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RESEARCH ARTICLE

Augmented Reality to Assess Short-Term Spatial Memory: A Comparative Study of Olfactory, Visual, and Tactile Stimuli

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ABSTRACT This work presents an Augmented Reality application based on SLAM (Simultaneous Localization and Mapping) for the assessment of spatial memory involving olfactory stimuli. A study was carried with twenty-five adults. The participants of the study completed two phases (a learning phase and an evaluation phase). In the learning phase, the participants physically walk around a real environment and have to remember the location of olfactory stimuli. In the evaluation phase, the participants have to remember the location of olfactory stimuli learned in the previous phase. The data of this study is compared with those obtained in a previous study involving visual and tactile stimuli ($N = 47$). The results indicate that the olfactory stimuli did not offer significant differences with respect to the visual stimuli for the correct placement of stimuli and the number of attempts in the evaluation phase. The olfactory stimuli had better results compared to the tactile stimuli for the correct placement of the stimuli in the evaluation phase and there was a significantly lower number of attempts. The time required in the learning and evaluation phases was greater for the olfactory stimuli compared to the other two stimuli, which is justified by the physical and mechanical characteristics of each of the stimuli. The results show that this type of memory task for the olfactory stimuli is independent of gender and age. All of these results suggest that olfactory stimuli are valid stimuli for assessing the memorization of olfactory-spatial associations and are similar to the level of visual stimuli and better than tactile stimuli.

INDEX TERMS Assessment, augmented reality, olfactory stimuli, short-term memory, simultaneous localization and mapping (SLAM), spatial memory, tactile stimuli, visual stimuli.

I. INTRODUCTION

In cognitive psychology, spatial memory refers to the memory system that stores and manages information about an individual's environment, including their spatial location within it. Short-term spatial memory is defined as the ability of a subject to remember the location of environmental elements for short periods of time [1]. Humans, like most animals, use short-term spatial memory for tasks such as orientating themselves in space, remembering a path or remembering where they have left their belongings. Most of the information stored in spatial memory comes from visual and auditory stimuli [2], [3], [4], [5]. However, the human brain stores information from all sensory modalities [6]. Undoubtedly, one of these sensory modalities is the sense of smell, which has not been a priority in research about spatial memory but is a sense that should be exploited. Studies of the last five years link the sense of smell in humans with spatial memory in an especially close way [7], [8], [9]. In this work, we study the behavior

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of short-term spatial memory in relation to the sense of smell.

Traditional tests assess short-term spatial memory in humans by showing visual items (e.g., objects [10]), on paper or a screen while the person is normally seated in a chair. However, some works have shown that physical displacement is important in the acquisition of spatial skills (e.g., [11]). Virtual Reality (VR) and Augmented Reality (AR) are two technologies to consider for the development of tools to assess spatial memory. In addition, AR and VR have been used for the rehabilitation of disabled people and have proven to be useful in various disciplines related to people with intellectual or physical disabilities or special needs [12], [13]. VR and AR are of special interest for developing applications in which the user has to physically move around the real world. If the subjects move around the real environment to perform the tasks, they have an experience that is similar to what they would experience in the same task in real life.

This work presents an AR application based on SLAM (Simultaneous Localization and Mapping) for the assessment of spatial memory using olfactory stimuli. SLAM is the technique for obtaining and updating a map of an unknown environment while tracking the position and orientation of the device within that area. Our AR application does not need to include elements in the environment for its functioning because it uses SLAM and can be used in any indoor environment; the subject physically walks around the real world. The task for the subjects is divided into two phases, a learning phase and an evaluation phase. In the learning phase, the subjects smell containers with different scents that are inside boxes and are distributed in a real room. The users must associate the scent with the place where they smelled it. In the evaluation phase, the participants smell the same containers and use the AR application to place the smelled stimulus (represented by a virtual box) in the correct location in the room. A study involving twenty-five participants was carried out. The data collected in this study is compared with the data from the study carried out by Muñoz-Montoya et al. [14]. They assessed the short-term spatial memory in relation to the sense of sight and touch. Their study, using a similar AR application, took place in the same room but included visual and tactile stimuli. To our knowledge, our work is the first one that uses AR to compare olfactory, visual, and tactile modalities in assessing memory associations between stimuli and spatial locations.

Comparing olfactory, visual, and tactile stimuli in spatial memory tasks is crucial for understanding sensory contributions to memory processing. This multimodal approach helps discern sensory preferences and differences in information transfer to the mental map, enriching our understanding of how individuals use sensory information to remember and locate stimuli in space. The comparison of sensory modalities has practical implications, especially in fields such as clinical psychology, education, and environmental design. Understanding the impact of stimuli on spatial memory is crucial for optimizing learning strategies, cognitive therapies, and physical space planning. Our work aims to provide insights into cognitive adaptability to diverse sensory modalities, which could be useful in tailoring therapeutic or educational approaches based on individual preferences.

II. RELATED WORK

A. SPATIAL MEMORY

Short and long-term spatial memory has been extensively studied in animals [15]. One of the most classic experiments consists of using a maze with rewards. If the animal is able to memorize the path, it will be able to find the reward more quickly [16]. Examples of experiments of this type with humans have also been studied [17], where the results of rodents and humans are compared by performing equivalent tasks using mazes. Other methods used to assess human spatial memory involve tests on paper [18], [19] or on a screen while the subject remains seated and without physical displacement [20], [21], [22].

As the subject physically moves, the mental map of the environment is updated by a neural process. This phenomenon does not happen when the subject remains static and the location of objects in the environment changes [23], [24]. In previous studies [23], [24], the subjects were shown a series of objects on a round table. After hiding the objects, sometimes the subjects would move around the table and other times the table would rotate. The users were able to remember the position of objects much better when they themselves were moving instead of the table. This indicates that the subjects are better able to remember milestones in their environment when they are the ones who move. This suggests that the use of AR in an environment where the user is in motion can positively impact the learning task compared to methods where the subject remains stationary.

B. SPATIAL MEMORY AND OLFACTORY STIMULI

Wayfinding based on landmarks with scents has been demonstrated in animals, for example in rats [25] and desert ants [26]. However, research on human olfaction has rarely been investigated regarding spatial cognition. To our knowledge, there is only one work that is directly related to our proposal [7]. That work analyzed the use of olfactory cues as reference landmarks for wayfinding in humans. The authors first conducted an experiment with forty subjects to identify distinguishable scents. They selected the twenty-four most identified scents out of the forty-four, and twelve of them were used in the main experiment. The main experiment involved twenty-four participants. The participants navigated a complex virtual maze-like environment (SQUARELAND). Scents were used at intersections as decision points. The participants were seated in front of a computer screen. SQUARELAND is a 10×10 matrix with orthogonal intersections. The task included a learning phase and an evaluation phase. In the learning phase, the participants were automatically led through a maze as if they were walking. The video stopped at each intersection for the participants to smell the scent. The participants had to memorize the direction of the turns at intersections with scents. In the evaluation phase, the participants had to follow the same route. At each intersection, the participants had to verbally select the direction by saying ''left'', ''right'', or ''straight''. This phase ended when the destination was reached. Even if the participants made a wrong choice, the application continued heading in the right direction. The authors indicated that, on average, the participants selected the correct route at the 12 intersections 64% of the times. The lowest performance was 49% correct decisions for the mandarin scent, and the highest performance was 83% of correct decisions for the strawberry scent. The authors concluded that the participants were able to orient themselves using olfactory cues, showing the importance of such cues in human orientation. The authors concluded that humans can use olfactory landmarks to enrich their mental map of the environment and to navigate through space.

A second work worthy of mention [8] studied the association between spatial memory and olfactory identification in humans. The MONEX-40 Test [27] was used to evaluate olfactory identification. The participants performed two spatial memory tasks (wayfinding in a town and in a 4-on-8 Virtual Maze). The wayfinding task consisted of two phases (learning and evaluation). In the learning phase, the participants explored a virtual town and learned the location of eight landmarks. In the evaluation phase, there were eight trials. The participants were placed in front of a landmark and had to reach another landmark using the most direct route. The 4-on-8 Virtual Maze task was a radial maze with a central platform and eight paths. The maze was surrounded by a mountainous landscape with distal and proximal landmarks. The maze task also consisted of two phases (learning and evaluation). The two phases were divided into two parts. Only four of the paths were open in the first part. The participants had to visit the accessible paths and recover the objects at the bottom of the wells. In the second part, all eight paths were accessible. The participants had to visit the paths not visited in the previous phase and retrieve the objects. In the first part of the evaluation phase, only four of the paths were accessible. In the second part, a wall was built around the radial maze. At the end of the task, the participants had to verbally describe how they solved the task from start to finish. The participants were classified as spatial learners or response learners depending on the strategy used. MRI data was acquired from the participants. With all of this data, the authors identified a positive correlation between olfactory identification and the percentage of target locations found. They also highlighted the important role played by the hippocampus in olfactory identification and spatial memory in humans.

