Virtual Reality for Object Location Spatial Memory: A Comparison of Handheld Controllers and Force Feedback Gloves

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Object Location Spatial Memory (OLSM) is used in everyday tasks for which it is important to remember where objects are in space. The spatial image of the environment to perform such OLSM tasks is created based on inputs from three spatial senses (visual, auditory, and haptic). Various causes, ranging from traumatic brain injury to Alzheimer's disease and dementia, can compromise OLSM, requiring OLSM rehabilitation techniques. Virtual reality (VR) can provide a safe environment for engaging rehabilitation experiences. In the last years, new technologies for multi-modal interaction such as force feedback gloves (FGs) have appeared on the market, but their possible advantages over handheld controllers (HCs) that come together with head-mounted displays have not been evaluated in the context of OLSM tasks. This paper investigates whether adding haptic input can lead to more effective OLSM training by comparing a pair of HCs with a pair of FGs in performing the same OLSM task, i.e. placing different objects in memorized locations. We conducted a within-subjects user study with 24 participants who performed the OLSM task in two conditions: with HCs and with FGs. Presence was measured with the IPQ questionnaire, and results showed statistically significant differences in favor of interacting with FGs on the general item about the sense of being there. Participants judged the system usability high in both conditions. Perceived fatigue was higher when using FGs. We expected better performance with FGs thanks to the addition of haptic input, but no statistically significant differences were found in the total number of correctly placed objects. Results showed that the time to complete the task was lower with the HCs than FGs. Future comparisons with other types of FGs may confirm that this type of OLSM task does not benefit from specialized haptic hardware, supporting the possibility of performing OLSM rehabilitation exercises at patients' home with affordable commercial VR kits.

CCS Concepts: • **Human-centered computing → Virtual reality**; *Haptic devices.*

Additional Key Words and Phrases: Virtual reality, spatial memory, force feedback gloves, handheld controllers, user study

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1 INTRODUCTION

Remembering everyday object positions, such as where we put the cup in the closet or where we left our sweater, and being able to describe the positional relations between a particular object and other objects in the space, are tasks that need Object-Location Spatial Memory (OLSM). This type of memory involves information about location, orientation, and direction. It is a representation or description of where things are in space, independent of how and in which order the observer wants to attend to these locations [31].

In order to perform OLSM tasks, people create and use a "spatial image" of the environment, which is a transient spatial representation regarding multiple points locations, simple paths, and oriented objects [25]. Such spatial image transcends the concept of modality as it can be based on input from three spatial senses (visual, auditory, and haptic), spatial language, and the recall of spatial layout from long-term memory (LTM) [25]. Spatial image is relatively short-lived and resides within the working memory (WM) [25]. WM refers to the system or systems assumed to be necessary to keep things in mind while performing complex tasks such as reasoning [3].

Various causes, including hippocampal lesions [18], infarcts in the right or left hemisphere of the brain [19], or more general memory deficiencies, like Alzheimer's disease and dementia [20], can compromise spatial memory. Moreover, one of the earliest indications of Alzheimer's disease is thought to be deficits in spatial memory [7]. The severity of these spatial memory deficits limits the quality of life of people who experience them, and the practice of memory rehabilitation techniques is recommended.

Virtual Reality (VR) is a computer-generated digital environment that can be experienced as if that environment were real [17]. In the rehabilitation context, VR experiences can provide different advantages compared to classic rehabilitation in the real world: a safe environment to train, the possibility of measuring users' performance without the users noticing it, and the possibility of creating more engaging experiences than just doing the required exercises [6, 27, 36, 39, 42].

Some VR setups, such as head-mounted displays (HMDs) or multiple projected screens, can make users feel surrounded by the virtual environment (VE), delivering immersive VR (iVR) experiences. The basic commercial VR kits include an HMD and two handheld controllers (HCs) allowing users to interact with the VE. The HMD provides users with visual and auditory inputs, while the controllers could provide basic vibrational feedback to the hands. Thanks to improved hardware and lower prices, consumer VR kits are increasingly widespread among consumers [2]. In 2021 only, over 10 million units were shipped [16].

