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RESEARCH ARTICLE

# The Effects of Interaction Mode and Individual Differences on Usability and User Experience of Mobile Augmented Reality Navigation

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**ABSTRACT** In the context of the rapid development of navigation technology and the deepening of users' diversified needs, as an emerging public service, mobile AR (Augmented Reality) navigation is supposed to focus on human-computer interaction and user experience. To extract the influencing factors of efficient service of mobile AR navigation, we constructed an experimental method for the usability of mobile AR navigation and the users' emotional experience based on behavior-emotion analysis. In this study, the user types were divided according to the differences in Mental Cutting Ability and Gender. We explored the effects of Interaction Mode, Mental Cutting Ability, and Gender on the usability of mobile AR navigation and the users' PAD (Please-Arousal-Dominance) three-dimensional emotion through the objective performance and subjective scoring of users when completing AR navigation tasks. The results showed that the Interaction Mode and Mental Cutting Ability had significant effects on the usability of mobile AR navigation and the users' emotional experience; the Ease of Learning, Ease of Use in usability indicators, and the Arousal experience of three-dimensional emotion were significantly affected by Gender. Based on the experimental results, we excavated the mechanism of effects between various factors, extracted the behavioral and emotional trends of different types of users, broadened the research scope of mobile AR navigation-related fields, and finally summarized the design strategies from the perspective of human-robot-environment.

**INDEX TERMS** Mobile AR navigation, usability, PAD 3D emotional experience, behavior-emotion analysis, difference research, mental cutting ability.

## I. INTRODUCTION

With the layout of public spaces becoming more and more complex, people are under the pressure of cognitive load while receiving services. In this context, navigation services have become an important part of urban management. The purpose of public navigation is to address the needs of citizens for way-finding and identification. Innovative navig-ation services can provide users with diversified experiences and optimize the interaction mode between the digital world and the real world [1]. In addition, favorable conditions such as technical support and market demand will provide broad development space for smart navigation services. In recent years, the application of mobile AR navigation has become a hot topic, and both Apple and Google have launched their AR navigation services. Mobile AR navigation is usually based on the mobile devices (mainly referred to smart-phones), and is a combination of AR technology, positioning technology, and mobile computing [2]. Currently, mobile AR is the most common and most mature form of innovative navigation, which is widely used in shopping malls, scenic areas, and other public places [3]. Nevertheless, there are still some defects in its research and application, so we need to make a deeper exploration. Compared with wearable devices, mobile AR devices are deficient in terms of immersive sense and expansibility [4]. However, the

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computing and proce-ssing power of them are getting stronger and can already meet the requirements of software and hardware for AR navigation [2]. In addition, mobile devices have the char-acteristics of small size, portability, and high penetration, so they are more able to reflect the publicity and universality of navigation. Compared to traditional flat navigation, mobile AR navigation has the advantage of increasing the depth and breadth of environmental information in the navigation interface and improving the user's perception and underst-anding of the navigation route [3]. Meanwhile, in practical applications, on the one hand, the superimposed virtual information and interactive gestures may increase the user's cognitive load and reduce navigation efficiency; on the other hand, the lack of flexibility and personalization of mobile AR navigation design may lead to large differences in the experience of different types of users [4].

In recent years, there has been a gradual increase in theoretical research on mobile AR navigation, which has driven technological progress and validated the positive effects of mobile AR navigation. The related studies have broadly covered two aspects: navigation technology and user behavior, and they have played a key role in the rapid development of mobile AR navigation.

Rubio et al. [5] proposed a navigation method combining augmented reality and Semantic Web technology based on mobile devices. They recorded the behavioral data of par-ticipants such as navigation time and location tracking, and the experimental results proved the feasibility of this method. Wang [6] constructed a mobile AR navigation system based on iBeacon indoor positioning technology and content recommendation algorithm, aiming to provide personalized suggestions corresponding to the user's context by analyzing their interest and location information. Jing et al. [7] designed a mobile AR navigation system for tourism using the technologies of location-based and multi-sensor tracking registration, 3D landscape maps, and augmented reality to provide a new perspective and interactive experience for tourists. Dünser et al. [8] compared three forms of navigation: mobile AR, digital map, and mobile AR+ digital map, the behavioral experiment showed no significant differences in navigation efficiency between the three, but users preferred the mobile AR+ map form of navigation. Lee et al. [9] developed a mobile AR navigation application for libraries: navAR. By comparing it with text-based navigation, they found that AR navigation has good usability and makes users' book-finding behavior more regular and faster. Sekhavat and Parsons [10] compared the performance and user acceptance of location-based and label-based mobile AR navigation. The results showed that the former is more advantageous. Zhou [11] studied the influence of the guiding form based on the fictional characters on mobile AR navigation and then an-alyzed the function from four aspects: speech recognition, role communication, micro-interaction, and restriction.

From the above, it can be seen that most of the current research on mobile AR navigation focused on technological innovation and the comparison of navigation behavior, few researchers have systematically explored the user characteristics, interaction modes, and user experience of AR navigation [12], which made mobile AR navigation services lack of holistic design references at the application level [3]. Studies have shown that the above factors have an impact on user behavior and interaction design. In the study of navi-gation in the virtual scenes, Halik and Kent [13] found that user differences will lead to the diversity of way-finding strategies, which can affect the effectiveness of navigation. Kim et al. [14] showed that user differences have an impact on their spatial affective perception and movement patterns. Chen and Chen [15] investigated users' performance and subjective preferences for way-finding tasks in a 3D virtual enviro-nment and found that interaction mode plays a key role. Afiqah et al. [16] studied mobile AR in historical tourism and they found that user experience is crucial for mobile AR applications as it tries to meet the needs of users and increase engagement. Lee and Oh [17] studied the factors that affect users' willingness to participate in the VR/AR movement and concluded that users' aesthetic experience and educational experience have a positive impact on their sense of presence.

As a basic public service, navigation has a wide range of target users, and there are great differences in their ability and quality. These individual differences will interact with the navigation design to influence the user experience and navigation effectiveness. Therefore, it is essential to study the intrinsic characteristics of AR navigation and its users.

Human-computer interaction and user experience are the primary features of mobile AR navigation services, so this study took the relationship of human-computer as the starting point and the analysis of behavior-emotion as the foothold. Finally, we applied the research findings to the human-computer interaction of mobile AR navigation to improve navigation efficiency and user experience. At the user level, Mental Cutting Ability is an important prerequisite for users to accept mobile AR navigation services efficiently, which greatly affects the interaction process [18]. Gender is one of the fundamental factors that lead to differences in user's behavior and emotional experience. On the interaction level, touch screen interaction and in-air gesture interaction not only embody the interactive relation between people and the mobile AR navigation system but also affect the user's behavior efficiency and experience [19]. Mental Cutting Ability and Gender are important individual differences between mobile AR navigation users, which may affect the efficiency and emotion of users when using different interaction modes. Based on the research status and depth considerations, we believe that a comprehensive study of these three factors will be beneficial to the formulation of mobile AR navigation design strategies. From the perspe-ctive of behavior-emotion, we measured the usability data of mobile

AR navigation and the user's emotional experience to reflect the results of human-computer interaction.

In summary, this study combined behavioral performance and emotional experience to construct an experimental meth-od to analyze the effects of Interaction Mode, Mental Cutting Ability, and Gender on mobile AR navigation. Finally, we established the relationship between user behavior-emotion and human-robot-environment design, and provided strategic references for the personalized design and humanized design of mobile AR navigation to meet the demands of different types of users.

## II. RESEARCH BASE

### A. AR INTERACTION MODE

AR is a basic technology that superimposes computer virtual information into the real world to form enhanced envi-ronmental effects [20]. Divided by spatial dimension, the main AR interaction modes include (1) Touch screen inte-raction based on single-touch or multi-touch, (2) In-air gesture interaction based on gesture recognition, as shown in Fig. 1.

