Effects of Interaction Mode and Gender Differences on User Experience in Tourism Augmented Reality: A Postprint

Authors: Wang Jiaqi, Chen Yan, Hang Lu

Date: 2023-04-01T00:00:00+00:00

Abstract

[Purpose/Significance] This study analyzes the effects of interaction methods and gender differences on tourists' emotional experience and usability of mobile augmented reality tourism products, providing a foundation for optimizing tourism AR application design. [Method/Process] Combining outdoor experimental research with qualitative interview methods, tourists were invited to complete object selection tasks using three common AR interaction modalities—touch interaction, air gesture interaction, and device-based interaction—to examine usability evaluations and PAD three-dimensional emotional experience among male and female participants. [Results/Conclusion] In mobile AR devices, interaction methods significantly impact usability and emotional experience. Touch interaction demonstrates the best usability experience and elicits the strongest pleasure and dominance; air gesture interaction produces the highest arousal level; contact-based interaction better aligns with tourists' usability and emotional experience requirements; user gender shows no significant differences in its effects on usability and emotional levels.

Full Text

Preamble

Research on the Influence of Interaction Mode and Gender Differences on Mobile Augmented Reality User Experience in Tourism

Wang Jiaqi, Chen Yan, Hang Lu School of Design, Jiangnan University, Wuxi 214122

Abstract: [Purpose/Significance] By analyzing the effects of interaction mode and gender differences on the emotional experience and usability of tourists using mobile augmented reality (AR) travel products, this study provides a basis for optimizing the design of tourism AR applications. [Method/Process] Combining outdoor experimental research with qualitative interviews, tourists were invited to complete object selection tasks using three common AR interaction methods: touch-based interaction, mid-air gesture interaction, and device-based interaction. The study examined male and female participants' usability evaluations and three-dimensional PAD emotional experiences across different interaction modes. [Result/Conclusion] In mobile AR devices, interaction mode has a significant impact on usability and emotional experience. Touch-based interaction offers the best usability experience and elicits the strongest pleasure and dominance emotions; mid-air gesture interaction produces the highest arousal levels; touch-based interaction better meets tourists' needs for usability and emotional experience; user gender shows no significant effect on either usability or emotional levels.

Keywords: mobile augmented reality; interaction mode; emotional experience; usability; emotional measurement

Classification Number: TB472

DOI: 10.13266/j.issn.0252-3116.2021.17.012

The National Tourism Administration' s "Guiding Opinions on Promoting the Development of Smart Tourism" emphasizes the need to orderly advance the construction of smart tourism public service systems. The "13th Five-Year National Science and Technology Innovation Plan" also calls for continued promotion of basic research and forward-looking deployment of technologies such as augmented reality. Synchronized efforts in national policy and industrial transformation, combined with China' s significant institutional advantages and enormous domestic market, have enabled the information technology and intelligent tourism product industries to demonstrate strong growth potential. Mobile Augmented Reality (MAR), as a key technology driving the development of smart tourism, holds great potential in enhancing urban landscapes, historical site reconstruction, scenic area navigation games, and dining applications. However, from a user experience perspective, domestic tourism AR research has primarily focused on technical implementation with relatively narrow research dimensions, urgently requiring academic attention and resolution. Interaction mode is a critical element in the interaction process between tourists and products, directly influencing travelers' perception of the tourism environment. Current research on AR interaction methods mainly emphasizes technological innovation and usability evaluation, with less measurement of users' emotional experiences and few empirical studies targeting specific tourism scenarios. Therefore, this study employs experimental psychology methods to explore how interaction modes and gender differences influence tourists' emotions and usability experiences in AR, ultimately improving AR user experience and providing references for subsequent tourism product design practice and related research.

1. Literature Review

AR interaction methods are human-computer interaction technologies that help users interact with virtual content intuitively, ranging from 2D user interfaces such as keyboards, mice, and touch interactions to 3D multi-channel interfaces like controllers, voice, and gestures. Current AR interaction design strategies proposed by academia and industry include rapid response, reduced movement, and feedback provision; reducing cognitive and physical load, ensuring user satisfaction, learnability, functional visibility, and fault tolerance; designing intuitive, familiar, and simple interaction processes; and providing visual cues while avoiding gesture repetition. These strategies primarily focus on general usability and efficiency issues, lacking targeted discussions for tourism scenarios, resulting in tourism products lacking specific and effective usability guidance. Therefore, exploring usability experiences of AR interaction design in tourism contexts is essential.

Emotion is an important factor influencing tourists' attitudes toward learning and using mobile AR. Emotional experience, as a crucial component of user experience, directly affects user satisfaction and guides user decision-making and behavior. Discussing emotional factors in the interaction design of tourism AR products not only facilitates personalized supply of tourism products and improves the intelligence level of scenic area management and operations but also enhances tourists' identification with scenic areas and further stimulates their willingness to revisit and recommend. Current domestic and international research on emotional experiences in tourism AR products is limited, mainly focusing on technology acceptance and usability. For example, Fang Wei et al. constructed an integrated model based on the Technology Acceptance Model and three-dimensional emotion theory, suggesting that pleasure and dominance influence tourists' attitudes and willingness to use AR. B. Stangl et al. argued that usability elements such as input methods affect emotional experiences in tourism AR products, while S. A. I. A. Shukri et al. proposed design strategies combining AR usability elements with three-dimensional emotional states. However, precise quantitative research and design recommendations on how AR interaction modes affect tourists' emotional experiences remain lacking.

Tourists' individual characteristics, such as gender differences, lead to different cognitive understanding mechanisms that directly affect user experience in tourism scenarios. First, gender differences directly result in different emotional experiences. Previous research generally suggests that men have more positive attitudes toward new technologies, but recent studies indicate that AR elicits more positive emotions from female participants, while men experience more boredom, frustration, and unpleasantness. Second, gender significantly affects usability experiences. E. Ibili et al. proposed that gender differences among AR users significantly impact subjective usability and cognitive load. Third, gender differences lead to different user experiences in public spaces. Typically, female travelers in public spaces experience stronger fear and discomfort and have more restricted behavior, but R. Potts et al. found that gender has minimal impact on user experience in public spaces when using outdoor AR products. Since gender differences' impact on AR user experience remains inconclusive in existing research, this study selects gender as an important factor to explore its influence on tourists' emotional and usability experiences.