A way to give users a greater sense of presence (i.e., the sense of being in the VE [38]) in the iVR experience is using specialized hardware capable of more advanced haptic feedback [32]. Haptics refers to the capability to sense a natural or synthetic mechanical environment through touch [11]. Haptic gloves (HGs) are wearable hand devices that deliver haptic feedback to the hands and the fingers. Some HGs are capable of vibrotactile feedback, while others are also capable of force feedback. Force feedback gloves (FGs) are HGs composed of sensors that can track the fingers' movements, apply vibrotactile feedback, and deliver kinesthetic feedback when

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grasping virtual objects. Thanks to the increasing popularity of VR kits, various commercial companies are interested in investing in HGs [1].

Notably, the combination of HMD and FGs provides the three spatial senses to users, allowing them to integrate visual and auditory inputs with haptics. Indeed, combining visual and tactile interactions is critical to building an efficient representation of the near-body space [26].

Therefore, this paper investigates whether adding haptic input can lead to more effective spatial memory training. More precisely, we compare a pair of HCs included in a commercial VR kit with a pair of commercial FGs to perform the same OLSM task.

The paper is organized as follows. Section 2 describes related work concerning user studies in iVR applied to OLSM tasks and user studies in iVR using HGs. Sections 3 and 4 present our study and its results. Sections 5 and 6 discuss the results and point out the limitations of the study. Section 7 concludes the paper by outlining future work.

2 RELATED WORK

To the best of our knowledge, there are no studies in the literature that concern iVR for OLSM tasks using FGs. Therefore, in this section, we separately present the results of previous studies in which participants were asked to perform OLSM tasks in iVR (Section 2.1), and previous studies concerning the use of HGs in iVR (Section 2.2).

2.1 IVR for OLSM Tasks

Several studies have already been conducted regarding OLSM tasks in iVR to find what enhances or worsens memorized position recall.

For instance, Xu et al. [44] explored the transfer of spatial knowledge from virtual to real spaces by developing a task requiring users to navigate with different locomotion techniques in a virtual reproduction of a physical environment and remember the location of virtual objects for later recall those positions in the physical world. Their findings showed no statistically significant differences in placement mistakes across the various locomotion techniques.

Hinterecker et al. [12] explored if the ability to remember object locations could depend on the horizontal or vertical alignment of the objects. According to their findings, if a person learns the locations from a single viewpoint, their memory for locations of horizontally and vertically aligned objects is similar. Their study also indicated that making judgments about the arrangement of objects is not solely based on remembering the relationships between the objects, but also includes the relationships between the objects and the surrounding environment.

Huang and Klippel [14] looked into how visual realism affected OLSM while also considering individual differences, gaze, and movement. The results indicated that high visual realism offers positive spatial learning affordances, even if the authors did not detect a significant relationship between visual realism and OLSM.

Liang et al. [24] developed a 3D virtual shopping mall with different shops where users had to remember the location of different items. Their study evaluated the effects of cooperation and competition in navigation tasks and spatial knowledge acquisition. The results showed different user behavior patterns for the three considered conditions (i.e., pairs of users in cooperation, pairs of users in competition, and single users), suggesting design guidelines for this OLSM task in VEs when multiple users are involved.

In the medical context, Maidenbaum et al. [28] compared the performance of epilepsy patients and healthy individuals in an OLSM task in which subjects had to recall the locations of numerous hidden items in a VE. Their findings showed that neurosurgical patients' data are comparable to the general population's data.

2.2 IVR and HGs

The new hardware devices led to an increasing number of studies in iVR enhanced by HGs, some of which included force feedback.