Overall, while existing methods [7], [8] focus on virtual environments, automated navigation, and cognitive strategies, our application emphasizes physical interaction with olfactory stimuli and the use of AR technology. The learning phase with our application uses physical exploration with olfactory and visual stimuli. In studies [7], [8], this phase uses automated navigation through a virtual maze and exploration of virtual environments with olfactory stimuli. In the evaluation phase, our application employs virtual box placement. In contrast, the study [7] utilizes verbal indications within a virtual maze, and [8] involves wayfinding in virtual environments.

The integration of physical exploration with olfactory and visuospatial information, coupled with the use of AR technology for virtual box placement, is the novelty of our application. Our AR application introduces a tangible and interactive dimension to the learning phase by allowing participants to physically move around and engage with visually indistinguishable boxes containing different scents. The use of AR for the evaluation phase adds a unique technological aspect that enhances the overall user experience. This hybrid approach combines sensory stimuli and advanced technology, providing a distinctive methodology for investigating spatial and olfactory memory associations.

C. COMPUTER-ASSESSED SPATIAL MEMORY

Short-term memory can be assessed using tests on paper and filled out in pencil [18], [19]. Computer-based tools offer some advantages over traditional tests, such as collecting variables automatically (successes, failures, times, etc.). With the incorporation of VR, and later AR, new possibilities have been opened for the assessment of spatial memory. These technologies offer the possibility of physical movement or natural interaction with objects. In addition, AR allows direct contact with the real world, without the need to model virtual environments. These are aspects that make the experience much more similar to daily activities.

Different works that use VR for the assessment of spatial memory in humans have been presented [28], [29], [30], [31]. In early proposals, the users explored a VR environment while remaining seated and looking at a computer screen without physical displacement [20], [21], [22]. However, it is important to take physical displacement into account when considering spatial ability [11]. Previous works have considered physical displacement in their VR applications [32], [33], [34]. One study [32] investigated the impact of physical displacement on a VR task by comparing an inactive physical condition with an active physical condition. However, the authors concluded that no statistically significant differences were found in the task performance outcomes between the two conditions. In another work [34], researchers examined a VR task that involved navigating a maze. The participants were required to physically pedal on a real bicycle. An active physical condition was also compared with an inactive physical condition. The inactive physical condition offered better performance outcomes.

There are previous works on the use of AR for the assessment of spatial memory. Most of these works were presented by our research group [14], [35], [36], [37], [38], [39]. The first works [35], [36] developed an AR application that used images as targets. These targets had to be physically placed in the real environment. In posterior works [37], [38], an AR application based on SLAM was presented. The main difference from the previous works [35], [36] is that physical images in the space are not required. The authors of [40] presented an AR application for distance estimation and location memory. They conducted a study to determine if displaying holographic grids on the ground affected distance estimation and object location memory. The study concluded that the distance estimations were more accurate when displaying a grid but that object location memory performance was worse when displaying a grid. Auditory stimuli have also been studied for the assessment of spatial memory [39]. This work presented an AR application that included visual and auditory stimuli for the assessment of spatial memory. The study included in [39] compared the performance of participants when receiving visual or auditory stimuli. The study concluded that the number of successes was similar for the two stimuli, but the memorization of spatial-visual associations was dominant. Tactile stimuli have also been studied for the assessment of spatial memory [14]. This work presented the framework used for the development of the application presented here, an AR application for the assessment of spatial memory involving visual and tactile stimuli. The study data included in [14] was used to compare data from our study involving olfactory stimuli. The study in [14] concluded that the number of successes was similar for the tactile and visual stimuli, but the memorization of spatial-visual associations was dominant.

FIGURE 1. Example of the box used, the container with scent, and the coffee-scented container.

III. DESIGN AND DEVELOPMENT

A. DESIGN RATIONALE

Our aim was to design a task for the assessment of spatial memory involving olfactory stimuli. Our first step was to analyze the protocol that the participants must follow. The scents to be used should be distinguishable from each other. The task must work in any environment without the inclusion of physical elements that help the user in the recall task. The task must be configurable. The manipulation of the device should be as easy as possible. The interaction with the applications must be as natural and intuitive as possible. The application must store the tasks so that they can be used by any user later on. The user's performance data must be persistently stored when using the application.

We made several decisions regarding these characteristics. The protocol for this study follows a similar structure to previous works, with users completing two phases: learning and evaluation. The learning phase involves learning the location of stimuli in space, while the evaluation phase requires the users to place the stimuli in their original location from the learning phase. Another decision to make was to decide if the users had to smell the scents in the environment in the desired positions or if the users did not physically move. We decided that the users had to physically move around the environment in order to make the task more ecological. Thus, it was decided that the users should physically smell the scents in the selected locations in the real environment. In order for the scents to be distinguishable from each other, we had the collaboration of a specialist in the production of 100% phytotherapeutic handmade products (e.g., soaps, candles, essences, oils, etc.). This specialist suggested the eight distinguishable and recognizable scents to be used. This expert also suggested that the users should smell the scent of coffee after experiencing each scent in order to neutralize it (Fig. 1). Coffee has previously been proposed as a neutralizer [7], [41]. The possibility of using an AR application in both the learning phase and the evaluation phase was studied, but taking into account that the users had to physically smell the containers in which the scents were located. Using an AR application in the learning phase was discarded because there were more disadvantages than advantages. The AR application could have been used in this learning phase to automatically record the time used in the phase as well as to record the order in which the different scents were smelled and their exact moment. However, the time that had to be invested to do this made the task take longer than necessary. Therefore, for the learning phase, we decided to use containers with scents and place them in the desired locations. We also had the advice of the phytotherapist to determine the containers to be used and how best to preserve the scents in them. We used eight identical containers with a hermetic closure. They were indistinguishable from each other with the naked eye, and each one was equipped with an interior cotton that was impregnated with a different scent (Fig. 1). The users only had to turn the lid of the container to open it. The scents were in hermetically sealed bottles and the cotton could be impregnated again when necessary. For the evaluation phase, an AR application was used to place an object representing the scent in the location where the user had smelled it. A virtual box was used to ensure that the object to be located in the environment would not help the user to relate it to the scent smelled. This box had the same appearance as a physical box that would contain the scents. In order to associate the virtual box with the scent inside a physical box, barcodes that were glued to the physical boxes were used (Fig. 1).

For development platforms, the two most commonly used platforms are Unity and Unreal. Unity was selected because the research group had already worked with this platform and switching to Unreal provided no benefit. For the programming of the AR application, we had to choose among several SDKs. These needed to include physical objects (Vuforia), recognize flat surfaces (Vuforia, ARCore), or recognize objects and their depth (Tango, ARKit). Vuforia with targets (model targets or image targets) was ruled out because it needs the inclusion of physical elements. The SDKs for the recognition of flat surfaces were also discarded. ARKit was ruled out because it requires an iOS device to run and a Mac to program. Therefore, at the time of making the decision, we decided to use Tango. Tango was chosen because the research group had already worked with this SDK, and we also had our custom-developed framework to build AR applications [14]. To make the handling of the device as easy as possible, an ad-hoc case was designed for the device (Fig. 2). This case had a double purpose, to protect the device and to facilitate handling by the user.

Another decision was to design the application to appear in landscape mode (Fig. 2), which allows a greater view of the scene. Any of the four sides of the screen could be used for button placement. The buttons were placed at the bottom since this area is easy to manipulate for both left-handed and right-handed users and is where the menus usually appear. We also decided that, if only two buttons were to appear, these buttons would be placed at the ends of the lower area (Fig. 2). To place the virtual boxes in the scene, the users only have to identify the location of the box and press a finger on the screen to fix the box in that location.

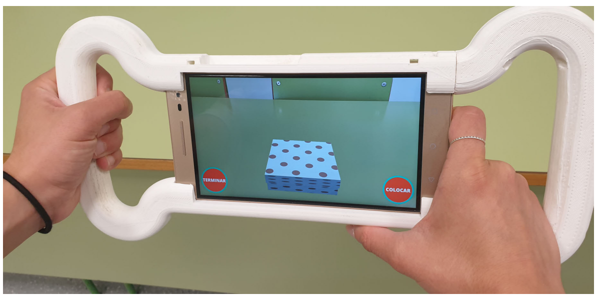

FIGURE 2. Placement of a virtual box in the desired location in the environment using the AR application.