2. Research Hypotheses

2.1 Mobile Augmented Reality Interaction Methods

AR can be primarily categorized into head-mounted, handheld, and spatial types. This study focuses on handheld mobile phone-based AR. Common interaction methods in mobile AR include touch-based interaction (TBI), device-based interaction (DBI), and mid-air gesture interaction (MBI). Tangible user interaction (TUI) is also common but was not considered in this study as it does not match the needs of scenic area mobile AR applications.

Touch-based interaction involves users directly interacting with objects on the screen using their fingers. It is a standard screen-based interaction, similar to traditional touch methods. In AR, object selection tasks are typically completed through single-point or multi-point touch operations. Current tourism AR applications primarily use touch-based interaction for human-computer interaction.

Mid-air gesture interaction aligns with natural interaction methods, specifically referring to interacting with virtual information through gesture recognition by cameras. The interaction space is primarily located in the three-dimensional space around the device. Various implementation methods exist, including single fingertip marker tracking and markerless 3D hand skeleton tracking. Among these, the pinch gesture—where users pinch their index finger and thumb together to trigger actions—is the most commonly used and was selected for this study.

Device-based interaction utilizes the camera as an input channel, where users primarily interact with virtual objects by changing the orientation and position of the handheld device. Various operation methods exist, such as AR-Jenga, which allows users to select objects through a virtual stick when touching anywhere on the screen, and Homer-S, which enables users to move and rotate virtual objects by changing device position after clicking the screen. This study referenced existing research by displaying a crosshair in the center of the screen to guide users in moving the crosshair to align with the selected object before clicking anywhere on the screen to select it.

These three interaction methods are illustrated in Figure 1 [Figure 1: see original paper]. Extensive research shows that these three interaction methods have different advantages and require different user abilities. Touch-based interaction is easier to use and primarily relies on users' hand-eye coordination and manual object manipulation abilities. Mid-air gesture interaction better reduces cognitive burden and helps users feel calm or generally pleasant, but requires larger movement amplitude and physical support, suffers from low gesture recognition accuracy, high degrees of freedom, and high ambiguity. Device-based interaction offers better user engagement but requires users' fine motor skills and spatial understanding abilities to complete operations. While existing research provides preliminary conclusions about user experiences with different interaction methods, tourism scenarios have unique characteristics, and relevant conclusions for tourism contexts remain unclear. Comparative studies on how these three operation methods affect emotional experiences are also lacking. Therefore, based on the above research, this study proposes the following hypotheses:

Hypothesis 1 (H1): Interaction mode changes have significant differential effects on tourists' mobile AR usability experience.

Hypothesis 2 (H2): Interaction mode changes have significant differential effects on tourists' mobile AR emotional experience.

Hypothesis 3 (H3): Non-contact interaction has superior effects on tourists' mobile AR experience compared to contact interaction.

Common interaction methods are typically divided into non-contact interaction (Touchless Interaction) and contact interaction (Touch Interaction). Non-contact interaction refers to interaction within different ranges from the system surface, allowing free movement without tactile feedback, while contact interaction requires proximity to a touchable surface, with movement constrained by the surface' s shape and properties and providing tactile feedback. This study selected three AR interaction methods as experimental independent variables, with touch-based interaction and device-based interaction belonging to contact interaction, and mid-air gesture interaction belonging to non-contact interaction. Existing evaluation studies found that tourists using mid-air gesture interaction systems can obtain usability and pleasant experiences. Considering that non-contact interaction can provide users with better immersion and more intuitive, comfortable, and natural interaction experiences compared to contact interaction, this study proposes the third hypothesis.

2.2 Gender Differences

Physiological, cognitive, and perceptual differences between men and women lead to differences in AR user experience. Physiologically, touch gestures are affected by different users' finger sizes, resulting in differences in touchscreen phone click reaction time and hit rates, while mid-air gesture interaction effects are more susceptible to differences in arm length between men and women. Cognitively, spatial cognitive abilities differ by gender, and attention differences in virtual environments directly lead to task performance differences. In perception processes, women have lower computer self-efficacy, while men have advantages in subjective evaluation and operational performance. Users with low self-efficacy are weaker in technology acceptance, evaluation, and operational performance.

Gender differences in usability perception and physiological differences lead to different emotional experiences. Compared to men, usability has a greater impact on emotional responses in female users. Research indicates that women are more likely to experience positive emotions when using AR, possibly related to ease of use. Additionally, women experience emotions more frequently than men and have more intense experiences. Therefore, this study lists gender as an important factor to examine the impact of different interaction methods on emotional experiences of male and female participants, proposing the following hypotheses:

Hypothesis 4 (H4): Gender differences have significant differential effects on tourists' mobile AR usability experience.

Hypothesis 5 (H5): Gender differences and interaction methods have significant interactive effects on tourists' mobile AR experience.

Hypothesis 6 (H6): Gender differences have significant differential effects on tourists' mobile AR emotional experience.

Compared to men, women' s emotions are more unstable and dependent, more susceptible to suggestion and environmental atmosphere. Male and female tourists have different preferences for folk customs, ancient towns, and garden attractions, but show almost no significant difference in preferences for natural landscape attractions, with both showing strong interest. Based on the above research, to avoid the influence of scenic environment on gender differences, this study selected natural landscape attractions—preferred equally by male and female participants—as the experimental site.

3. Research Subjects and Methods

3.1 Experimental Participants

Between October and December 2020, on weekends, the research team randomly recruited tourists interested in the test at Baojie Mountain Scenic Area. Four tourists participated in the pilot experiment, and 33 tourists participated in the formal experiment. After excluding three abnormal data samples, the final valid sample consisted of 30 participants with a 1:1 male-to-female ratio, aged between 18-32 (mean age 24.6 years, SD = 4.004), all with undergraduate education or above. The specific distribution is shown in Table 1 . All participants had no difficulty with learning tasks or completing the experiment, had not previously participated in AR experiments, had normal corrected vision, were right-handed, and three participants self-reported having experienced AR applications.

3.2 Experimental Design

This study employed a 3$×$2 mixed factorial experimental design with two independent variables: interaction method (three levels: touch-based interaction, mid-air gesture interaction, and device-based interaction) and gender (two levels: male and female). Emotional and usability experiences served as dependent variables. Interaction method was a within-subjects factor with 15 participants per gender, while gender was a between-subjects factor. To balance recency effects, experimental materials were presented in a Latin square design sequence, ensuring each interaction method appeared only once in any row or column and that the appearance order of each interaction method was evenly distributed with equal probability. The specific sequence is shown in Table 2 . Each participant sequentially experienced the prepared experimental materials.