For instance, Kreimeier et al. [23] carried out a user study to compare visual, vibrotactile, and force feedback to examine the influence of feedback type on the sense of presence and task performance in three different manual tasks performed in iVR: i) throwing, ii) stacking, and iii) object identification. Their results indicated that the vibrotactile feedback most positively influences the sense of presence, and force feedback significantly lowered the execution time for the throwing and stacking tasks, but not for the object identification task.

Pratticò et al. [34] investigated the user experience of two commercial HGs in a task requiring participants to use an electric screwdriver. The authors compared the task in two conditions: i) FGs capable of vibrational and force feedback, ii) HGs with vibrational feedback combined with a 3D-printed mock-up of the same shape and weight as the electric screwdriver. The results indicated superior task accuracy for the HGs with mock-up, which the users perceived as moderately more usable than the FGs. FGs, instead, allowed users to better discern among the different haptic sensations associated with the phases of the task. Participants judged the task done with FGs as more physically demanding compared to the other condition. The authors expected the opposite since the combination of the HGs with the mock-up was heavier than the FGs. Pratticò et al. [34] suggested that a possible cause of this discrepancy is that, using the FGs, the weight of the gloves is directly on the hands rather than on a grabbed object, as in the HGs combined with the mock-up.

Moon et al. [32], instead, investigated the effects of interaction methods and vibrotactile feedback on users' sense of presence, engagement, and usability in a iVR game. The authors compared the game in three conditions: i) HCs, ii) bare hand tracking, and iii) gloves with vibrotactile feedback at the fingertips. The results showed that bare hand tracking and gloves with vibrotactile feedback delivered an experience with more presence, usability, and engagement compared to the HCs.

Nakao et al. [33] recently created FingerFlex, a standalone wearable glove capable of actuating the metacarpophalangeal joint and providing kinesthetic feedback. Authors found that, when operating a virtual number pad, participants made significantly fewer errors with kinesthetic feedback enabled than without it. Furthermore, participants reported that they were not sure if the buttons were pressed or not in the no feedback condition.

In the rehabilitation context, Wang et al. [41] developed a serious game (i.e., a game that uses entertainment to further serious objectives [45]) for home rehabilitation in which users interact in the VE with an HMD and FGs. Their results indicated how immersion, force feedback, and game mechanics improved the system perceived playfulness.

Regarding the educational field, Gebhardt et al. [8] created MolecuSense, a iVR version with FGs of the physical molecule construction kit used to teach chemistry. The preliminary study results showed that MolecuSense is closer to the physical models in terms of interaction than PC-based tools.

Given the positive results of using iVR in OLSM tasks and the enhanced experiences users perceive with FGs, this paper will investigate if and how FGs could improve OLSM performance in a specific task in iVR.

3 USER STUDY

This user study investigates whether the hardware used to interact in the iVR can influence OLSM. More precisely, two interaction methods with virtual objects are compared: 6-DOF tracked handheld controllers (HCs) and 6-DOF tracked force-feedback gloves (FGs).

We designed a task to train OLSM that consists of remembering different objects' spatial locations. The task is composed of four steps:

1. Memorize the locations of different objects over a table.
2. Move the objects one by one to a box over another table.
3. When all objects are moved inside the box, wait for the objects to be shuffled.
4. Move the objects from the box to the starting table in the memorized locations.

The task is repeated three times with an increasing level of difficulty. The difficulties were chosen according to Miller [30] magic number 7 ± 2 of uncompressed chunks in working memory[29]. The first level (3 items) has few objects to remember, so the users can perform the task while familiarizing themselves with the system. The difficulty of the second level (5 items) was chosen as the lower bound of the magic number, and the third level (10 items) as the upper bound with an additional object to give a higher challenge.

3.1 Design and Hypotheses

We conducted a within-group user study to evaluate the HCs and FGs interaction methods. Half of the users tried the HCs first and the FGs next, while the other half did the opposite. All the users attempted the three different levels of the application two times, one for each interaction method.