The application was developed using this design. The application can work in any indoor environment. The supervisor customizes the task with the number of stimuli and their locations. The application stores the different configurations, and the supervisor selects the desired configuration for a particular session.

B. DEVELOPMENT

The main task that the participants must perform consists of two phases: a learning phase and an evaluation phase. In the learning phase, the participants must walk around a real environment and remember the location of the olfactory stimuli. In the evaluation phase, the participants have to indicate the location where they smelled the different scents using the AR application (Fig. 2). The room is around 38 m^2 (5 $\times$ 7.5 meters). The room used in this study is shown in Fig. 3. The participants must look for physical boxes distributed around the room. The participants open the container inside the box, smell, and remember its location. After smelling a container with a scent, the participant smells a container with the scent of coffee to neutralize the previous scent (Fig. 1). Only the time used by the participants is stored in this learning phase. In the evaluation phase, the AR application is used. In this phase, the participants smell the scent of one of the containers, using the application, the supervisor then scans the barcode of the box to know the scent it contains (Fig. 4). Using the AR application, the participants only see a box that they place in the location in which they think they have smelled its scent (Fig. 2). For this purpose, the environment must be set up in two phases: room scan and box configuration. In the room scan phase, the supervisor scans the room to be used in a study. This scan allows the AR application to store the geometry of the room. This stored information allows the application to relocate the device and the objects in the scanned area. This scan includes all of the physical elements (e.g., walls, tables, chairs, etc.). In the box configuration phase, each of the physical boxes to be used has a barcode attached to it so that the AR application can associate the scent that each box contains. The supervisor scans the barcode on a box (Fig. 4) and places the associated virtual box in the desired location in the environment using the AR application. On the device screen, the supervisor only sees one box, which is the same for all of the scents. In our study, we used eight scents. These scents were: chocolate, vinegar, strawberry, mint, cinnamon, lavender, vanilla, and tangerine. The AR application allows the supervisor to place the boxes on flat surfaces (horizontal or vertical). In this study, the boxes were placed on tables. The bottom side of the virtual box is placed on the detected surface. The boxes appear parallel to the device screen and cannot be rotated. The boxes always face the device's camera position and their up vectors are perpendicular to the detected surface plane.

Another application was developed for a map-pointing task (Fig. 5). The map-pointing application displays a map of the environment. This map is a two-dimensional map that reproduces the room in which the study was carried out. The subjects smell the scents in the boxes and place that scent (represented as a box) on the map using a tablet. A discrepancy of 0.5 meters (at map scale) is allowed between the selected position and the real position. The participants have one opportunity to place the box in the correct location. They

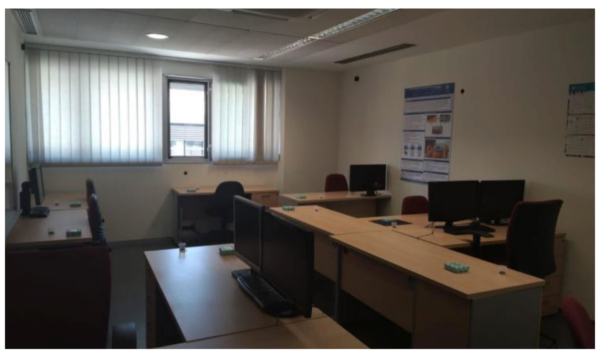

FIGURE 3. Room used in our study.

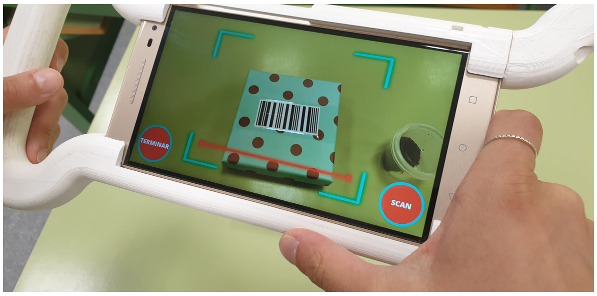

FIGURE 4. The barcode of a container being scanned.

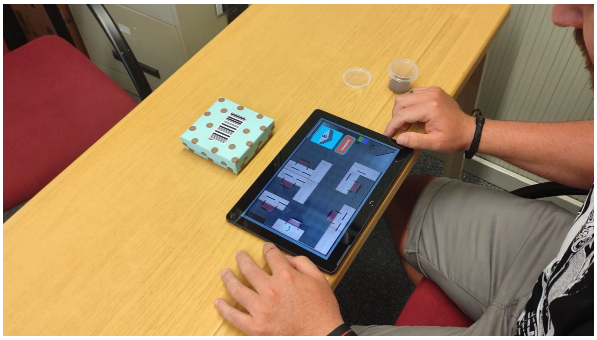

FIGURE 5. The map-pointing application.

are not notified of successes or errors. The repositioning of a box after its placement is not allowed.

C. HARDWARE & SOFTWARE

The Lenovo Phab 2 Pro mobile device was used as hardware support for the AR application. This mobile device is equipped with four cameras (three rear and one front) that are compatible with Tango SDK. Its rear camera system is made up of: a 16MP RGB camera, a depth camera, and a wide-angle lens camera to capture panoramic images. The screen is a 6.4-inch Quad HD panel with good contrast, even outdoors. The weight of the device is 259 g. To facilitate its manipulation, it was attached to a case that was specifically designed for the device. The case was printed on a 3D printer that uses ABS white material. This case protects the device and allows users to hold and move it comfortably. The device with its case is shown in Figs. 2 and 4.

For the development, we used Unity and our own framework for building AR applications [14]. For this application, our framework used the Tango SDK as base SDK because the device used was compatible with this SDK. In our framework, another SDK can be used as a base, e.g., ARKit. In our AR application, we used three core SLAM features: 1) Area Learning. This allows the scene morphology to be scanned and stored. It is possible to specify certain points where the virtual elements will be located. These points in the space are stored together with the characteristics of the environment. 2) Motion Tracking. The device always knows its relative position with respect to the real environment at all times. 3) Depth Perception. The depth camera is used to detect flat surfaces on which virtual objects can be placed.

IV. STUDY

A. PARTICIPANTS

The participants were adults who were recruited from a university campus. They were randomly selected, but we tried to maintain a balanced percentage between men and women. Before starting, we explained the steps and aims of the study and how we would process the data collected, and we gave each participant basic instructions on how to use the device and the application.

The study involving olfactory stimuli was carried out with a total of twenty-five participants between the ages of 21 and 58, with a median of 29 and a mean of 29.88 ± 8.45 of whom 14 (56%) were men and 11 (44%) were women. A total of 28% of the participants were students or had training in the humanities or human or social sciences. A total of 72% of the participants were students or had training in physical-natural sciences, exact sciences, and technology.

The participants signed the informed consent before carrying out the experiment. The study was approved by the Research Ethics Committee of the Universitat Politècnica de València, Spain, and was conducted in accordance with the declaration of Helsinki. The data of the study was compared with the data of a previous study [14] that involved tactile and visual stimuli. In that study, there were forty-seven participants with a mean age of 30.98 ± 9.72, consisting of 70% men and 30% women.

B. MEASURES

The performance variables stored by the AR application are the following:

- Total Stimuli - the total number of scents that the subjects located correctly in the evaluation phase. The minimum and maximum values are 0 and 8, respectively. This variable does not consider multiple attempts to locate a scent as long as the maximum of three attempts per scent is not exceeded.
- Total Attempts - the total number of failed attempts. This variable stores the total number of failed attempts by the user to locate a scent, adding up the number of failures of each of the scents. The minimum is 0 and the maximum is 24 (3 for each of the 8 scents).
- Learning Time - the time taken (in seconds) by the subject to learn the location of the scents. The learning order of the scents is not considered since this is at the discretion of the subject.
- Evaluation Time - the time taken (in seconds) by the subject to place all of the scents in their remembered locations. The time is automatically stored when the user places the last scent.