3.3 Experimental Tasks and Procedures

The formal experimental task was set as an object selection task, with the goal of opening a menu and selecting one button from it. Object selection tasks typically precede most other operations and navigation actions and facilitate comparison with previous research results. Ideally, AR systems should support multiple standard operations including selection, translation, scaling, rotation, copying, and undoing. To better compare different interaction methods, this study only examined the selection operation.

Before the experiment, participants entered a practice environment for free operation. The practice phase ended after participants confirmed they had fully mastered the three interaction methods, lasting approximately 5 minutes. Before each formal experimental task, participants freely browsed through 20 neutral emotion pictures selected from the Chinese Affective Picture System (pleasure: 5.27$±1.45, *arousal* : 4.28±$1.91) until they felt emotionally calm, averaging about 30 seconds to relieve fatigue and reduce differential carryover effects. Participants then completed the PAD scale to measure emotional baseline. Researchers provided task instructions and reloaded the mobile application. In the formal experiment, participants needed to use their phones to complete object selection tasks for touch-based interaction, device-based interaction, and mid-air gesture interaction sequentially. Emotional responses and satisfaction were measured immediately after each task. The formal testing required approximately 10-20 minutes.

After completing all tasks, participants underwent qualitative interviews lasting about 15 minutes. The interviews focused on participants' preferences for interaction methods, emotional experiences, and reasons, primarily addressing three questions: 1) How usable do you find the three interaction methods? 2) What problems did you encounter during use and why? 3) What feelings or emotions did you experience using the three interaction methods? Gifts were distributed after the interviews. The specific experimental steps are shown in Figure 2 [Figure 2: see original paper].

3.4 Measurement Methods

(1) Usability Assessment. ISO usability indicators define usability as the degree to which users can achieve specific goals with effectiveness, efficiency, and satisfaction in particular contexts. Different evaluation standards can be adopted based on measurement objectives and research environments. Lin Yi et al. used the NASA-TLX task load index; S. M. Ko used post-scenario questionnaires; D. Fiorino et al. measured usability through success rate, task completion time, and ASQ questionnaires, also employing SUS questionnaires. Since satisfaction and efficiency need to be balanced when measuring user experience, and subjective satisfaction is particularly important for evaluating systems in non-work environments, this study selected traditional usability evaluation indicators, conducting comprehensive subjective and objective assessments of error rate, task completion time, and subjective satisfaction to compare usability experiences across different interaction methods. The measurement index system is shown in Table 3 .

Error rate refers to the ratio of tourists who made invalid clicks (number of erroneous participants / total number of participants). For touch-based interaction: users touching outside the target button range count as invalid clicks. For mid-air gesture interaction: users pinching outside the target button range count as invalid. For device-based interaction: when users click while the crosshair at the center of the screen is outside the target button, it counts as invalid.

Task completion time refers to the time from when tourists click the first button until they click the last button, excluding time spent on tracking loss and recovery.

Satisfaction was measured using the ASQ post-scenario questionnaire.

(2) Emotional Measurement. The study used the Chinese simplified PAD emotional scale revised by the Institute of Psychology, Chinese Academy of Sciences—a 9-point scale with good reliability and validity. The scale includes three dimensions: pleasure, arousal, and dominance (PAD). Pleasure (P) represents the positivity/negativity of an individual' s emotional state; arousal (A) represents the level of neurophysiological activation; dominance (D) represents the individual' s control state over the situation and others. Based on these three dimensions, emotional states can be divided into eight categories. Each dimension has four items, totaling 12 adjectives measuring different emotional states. Scoring: Pleasure P = (Q1 - Q4 + Q7 - Q10)/4, Arousal A = (-Q2 + Q5 - Q8 + Q11)/4, Dominance D = (Q3 - Q6 + Q9 - Q12)/4. Each dimension contains two forward-scored and two reverse-scored items, with the dimension score being the average of the four items. Higher scores indicate higher pleasure, arousal, and dominance. Commonly used emotional measurement methods include self-report, autonomic nervous system measurement, behavioral measurement, and brain measurement. This study selected self-report methods for easier testing in outdoor environments. Compared with other emotional scales, the PAD scale enables more precise emotional annotation, providing an excellent perspective for exploring tourist emotions and facilitating comparison with other studies.

(3) Satisfaction Measurement. The ASQ post-scenario questionnaire reflects three important aspects of system usability satisfaction: difficulty level, completion time, and supporting information (AR prompts in this experiment).

The specific indicators were evaluated by IBM usability experts and have been used in many studies to measure satisfaction. The questionnaire consists of three questions on a 7-point scale (1 = most satisfied, 7 = least satisfied), with the satisfaction score being the average of the three items. Participants completed the questionnaire immediately after each scenario task.

3.5 Experimental Instruments and Materials

(1) Instruments. The study used Xiaomi 8 Android phones with 6.67-inch screens and 2340$×$1080 pixel resolution. Software used the Unity3D platform, with gesture recognition assisted by Leap Motion devices and Manomotion.

(2) AR Virtual Environment. To exclude content effects, the three formal experimental environments had identical scenes except for the practice environment. Each experimental environment contained one interaction method, with a pie menu set up to avoid effects of object density and visibility on usability. Target buttons appeared randomly at four fixed positions to prevent participants from memorizing menu spatial locations, as shown in Figure 3 [Figure 3: see original paper].

3.6 Experimental Environment and Location

The experiment was conducted at the observation deck of Wuxi Baojie Mountain Forest Park Scenic Area, where the surrounding sky and natural landscape contours were clearly visible and representative. Experiments were conducted on clear days between 8-10 AM and 3-5 PM to ensure consistent lighting and weather conditions, avoiding difficulties in viewing AR phone screens due to insufficient light and preventing outdoor weather effects on devices.

4. Results

4.1 Task Duration Analysis

Descriptive statistics of task completion time (Table 5) showed the following order: mid-air gesture interaction > device-based interaction > touch-based interaction. Mid-air gesture interaction required the longest average completion time (approximately 25.27 seconds), followed by device-based interaction (approximately 6.95 seconds), with touch-based interaction being the fastest (approximately 2.48 seconds).

A two-way repeated measures ANOVA comparing the effects of interaction method and gender on task completion time revealed a highly significant main effect of interaction method ($F = 54.561$, $p = 0.000 < 0.01$). The between-subjects factor of gender showed no significant effect ($F = 0.776$, $p = 0.386$), and the interaction between interaction method and gender was not significant ($F = 0.739$, $p = 0.405$).