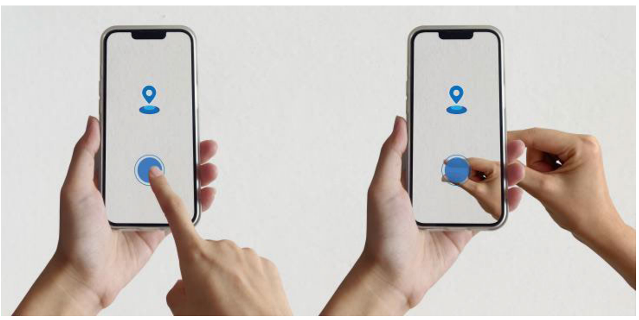

**FIGURE 1. Left: touch screen interaction, right: in-air gesture interact-ion.**

Studies have shown that the advantage of touch screen interaction lies in easy operation [21], but its interactive actions and interactive content are limited by the size of the device. In-air gesture interaction has a high degree of freedom and participation, and it is easy to stimulate the pleasant emotions of users [22], while the low accuracy of gesture recognition will decrease its usability. For users, Interaction Mode as an external factor can directly affect the standards of their interactive behavior and the process of navigation [23]. Therefore, the Interaction Mode will affect mobile AR navigation efficiency and user experience with individual differences such as usage habits and hand size, and these individual differences may influence users' acceptance and preference for different interaction modes. At present, the lack of academic research on the usability, experience, and user differences of mobile AR navigation interaction mode lead to the lack of specific guidance for related designs. However, AR navigation service has an obvious attribute of strong interaction [8], so it is very significant to explore the Interaction Mode of mobile AR navigation.

### B. MENTAL CUTTING ABILITY AND GENDER

As the internal factors of users, Mental Cutting Ability and Gender are easily ignored in different research of interactive behavior. The interaction effects of them will affect AR navigation in terms of thinking ability, attention level, and self-evaluation [24]. As an innovative technology, mobile AR navigation will superimpose the virtual icons on the real scene, and match the navigation information with the environment to enhance the user's spatial perception [20]. However, in practical applications, this superposition rela-tionship will confuse users' attention. If the visual image of some virtual information is close to the objects in the real scene, it will make it difficult for some users to distinguish them. The explanation for this phenomenon is as follows.

Mental Cutting Ability can reflect people's mental super-position thinking and mental transformation thinking to a certain extent, indicating the spatial cognition level of users [24]. The ability of mental cutting will affect the users' reception efficiency of navigation information and perception level of enhanced environment [25]. In the augmented reality navigation environment, to adapt to the superposition relation between the virtual icons and the real environments, the users need to recognize the navigation information through identification, interpretation, transformation, and reasoning [26]. Mental superposition thinking and mental transformation thinking may directly affect the users' perception of the positional relationship and attention order between virtual information and the real environment. Specifically, most of the AR navigation information (virtual button and navigation arrows, etc.) is static in the interface, but the process of way-finding (the real environment) is dynamic, and the super-position between them will test the users' ability of Mental Cutting Ability. This kind of mental ability can help users pay attention to the transition of icons and the change of environment at the same time [4]. Therefore, to improve the effects of mobile AR navigation, it is meaningful to study the ability of mental cutting.

To classify the Mental Cutting Ability of users, this res-earch adopted the internationally recognized MCT (Mental Cutting Test) scale. The MCT scale cuts objects of different shapes from different angles, requiring participants to judge the actual shape of the cut surface. The scale has 25 items, each with 1 point, as shown in Fig. 2. To simulate the superimposed relationship between AR navigation icons and the real environment, we set the background of the MCT scale to a dynamic real scene.

For a long time, there has been a phenomenon of ''gender blindness'' in architectural planning. Architects often ignore the influence of Gender on space design, which leads to large differences in the spatial experience between men and women [27]. Although studies have shown that there are differences in the Mental Cutting Ability of men and women [24], it has not been verified in the field of mobile AR navigation. At the attention level, there are significant dif-ferences in the degree of attention paid to navigation signs between men and women in the study of visual perception within public commercial spaces [28]. In terms of subjective perception, women's computer self-efficacy is lower, and their interaction behavior is more cautious to avoid mistakes [29]. Conversely, men perform better with innovative techn-ologies and are more competent for complex and creative tasks [28]. Studies have shown that there are Gender diff-erences in emotional responses triggered by the availability of AR [30], and women are more possible to experience positive emotions [31].

It can be seen that Mental Cutting Ability and Gender are the key factors affecting mobile AR navigation. The research on them will help investigators analyze the internal mech-anism of user characteristics, thus helping designers to make flexible service plans for user differences, meet the needs of more people, and expand the scope of application.

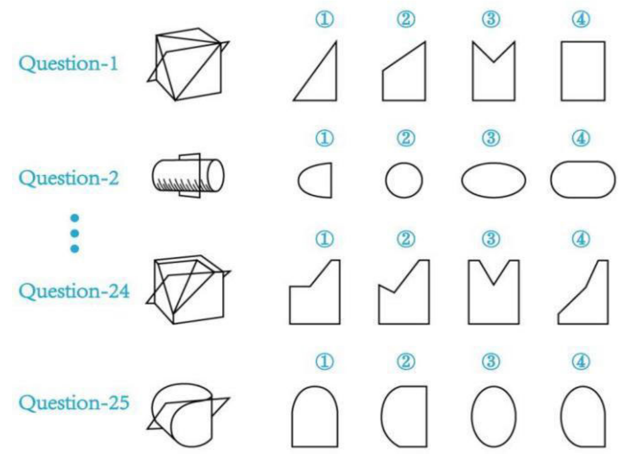


**FIGURE 2.** MCT test question items.

### C. USABILITY

According to the ISO 9241-11 standard, usability is defined as the effectiveness, efficiency, and satisfaction of the produ-cts or services which are used by users in a specified scenario. For different experimental purposes, researchers can regard user satisfaction score, task completion time [32], error rate, etc. as usability indicators. Combining the research results of Nielsen and Fiorino et al. [32], and referring to the existing AR usability evaluation methods [33], this study uses the Ease of Learning and the Ease of Use as the usability indicators of mobile AR navigation, as shown in Table 1.

### D. PAD 3D EMOTIONAL EXPERIENCE

Studies have shown that emotions can directly affect users' satisfaction with products or systems and their willingness to continue using them [34]. User's emotions during navigation may affect the efficiency of way-finding [3]. As a service system that needs to be gradually perfected, mobile AR navigation should focus on the emotions of users to optimize the user experience in omnidirectional ways. The PAD three-dimensional emotion model combines flexibility and

**TABLE 1.** AR navigation usability evaluation system.

| Tier 1 indicators | Tier 2 indicators | Interpretation of indicators |
|---|---|---|
| Ease of Learning | Difficulty rating | Participants completed the Single Ease Question according to their practice experience, and the higher the score, the higher the ease of learning |
| Ease of Use | Completion time | The time from the participant entered the task interface to the end of the navigation task |

app-licability, and is widely used in the measurement of user's emotions [3]. It aims to make the emotion analysis deeper and more comprehensive by classifying the user's emotional experiences. This model can quantitatively describe the user's emotions from three dimensions: Please-P (the user's positive or negative emotion), Arousal-A (the user's degree of excitement), and Dominance-D (the user's state of control over the environment), and obtain scores. When the value of P, A, and D is greater than 0, it means positive or active emotion; when the value of P, A, and D is less than 0, it means negative or passive emotion; when P, A, and D are equal to 0, it means that the user's emotion does not fluctuate. The PAD three-dimensional emotion scale set up 12 groups meaning opposite vocabulary items, with 4 items for each emotion dimension, as shown in Fig. 3. In this study, a 9-point scale ranging from -4 to 4 was used to quantitatively describe the participants' emotional experience of the mobile AR navigation, and the final scores of P, A, and D corre-spond to the mean of the total scores of the four emotional vocabulary items.