The within-group design was chosen to balance the possible differences in the OLSM ability of the participants, since each user provides data for both conditions, and to improve the statistical efficiency, as pointed out by Greenwald [9]. The main problem of this design is that the subjects are susceptible to the possible effect of practice, sensitization, and carryover [9]. In this user study, however, these effects are limited for these reasons: i) the task is focused mainly on WM, and the task does not involve LTM; ii) the objects to remember are not significative, and thus they should not stimulate LTM; iii) between the two trials, there is a break from performing the task where the participants have to fill out the questionnaires and, therefore, it should empty the WM; iv) the groups are counterbalanced in the order they tried the two conditions.

Besides evaluating the performance of the task, we considered other aspects of the experience that may have an impact on training: i) presence may influence the user's focus on the OLSM task rather than being distracted by external distractions in the real environment; ii) the system's usability could lead to a high task success rate, as pointed out by [21], and thus it may lead to more successful training of the OLSM; iii) muscle fatigue could lead to a deterioration in cognitive performance [43], thus to an inefficient effect of the OLSM training.

We made seven hypotheses: four regarding the performance of the OLSM tasks and three for the overall experience.

- H1) We expected that users would remember more object locations with the FGs than HCs throughout the levels because, as described in Section 1, the FGs could provide haptic inputs about the shape of the objects. This FG capability can contribute to updating users' spatial image of the environment [25], enhancing the OLSM.
- H2) We expected that the proportion of correctly placed objects after the shuffle would be higher in the first two levels than in the third one, because the number of objects in the third level is higher than the upper bound of Miller [30] magic number, while it is lower in the first two levels.
- H3) We expected that users would complete the task in less time with the FGs than HCs because they can use their hands like in the real world, thus using the same abilities to move objects acquired during their lifetime.
- H4) We expected that the average time elapsed to handle an object would be higher in the first level than in the last two, because the first time the users try a new interaction method they would need to familiarize with it.
- H5) We expected that users would feel a greater sense of presence with the FGs because of the more natural interaction with the objects, in line with the results seen in [32].
- H6) We expected that users would find the application more usable with the FGs because of the more natural interaction with the objects, in line with the results seen in [32].
- H7) We expected that users would feel more fatigue in the fingers and the wrist with the FGs because of the weight of the glove, as suggested by [34].

3.2 Materials

Figure 1 shows the VE used for the OLSM task. The VE is composed of an empty room to limit distractions, the two tables necessary for the task, and the instructions in the users' native language. There are several slots based on the number of objects to remember over the table on which objects are located at step 1 of the task. The objects used for the OLSM task are 3D shapes of different solids: a cube, an ovoid, a capsule, a sphere, and a cylinder. The application has three levels of difficulty as described above.

The HCs employed for the task were the HTC Vive Pro Controllers [13]. Users could press or release the "Grip" or "Trigger" buttons to grab or drop objects. Instead, the FGs worn by users