Pairwise comparisons of the three interaction methods found that touch-based interaction completion time was significantly shorter than both mid-air gesture and device-based interactions ($p = 0.000 < 0.01$). Tourists using mid-air gesture interaction had significantly longer task completion times than both touch-based ($p = 0.000 < 0.01$) and device-based interactions ($p = 0.000 < 0.01$). Device-based interaction completion time was significantly longer than touch-based interaction ($p = 0.000 < 0.01$) but significantly shorter than mid-air gesture interaction ($p = 0.000 < 0.01$).

4.2 Error Rate Analysis

Screen recording videos revealed the highest error rate for mid-air gesture interaction (63%), followed by device-based interaction (42%), with touch-based interaction having the lowest rate at only 7%. Further chi-square tests on error rates showed significant differences in error rates across interaction methods (^{2} = 21.900, $p = 0.000 < 0.01$), indicating that error rates changed significantly with interaction method. Gender had no significant effect on error rates (Table 6).

4.3 Emotional Experience Analysis

Emotional experience was measured by emotional difference values. Participants' pre-task emotional values were recorded as P1 (pre-pleasure), A1 (pre-arousal), and D1 (pre-dominance). Post-task emotional values were recorded as P2, A2, and D2. Participants'three-dimensional emotional difference values were calculated by subtracting pre-test from post-test values, recorded as P (pleasure difference), A (arousal difference), and D (dominance difference). Descriptive statistics for baseline and post-test emotional dimensions under different test conditions are shown in Table 7 .

Descriptive statistics of emotional difference values (Figure 4 [Figure 4: see original paper]) showed that users experienced happy emotions (+P+A+D) after all three operation methods. Mid-air gesture interaction had the highest pre-test pleasure, while device-based interaction had the highest pre-test arousal and dominance. Mid-air gesture interaction had the highest post-test arousal, while touch-based interaction had the highest post-test pleasure and dominance. Analysis of difference values across three interaction methods revealed that touch-based interaction increased pleasure ($\Delta P = 0.22$) and substantially increased arousal ($\Delta A = 0.43$) and dominance ($\Delta D = 0.49$). Mid-air gesture interaction significantly decreased pleasure ($\Delta P = -0.29$) but increased arousal ($\Delta A = 0.16$) and slightly increased dominance. Device-based interaction decreased arousal ($\Delta A = -0.12$) with minor fluctuations in pleasure and dominance.

Two-way repeated measures ANOVA with pleasure, arousal, and dominance difference values as dependent variables showed that interaction method had a marginally significant main effect on pleasure ($F = 2.703$, $p = 0.076 < 0.1$) and no significant main effect on arousal ($F = 1.846$, $p = 0.167$), but a significant main effect on dominance ($F = 4.403$, $p = 0.017 < 0.05$). This indicates that pleasure and dominance changed significantly according to interaction method. The between-subjects factor of gender showed no significant main effects on pleasure (F = 0.061, p = 0.806), arousal (F = 0.561, p = 0.460), or dominance (F = 0.444, p = 0.511). The interaction between interaction method and gender showed no significant effects on pleasure (F = 0.325, p = 0.724), arousal (F = 1.189, p = 0.312), or dominance (F = 1.638, p = 0.204).

Pairwise comparisons of the three interaction methods for pleasure and dominance revealed that touch-based interaction' s pleasure difference was significantly greater than mid-air gesture interaction ($p = 0.029 < 0.05$). Device-based interaction had lower dominance difference than touch-based interaction ($p = 0.002 < 0.05$), while mid-air gesture interaction' s dominance difference was lower than touch-based interaction at a marginal significance level (p = 0.055). No significant differences were found between mid-air gesture and device-based interactions.

4.4 Satisfaction Analysis

Overall, tourists were relatively satisfied with all three operation methods. The mean satisfaction scores (lower ASQ scores indicate higher satisfaction) ranked as follows: touch-based interaction > device-based interaction > mid-air gesture interaction, indicating touch-based interaction was perceived as having the highest overall satisfaction, followed by device-based interaction, with mid-air gesture interaction having the lowest satisfaction (Table 8).

Males showed higher overall satisfaction, with the highest satisfaction for touch-based interaction and extremely low satisfaction ratings for both mid-air gesture and device-based interactions. Females showed lower overall satisfaction, with extremely unsatisfactory ratings for mid-air gesture interaction (Table 9).

5. Discussion and Analysis

Interaction behavior is the necessary medium for tourists to engage with AR applications. Tourists must perform interaction operations to create, move, and edit virtual objects. Analyzing tourists' behavioral performance and emotional experiences can quantify their AR usage experience, thereby providing theoretical guidance for AR application design innovation. This study investigated AR emotional and usability experiences from the perspectives of interaction method and gender. The following sections discuss the experimental results in relation to the research hypotheses.

5.1 Influence of AR Interaction Method on Tourist Usability Experience

Interaction method changes have significant differential effects on tourists' usability experience, supporting Hypothesis H1. Results show that interaction method differences significantly affect tourists' task completion time, error rate, and satisfaction. Touch-based interaction had the shortest completion time, followed by device-based interaction, with mid-air gesture interaction requiring the longest time. Compared to touch-based and device-based interactions, participants using mid-air gesture interaction were most prone to errors. Descriptive statistics show high satisfaction for touch-based interaction, moderate satisfaction for device-based interaction, and low satisfaction for mid-air gesture interaction. The findings can be explained from two aspects:

(1) Comfortable and efficient operation is the primary goal when completing selection tasks. First, according to Meyer et al.' s optimal initial impulse model, click tasks can be divided into a "ballistic phase" and a "correction phase." Unlike touch-based interaction, fingertip feature points in gesture recognition technology cannot stably align with buttons, resulting in a longer "correction phase" and thus longer total operation time. Second, the hand fatigue problem in mid-air gesture interaction is significant. While touch-based and device-based interactions primarily involve finger movements, mid-air gesture interaction requires users to maintain stable, elevated arm positions for extended periods to support finger movement, causing muscle soreness that makes precise gesture control difficult, reduces alignment accuracy, and decreases operational efficiency and subjective satisfaction. Third, consistent with I. Radu et al.' s findings, device-based interaction is slower than touch-based interaction, with data showing nearly double the error rate. Analysis suggests device-based interaction may be limited by tourists' ability to use their non-dominant hand for micro-movements and precise target capture. All participants used their left hand to aim the device and right hand to click the screen for confirmation; left-hand operation typically struggles with stability and aiming precision, resulting in higher mis-touch rates. Additionally, participants frequently rotated the phone view to align with target buttons, making tracking loss more likely than with touch-based interaction and increasing operation time.