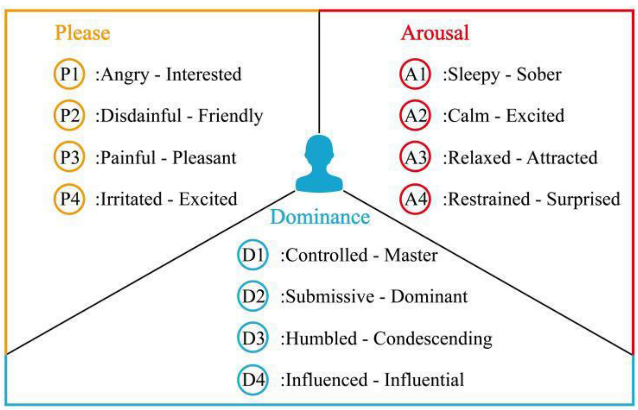


**FIGURE 3.** PAD 3D Emotion Model.

## III. EXPERIMENT CONTENT

In this study, a 2 × 2×2 multi-factor mixed experiment was created, with the independent variables being Interaction Mode (touch screen interaction and in-air gesture interaction), Mental Cutting Ability (high and low), and Gender (male and female), and the dependent variables were the

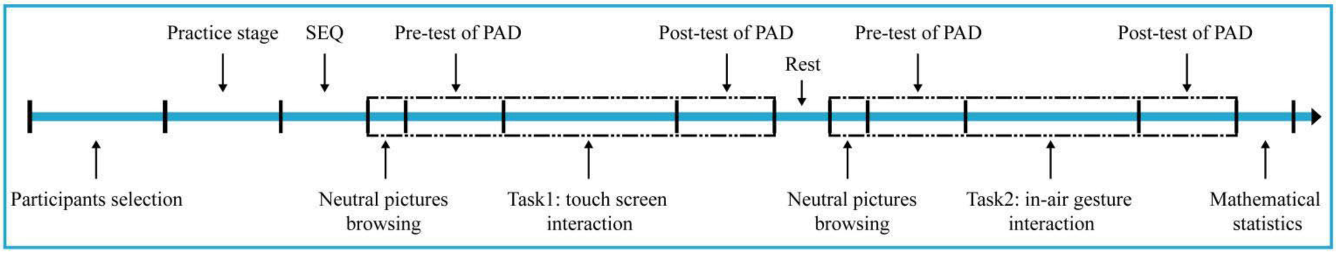


**FIGURE 4.** **Experimental Procedure.**

usability data of mobile AR navigation and the 3D emotional experience of users. The purpose of this experiment is to analyze the influence of internal factors (user characteristics) and ex-ternal factors (interaction modes) on mobile AR navigation by recording the behavioral performance and emotional exp-erience of the participants using different interaction modes to complete mobile AR navigation tasks.

### A. EXPERIMENTAL PROCEDURE

The experimental procedure is shown in Fig. 4.

Sun [35] showed that educational experience has a positive effect on users' mental cognition. However, with the popularization of education, the difference in educational degrees among citizens has gradually become smaller, especially among youth people (the main user group of mobile AR navigation) [35]. From the perspective of society, the overall influence of the education factor on this experiment is limited. Therefore, like Wang's et al. research [3], we did not set it as an independent variable to make this study more concise and clearer. In this experiment, 268 participants with bachelor's degrees or above were selected for the MCT test in Hubei Yintai Creative Mall. We grouped high and low mental cutting ability according to the 27% principle (the top 27 % and the last 27 % of the score ranking) [36]. Finally, two groups of men with high/low mental cutting ability and two groups of women with high/low mental cutting ability were selected, with 36 people in each group, ranging in age from 21 to 30 years old (mean age M = 23.78, standard deviation SD = 2.40). All participants were competent to complete the training and tasks, with normal corrected vision and right-handed. None of them had ever participated in a similar experiment, of which 56 people had used AR equipment or software less than three times.

In the experimental practice stage, participants need to master the operation attributes of different interaction modes, and the practice time was uniformly set to 4 minutes to avoid the factor of time affecting the results. At the end of the practice of each interaction mode, the participants were invited to fill out a single task difficulty questionnaire (SEQ, Single Ease Question), which uses scores of 1 to 7 to express the ease of practice (the higher the score, the higher the ease of learning).

In the process of AR navigation, icon selection is the main interactive content and arrow display is the basic navigation method, all of which are superimposed on the real scene in the form of virtual information. Icon selection and arrow display are important in the AR navigation process, where icon selection usually precedes other operations [37], and arrow display is the main function presentation that guides the users to the destination. Therefore, this experiment took participants' action of icon selection and arrow following in the navigation interface as the completion goal. The exper-imental tasks were divided into touch screen interaction (task 1) and in-air gesture interaction (task 2). We regarded the "pinch gesture" (the pinching of the index finger and thumb to trigger the operation) as the standard action of in-air gesture interaction, which is a common and important hand action in mobile AR applications.

The task background was: participants used mobile AR na-vigation to find their way in the mall. The task process is as follows: In the first step, the participants needed to hold the mobile AR device to face the front environment, entered the task interface, and then clicked the icon of "Start Navigation"; In the second step, the navigation arrow appeared in the interface, and the participants followed the arrow to reach the target position 1; In the third step, participants clicked the "Continue Navigation" icon that appeared in the interface; In the fourth step, the AR navigation arrow appeared again, participants followed the arrow to reach the target position 2; In the fifth step, participants clicked the icon of "End Navigation" that appeared in the interface to end the task. To exclude the influence of route memory on the experimental results, we set an angular deviation of 30° for the navigation routes of task 1 and task 2. The task operation form is shown in Fig. 5.

In addition to the above steps, neutral pictures are browsing. A previous study has shown that emotional states can be regulated by viewing emotional pictures [38]. To ensure the participants' self-emotional stability, we invited the participants to spend 30 seconds viewing 10 neutral em-otional pictures selected from the International Affective Picture System (IAPS) [39] before each experimental task. The emotional values of P, A, and D were divided into pre-test and post-test for comparative study.

### B. EXPERIMENTAL MATERIALS AND ENVIRONMENT

#### 1) EXPERIMENTAL MATERIALS

For the hardware, the handheld device is an iPhone 13 with iOS15 operating system, the screen is 6.1 inches with a

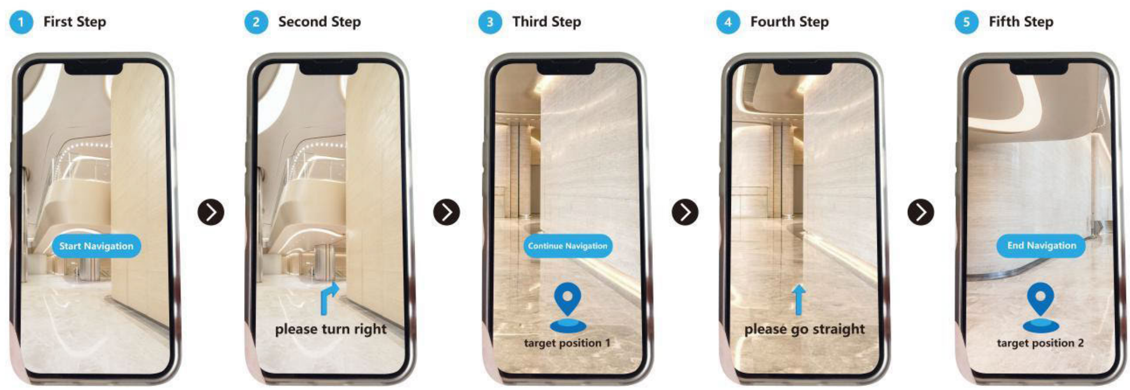


**FIGURE 5.** Task operation form.

re-solution of 2532 × 1170 pixels. About the software, we combined Unity 3D and Mano Motion to implement the interface design and gesture recognition [3]. During the experiment, participants allowed smartphone screen recorder software to automatically record their actions for statistical analysis after the experiment, and SPSS 26.0 software was used for data analysis in this study [40].