The performance variable stored by the map-pointing application is the following:

- Total Stimuli - the total number of scents that the subjects located correctly on a map that represents the same space in which the AR application was used. The subjects indicate the location of the scents that they have previously smelled on a map. The subjects are asked to

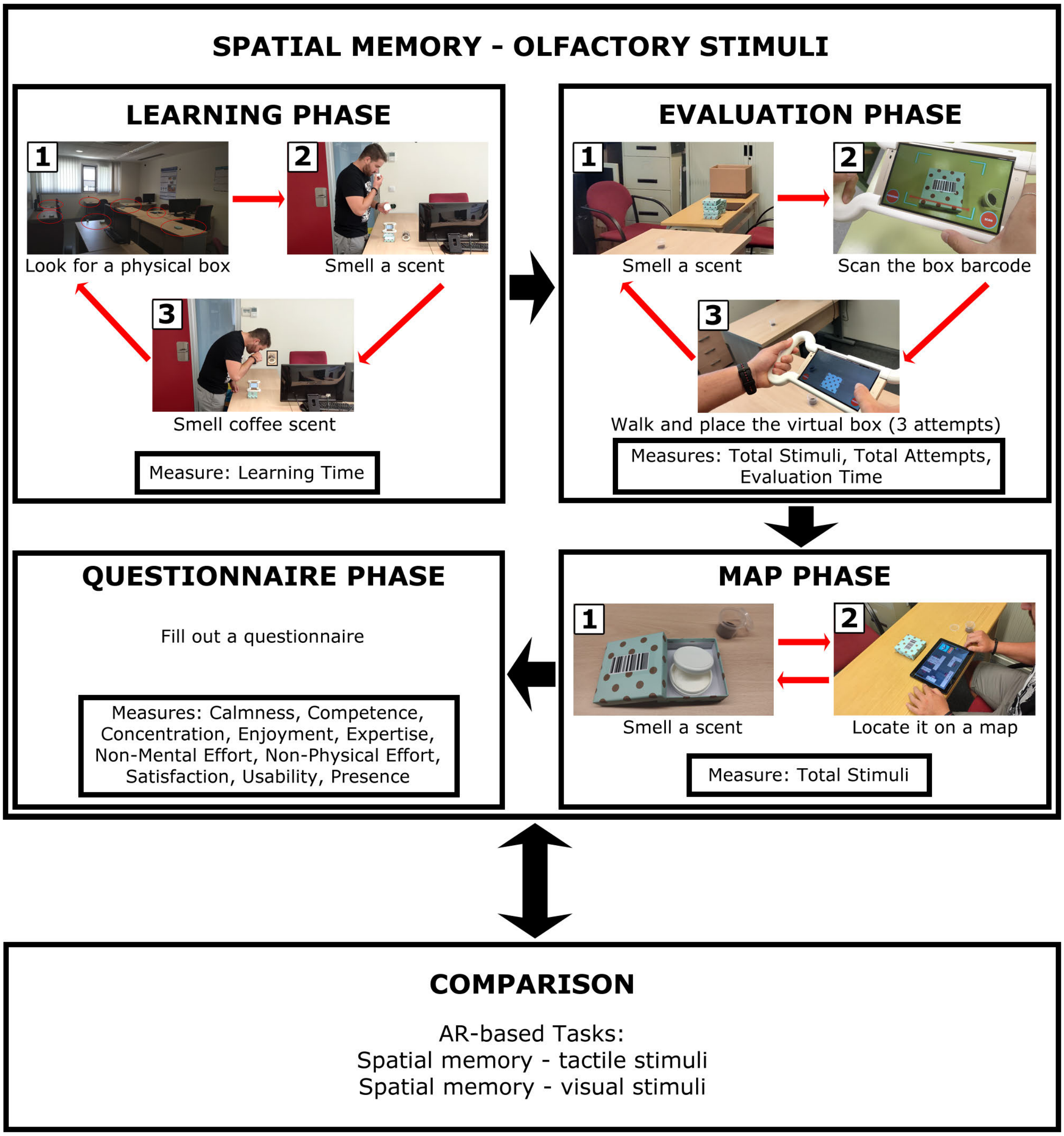

FIGURE 6. Schematic diagram of the study.

carry out this task without looking at the physical space where they carried out the main task with the mobile device.

The subjective variables for the AR application are the following:

After using the AR application, the participants completed a 75-question online questionnaire. This questionnaire collected demographic and subjective data. The subjective data was related to the user's perception of the experience performing the task and using the AR application. This data was grouped and averaged into 10 variables for statistical analysis: calmness, competence, concentration, enjoyment, expertise, non-mental effort, non-physical effort, satisfaction, usability, and presence. To calculate the score for these variables, we grouped the scores of the questionnaire answers related to these concepts and calculated their arithmetic mean. All of the questions were formulated in a positive way. The questionnaire was designed to allow answers with Likert scale values between 1 (Strongly disagree) and 7 (Strongly agree). The questionnaire was specifically designed for this study, although some questions are adaptations of commonly used questionnaires [42], [43], [44].

C. PROCEDURE

We divided the complete study for the participants into four sequential phases: Learning, Evaluation, Map, and

Questionnaire. The main aspects of this study are represented in a schematic diagram as shown in Fig. 6.

1) LEARNING PHASE

In this phase, the participant must move around the environment examining each of the boxes with olfactory stimuli (Fig. 6-Learning Phase (1)). For this purpose, visually indistinguishable boxes are distributed around the room, each of which has a recognizable characteristic scent inside. Eight identical boxes were prepared. They are indistinguishable from each other with the naked eye and each one is equipped with an inner cotton impregnated with a different scent as follows: chocolate (box 1); vinegar (box 2); strawberry (box 3); mint (box 4); cinnamon (box 5); lavender (box 6); vanilla (box 7); and tangerine (box 8). These boxes were distributed throughout the room, repeating the same scheme and the same positions for each participant. The boxes and their location can be observed in Fig. 7. The participant smells each container, one by one, trying to identify the scent and trying to remember its location in the room (Fig. 6-Learning Phase (2)). After smelling a container with a scent, the participant smells a container with the scent of coffee to neutralize the previous scent (Fig. 6-Learning Phase (3)). There is no time limit for this phase, although the time spent by each participant is stored.

2) EVALUATION PHASE

In this phase, the physical boxes are removed from the room, and, using the AR application, the participants must try to place the virtual boxes that represent each scent in the location they remember from the learning phase. To achieve this, the boxes with the scents are on a side table (Fig. 6-Evaluation Phase (1)). The participants smell the scents from the boxes one by one, in the same order for all participants. The supervisor scans the barcode of the box (Fig. 6-Evaluation Phase (2)) and the participants walk around the environment and place the virtual box in the location they consider to be correct (Fig. 6-Evaluation Phase (3)). A certain degree of tolerance is allowed in the positioning coordinates of the boxes (approximately 50 cm). If the box is misplaced, the participant is informed and is allowed two more attempts. This phase ends when the participants have finished placing all 8 boxes.

3) MAP PHASE

In this phase, the participants smell scents in the boxes, then locate them on a map using a tablet. They do this without looking at the real environment, relying solely on the two-dimensional map.

4) QUESTIONNAIRE PHASE

In this phase, the participants fill out an online questionnaire with 75 questions.

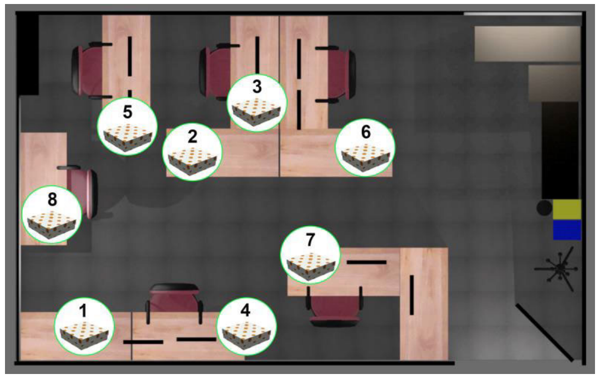

FIGURE 7. Location of the boxes in the room used in the study.

V. RESULTS

This section presents the data obtained by the study and the statistical analyses performed on them. Statistical analyses were applied to the performance variables and the subjective variables involving olfactory stimuli. The data from this study was compared with data involving visual and tactile stimuli [14]. The study collected data on visual and tactile stimuli from 53 adults (70% men) using a longitudinal design. The tactile condition was tested in the first session, followed by the visual condition two months later.

To check the normality of the data, we applied the Shapiro-Wilk test. This test indicates that the data does not come from a normal distribution, and, for this reason, non-parametric tests were applied. The results were considered to be statistically significant if $p < 0.05$. The software used for the statistical analyses was R (http://www.r-project.org).