(2) Appropriate interaction methods facilitate tourists'rapid cognition and learning. Different interaction types occupy different attention resources. Mid-air gesture interaction requires users to simultaneously focus on moving the device and performing mid-air pinch gestures, which disperses attention, while recognizing skeletal feature points and full hand models on the screen consumes more cognitive resources. In contrast, touch-based and device-based interactions only require operation on the phone' s 2D screen, allowing more concentrated attention and easier understanding and operation. Mid-air gesture interaction also requires users to cognitively process three-dimensional hand movement space, needing precise right-hand movement in forward-backward, left-right, and up-down dimensions; otherwise, hands cannot be recognized due to being too close or too far from the camera, increasing operation time. Touch-based interaction only requires 2D finger movement on the phone screen. Furthermore, B. Kollée et al. found that users prefer mid-air gesture interaction over touch-based interaction, contrary to this study' s results. Analysis suggests that because this experiment targeted domestic ordinary tourists who are generally unfamiliar with AR, conflicts between new gestures and common touchscreen operations may hinder users'operational intuition when interacting with new systems. Touch-based interaction offers higher familiarity, making it easier for the public to understand AR behavior patterns. This phenomenon was mentioned in post-experiment interviews, where most participants considered touch-based interaction "easy because I' ve used it before," while device-based interaction was evaluated as "similar to operations in games I' ve played" and "not difficult but quite fun, like shooting."

5.2 Influence of AR Interaction Method on Tourist Emotional Experience

Different interaction methods have significant differential effects on mobile AR user emotional experience, supporting Hypothesis H2. Descriptive statistics show that users experienced happy emotions (+P+A+D) during all three interaction methods. Touch-based interaction substantially increased pleasure, arousal, and dominance; mid-air gesture interaction increased arousal but decreased pleasure; device-based interaction decreased arousal with minor fluctuations in pleasure and dominance. Inferential statistics found that pleasure and dominance were significantly affected by different interaction methods, while arousal showed no significant differences across the three methods. The findings can be explained from four aspects:

(1) User emotion is indirectly affected by the usability of different interaction operations. Empirical results show that mid-air gesture interaction' s low usability elicited lower pleasure, while touch-based interaction' s high usability resulted in higher operator pleasure, consistent with existing research conclusions. Pre-test emotional data indicated that before formal experiments, mid-air gesture interaction induced the highest user pleasure, suggesting participants had high expectations and interest in this interaction type. However, after experiencing low usability, users felt psychological imbalance due to inconsistency between cognition and behavior, reducing positive emotions. Additionally, high-usability interaction methods induced stronger dominance. Compared to device-based or mid-air gesture interactions, touch-based interaction is simpler and easier to operate, giving users better task coping abilities and sense of control, thus significantly enhancing emotional dominance indicators.

(2) Interaction methods inducing moderate arousal help enhance pleasure. Previous research suggests that mid-air gesture interaction brings more fun than touch-based or device-based interactions on mobile devices. However, this study' s data show that mid-air gesture interaction' s pleasure decreased overall, with post-test pleasure far lower than touch-based interaction but accompanied by increased arousal. Wundt and Berlyne' s theories indicate an inverted U-shaped relationship between stimulus intensity and pleasure, where moderate-intensity stimuli produce optimal arousal levels that are more pleasurable. Previous mid-air gesture interaction experiments only measured fingertip tracking forms, which are relatively simple. This study selected pinch gestures matched with full-hand skeletal information virtual presentation, where rich interaction behaviors and virtual information may have exceeded the optimal critical point for arousal, thereby reducing pleasure—a phenomenon similar to the effect of appearance complexity on emotions.

(3) The practice phase affects emotional measurement in formal testing, reducing tourists' emotional arousal fluctuations. This study' s results show no significant differences in emotional arousal induced by different interaction methods. Existing research indicates that higher novelty correlates with higher tourist emotional arousal. In this study, participants' familiarity with the three interaction methods during the practice phase undoubtedly increased result predictability, reducing novelty differences among interaction methods after this phase and leading to smaller arousal variation differences.

(4) Emotion is affected by the privacy level of interaction methods. Outdoor studies show that users feel uncomfortable using gesture operations when observers are present. Service experience research also indicates that consumer mistakes and unnatural behaviors cause embarrassment and other negative emotions. This study confirms these conclusions. Unlike contact interactions, mid-air gesture interaction involves larger movement amplitudes and weaker privacy, resulting in generally lower emotional pleasure indicators. This suggests that operators' emotional changes may be more influenced by the public environment of scenic areas.

5.3 Influence of Gender on Tourist Usability and Emotional Experience

Descriptive statistics show males were more satisfied than females overall. Inferential statistics indicate no significant gender differences in reaction time, error rate, or subjective emotional evaluation when using different interaction methods, and no interactive effects between gender and the three interaction methods on user experience. This suggests that male and female usability and emotional experiences are roughly the same across the three interaction methods.

Gender differences have no significant effect on usability experience, rejecting Hypothesis H4. Analysis suggests several reasons: First, gender differences do not stem from actual usage ability differences but are often situation-dependent, with task type playing a key role. Even though this study involved new AR technology, if task types are not obviously male-related (e.g., neutral interaction actions, scenarios, and visual effects), task performance similarities between genders still occur—a result consistent with multiple studies showing minimal gender impact on interaction time and usability. Second, observations recorded some participants accidentally touching the lower right screen area or gesture misrecognition, introducing reaction time and error rate variations that increased within-group differences and reduced between-group differences. Third, while gender differences in spatial tasks are substantial, they only appear under "unfavorable" conditions requiring strong spatial abilities. This study' s task difficulty may have been insufficient to reveal gender spatial ability differences, consistent with previous AR spatial research.

Gender differences have no significant effect on emotional experience, and no significant interactive effect exists between gender and interaction method, rejecting Hypotheses H5 and H6. Analysis suggests several reasons: First, this study' s conclusion aligns with existing public AR research that appropriate environments increase AR users' sense of security, comfort, and reduce fear. Since natural landscapes help relieve anxiety and promote calmness, this study' s scenic environment may have reduced emotional differences. Second, individual self-efficacy affects emotion, and gender differences in self-efficacy are generally recognized. However, this study randomly recruited mostly AR-interested participants, while those with low technology self-efficacy were less likely to participate, reducing gender differences. Finally, participants tend to suppress emotional expression when facing strangers, possibly causing experimental error.