### 2) EXPERIMENTAL ENVIRONMENT

The experimental site was selected as the third floor of Yintai Creative Mall in Hubei. The lighting in the indoor space was constant, and the participants' operations were not affected by the weather or period time. During the experiment, we ensured that the hardware equipment is unified, the scene is the same, and the operation perspective is consistent.

## IV. RESEARCH FINDINGS AND DISCUSSION

Based on the experimental data and relevant conclusions, we analyzed the research results and extracted the behavior char-acters and emotional tendencies of different types of users when using different interaction modes.

### A. USABILITY

### 1) ANALYSIS OF DESCRIPTIVE STATISTICAL

The results of descriptive statistical analysis of mobile AR navigation usability data are shown in Fig. 6.

People with high mental cutting abilities and men found the two modes of interaction were easier to learn (Ease of Learning), and they were able to complete navigation tasks faster (Ease of Use). At the level of Interaction Mode, touch screen interaction had a higher degree of Ease of Learning and Ease of Use. Compared with the men with low mental cutting ability, the women with high mental cutting ability scored higher on the Ease of Learning of the two interaction modes, but their task completion time was similar.

### 2) ANALYSIS OF VARIANCE

In this study, a multi-factor analysis of variance (ANOVA) was conducted for the usability data of mobile AR navigation,

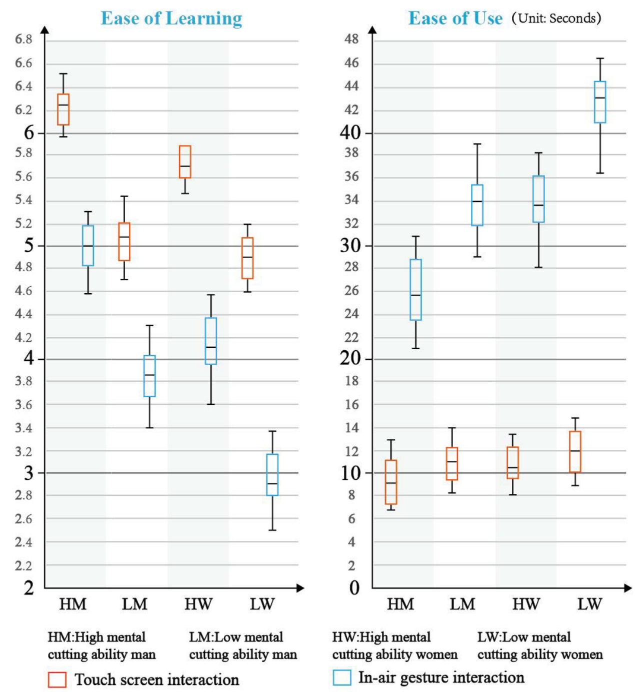


**FIGURE 6.** Descriptive statistics of usability.

the results of the analysis are shown in Fig. 7. When the dependent variable is affected by two or more independent variables, multi-factor ANOVA can be performed on the data. The method of variance comparison can be used to determine whether independent variables have significant effects on the dependent variable through the process of hypothesis-test. The effect of an independent variable on the dependent variable is the "main effect", and the effect of multiple indep-endent variables on the dependent variable is the "interaction effect". This study adopted the commonly used mathematical analysis software: SPSS 26.0 [1], which has a "multi-factor ANOVA" function for the rapid processing of sample data. The purpose of the F-test is to test the true degree that the results of the sample to represent the overall research, and the larger its value the more obvious the effect of sample. The P represents the significance of the effects of the independent variable on the dependent variable, and the significance level (P) is $< 0.05$. In the analysis of variance, if the main effect of an independent variable is significant, its corresponding Partial Eta squared $\eta^2$ should be reported, indicating the size of the dependent variable's overall variance variation exp-lained by the independent variable.

| Effects | | P | F-test | Partial Eta squared η2 |
|---|---|---|---|---|
| Interaction Mode | → Ease of Learning | 0.000 | 140.870 | 0.796 |
| Gender | → Ease of Learning | 0.009 | 7.601 | 0.174 |
| Mental Cutting Ability | → Ease of Learning | 0.000 | 27.924 | 0.437 |
| Interaction Mode* Gender | → Ease of Learning | 0.126 | 2.504 | 0.065 |
| Interaction Mode* Mental Cutting Ability | → Ease of Learning | 0.056 | 3.913 | 0.098 |
| Gender* Mental Cutting Ability | → Ease of Learning | 0.820 | 0.053 | 0.001 |

The color represents the significance of the effect of the independent variable on the dependent variable.

Not significant Marginally significant Generally significant Very significant

**FIGURE 7. Analysis of variance for repeated measures of usability.**

In the dimension of Ease of Learning, the main effects of Interaction Mode, Gender, and Mental Cutting Ability were all significant; the interaction effects between Interaction Mode and Mental Cutting Ability were marginally significant. This study provided a simple effect analysis of Interaction Mode and Mental Cutting Ability to explore the internal influencing mechanism between the two factors, the paired comparison results showed that Mental Cutting Ability sig-nificantly influenced participants' scores of Ease of Learning for touch screen interaction ($P = 0.001 < 0.05$) and in-air gesture interaction ($P = 0.000 < 0.05$); Interaction Mode significantly influenced the scores of Ease of Learning for those with the high mental cutting ability ($P = 0.000 < 0.05$) and low mental cutting ability ($P = 0.000 < 0.05$).

In the dimension of Ease of Use, the main effects of Interaction Mode, Mental Cutting Ability, and Gender were significant; the interaction effects between Interaction Mode and Gender, Interaction Mode, and Mental Cutting Ability were significant. Simple effect analysis was conducted for Interaction Mode and Gender, the pairwise comparisons showed that Gender significantly influenced the Ease of Use of mobile AR navigation when participants used touch screen interaction ($P = 0.001 < 0.05$) and in-air gesture interaction ($P = 0.000 < 0.05$); Interaction Mode significantly affected the Ease of Use of mobile AR navigation for both males ($P = 0.000 < 0.05$) and females ($P = 0.000 < 0.05$). Simple effect analysis of Interaction Mode and Mental Cutting Ability, with pairwise comparisons, showed that Mental Cutting Ability significantly influenced the Ease of Use of touch screen interaction ($P = 0.000 < 0.05$) and in-air gesture interaction ($P = 0.000 < 0.05$); Interaction Mode also significantly affected the data of Ease of Use for those with the high mental cutting ability ($P = 0.000 < 0.05$) and the low mental cutting ability ($P = 0.000 < 0.05$).

### 3) DISCUSSION OF USABILITY

Interaction Mode has a significant impact on the usability of mobile AR navigation. Touch screen interaction requires less Mental Cutting Ability, and users only need to interact with the physical screen, its high degree of Ease of Use signi-ficantly reduces the learning cost and operation difficulty of users [21], and the familiarity of touch screen interaction enables different types of users to enter the state of use quickly. In-air gesture interaction requires the user to adjust and determine the position of their air gesture in a moving environment, its features of difficult operation, low accuracy, high spatial thinking requirement, and low familiarity all negatively affect the efficiency and user experience of mobile AR navigation. Therefore, the overall usability of touch screen interaction is better than that of in-air gesture inter-action.

Mental Cutting Ability significantly affects the usability of mobile AR navigation, which is consistent with the con-clusion that the users' spatial perception ability will affect the navigation efficiency [24]. People with high mental cutting ability are more likely to understand the location of virtual information in the real environment and apply navigation information to the process of way-finding [29]. However, people with low mental cutting ability lack the identification thinking and conversion thinking of three-dimensional icons and superimposed images, therefore, it is difficult for them to match the virtual navigation information with the spatial scene and their in-air gesture positions are also prone to deviation. In addition, users with high mental cutting ability have stronger fault tolerance for the defects of mobile AR navigation technology, so their behavioral efficiency is less affected. There is a significant interaction effect between Interaction Mode and Mental Cutting Ability on usability. Different interaction modes reflect the difficulty level of mobile AR operation, people with high mental cutting ability performed better in a variety of tasks, and this advantage will be further magnified in the tasks of higher difficulty. People with low mental cutting ability perceive a greater difference in difficulty between the two interaction modes, so their performance gap is greater, and the mobile AR navigation usability is affected to a greater extent.