A. PERFORMANCE VARIABLES

The box plots of Figures 8 – 11 show the performance variables for the olfactory, tactile, and visual stimuli. Slightly thicker horizontal lines represent the value of the median. The tinted area of the boxes shows the interquartile range. Circles are outliers. To determine if there were statistically significant differences, the Mann-Whitney U test was applied to the performance variables. Table 1 shows the results for olfactory and tactile stimuli, while Table 2 shows the results for olfactory and visual stimuli. The data of the variables included in these tables are the medians and interquartile range separated by semicolons, and the statistical significances are shown in bold. There were no significant differences for the number of stimuli correctly placed between olfactory and visual stimuli. However, although not statistically significant, the results obtained with olfactory stimuli were slightly better than those obtained with the tactile stimuli. With regard to the number of attempts, the olfactory stimuli were the ones that required fewer attempts, and this number was significantly lower when compared to tactile stimuli. With regard to the time in the learning phase, the olfactory stimuli required significantly more time than the visual and tactile stimuli. Similarly, in the evaluation phase, the olfactory stimuli took longer than the visual stimuli.

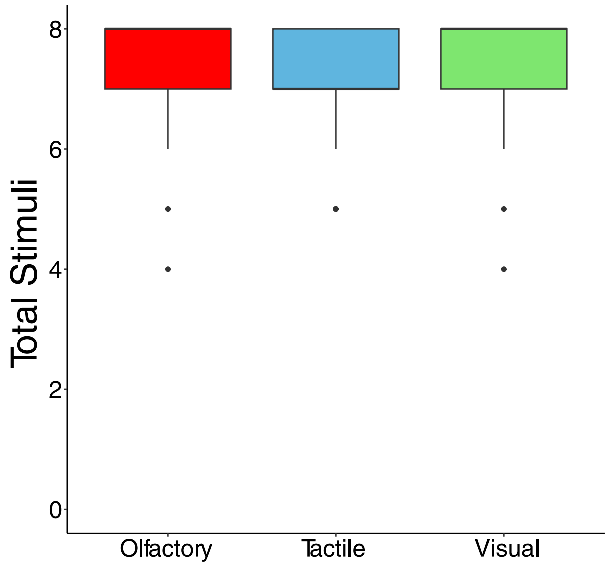

FIGURE 8. Box plot of the total stimuli variable for the olfactory, tactile, and visual stimuli.

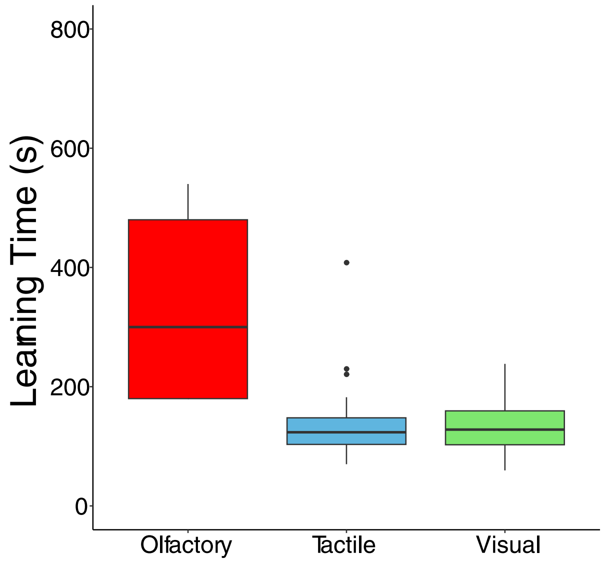

FIGURE 10. Box plot of the learning time variable for the olfactory, tactile, and visual stimuli.

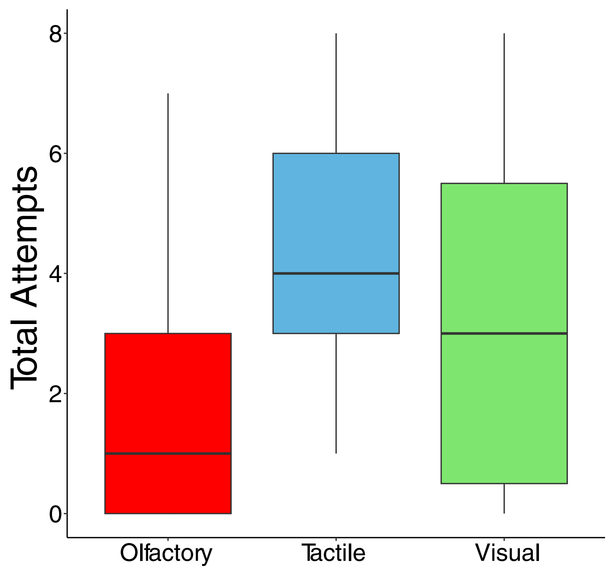

FIGURE 9. Box plot of the Total attempts variable for the olfactory, tactile, and visual stimuli.

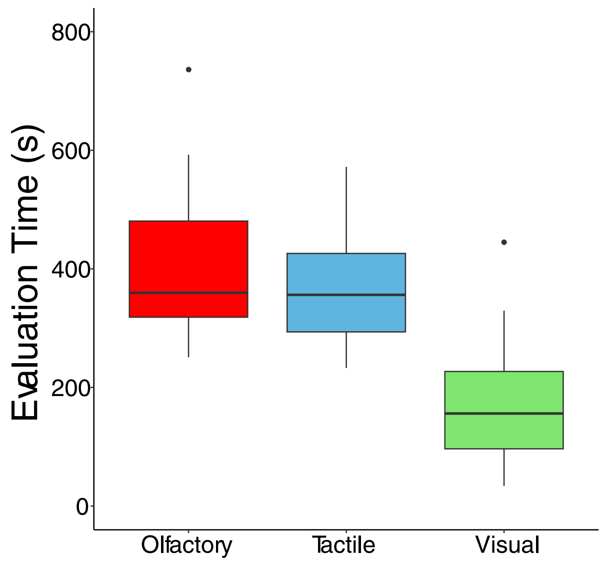

FIGURE 11. Box plots of the evaluation time variable for the olfactory, tactile, and visual stimuli.

TABLE 1. Mann-Whitney U test for performance variables comparing experiments with olfactory and tactile stimuli.

	Olfact.	Tactile	U	Z	p	r
T.Stimuli	8;1	7;1	734	1.89	0.06	0.22
T.Attempts	1;4	5;4	276	-3.71	**<0.001**	0.44
Learning.T	300;300	124;45	1130	6.43	**<0.001**	0.76
Evaluat.T	360;162	356;132	662	0.88	0.38	0.10

The variables Total Stimuli and Total Attempts are represented as T.Stimuli and T.Attempts, respectively. The variables Learning Time and Evaluation Time are represented as Learning.T and Evaluat.T, respectively.

TABLE 2. Mann-Whitney U test for performance variables comparing experiments with olfactory and visual stimuli.

	Olfact.	Visual	U	Z	p	r
T.Stimuli	8;1	8;1	644	0.76	0.45	0.09
T.Attempts	1;4	3;5	449	-1.67	0.09	0.20
Learning.T	300;300	128;57	1121	6.32	**<0.001**	0.75
Evaluat.T	360;162	156;130	1114	6.23	**<0.001**	0.73

The variables Total Stimuli and Total Attempts are represented as T.Stimuli and T.Attempts, respectively. The variables Learning Time and Evaluation Time are represented as Learning.T and Evaluat.T, respectively.

The Mann-Whitney U test was applied to determine whether there were statistically significant differences for the stimuli placed on the two-dimensional map and between the olfactory stimuli and the other two stimuli (visual and olfactory). Table 3 shows the results. The data of the variables included in this table are the medians and interquartile range

TABLE 3. Mann-Whitney U test for the total stimuli located in the map-pointing application and comparing the olfactory stimuli with visual and tactile stimuli.

Olfactory	Visual	Tactile	U	Z	p	r
6;3	6;1.5		536	-0.63	0.54	0.07
6;3		4;1.5	867	3.36	< **0.001**	0.40

separated by semicolons, and the statistical significances are shown in bold. No statistically significant differences were found between the olfactory and visual stimuli. However, there were statistically significant differences between the olfactory and tactile stimuli in favor of the olfactory stimuli.

In summary, the analysis of performance variables revealed that olfactory stimuli showed better performance than tactile stimuli, requiring fewer attempts and longer times in the learning and evaluation phases. No significant differences were observed between olfactory and visual stimuli in the number of correct memory associations between stimuli and spatial locations. In addition, olfactory stimuli outperformed tactile stimuli in terms of performance on the map-pointing task.

B. GENDER

The Mann-Whitney U test was applied to check whether there were significant differences in the performance variables based on the gender of the participants. Table 4 shows the results of the test for comparisons between women and men for each of the four performance variables. The data of the variables included in these tables are the medians and interquartile range separated by semicolons. No statistically significant differences were found for any of the performance variables based on the gender of the participants. Figures 12-15 show the interaction graphs for the performance variables, considering the age and gender of the participants. In Figures 12-15, to keep the plots from being cluttered and visually confusing, not all of the participants in the same group (men and women) are connected.