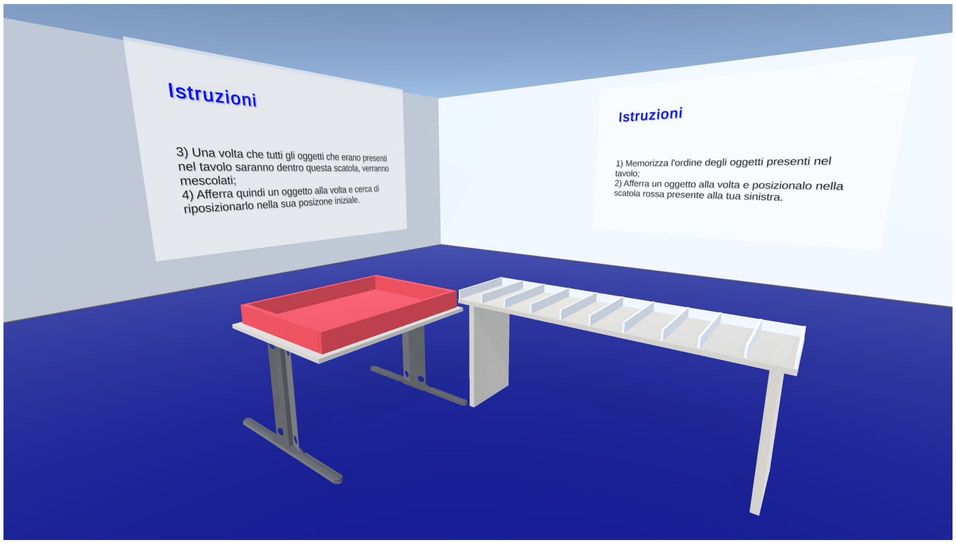

Fig. 1. Virtual Environment used for the task composed by an empty room, the two tables, and the instruction in the users' native language.

were the SenseGlove DK1 gloves [37]. Users could grab and release objects like in real life by closing or opening their hands near a target object. Figure 2 presents an example of the user interacting with the HC and the FG. In both conditions, users could see the VE using a commercial VR headset (HTC Vive Pro) [13].

The application was developed with Unity 2020.3 LTS [40] and the Open XR framework [10]. A logger in the application saved in a file the total number of correctly placed objects after the shuffle and the time elapsed to complete the task. The simulation was run on a PC equipped with a 3.30 GHz Intel i7-5820K processor, 16 GB RAM, and a Nvidia GTX 980 graphic card.

3.3 Participants

The evaluation involved a sample of 24 participants (17M, 7F). Participants were volunteers that received no compensation and were recruited through personal contact. Age ranged from 20 to 28 (M = 22.71, SD = 2.01). We asked participants if they had previously used any HMDs and, in case of a positive answer, for how many hours. Answers of the 9 participants who had previously used an HMD ranged from 0.3 to 20 hours (M = 3.59, SD = 6.31). We also asked all participants how many hours per week they use video games. Answers ranged from 0 to 18 hours (M = 4.44, SD = 5.34), with 7 of them not playing at all and 4 of them playing at least 10 hours.

3.4 Measures

3.4.1 Performance of the OLSM task. The performance was evaluated with the data gathered by the application logger. More precisely, we considered two measures: i) the proportion of correctly placed objects (PO) after the shuffle (correctly placed objects over total objects in that level); ii) the average time elapsed (TE) to handle an object during the OLSM task at each level (total time spent for the task without the waiting time over total objects in that level).

3.4.2 Sense of presence. We measured sense of presence by administering participants the Igroup Presence Questionnaire [35]. It includes a general item for the sense of "being there" (IPQ-G1P), and 13 other items organized in three different subscales (spatial presence IPQ-SPP, involvement IPQ-INVP, and experienced realism IPQ-REALP). The global value of presence IPQ-TOTP is calculated by averaging answers from all items. Global value and subscales can range from 0 to 6, where 6 indicates the greatest sense of presence.

3.4.3 Usability. The system usability was evaluated with the well-known SUS questionnaire [4], which includes 10 items and gives the result on a scale from 0 to 100.

3.4.4 Fatigue. The fatigue was measured with the Device Assessment Questionnaire (DAQ) [5], which includes 13 items concerning the required force, smoothness, mental and physical effort, the accuracy and speed of the movements, the fatigue in different parts of the body, the general comfort, and the ease of use. Each item can be rated on a 5-point scale, ranging from 1 to 5. For items 1, 3, 4, 6, the most desirable value is at the central point (3). For items 2, 12, 13 the most desirable value is the highest endpoint (5). For items 5, 7, 8, 9, 10, 11 the most desirable value is the lowest endpoint (1).