Gender has a significant effect on the usability of mobile AR navigation. With the same mental cutting ability, men outperformed women, but women made fewer mistakes. This result validates the conclusion that women tend to spend mo-re time choosing a more cautious route during way-finding, and men are more confident in their abilities and want to complete tasks quickly. The reason for this phenomenon is that there are differences between men and women in

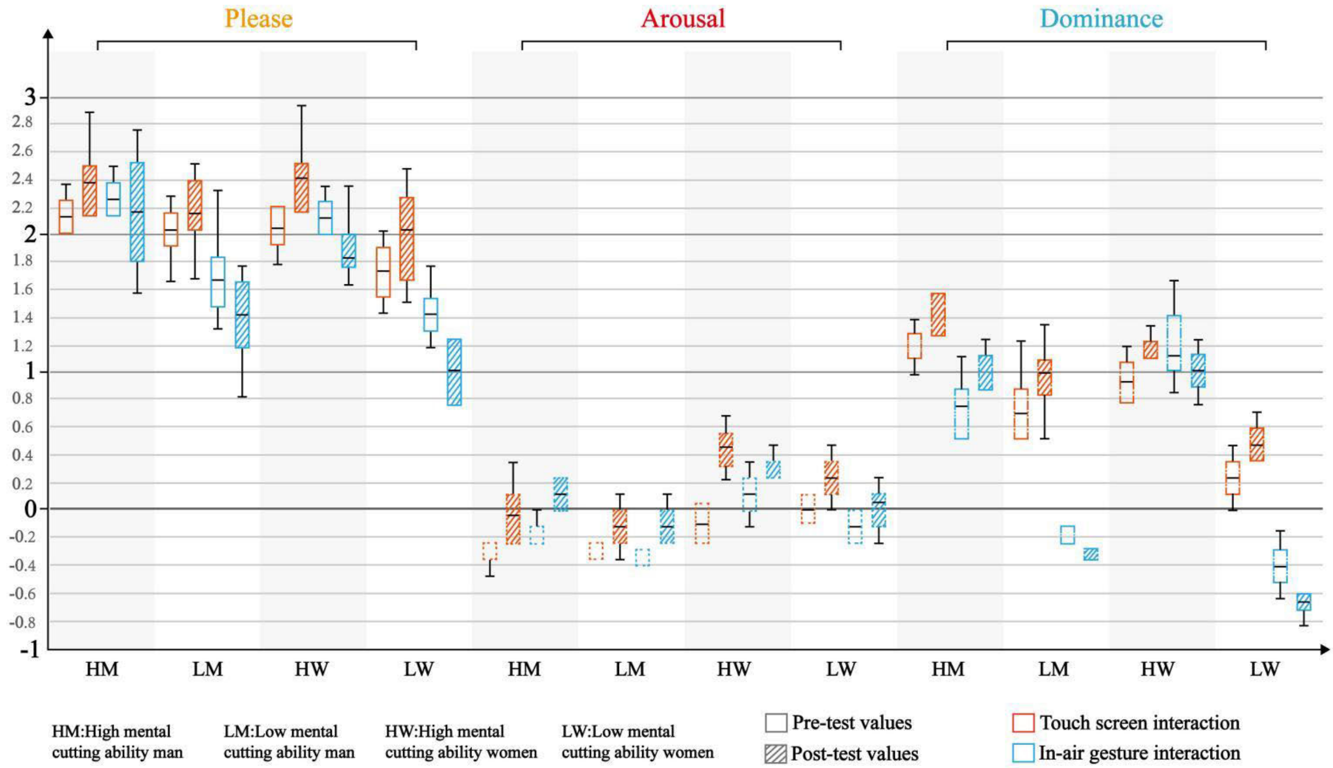


**FIGURE 8.** PAD 3D emotional experiences distribution chart.

route-finding strategies, self-evaluation, attention, and so on, which are directly reflected in the users' AR navigation process. In addition, men are calmer in the face of operational errors, gesture deviations, etc., and have less influence on subse-quent actions; women are more likely to slow down or pause in this situation, thus increasing the completion time.

### B. THREE-DIMENSIONAL EMOTIONAL EXPERIENCE

In order to clearly and completely display the distributions and differences of the participants' emotional experiences, we plotted the maximum value, upper quartile, median, lower quartile, and minimum value of the data in turn by drawing a box plot.

#### 1) DISTRIBUTION OF THE THREE-DIMENSIONAL EMOTIONAL EXPERIENCE

In the ar navigation process, the distribution of users' three-dimensional emotional experience are shown in Fig. 8

In the dimension of Interaction Mode, touch screen inter-action could increase the Please, Arousal, and Dominance of different types of participants. For in-air gesture interaction, the Please and Dominance of men with high mental cutting ability and the Arousal of all types of participants increased. In-air gesture interaction had a great negative impact on the emotions of people with low mental cutting ability. In the dimension of Mental Cutting Ability, the overall Please, Arousal, and Dominance of the pre-test and post-test of the high mental cutting ability are higher than those of the low mental cutting ability. For those with low mental cutting ability, the average value of Please and Dominance of touch screen interaction is significantly higher than that of in-air gesture interaction, while the Arousal degree is flat. In the Gender dimension, the Please data of men and women are basically the same, the Arousal degree of women is slightly higher than that of men, and men's Dominance is higher than women's.

#### 2) ANALYSIS OF VARIANCE

The results of repeated measures ANOVA of users' three-dimensional emotional experience are shown in Fig. 9. Note that the significant level (P) is $< 0.05$.

In the dimension of Please, the main effects of Interaction Mode, and Mental Cutting Ability were all significant; the interaction effects between Interaction mode and Gender, Interaction Mode and Mental Cutting Ability were significant. A simple effects analysis was conducted to explore the internal influencing mechanism between the two factors, the pairwise comparisons showed that Gender significantly inf-luenced the participants' Please of using touch screen inter-action ($P = 0.000 < 0.05$) and in-air gesture interaction ($P = 0.025 < 0.05$); Interaction Mode also significantly affected the experience of Please for those with the high mental cutting ability ($P = 0.000 < 0.05$) and low mental cutting ability ($P = 0.000 < 0.05$). A simple effects analysis of Interaction Mode and Mental Cutting Ability with pair-wise comparisons showed that Mental Cutting Ability had non-significant effect on participants' Please of using touch screen interaction ($P = 1.000 > 0.05$) and a significant effect on the in-air gesture interaction ($P = 0.000 < 0.05$); Inter-action Mode also significantly affected those with the high mental cutting ability ($P = 0.000 < 0.05$) and low mental cutting ability ($P = 0.000 < 0.05$) on the experience of Please.

| Effects | | P | F-test | Partial Eta squared η2 |
|---|---|---|---|---|
| Interaction Mode | → Please | 0.000 | 480.282 | 0.930 |
| Gender | → Please | 0.425 | 0.651 | 0.018 |
| Mental Cutting Ability | → Please | 0.003 | 17.216 | 0.324 |
| Interaction Mode* Gender | → Please | 0.000 | 41.415 | 0.535 |
| Interaction Mode* Mental Cutting Ability | → Please | 0.000 | 39.207 | 0.521 |
| Gender* Mental Cutting Ability | → Please | 0.425 | 0.651 | 0.018 |
| Interaction Mode | → Arousal | 0.000 | 24.775 | 0.408 |
| Gender | → Arousal | 0.053 | 3.403 | 0.086 |
| Mental Cutting Ability | → Arousal | 0.004 | 9.454 | 0.208 |
| Interaction Mode* Gender | → Arousal | 0.040 | 4.551 | 0.112 |
| Interaction Mode* Mental Cutting Ability | → Arousal | 0.482 | 0.506 | 0.014 |
| Gender* Mental Cutting Ability | → Arousal | 0.542 | 0.378 | 0.010 |
| Interaction Mode | → Dominance | 0.000 | 260.283 | 0.796 |
| Gender | → Dominance | 0.300 | 1.107 | 0.174 |
| Mental Cutting Ability | → Dominance | 0.000 | 92.144 | 0.437 |
| Interaction Mode* Gender | → Dominance | 0.831 | 0.046 | 0.065 |
| Interaction Mode* Mental Cutting Ability | → Dominance | 0.000 | 18.509 | 0.098 |
| Gender* Mental Cutting Ability | → Dominance | 0.896 | 0.017 | 0.001 |

The color represents the significance of the effect of the independent variable on the dependent variable.