5.4 Contact Interaction Experience Superior to Non-Contact Interaction in Mobile AR

Tourists' contact interaction experience in mobile AR is superior to non-contact interaction experience, rejecting Hypothesis H3. Existing research suggests that compared to 2D touch operations requiring mapping interactions, mid-air gesture interaction provides more natural and intuitive control. However, in this experiment, both contact-based interaction methods were superior to non-contact interaction in usability and emotional experience. Analysis suggests that touch-based and device-based interactions both rely on screen carriers, where interaction with the screen surface provides subtle tactile feedback that enables users to easily fine-tune finger movements according to task requirements, resulting in high usability and better emotional experience. Non-contact interaction requires no screen touching, and when users perform gesture operations without tactile feedback, they must rely mainly on visual information for action adjustment, which is more difficult and affects emotional experience.

This conclusion indicates that although contact interaction is objectively constrained by touch surface properties, it offers higher effectiveness and precision, greater user familiarity, and facilitates knowledge transfer from previous interaction methods, enhancing user control and positive emotional levels. Non-contact mid-air gesture interaction has high hedonic levels and greater space and movement freedom, but users find it more unfamiliar, requiring good motor-visual association abilities. When click targets are small, users must bear more physical load and occupy more cognitive resources, causing usability issues that significantly affect emotional responses.

5.5 Design Recommendations

Based on experimental data and observations, the following approaches can enhance tourism AR application user experience:

(1) Reduce tourists' learning costs and cognitive load for interaction methods. While interesting interaction operations can attract tourists' curiosity, considering that tourists commonly encounter problems such as complex feedback information, attention burden, inability to understand spatial relationships, and mismatched knowledge experience, learning costs should be minimized. Specific approaches include: Leveraging tourists' existing knowledge and skills by referencing widely accepted touch-based interaction behaviors and cognitive models to improve interaction methods and reduce conversion costs when facing unfamiliar interactions. Utilizing multi-sensory advantages by combining non-contact interaction behaviors with rich tactile, visual, or auditory feedback, especially providing timely help at error-prone points to prevent accidental touches. Customizing interaction operations for specific tasks in scenic area scenarios, as tailored interaction methods are more beneficial for good usability and emotional experience.

(2) Use simple and efficient interaction methods. For tourists, touch-based interaction offers better usability and can induce stronger positive emotions. Since usability indirectly affects emotional experience, improving interaction method usability in tourism AR applications facilitates flexible tourist control, reduces unnecessary interaction steps, lowers error rates, reduces physical fatigue, and induces more positive tourist emotional experiences while ensuring functional input.

(3) Provide subtle and ingenious micro-innovation interaction support. Since interaction methods inducing moderate arousal maintain optimal pleasure levels, it is recommended to design micro-innovation interactions on existing models that provide just enough activation for optimal emotional experience. Additionally, for gesture interaction methods with weak privacy, design subtle gesture movements that reduce operation scope, provide quick interaction mode switching functions, and promptly alleviate discomfort emotions in public settings.

6. Conclusion

This study examined how male and female tourists completed mobile AR object selection tasks under three interaction methods: touch-based, mid-air gesture, and device-based interaction. Results found: AR interaction methods have significant differential effects on tourist usability experience, with touch-based interaction significantly superior to device-based and mid-air gesture interactions; AR interaction methods have significant differential effects on tourist emotional experience, with touch-based interaction inducing significantly higher pleasure than mid-air gesture interaction and significantly higher dominance changes than both device-based and mid-air gesture interactions; gender differences have minimal impact on usability and emotional experiences; contact interaction user experience is superior to non-contact interaction.

This study' s theoretical significance includes: Enriching AR human-computer interaction research by providing empirical comparison of contact vs. non-contact interactions in AR and quantifying users' internal emotional responses, supplementing and expanding related research. Enriching user emotional experience research by using interaction methods as emotional stimuli, providing theoretical basis for product interaction design emotion induction research.

Practically, designers can provide appropriate interaction methods for different scenarios and targets based on experimental results and design recommendations, thereby improving tourists' AR user experience and providing research support for subsequent mobile AR product design.

This study has limitations: Participant recruitment methods limit conclusions, as different age groups have different cognition and preferences affecting interaction method experiences. Future research should ensure balanced age and education levels to improve accuracy. Only object selection tasks were examined; different task types may yield different user responses. Future research should adopt multiple task types meeting tourism scenario needs and combine diverse interaction methods like multi-touch and voice input. Emotional measurement used self-report methods focusing on post-experiment evaluation, which differs from real-time emotional experiences during operation. Future research could combine physiological measurement for synchronous emotional experience assessment.

References

[1] Wang Xiwei, Liu Yutong, Wang Duo, et al. Analysis of international research trends in user information behavior in augmented reality environments[J]. Library and Information Service, 2020, 64(5): 4-11.

[2] Lv M, Wang L, Yan K. Research on cultural tourism experience design based on augmented reality[C]//International conference on human-computer interaction. Cham: Springer, 2020: 172-183.

[3] Zhang Mei, Zhang Li. Research on AR interaction mode application for tourism experience[J]. Packaging Engineering, 2019, 40(2): 191-195.

[4] Liang Huan, Chen Yimin, Li Dexu, et al. Hand gesture interaction method for mobile augmented reality[J]. Microcomputer Applications, 2018, 34(5): 9-13.

[5] Hürst W, van der Weel C. Gesture-based interaction via finger tracking for mobile augmented reality[J]. Multimedia Tools and Applications, 2013, 62(1): 233-258.

[6] Zhou F, Duh H B L, Billinghurst M. Trends in augmented reality tracking, interaction and display: A review of ten years of ISMAR[C]//2008 7th IEEE/ACM International Symposium on Mixed and Augmented Reality. Piscataway: IEEE, 2008: 193-202.

[7] Billinghurst M, Clark A, Lee G. A survey of augmented reality[J]. Foundations and Trends in Human-Computer Interaction, 2015, 8(2/3): 165-178.

[8] Ko S M, Chang W S, Ji Y G. Usability principles for augmented reality applications in smartphone environment[J]. International Journal of Human-Computer Interaction, 2013, 29(8): 501-515.

[9] Dünser A, Grasset R, Seichter H, et al. Applying HCI principles to AR system design[C]//2nd International Workshop at the IEEE Virtual Reality 2007 Conference. Christchurch: University of Canterbury, 2007: 37-42.