In summary, no significant gender differences were found for the performance variables (Total Stimuli, Total Attempts, Learning Time, and Evaluation Time) with olfactory stimuli.

TABLE 4. Mann-Whitney U test for performance variables considering the gender of the participants in the study with olfactory stimuli.

	Women	Men	U	Z	p	r
T.Stimuli	8;1	8;0.75	72	-0.33	0.77	0.06
T.Attempts	1; 3.5	1;3.75	70	-0.40	0.71	0.08
Learning.T	180;150	300;240	49	-1.60	0.12	0.32
Evaluat.T	354;81	393;188	65	-0.66	0.54	0.13

The variables Total Stimuli and Total Attempts are represented as T.Stimuli and T.Attempts, respectively. The variables Learning Time and Evaluation Time are represented as Learning.T and Evaluat.T, respectively.

C. AGE

Kruskal-Wallis tests were used to determine whether age affected the performance variables. The results showed no statistically significant differences for age when considering the Total Stimuli variable (χ^2 (14) = 18.04, p = 0.21), the

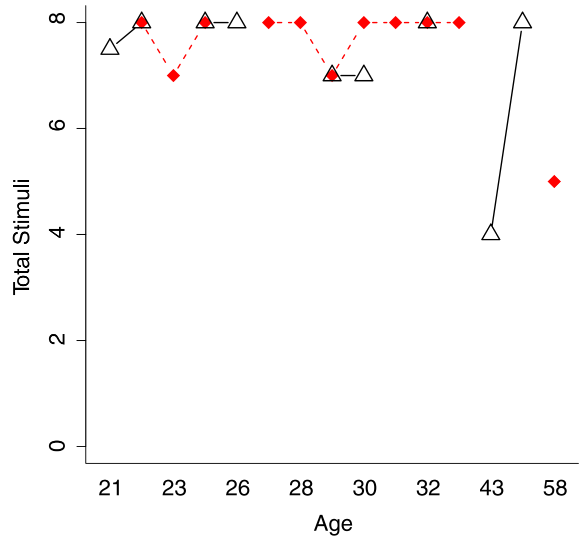

FIGURE 12. Interaction graph for the total stimuli variable considering the age and gender of the participants. The red rhombuses represent men. The triangles represent women.

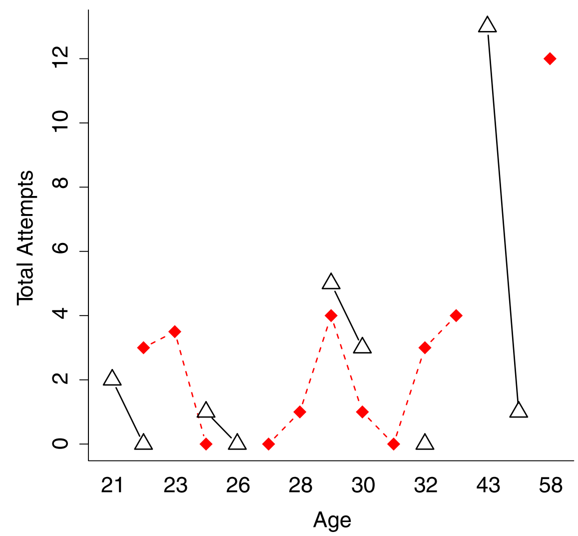

FIGURE 13. Interaction graph for the Total Attempts variable considering the age and gender of the participants. The red rhombuses represent men. The triangles represent women.

Total Attempts variable (χ^2 (14) = 14.34, p = 0.43), the Learning Time variable (χ^2 (14) = 13.73, p = 0.47) and the Evaluation Time variable (χ^2 (14) = 12.64, p = 0.56).

In summary, no significant age differences were found for the performance variables (Total Stimuli, Total Attempts, Learning Time, and Evaluation Time) with olfactory stimuli.

D. SUBJECTIVE VARIABLES

Mann-Whitney U tests were used to check if there were statistically significant differences between the subjective variables for the olfactory and visual stimuli (Table 5; the data of the variables are the medians and interquartile range separated by semicolons). Statistically significant differences were found for the variables of enjoyment, usability,

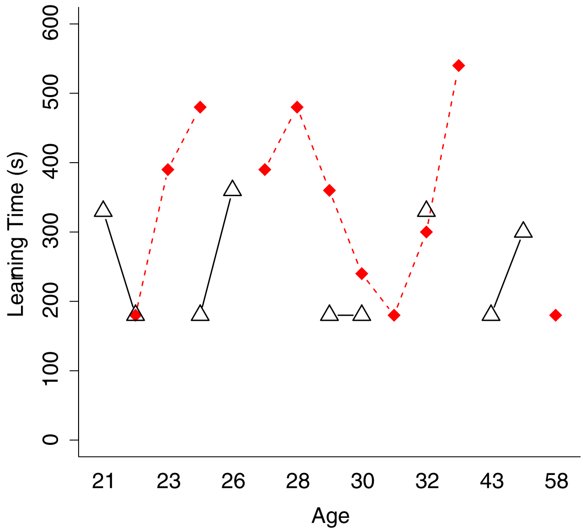

FIGURE 14. Interaction graph for the learning time variable considering the age and gender of the participants. The red rhombuses represent men. The triangles represent women.

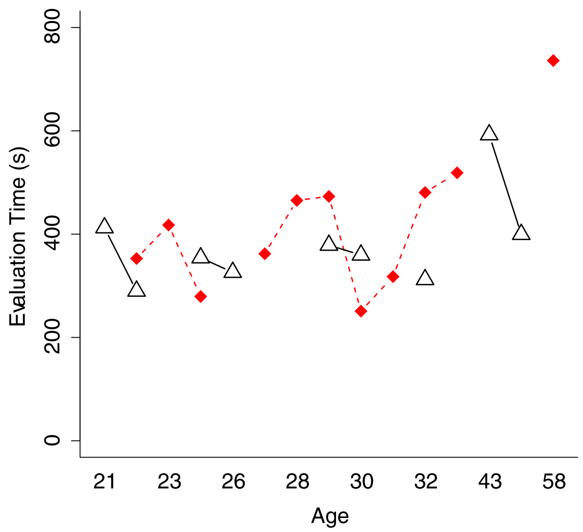

FIGURE 15. Interaction graphs for the evaluation time variable considering the age and gender of the participants. The red rhombuses represent men. The triangles represent women.

calmness, non-mental effort, non-physical effort, and satisfaction in favor of the olfactory stimuli.

Mann-Whitney U tests were applied to check if there were statistically significant differences between the subjective variables for the olfactory and tactile stimuli (Table 6; the data of the variables are the medians and interquartile range separated by semicolons). Statistically significant differences were found for the variables of enjoyment, competence, and calmness in favor of the olfactory stimuli.

Fig. 16 shows a radial graph with the means of the subjective variables.

The Mann-Whitney U test was also applied to the two sub-groups separated by gender from the olfactory stimuli. Table 7 shows the results. No significant differences were found for the subjective variables and considering gender.

TABLE 5. Mann-Whitney U test for the subjective variables between the olfactory and the visual stimuli.

	Olfactory	Visual	U	Z	p	r
enjoyment	7.0;0.5	6.0;1.0	806.5	2.82	**0.005**	0.330
concentration	6.0.5;1	6.5;1.0	669.5	1.00	0.320	0.120
usability	6.7;0.3	6.7;1.3	768.0	2.21	**0.028**	0.260
competence	7.0;1.0	7.0;1.0	589.0	0.02	0.990	0.002
calmness	7.0;0.0	6.0;2.0	781.0	2.62	**0.009**	0.310
expertise	6.0;2.0	6.0;2.0	594.0	0.08	0.940	0.010
n-mental eff	7.0;1.0	6.0;1.0	754.0	2.20	**0.030**	0.250
n-physical eff	7.0;0.0	6.0;2.0	813.5	3.01	**0.003**	0.360
satisfaction	7.0;1.0	6.0;1.0	905.5	3.93	**<0.001**	0.460
presence	5.7;2.0	5.3;1.2	633.0	0.54	0.590	0.060

The variables non-mental effort and non-physical effort are represented as n-mental eff and n-physical eff, respectively.

TABLE 6. Mann-Whitney U test for the subjective variables between the olfactory and the tactile stimuli.