Not significant   Marginally significant   Generally significant   Very significant

**FIGURE 9. PAD 3D emotional experiences repeated measures analysis of variance.**

In the dimension of Arousal, the main effects of Inte-raction Mode and Mental Cutting Ability were signifi-cant; the main effect of Gender was marginally significant; the interaction effects of Interaction Mode and Gender were significant. A simple effects analysis of Interaction Mode and Gender with pairwise comparisons indicated that Gender significantly affected participants' Arousal when using touch screen interaction ($P = 0.032 < 0.05$), while it was not sig-nificant in in-air gesture interaction ($P = 1.000 > 0.05$); Interaction Mode showed a marginally significant effect on Arousal for men ($P = 0.052 > 0.05$) and a significant effect for women ($P = 0.000 < 0.05$).

In the dimension of Dominance, the main effects of Inte-raction Mode and Mental Cutting Ability were signifi-cant; the interaction effects of Interaction Mode and Mental Cutting Ability were significant. Simple effect analysis was conducted for Interaction Mode and Mental Cutting Ability, the pairwise comparisons showed that Mental Cutting Ability significantly influenced the Dominance of participants when using touch screen interaction ($P = 0.000 < 0.05$) and in-air gesture interaction ($P = 0.000 < 0.05$); Interaction Mode sig-nificantly influenced the Dominance of the participants with the high mental cutting ability ($P = 0.000 < 0.05$) and those with the low mental cutting ability ($P = 0.000 < 0.05$).

### 3) DISCUSSION OF THE THREE-DIMENSIONAL EMOTIONAL EXPERIENCE

It can be seen from the above conclusions that Interaction Mode, Gender, and Mental Cutting Ability all significantly affected the usability of mobile AR navigation. Usability played a key role in interactive experiences such as smooth operation and fast response could effectively improve the user's emotional experience [21]. This study also proves that the user's 3D emotional experience is affected by the usa-bility of mobile AR navigation.

In the dimension of Interaction Mode, some studies have shown that AR interaction can increase the user's pleasant mood [3]. Nevertheless, they didn't consider the difference in AR interaction modes will cause a gap in task difficulty, which is likely to affect the user's mental state. An increase in task difficulty can directly lead to a decrease in the behav-ioral performance of some people, thus negatively affecting their emotional experience. The difficulty of in-air gesture interaction is significantly higher than that of touch screen interaction, and the technical defects of in-air gesture inter-action will lead to inaccurate gesture recognition, which will make the users lose control of the navigation envir-onment, resulting in anxiety. According to the statistical chart, the overall level of Please and Dominance of participants using in-air gesture interaction is lower than that of touch screen interaction. However, in-air gesture interaction with novel feedback modes and free operating experience can arouse the interest of different types of users, which will increase their Arousal.

The Mental Cutting Ability represents the individual's spatial superposition thinking and spatial transformation thinking, which directly influences self-perception, thus sig-nificantly affecting their emotional experience of Please, Arousal, and Dominance in the AR navigation. Interac-tion Mode and Mental Cutting Ability showed signifi-cant inte-raction effects in Please and Dominance, we will explain this phenomenon with psychological theory. In flow theory, personal ability (Mental Cutting Ability) directly affects users' confidence in completing tasks [41], and the difficulty of tasks (Interaction Mode) will play a key role in their psychological experience. In the self-efficacy theory, users' perception and definition of task difficulty is based on their abilities, and the perception significantly affects their spe-culation and judgment on task completion, and there are gender differences in this phenomenon [29]. The Mental Cutting Ability also affects the user's subjective environment perception, it is more difficult for people with the low mental cutting ability to control virtual 3D information, and they feel more strange and threatened in the augmented reality envi-ronment, resulting in negative emotions.

Gender showed marginally significant only in user's Aro-usal, and females with the same Mental Cutting Ability have higher Arousal than males in different Interaction Modes. A study has shown that female users have stronger perception of task stimuli [3], which in turn produces higher activation emotions. According to the above, although the usability data of women is lower than that of men, there is no signifi-cant difference in emotional level between the two. Women gene-rally mentioned words such as ''excited'' and ''novelty'' after the experiment. In addition, compared with men, women are more likely to feel depressed when performing difficult tasks, and they need more emotional motivation to obtain sufficient self-efficacy.

## V. DESIGN STRATEGY

Mobile AR navigation has the strong attributes of digital interaction and environmental perception. Therefore, this study transformed the results of behavior-sentiment analysis into the design strategy for mobile AR navigation human-computer interaction. In terms of the system, we proposed a mobile AR navigation design strategy consisting of User Characteristics-Interaction Form-Environmental Experience (corresponding to Human-Robot-Environment), as shown in Fig. 10.

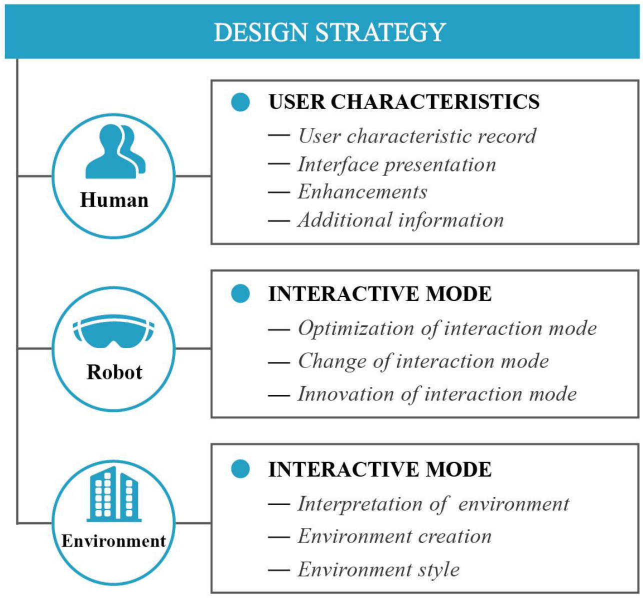


**FIGURE 10.** Design strategy.

### A. CHARACTERISTICS OF USERS

It can be seen from the above conclusions that, as the inter-nal factors of users, Mental Cutting Ability and Gender had significant influences on the usability and user experi-ence of mobile AR navigation. Therefore, the differentiated prese-ntation of navigation information and the personalized setting of navigation schemes based on user characteristics can make mobile AR navigation more effective. The per-sonalized design of mobile AR navigation can weaken the negative impact of users' quality differences on the group experience, thus interpreting the publicity and welfare of navigation services [6]. The relevant design strategies are as follows.

User characteristic record: Before use, mobile AR nav-igation can record the user's gender, mental cutting abil-ity, and other characteristics, and then set the most suitable AR navigation parameters [14].

Interface presentation: mobile AR navigation can try to provide men with a dynamic and technological interface to increase their excitement; show women a gentle, warm-colored interface to increase their sense of security in the AR navigation environment.

Enhancements: Navigation systems can provide non-realistic icons and arrows (such as cartoon style) for peo-ple with low mental cutting ability, which will help them distinguish between virtual information and real environm-ents. In addition to this, they also need multimodal feedback effects (such as sound, vibration, image, etc.). People with high mental cutting ability need concise and moderate AR information, which is conducive to improving navigation efficiency.