[10] Apple. Human interface guidelines[EB/OL]. [2020-12-14]. https://developer.apple.com/design/human-interface-guidelines/ios/system-capabilities/augmented-reality.

[11] Google. Augmented reality design guidelines[EB/OL]. [2020-12-14]. https://developers.google.com/ar/develop/developer-guides/design-guidelines.

[12] Kourouthanassis P, Boletsis C, Bardaki C, et al. Tourists'responses to mobile augmented reality travel guides: The role of emotions on adoption behavior[J]. Pervasive and Mobile Computing, 2015, 18: 71-87.

[13] Liu Luchuan, Sun Kai. The relationship between social media users' emotional experience and satisfaction: Taking Weibo as an example[J]. Journal of Library Science in China, 2015, 41(1): 76-91.

[14] Fang Wei, Zhou Bo, Shen Xuwei. Research on tourists' willingness to use mobile augmented reality technology in smart tourism context: An integrated model based on technology acceptance and PAD theory[J]. Journal of Zhejiang Shuren University (Humanities and Social Sciences), 2017, 17(3): 37-45.

[15] Stangl B, Ukpabi D C, Park S. Augmented reality applications: The impact of usability and emotional perceptions on tourists' app experiences[C]//Information and communication technologies in tourism 2020. Cham: Springer, 2020: 181-191.

[16] Shukri S A I A, Arshad H, Abidin R Z. Mobile augmented reality system design guidelines based on tourists' emotional state[J]. Journal of Telecommunication, Electronic and Computer Engineering, 2017, 9(2-12): 75-79.

[17] Dirin A, Alamäki A, Suomala J. Gender differences in perceptions of conventional video, virtual reality and augmented reality[EB/OL]. [2021-03-22]. https://www.learntechlib.org/p/216491/.

[18] Ibili E, Billinghurst M. Assessing the relationship between cognitive load and the usability of a mobile augmented reality tutorial system: A study of gender effects[J]. International Journal of Artificial Intelligence in Education, 2019, 29(4): 527-545.

[19] Wilson E, Little D E. The solo female travel experience: Exploring the "geography of women' s fear" [J]. Current Issues in Tourism, 2008, 11(2): 167-186.

[20] Jin X, Whitson R. Young women and public leisure space in contemporary Beijing: Recreating (with) gender, tradition, and place[J]. Social & Cultural Geography, 2014, 15(4): 449-469.

[21] Potts R, Yee L. Pokémon Go-going or staying: Exploring the effect of age and gender on augmented reality gameplay experiences in public spaces[J]. Journal of Urban Design, 2019, 24(6): 878-895.

[22] Krevelen D W F V, Poelman R. A survey of augmented reality technologies, applications and limitations[J]. International Journal of Virtual Reality, 2010, 9(2): 1-20.

[23] Goh E S, Sunar M S, Ismail A W. 3D object manipulation techniques in handheld mobile augmented reality interface: A review[J/OL]. IEEE Access, 2019, 7: 40581-40601. [2020-12-14]. https://ieeexplore.ieee.org/document/8672062?denied=.

[24] Liu Jie, Huang Jin, Tian Feng, et al. Hybrid gesture interaction model in continuous interaction space[J]. Journal of Software, 2017, 28(8): 2080-2095.

[25] Yusof C S, Bai H, Billinghurst M, et al. A review of 3D gesture interaction for handheld augmented reality[J]. Jurnal Teknologi, 2015, 78(2-2): 15-20.

[26] Jakobsen M R, Jansen Y, Boring S, et al. Should I stay or should I go? Selecting between touch and mid-air gestures for large-display interaction[C]//IFIP Conference on Human-Computer Interaction. Cham: Springer, 2015: 455-473.

[27] Li N, Duh H B L. Cognitive issues in mobile augmented reality: An embodied perspective[C]//Human Factors in Augmented Reality Environments. New York: Springer, 2013: 109-135.

[28] Radu I, MacIntyre B, Lourenco S. Comparing children's crosshair and finger interactions in handheld augmented reality: Relationships between usability and child development[C]//Proceedings of the 15th International Conference on Interaction Design and Children. New York: Association for Computing Machinery, 2016: 288-298.

[29] Bai H. Mobile augmented reality: Free-hand gesture-based interaction[D]. New Zealand: University of Canterbury, 2016.

[30] Beurden M H P H V, IJsselsteijn W A, Kort Y A W D. User experience of gesture based interfaces: A comparison with traditional interaction methods on pragmatic and hedonic qualities[C]//International Gesture Workshop. Berlin: Springer, 2011: 36-47.

[31] Kollée B, Kratz S, Dunningan A. Exploring gestural interaction in smart spaces using head-mounted devices with ego-centric sensing[C]//Proceedings of the 2nd ACM Symposium on Spatial User Interaction. New York: Association for Computing Machinery, 2014: 40-49.

[32] O' Hara K, Harper R, Mentis H, et al. On the naturalness of touchless: Putting the "interaction" back into NUI[J]. ACM Transactions on Computer-Human Interaction, 2013, 20(1): 1-25.

[33] Brancati N, Caggianese G, Pietro G D, et al. Usability evaluation of a wearable augmented reality system for cultural heritage enjoyment[C]//2015

11th International Conference on Signal-Image Technology & Internet-Based Systems. Piscataway: IEEE, 2015: 768-774.

[34] Zhang Y, Ou B, Ding Q, et al. Touch behavior analysis for large screen smartphones[C]//Proceedings of the Human Factors and Ergonomics Society Annual Meeting. Los Angeles: SAGE, 2015: 1433-1437.

[35] Zhu Yongheng. Investigation and analysis of relevant human body dimensions of adult men and women in Jiangsu in 2015[J]. Journal of Wenzhou University (Social Sciences), 2016, 29(3): 84-89.

[36] Feng J, Spence I, Pratt J. Playing an action video game reduces gender differences in spatial cognition[J]. Psychological Science, 2007, 18(10): 850-855.

[37] Suma E A, Finkelstein S L, Clark S, et al. Effects of travel technique and gender on divided attention task in a virtual environment[C]//2010 IEEE Symposium on 3D User Interfaces. Piscataway: IEEE, 2010: 27-34.

[38] Ong C S, Lai J Y. Gender differences in perceptions and relationships among dominants of e-learning acceptance[J]. Computers in Human Behavior, 2006, 22(5): 816-829.