3.5 Procedure

The experimenter told participants we were testing different interaction methods in an iVR experience. He also informed participants that VR users could suffer from nausea or headache in rare cases, and they could refrain from continuing the experiment at any time and for any reason. The experimenter then explained that he would ask participants to fill out some questionnaires in an anonymized form. After they gave informed consent, participants completed an initial questionnaire concerning the information described in Section 3.3.

Then, the experimenter asked participants to go to the middle of the room, and he helped them wear the HMD and the HCs or the

Fig. 2. The two interaction methods used to handle virtual objects. On the left side, the user has the HC (HTC Vive Pro Controller) in his hand, and on the right side, he is using the FG (Senseglove DK1).

FGs. As described in Section 3.1, half of the participants tried the HCs first and the FGs next, while the other half did the opposite. For the HCs, the experimenter explained the "trigger" and "grip" buttons to interact with for grabbing the objects. Instead, for the FGs, the experimenter asked the participants to move their fingers to calibrate the gloves and told them that they can grab and drop the virtual objects like in the physical world.

Then the experimenter explained the task participants had to perform in the iVR experience as described in Section 3. The experimenter told the participants to notify him when they had finished the task so he could make the application proceed to the next level.

After completing all levels for the first interaction method, the experimenter helped the participants to remove the devices and invited them to fill out the three questionnaires described in Section 3.4: IPQ, SUS, and DAQ. Then participants tried the second interaction method and filled the questionnaires a second time.

4 RESULTS

All data have been statistically analyzed with SPSS, version 28 [15]. Results concerning performance in the OLSM task were analyzed using 3x2 repeated measures ANOVA, since each participant tried all the three levels with both interaction methods. When Mauchly's test indicated that the assumption of sphericity was violated, degrees of freedom were corrected using Greenhouse-Geisser. When we found a main effect of level, we proceeded with Bonferroni pairwise comparisons. When we found an interaction between the two independent variables, we analyzed simple effects, considering the effects of level separately for each of the two interaction methods, and the effects of interaction method separately for each level. Results concerning measures of presence and usability were analyzed using paired t-Tests. Results concerning the items of DAQ questionnaire were analyzed using Wilcoxon Signed-Ranks Tests.

4.1 Performance

Figure 3 shows the results of the performance measures for each level (on x axis) and condition (separate lines).

Considering PO (Figure 3a), we found no main effect of interaction method, $F(1,23) = 0.00$, $p > 0.05$, $\eta_p^2 = 0.00$, a main effect of level, $F(2,46) = 61.41$, $p < 0.001$, $\eta_p^2 = 0.73$, and no interaction, $F(2,46) = 0.68$, $p > 0.05$, $\eta_p^2 = 0.03$. Post-hoc analyses showed that PO was higher in the first two levels than in the third, $p < 0.001$, and no statistically significant difference between the first and the second level, $p > 0.05$.

Considering TE (Figure 3b), we found a main effect of interaction method, $F(1,23) = 74.15$, $p < 0.001$, $\eta_p^2 = 0.76$, a main effect of level, $F(1.59, 36.55) = 28.79$, $p < 0.001$, $\eta_p^2 = 0.56$, and an interaction between the two independent variables on TE, $F(1.24, 28.62) = 5.91$, $p < 0.05$, $\eta_p^2 = 0.20$. TE was higher with FG than HC, $p < 0.001$. Post-hoc analyses showed that TE was higher in the first than in second and third level, $p < 0.001$, and that TE was lower in the second than in the third level, $p < 0.05$. The analysis of simple effects showed that TE was higher with FG than HC at all levels, $p < 0.001$. When interaction method was FG, TE was higher in the first than in the last two levels, $p < 0.001$, and no statistically significant difference was found between the second and the third level. When interaction method was HC, TE was higher in the first than in the second level, $p < 0.005$, TE was lower in the second than in the third level, $p < 0.05$, and no statistically significant difference was found between the first and the third level.

