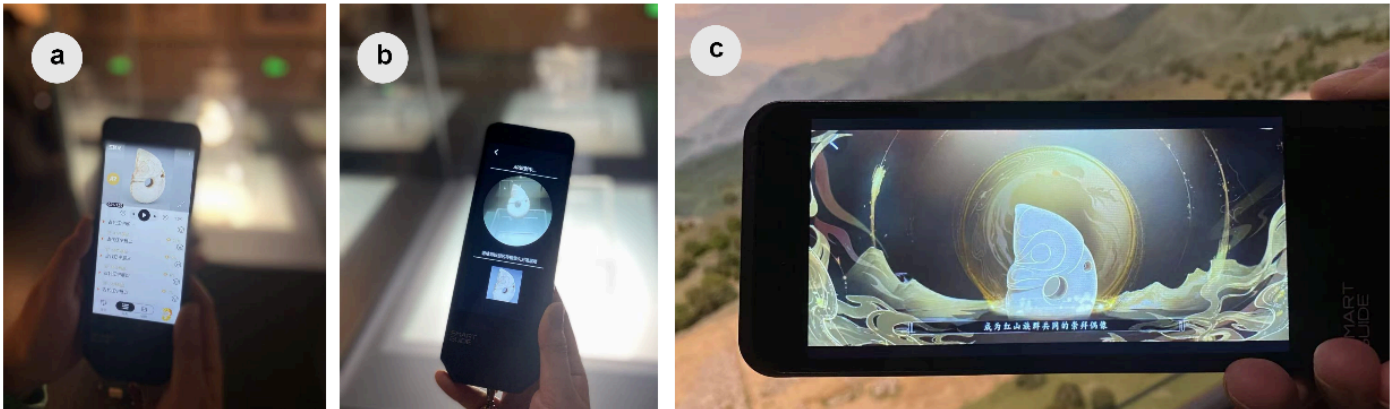


Figure 2

SAR interface and interaction flow.

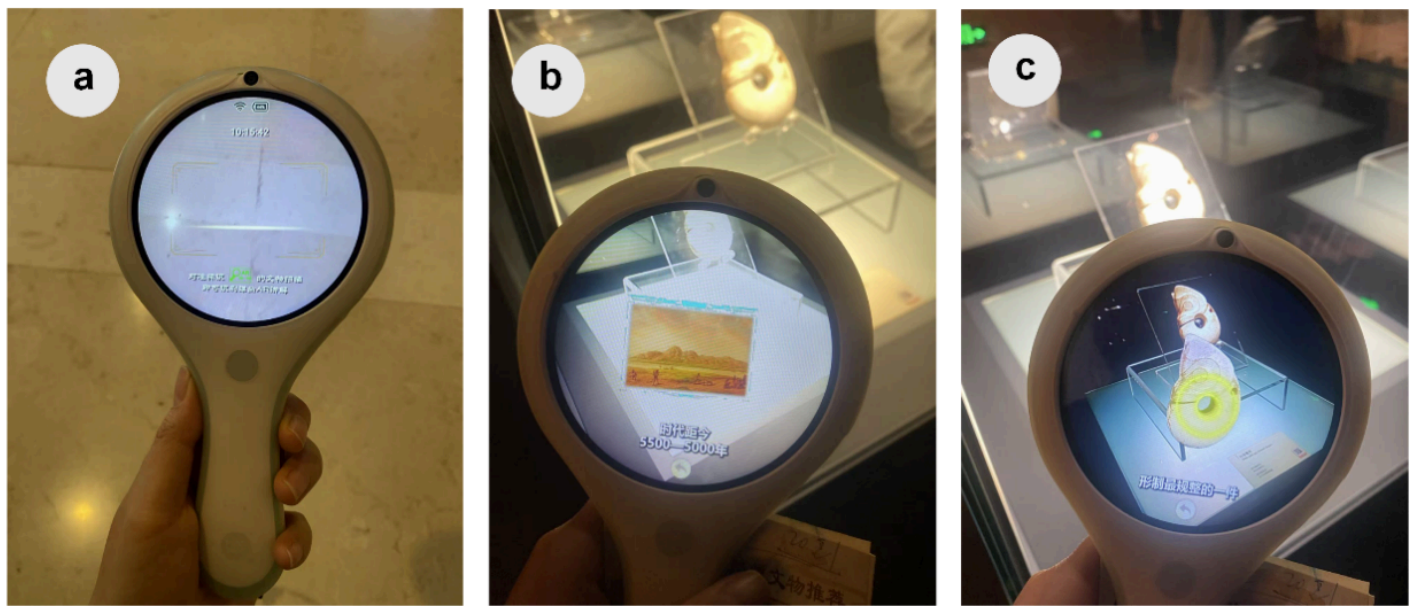


Figure 3

HAR interface and interaction flow.