[39] Li Rong, Zhang Hongliang. A review of research on computer self-efficacy measurement[J]. Journal of Chifeng University (Natural Science Edition), 2015, 31(5): 125-127.

[40] Ferreira D J, Melo T F N, Nogueira T D C. Unveiling usability and UX relationships for different gender, user habits and contexts of use[J]. Journal of Web Engineering, 2020, 19(5/6): 799-817.

[41] Li Fei, Lu Shenghua. Gender differences in emotional experience and their causes[J]. Social Psychology Science, 2014, 29(2): 40-43.

[42] Su Aiyun, Hu Xiaohai, Chen Xiaoxue. Research on gender differences in tourism consumption behavior: Taking Changzhou tourists as an example[J]. Journal of Sichuan Tourism University, 2016(5): 54-58, 69.

[43] Looser J, Billinghurst M, Grasset R, et al. An evaluation of virtual lenses for object selection in augmented reality[C]//Proceedings of the 5th International Conference on Computer Graphics and Interactive Techniques in Australia and Southeast Asia. New York: Association for Computing Machinery, 2007: 203-210.

[44] Bai Lu, Ma Hui, Huang Yuxia, et al. Development of the Chinese Affective Picture System: A trial among 46 Chinese college students[J]. Chinese Mental Health Journal, 2005, 19(11): 719-722.

[45] Bevan N, Carter J, Earthy J, et al. New ISO standards for usability, usability reports and usability measures[C]//International Conference on Human-Computer Interaction. Berlin: Springer, 2016: 268-278.

[46] Lin Yi, Chen Jing, Zhou Qi, et al. Information visualization and interaction design for mobile augmented reality browsers[J]. Journal of Computer-Aided Design & Computer Graphics, 2015, 27(02): 320-329.

[47] Fiorino D, Collotta M, Ferrero R. Usability evaluation of the after-scenario questionnaire for augmented reality applications[J]. Journal of Wireless Mobile Networks, Ubiquitous Computing, and Dependable Applications, 2019, 10(2): 22-36.

[48] Wilson C. User experience re-mastered: Your guide to getting the right design[M]. Burlington: Morgan Kaufmann, 2009: 11-13.

[49] Li Xiaoming, Fu Xiaolan, Deng Guofeng. Preliminary trial of the Chinese simplified PAD emotional scale among Beijing college students[J]. Chinese Mental Health Journal, 2008, 22(05): 327-329.

[50] Sauro J, Lewis J R. Quantifying the user experience: Practical statistics for user research[M]. Beijing: China Machine Press, 2014: 192-193.

[51] Bazzano F, Gentilini F, Lamberti F, et al. Immersive virtual reality-based simulation to support the design of natural human-robot interfaces for service robotic applications[C]//International Conference on Augmented Reality, Virtual Reality and Computer Graphics. Cham: Springer, 2016: 33-51.

[52] Qian J, Ma J, Li X, et al. Portal-ble: Intuitive free-hand manipulation in unbounded smartphone-based augmented reality[C]//Proceedings of the 32nd Annual ACM Symposium on User Interface Software and Technology. New York: Association for Computing Machinery, 2019: 133-145.

[53] Meyer D E, Abrams R A, Kornblum S, et al. Optimality in human motor performance: Ideal control of rapid aimed movements[J]. Psychological Review, 1988, 95(3): 340-370.

[54] Liang Zhuorui, Xu Xiangmin. Adaptive adjustment of mapping relationships for visual mid-air gesture interaction[J]. Journal of South China University of Technology (Natural Science Edition), 2014, 42(8): 52-58.

[55] Ingram A, Wang X, Ribarsky W. Towards the establishment of a framework for intuitive multi-touch interaction design[C]//Proceedings of the International Working Conference on Advanced Visual Interfaces. New York: Association for Computing Machinery, 2012: 66-73.

[56] Hang Lu, Chen Yan, Wang Jiaqi. Influence of search input method and gender differences on children' s information search experience[J]. Library and Information Service, 2020, 64(19): 109-118.

[57] Yang Yuting. The motivational role of emotion and anticipated emotion[J]. Social Psychology Science, 2015, 30(175): 3-5.

[58] Berlyne D E. Ends and means of experimental aesthetics[J]. Canadian Journal of Psychology, 1972, 26(4): 303-325.

[59] Vitz P C. Preference for different amounts of visual complexity[J]. Behavioral Science, 1966, 11(2): 105-114.

[60] Ma J, Gao J, Scott N, et al. Customer delight from theme park experiences: The antecedents of delight based on cognitive appraisal theory[J]. Annals of Tourism Research, 2013(42): 359-381.

[61] Williamson J R, Brewster S, Vennelakanti R. Mo! Games: Evaluating mobile gestures in the wild[C]//Proceedings of the 15th ACM International Conference on Multimodal Interaction. New York: Association for Computing Machinery, 2013: 173-180.

[62] Grace D. How embarrassing! An exploratory study of critical incidents including affective reactions[J]. Journal of Service Research, 2007, 9(3): 271-284.

[63] Deaux K. From individual differences to social categories: Analysis of a decade' s research on gender[J]. American Psychologist, 1984, 39(2): 105-116.

[64] Hou Guanhua, Wang Liying, Xu Bing. Influence of interactive book design on reading among preschool children[J]. Journal of the National Library of China, 2019, 28(4): 32-41.

[65] Billestrup J, Bruun A, Stage J. Usability problems experienced by different groups of skilled internet users: Gender, age, and background[C]//Human-Centered and Error-Resilient Systems Development. Cham: Springer, 2016: 45-55.

[66] Piccardi L, Risetti M, Nori R, et al. Perspective changing in primary and secondary learning: A gender difference study[J]. Learning and Individual Differences, 2011, 21(1): 114-118.

[67] Munoz-Montoya F, Fidalgo C, Juan M C, et al. Memory for object location in augmented reality: The role of gender and the relationship among spatial and anxiety outcomes[J]. Frontiers in Human Neuroscience, 2019, 13: 113.

[68] Kopinski T, Handmann U. Touchless interaction for future mobile applications[C]//2016 International Conference on Computing, Networking and Communications. Piscataway: IEEE, 2016: 1-5.

Author Contributions: Wang Jiaqi: Responsible for data collection, research framework construction, data processing, and paper writing. Chen Yan: Responsible for topic selection and paper revision. Hang Lu: Responsible for experiment organization and data collection.

Note: Figure translations are in progress. See original paper for figures.