Additional information: mobile AR navigation should pro-vide more spatial interpretation for users with the low mental cutting ability [28], and add more misoperation reminders for men. Interaction mode: the AR navigation system should be compatible with different interaction modes for users to experience and choose. In addition to this, de-signers should add more motivational messages for women or those with low mental cutting abilities in the AR interface to remove their negative emotions [29].

### B. INTERACTIVE MODE

Due to the limitation of screen size, the existing hand-held devices cannot better meet the users' needs for effi-cient and comfortable navigation. Complicated manipulation actions and limited interaction range will reduce the usabil-ity of mobile AR navigation, thus negatively impacting the user experience. Therefore, the optimization, change, and innova-tion of the interaction mode are crucial. The relevant design strategies are as follows.

Optimization of interaction mode: For people with diffe-rent mental cutting abilities, mobile AR navigation should set the operation range and feedback force of the in-air gesture interaction adjustable [28], which will be conducive to en-hancing the user's environmental perception and providing personalized services. For new users and those with low mental cutting ability, the operation guidance will increase their friendliness of the system. Women's limbs are usually smaller in size, so mobile AR navigation can expand the angle and range of gesture recognition for them.

Change of interaction mode: For the AR navigation design of hand-held devices, designers can mainly adopt the form of voice interaction to avoid the occupation of the user's hands [42], which can also solve the problem of insufficient perce-ption of gesture positions for people with low mental cutting ability.

Innovative interaction method: AR navigation design can be adopted in the form of wearable augmented reality devices, which can reduce the operational burden and expand the scope of interaction while ensuring the navigation effect. Wearable AR navigation will make the process of human-computer interaction more natural and efficient. Designers can use the form of lightweight AR glasses to enhance the user's comprehensive understanding of navigation informa-tion, expand the visual angle of navigation, improve the interactive experience, and reduce cognitive load [43]. For example, a wider angle of view may increase the women's sense of security. This innovative navigation method can stimulate the operating interest of male and female users, and provide a navigation atmosphere with a stronger sense of experience for people with different mental cutting abilities.

### C. ENVIRONMENTAL EXPERIENCE

As a key factor affecting the usability of mobile AR navi-gation and user's emotional experience, the enhancement of environment perception will help users understand the route content in the process of way-finding and measure the positional relationship between objects in the augmented reality environment. The relevant design strategies are as follows.

Interpretation of the environment: To effectively increase the trust of those with low mental cutting ability in the navigation system, designers can display a three-dimensional image of the global environment in the navigation interface and mark the current location of the user. In addition, the AR navigation services can be planned and recommended pr-omptly according to the user's demands of accommodation, shopping, work, etc. [25].

Environment creation: Catering to the user's mood can increase their Please and Arousal. For consumption and travel scenarios, lively and distinctive augmented reality decorative patterns can be added to the environment [16]; for office and business scenarios, a concise and stable navigation atmosphere can be created.

Environment style: The creation of an AR navigation atm-osphere will help to eliminate the boring feeling of the way-finding process and improve the user's Please emotions. Designers can carry out cartoon style or technological style design of navigation icons, auxiliary information, etc., and make independent choices of display modes by men and women, with high/low mental cutting ability. It will help to provide users with a differentiated and interesting interactive environment. To improve the Dominance of people with low mental cutting ability without increasing their psychological burden, mobile AR navigation can create an anthropom-orphic augmented reality navigation assistant to interpret information for them.

## VI. CONCLUSION

This study combined the methods of behavior recording, effect analysis, etc., to construct a systematic experimental framework, which integrated the usability of mobile AR navigation with the emotional experience of users in multiple dimensions. We found the influencing mechanism among the three factors of Interaction Mode, Mental Cutting Ability, and Gender, which enriched the research content of mobile AR navigation. The conclusion provided design strategies at the level of human-robot-environment for mobile AR nav-igation, and proposed differentiated design guidelines based on user characteristics, interaction modes, and environmental experiences for the differences of navigation purposes and aesthetic preferences, which are conducive to improving way-finding efficiency and optimizing navigation experi-ences for different users.

In addition to the design, the conclusion can also help different types of users choose a more suitable interaction mode, and navigation interface for them. For example, this study showed that the usability of touch screen interaction is higher, therefore, when users pursue practicality and con-venience or their spatial cognitive ability is limited, mobile AR navigation based on touch screen interaction can be selected, which can improve their sense of control and behavior efficiency. When users enjoy a fun experience, in-air gesture interaction is more appropriate, because it can activate their emotions and create a sense of space, especially for women. Users with low cognitive ability can choose the touch screen interaction and the navigation interface with high enhancement, while users with high cognitive ability may prefer in-air gesture interaction and a more stylized navigation interface.

Although mobile AR navigation has a large number of users, it is still insufficient in the level of subjective feelings compared to wearable devices. Therefore, the subsequent research can focus on the user experience of wearable AR navigation, and put more emphasis on the environmental design and emotional design of AR navigation. Besides, there are some defects in the experimental condition and data extraction in this study, the further research can measure, evaluate, analyze, and summarize the anthropogenic effects of mobile AR navigation behaviors by combining behavioral observation recorders and psychological anthropogenic synchronization software.

## REFERENCES


[1] S. Hu, X. Jiang, and K. J. Fu, "Research on the experience design of interactive public guidance system based on SEM," *J. Graph.*, vol. 41, pp. 204–209, Mar. 2020.

[2] H. Xue and N. N. Zhu, "Mobile augmented reality technology drives library experience innovation," *Library Sci. Res.*, vol. 7, pp. 35–40, Jun. 2015.

[3] J. Q. Wang, Y. Chen, and L. Hang, "A study on the influence of interaction style and gender differences on user experience of travel AR," *Library Inf. Service*, vol. 65, pp. 117–130, Feb. 2021.

[4] K. A. Satriadi, B. Ens, M. Cordeil, B. Jenny, T. Czauderna, and W. Willett, "Augmented reality map navigation with freehand gestures," in *Proc. IEEE Conf. Virtual Reality 3D User Interfaces (VR)*, Los Alamitos, CA, USA, Mar. 2019, pp. 593–603.

[5] J. I. Rubio-Sandoval, J. L. Martinez-Rodriguez, I. Lopez-Arevalo, A. B. Rios-Alvarado, A. J. Rodriguez-Rodriguez, and D. T. Vargas-Requena, "An indoor navigation methodology for mobile devices by integrating augmented reality and semantic web," *Sensors*, vol. 21, no. 16, p. 5435, Aug. 2021.

[6] C.-S. Wang, "An AR mobile navigation system integrating indoor positioning and content recommendation services," *World Wide Web*, vol. 22, no. 3, pp. 1241–1262, May 2019.

[7] S. Y. Jing, Y. Han, X. W. Meng, and L. K. Jiang, "Design and implementation of tourism GIS system supported by mobile AR + VR," *Surv. Mapping Bull.*, vol. 1, pp. 79–84, May 2019.

[8] A. Dünser, M. Billinghurst, J. Wen, V. Lehtinen, and A. Nurminen, "Exploring the use of handheld AR for outdoor navigation," *Comput. Graph.*, vol. 36, no. 8, pp. 1084–1095, Dec. 2012.

[9] C.-I. Lee, F.-R. Xiao, and Y.-W. Hsu, "AR book-finding behavior of users in library venue," *Appl. Sci.*, vol. 10, no. 20, p. 7349, Oct. 2020.

[10] Y. A. Sekhavat and J. Parsons, "The effect of tracking technique on the quality of user experience for augmented reality mobile navigation," *Multimedia Tools Appl.*, vol. 77, no. 10, pp. 11635–11668, May 2018.

[11] X. Zhou, "User experience of AR walking navigation map based on character image design," *Art View*, vol. 4, pp. 150–152, Jan. 2020.