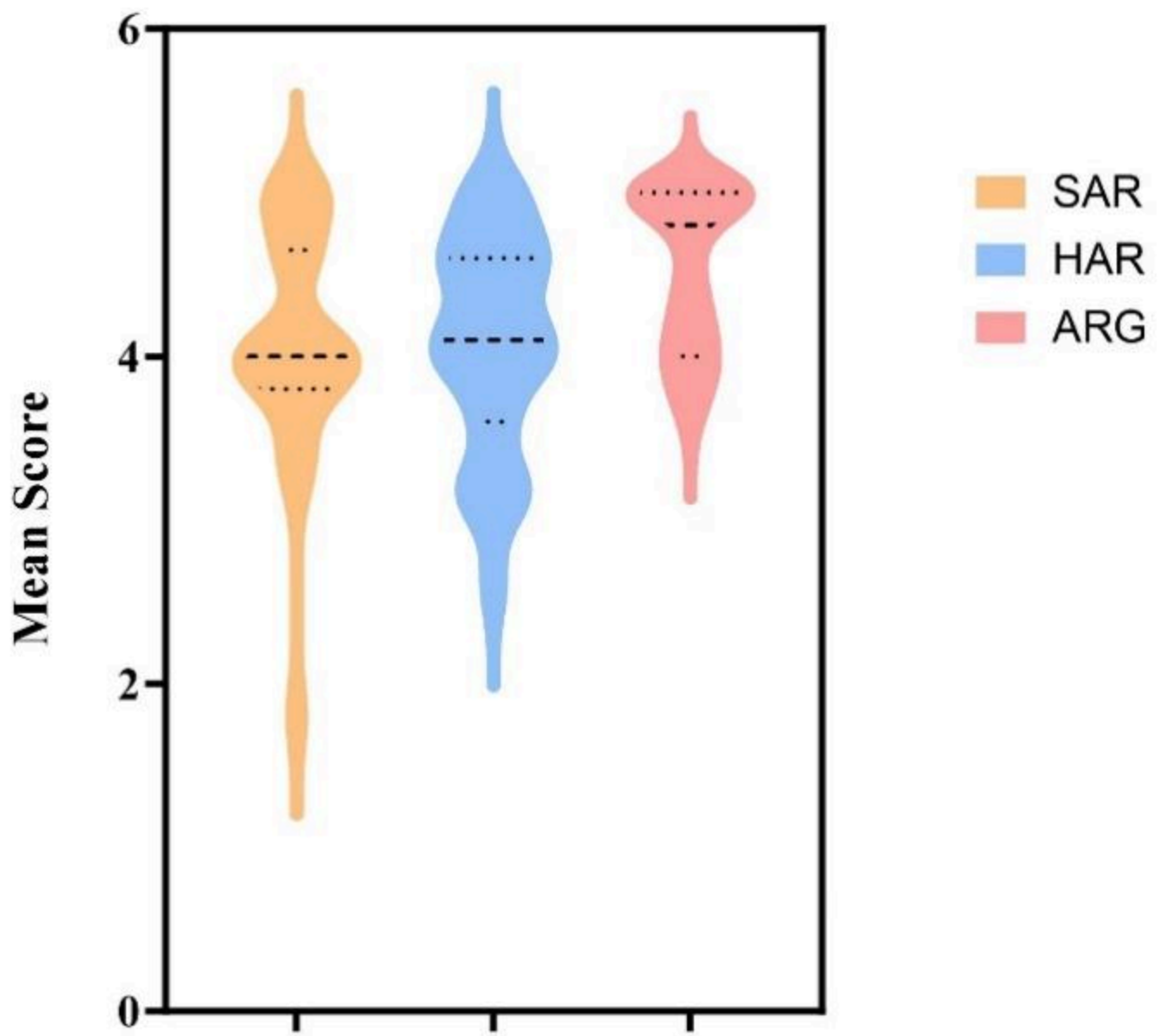


Figure 4

Distribution of engagement scores across guide modalities.