	Olfactory	Tactile	U	Z	p	r
enjoyment	7.0;0.5	6.0;1.0	839.0	3.21	**0.001**	0.38
concentration	6.5;1.0	6.5;1.0	596.5	0.11	0.910	0.01
usability	6.7;0.3	6.7;0.7	716.5	1.59	0.110	0.19
competence	7.0;1.0	6.0;2.0	792.5	2.57	**0.010**	0.30
calmness	7.0;0.0	6.0;1.0	819.0	3.05	**0.002**	0.36
expertise	6.0;2.0	6.0;2.0	615.5	0.35	0.730	0.04
n-mental eff	7.0;1.0	7.0;1.0	621.5	0.49	0.630	0.06
n-physical eff	7.0;0.0	7.0;0.5	635.5	0.78	0.440	0.09
satisfaction	7.0;1.0	7.0;1.0	641.5	0.75	0.460	0.09
presence	5.7;2.0	5.4;1.1	634.0	0.55	0.590	0.07

The variables non-mental effort and non-physical effort are represented as n-mental eff and n-physical eff, respectively.

TABLE 7. Mann-Whitney U test for the subjective variables in the olfactory stimuli considering the gender of the participants.

	Women	Men	U	Z	p	r
enjoyment	7.0;0.5	7.0;0.5	82.5	0.35	0.75	0.07
concentration	6.5;0.8	6.5;1.0	79.5	0.14	0.91	0.03
usability	7.0;0.3	6.7;0.7	95.5	1.10	0.29	0.22
competence	7.0;1.0	7.0;1.0	72.0	-0.31	0.78	0.06
calmness	7.0;0.0	7.0;0.0	74.0	-0.26	0.83	0.05
expertise	6.0;1.0	6.0;2.0	98.5	1.25	0.22	0.25
n-mental eff	7.0;0.5	7.0;0.8	77.0	0.00	1.00	0.00
n-physical eff	7.0;0.5	7.0;0.0	60.5	-1.42	0.17	0.28
satisfaction	7.0;0.5	7.0;1.0	85.0	0.54	0.62	0.11
presence	6.3;2.7	5.7;1.4	88.0	0.61	0.56	0.12

The variables non-mental effort and non-physical effort are represented as n-mental eff and n-physical eff, respectively.

In summary, olfactory stimuli outperformed visual stimuli on subjective variables such as enjoyment, usability, calmness, non-mental effort, non-physical effort, and satisfaction. Olfactory stimuli also outperformed tactile stimuli on variables such as enjoyment, competence, and calmness. Notably, no gender differences were found for subjective variables with olfactory stimuli.

E. CORRELATION ANALYSIS

Spearman's correlation test was applied to check the relationships between performance variables. Table 8 shows the results. Three significant correlations were found. The greater the total number of stimuli, the fewer number of attempts and the shorter the time used in the evaluation phase. The

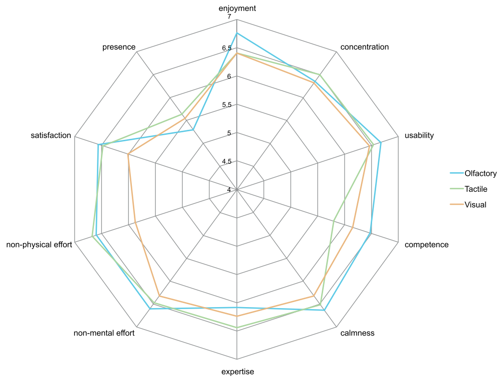

FIGURE 16. Radial graph showing the means of the subjective variables considering the olfactory, tactile, and visual stimuli.

TABLE 8. Spearman's correlation for the performance variables using the olfactory stimuli.

	Total Attempts	Learning Time	Evaluation Time
Total Stimuli	**-0.77**	0.46	**-0.65**
Total Attempts		-0.38	**0.80**
Learning Time			-0.12

greater the number of attempts, the more time required in the evaluation phase.

Spearman's correlation test was used to examine the relationships between subjective variables. Table 9 shows the results. There were significant and positive correlations between the perception of concentration and usability and between competence and calmness. These relationships are shown in the scatter plots of Figures 17-18 (the green area of each of the scatter plots represents a 95% confidence level interval for predictions from a linear model).

TABLE 9. Spearman's correlation for the subjective variables considering the olfactory stimuli.

	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1)	0.36	0.38	0.05	-0.04	-0.07	0.15	0.34	-0.08
(2)		**0.69**	0.24	0.36	-0.07	0.06	0.04	0.07
(3)			0.14	0.27	-0.02	0.09	0.21	0.20
(4)				**0.59**	-0.03	0.11	-0.13	0.08
(5)					-0.02	0.43	-0.07	0.15
(6)						0.50	-0.20	0.01
(7)							0.16	-0.01
(8)								0.07

The numbers included in the table in the headers of rows and columns have the following meaning: (1) enjoyment; (2) concentration; (3) usability; (4) competence; (5) calmness; (6) non-mental effort; (7) non-physical effort; (8) satisfaction; (9) presence.

In summary, the correlations revealed insightful relationships: fewer attempts and shorter time with an increased total number of stimuli; and positive associations between perceptions of concentration and usability and between competence and calmness in subjective ratings.

VI. DISCUSSION

A SLAM-based AR application was developed to assess olfactory stimuli. This application allows subjects total

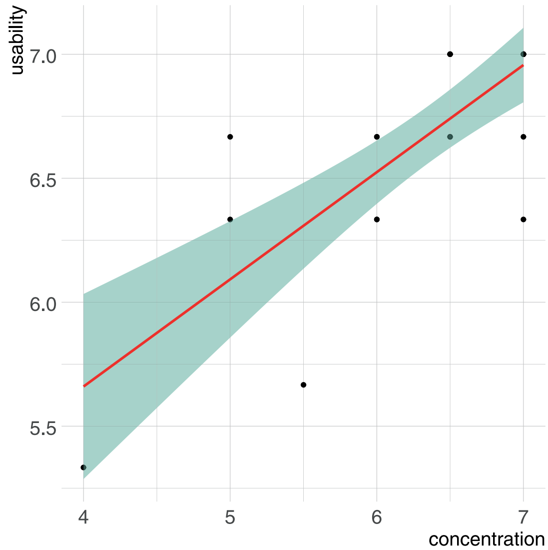

FIGURE 17. Scatter plot for the positive correlations between usability and concentration.

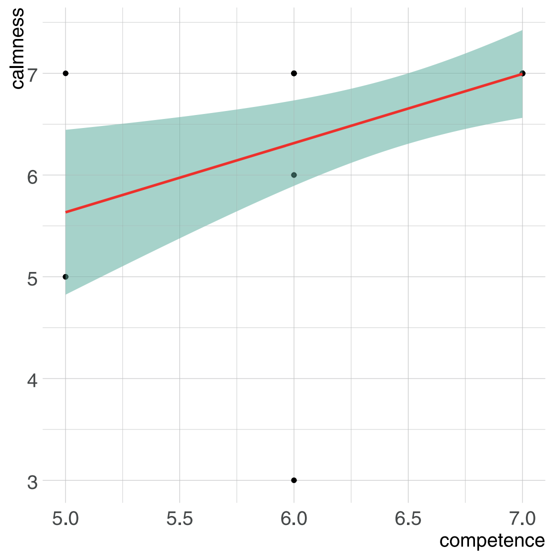

FIGURE 18. Scatter plots for the positive correlations between competence and calmness.

freedom of movement around the environment where they can observe both physical and virtual objects. Because our AR application uses SLAM, it does not require any physical elements in the environment to work. Research has shown that allowing subjects freedom of movement around the environment is a positive aspect for assessing short-term memory [23], [24].

Previous studies focused on assessing spatial memory using mainly visual [14], [33], [35], [40], auditory [39], [45], or tactile [14], [46], [47] modalities. Olfactory stimuli were considered in this work. To our knowledge, our work is the first one that uses olfactory stimuli to assess spatial memory for the location of stimuli in a 3D space. The work that is most related to ours is for wayfinding tasks [7]. In that work, the users also smell real scents. However, our task, procedure, and objectives were different. Nevertheless, we share the conclusion of how important the sense of smell is in spatial memory and that a landmark must be perceptually salient regardless of the sense used [7], [48].

With regard to the performance variables, there were no significant differences for the number of stimuli correctly placed between olfactory and visual stimuli. However, although not statistically significant, better results were obtained when using olfactory stimuli compared to tactile stimuli. With regard to the number of attempts, the olfactory stimuli were the ones that required fewer attempts with the number being significantly lower than that of tactile stimuli. These results suggest that olfactory stimuli are valid stimuli for assessing the memorization of olfactory-spatial associations. This modality is comparable to using visual stimuli and superior to using tactile stimuli. Our conclusion regarding visual and olfactory stimuli is in line with the results reported in a previous study [7] that found that humans perform almost equally well with visual, acoustic, or olfactory stimuli.