[12] B. B. de Koning, N. Marcus, B. Brucker, and P. Ayres, "Does observing hand actions in animations and static graphics differentially affect learning of hand-manipulative tasks?" *Comput. Educ.*, vol. 141, pp. 103636.1–103636.12, Nov. 2019.

[13] Ł. Halik and A. J. Kent, "Measuring user preferences and behaviour in a topographic immersive virtual environment (TopoIVE) of 2D and 3D urban topographic data," *Int. J. Digit. Earth*, vol. 14, no. 12, pp. 1835–1867, Dec. 2021.

[14] J. Y. Kim, J. K. Choi, W. H. Han, and J. H. Kim, "The influence of users' spatial familiarity on their emotional perception of space and wayfinding movement patterns," *Sensors*, vol. 21, no. 8, p. 2583, Apr. 2021.

[15] C.-H. Chen and S.-C. Chen, "Effects of 2D wedge design as a wayfinding facilitator in a 3D virtual environment," *J. Soc. Inf. Display*, vol. 23, no. 1, pp. 27–35, Jan. 2015.

[16] A. Basir, M. H. L. Abdullah, and M. H. Zakaria, "User experience guidelines of augmented reality application for historical tourism," *Int. J. Adv. Sci., Eng. Inf. Technol.*, vol. 12, no. 3, p. 1196, May 2022.

[17] K. Lee and S. Oh, "The users' intention to participate in a VR/AR sports experience by applying the extended technology acceptance model (ETAM)," *Healthcare*, vol. 10, no. 6, p. 1117, Jun. 2022.

[18] C. A. Lawton, *Gender, Spatial Abilities, and Wayfinding*. New York, NY, USA: Springer, 2010, pp. 317–341.

[19] N. Marquardt, R. Jota, S. Greenberg, and J. A. Jorge, "The continuous interaction space: Interaction techniques unifying touch and gesture on and above a digital surface," in *Proc. 13th IFIP TC 13 Int. Conf. Hum.-Comput. Interact. (INTERACT)*. Berlin, Germany: Springer-Verlag, 2011, pp. 461–476.

[20] S. Zlatanova, *Augmented Reality Technology*. Delft, The Netherland: GISt Report, 2002, pp. 57–58.

[21] I. Radu, B. Macintyr, and S. Lourenco, "Comparing children's crosshair and finger interactions in handheld augmented reality: Relationships between usability and child development," in *Proc. 15th Int. Conf. Interact. Design Children*. New York, NY, USA: Association for Computing Machinery, 2016, pp. 288–298.

[22] B. Kollee, S. Kartz, and A. Dunnigan, "Exploring gestural interaction in smart spaces using head mounted devices with ego-centric sensing," in *Proc. 2nd ACM Symp. Spatial User Interact.* New York, NY, USA: Association for Computing Machinery, 2014, pp. 40–49.

[23] E. S. Goh, M. S. Sunar, and A. W. Ismail, "3D object manipulation techniques in handheld mobile augmented reality interface: A review," *IEEE Access*, vol. 7, pp. 40581–40601, 2019.

[24] A. J. Castro and K. Atit, "Different abilities controlled by visuospatial processing," in *Visuospatial Processing for Education in Health and Natural Sciences*. Cham, Switzerland: Springer, 2019, pp. 23–51.

[25] T. Wolbers and M. Hegarty, "What determines our navigational abilities?" *Trends Cognit. Sci.*, vol. 14, no. 3, pp. 138–146, Mar. 2010.

[26] S. M. Ko, W. S. Chang, and Y. G. Ji, "Usability principles for augmented reality applications in a smartphone environment," *Int. J. Hum.-Comput. Interact.*, vol. 29, no. 8, pp. 501–515, Aug. 2013.

[27] K. Suzuki, "Activities of the Japan society for graphic science-research and education," *J. Geometry Graph.*, vol. 6, pp. 221–229, Jan. 2002.

[28] X. M. Guo, X. T. Wu, and T. T. Lu, "Gender differences and attention preferences—An analysis of space use in commercial complexes based on virtual eye-movement perception detection," *Archit. J.*, pp. 112–118, Sep. 2021.

[29] S. Ying, L. Manor, and N. Huang, "The effects of gender and cognitive differences on three-dimensional spatial pathfinding outcomes," *Geomatics Inf. Sci. Wuhan Univ.*, vol. 45, pp. 317–324, Jun. 2020.

[30] D. J. Ferreira, T. F. N. Melo, and T. D. C. Nogueira, "Unveiling usability and UX relationships for different gender, users habits and contexts of use," *J. Web Eng.*, vol. 19, pp. 799–817, Sep. 2020.

[31] A. Dirin, A. Alamäki, and J. Suomala, "Gender differences in perceptions of conventional video, virtual reality and augmented reality," *Int. J. Interact. Mobile Technol.*, vol. 13, pp. 93–103, Feb. 2019.

[32] D. Fiorino, M. Collotta, and R. Ferrero, "Usability evaluation of touch gestures for mobile augmented reality applications," *J. Wireless Mobile Netw., Ubiquitous Comput., Dependable Appl.*, vol. 10, pp. 22–36, Mar. 2019.

[33] N. Guo, T. T. Wang, and L. Hu, "Human-computer interaction technology for ACL reconstructed surgical AR navigation system," *Comput. Eng. Appl.*, vol. 56, pp. 224–230, Jun. 2020.

[34] B. B. Tang, G. Guo, and X. L. He, "Research on multi-sensory expression user experience testing method for product design based on fuzzy theory," *J. Mach. Des.*, vol. 36, pp. 65–72, Aug. 2019.

[35] J. S. Sun, "Spatial ability enhancement of secondary school students based on 3D CAD: Model construction and classroom practice," *China Educ. Technol.*, vol. 9, pp. 114–121, Jan. 2022.

[36] H. Fang et al., "Spatial cognitive elements in the design of VR mobile urban navigation maps," *Geomatics Inf. Sci. Wuhan Univ.*, vol. 44, pp. 1124–1130, Feb. 2019.

[37] J. Looser, M. Billinghurst, R. Grasset, and A. Cockburn, "An evaluation of virtual lenses for object selection in augmented reality," in *Proc. 5th Int. Conf. Comput. Graph. Interact. Techn. Aust. Southeast Asia*, Perth, WA, Australia, Dec. 2007, pp. 1–4.

[38] C. L. Larson, D. Ruffalo, J. Y. Nietert, and R. J. Davidson, "Stability of emotion-modulated startle during short and long picture presentation," *Psychophysiology*, vol. 42, pp. 604–610, Jan. 2005.

[39] N. Irrazabal, M. Aranguren, E. Zaldua, and N. Giuliano, "Datos normativos del sistema internacional de imágenes afectivas (IAPS) en una muestra Argentina," *Revista Argentina De Ciencias Del Comportamiento*, vol. 7, no. 3, pp. 34–50, 2015.

[40] *GPL Reference Guide for IBM SPSS Statistics*, IBM Crop., New York, NY, USA, 2021.

[41] J. B. Barhorst, G. McLean, E. Shah, and R. Mack, "Blending the real world and the virtual world: Exploring the role of flow in augmented reality experiences," *J. Bus. Res.*, vol. 122, pp. 423–436, Jan. 2021.

[42] Z. Wang, H. Wang, H. Yu, and F. Lu, "Interaction with gaze, gesture, and speech in a flexibly configurable augmented reality system," *IEEE Trans. Human-Machine Syst.*, vol. 51, no. 5, pp. 524–534, Oct. 2021.

[43] W. W. Wang, Y. Ning, and T. Wei, "User perception experience emotion evaluation method based on cognitive load," *Packag. Eng.*, vol. 43, pp. 147–155, Feb. 2022.

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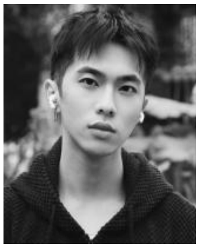

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