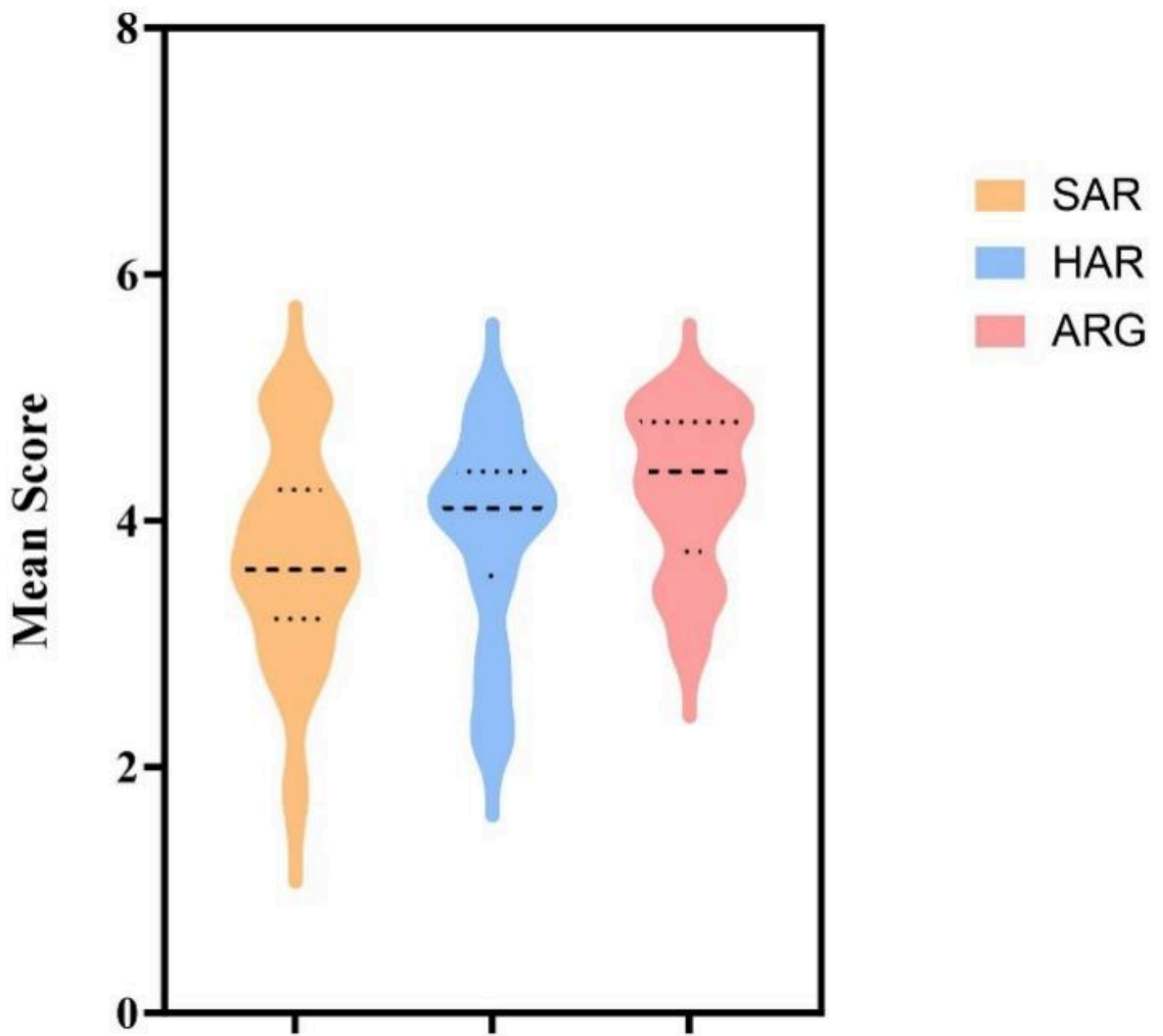


Figure 5

Distribution of emotional connection scores across guide modalities.