With regard to the time spent in the learning phase, the learning of olfactory stimuli required significantly more time than the other learning modalities. With regard to the time needed in the evaluation phase, the olfactory stimuli required significantly more time than the visual stimuli, but no significant differences were found regarding the tactile stimuli. The fact that the time required in the learning phase was significantly greater for the olfactory stimuli is justified by the physical and mechanical features of each stimulus. The steps that the participants had to carry out to smell the scents in the containers took time (opening the box, opening the container, smelling, opening the neutralizing container and smelling). The time required in these steps is greater than placing their hands inside boxes (tactile) or simply looking through the mobile device (visual). The same rationale can be used to justify the greater time required by the participants for the location of the olfactory stimuli compared to the visual stimuli in the evaluation phase.

In addition, the olfactory identification and discrimination processes performed during the learning and evaluation phases include the so-called olfactory quality discrimination. It has been shown by brain stimulation that the quality discrimination of a scent is facilitated by the mental-visual representation of the scent [49]. Thus, to acquire quality discrimination of a scent, a mental-visual representation of the scent is created. We believe that this influence of the mental-visual representation on the olfactory condition affects the timing of the two phases in our study. The participants were not blindfolded. This is a common practice to facilitate olfactory discrimination because, by avoiding visual stimulation, there is no interference of visual stimulation in the process of identifying the quality of a scent with its mental-visual representation. In our study, visual stimulation was necessary to associate olfactory stimuli with spatial locations. This complicates the discrimination among scents as visual cues from the real world interfere with the visual representation of the scents in the mind.

No statistically significant differences were found for the performance variables considering gender and age. Our results are in line with previous studies [39], [50].

With regard to the number of stimuli correctly located on a two-dimensional map (map-pointing application), no statistically significant differences were found between the olfactory and visual stimuli. However, there were statistically significant differences between the olfactory and tactile stimuli in favor of the olfactory stimuli. These results suggest that the information acquired through olfactory and visual stimuli was equivalently transferred to the mental map of the environment and to a lesser extent, through tactile stimuli.

For the AR experience, no statistically significant differences were found for the subjective variables considering gender. The scores are very high with values close to or greater than 6 in all of the variables analyzed, as shown in Tables 5-7 and in Fig. 16. This confirms that our AR application satisfied the expectations of the participants for all of the variables analyzed. When comparing the scores based on the sense of smell with those based on the sense of sight or touch, the scores favor the sense of smell.

With regard to the correlations obtained, positive and significant correlations were obtained between the variables of concentration and usability and between competence and calmness. These results indicate that the higher the concentration, the greater the perceived usability, and also the more competence, the calmer the participants. These results suggest the importance of the participant's state of anxiety during the task. They are consistent with previous findings demonstrating the role of anxiety in spatial orientation [38].

It can be concluded that the tactile modality is less accurate in terms of localization than the visual and olfactory modalities when comparing the three sensory modalities used in the AR spatial task. Compared to the olfactory and visual modalities, users tend to make more attempts to correctly place stimuli in this modality [14]. Object recognition by touch is less accurate than other modalities because it is more susceptible to the influence of practice, which negatively affects the accuracy and mental representation of associations between the stimulus and its location on a map. Therefore, we believe that the disadvantage of the tactile modality is related to the intrinsic cognitive difficulty in identifying stimuli through this sensory modality. The disadvantage of the olfactory modality compared to the visual modality is, however, a procedural one. It only affects the duration of the learning and evaluation phases.

The visual modality of the AR application is more reliable than the olfactory mode since it allows the user to consistently rely on their sense of sight. The results of the correlation analysis between subjective perception variables indicate that the AR application with visual stimuli is more advantageous than the one with olfactory stimuli. The association between usability and concentration in the AR application was found specifically with olfactory stimuli, but not with visual stimuli [14]. This suggests that the AR application with visual stimuli may be more accessible to a wider range of users, including those with cognitive difficulties. In addition, the correlation found between enjoyment and sense of presence in the AR application using visual stimuli [14] supports the fact that visual stimuli play an important role in creating a sense of presence and improving the overall user experience.

To our knowledge, our work is the first olfactory system that allows user responses to be stored in a navigation task for learning spatial-olfactory associations. However, different olfactory systems have been proposed for their use in VR so that users have a more satisfactory experience. For example, an olfactory system attached to the HTC Vive hand controller was presented in a recent work [51]. The users can manipulate virtual objects in a VR environment and smell them, which is similar to real life. In real life, users would hold a cup of coffee to their nose in order to smell it. The system includes four different scents. The user releases the scent by pressing the trigger button on the controller. Another option is the passive release of the scent based on how close the hand controller is to the headset. The authors presented a smell training game in a virtual wine tasting cellar as an example of use.

VII. LIMITATIONS

The time taken by the participants during the learning phase was influenced by their ability to identify scents, the procedure for accessing scents via containers, and the use of a neutralizing scent. The supervisor had to ensure that all of the participants used the neutralizing essence because some participants wanted to skip that step in the learning phase. Furthermore, in terms of participant perception, although the scents were chosen based on expert opinion, one participant mentioned the similarity between the scents of chocolate and vanilla. Additionally, some participants found the scents of cinnamon or vinegar to be unpleasant. Finally, with regard to the use of the AR application, bad lighting conditions and fast camera movements affected the performance of the AR application. Some participants expressed a preference for having the physical scent containers brought to their location rather than using the AR application during the evaluation phase.

The distribution or dispersion of odor molecules can follow specific patterns that are influenced by external factors, such as air currents, temperature, humidity, ventilation or the presence of other odors. These confounding external factors could alter what a participant might smell at any given time. Therefore, in future studies involving the sense of smell, the presence of confounding external factors should be kept to a minimum. Some of the recommendations we followed in our study are the following: (1) verify that doors and windows are kept closed during tasks to avoid air currents; (2) control the temperature, humidity, and ventilation of the room; (3) verify that items that could be a source of odors, such as food, are not brought into the room.

The study had a relatively small sample size, with most participants coming from backgrounds in the physical sciences, exact sciences, and technology. This may limit the generalizability of the findings to populations with different educational backgrounds.

VIII. FUTURE WORK

It would be very interesting to extend our system to use some diffuser devices similar to those used in [51]. Passive scent release would be a good option to control exposure to scents, including the neutralizing scent. Additionally, this option would eliminate the manipulation of containers that affects the time spent in the learning phase. With regard to the scents used, it could be interesting to analyze participants' ability to differentiate between scents beforehand. This would also be useful for ruling out any odors that might be unpleasant.

Future research should examine task complexity by adjusting the number of stimuli or varying the spatial complexity of indoor environments. In addition, it would be revealing to analyze differences in application performance across age groups. Evaluating the performance of the application in clinical populations with spatial learning or memory difficulties could provide valuable insights.

Although movement during task performance with the application may complicate the study of neural activity using functional neuroimaging techniques, alternative approaches such as recording psychophysiological variables (e.g., electrodermal conductance or heart rate variability) remain feasible.

IX. CONCLUSION

The AR application for olfactory stimuli is flexible. It allows configuring various tasks in different environments and storing them. It maintains consistent conditions for all users and automatically collects data for further analysis.

The use of AR is effective for the assessment of short-term memory using olfactory stimuli. The olfactory stimuli offer values (median and interquartile range) for the performance variables (Total Stimuli and Total Attempts) that are equal to or better than those provided by visual and tactile stimuli. The greater time required in the learning and evaluation phases is justified by the physical and mechanical features of each of the stimuli. With regard to the performance variable in the map-pointing application (the number of stimuli correctly located on a two-dimensional map), these results suggest that the information from olfactory and visual stimuli was equally transferred to the mental map of the environment. This occurred to a lesser extent for tactile stimuli.

From these results, it can be concluded that the olfactory stimuli provided results similar to those for visual stimuli and better results than tactile stimuli. Gender and age did not have a significant impact on performance or subjective variables when considering olfactory stimuli. To conclude, olfactory stimuli are stimuli that can be used to assess spatial memory.

This study considers various sensory modalities and their impact on how individuals process and adapt to different stimuli. The implications of these findings extend beyond spatial memory tasks and could have an impact on personalized therapy or customized education based on individual sensory preferences. For example, this application and its potential enhancements can improve the identification and guidance of people with visual or hearing impairments to points of interest in educational or therapeutic settings. In addition, it could aid in therapies for individuals with cognitive impairments by facilitating the retrieval of autobiographical memories of places if an association of those places with specific olfactory properties can be established.

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