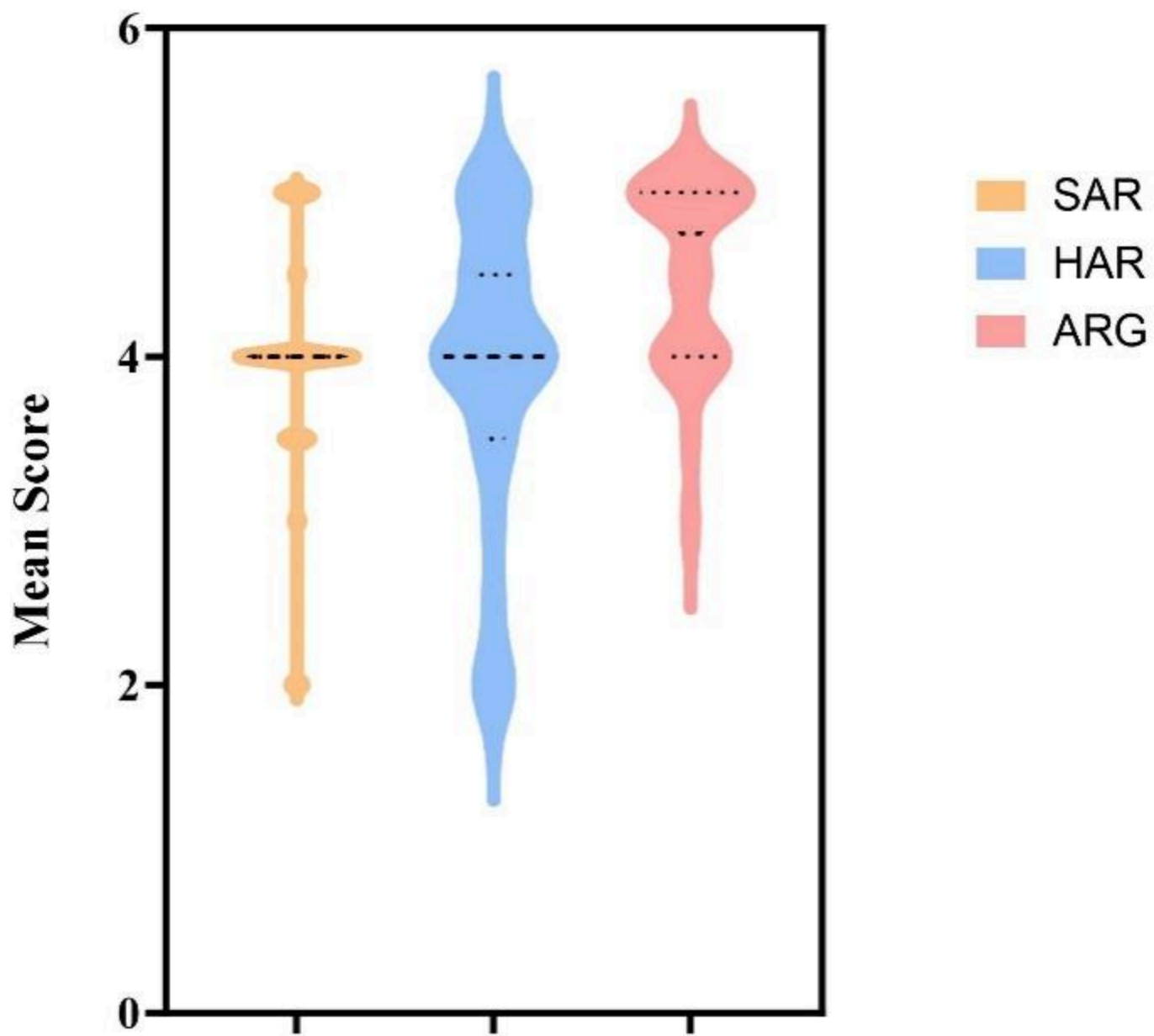


Figure 6

Distribution of satisfaction scores across guide modalities.

Supplementary Files

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- [alldata.sav](#)