4.2 Presence

Considering presence (Table 1), the analysis revealed that the difference in the means for the general item about the sense of being there (IPQ-G1P) was statistically significant, $p < 0.05$. The mean was higher with FGs than with HCs. The differences in the means for the spatial presence subscale (IPQ-SPP), the involvement subscale

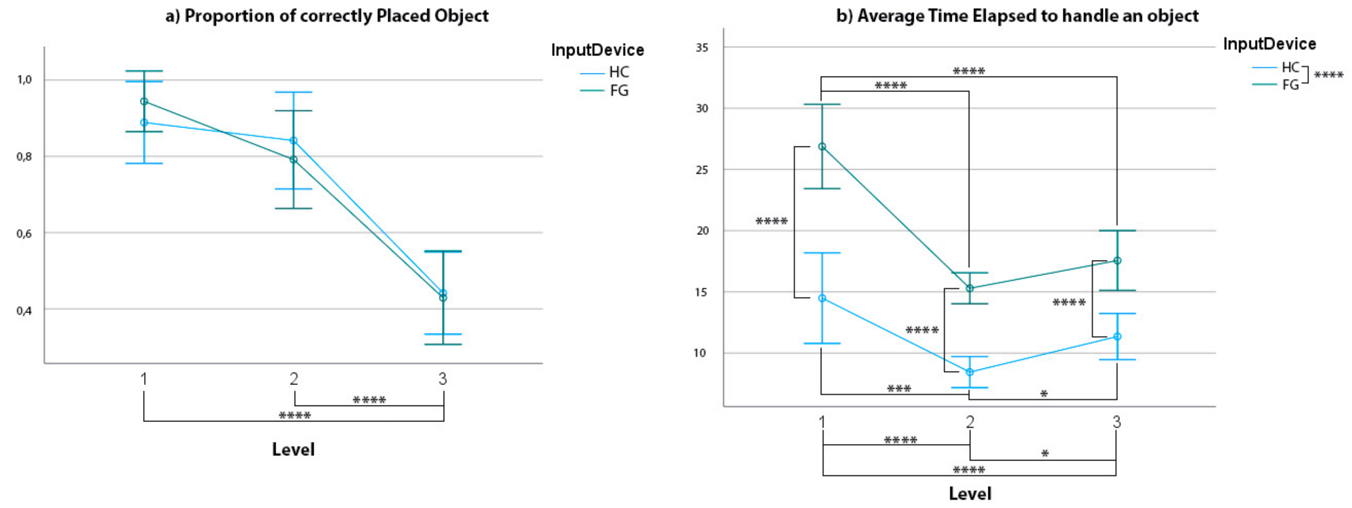

Fig. 3. PO (a) and TE (b) for each level (on x axis) and condition (separate lines). Capped vertical bars show 95% CI. The $*$, $***$, $****$ signs indicate differences with p-values respectively < 0.05, < 0.005, < 0.001.

(IPQ-INVP), the experienced realism subscale (IPQ-REALP), and the global value (IPQ-TOTP) were not statistically significant.

4.3 Usability

Considering usability (Table 1), the analysis revealed no statistically significant difference for the overall SUS score.

4.4 Fatigue

Regarding perceived fatigue (Table 2), the analysis of the DAQ questionnaire reported that the differences in the means for Item 1 ($p<0.005$), Item 2 ($p<0.01$), Item 7 ($p<0.005$), and Item 8 ($p<0.05$) were statistically significant. Instead, the differences in the other DAQ items were not statistically significant.

5 DISCUSSION

Considering H1, we expected that users would remember more object locations with the FGs than HCs, thanks to the FG's capability of suggesting the shape of the objects and the possible influence of haptic feedback in updating the spatial image of the environment[25]. We could not confirm our hypothesis since there were no statistically significant differences in the PO.

Hypothesis H2 was instead confirmed by statistically significant differences in the means that showed how, on average, the PO was higher in the first two levels than in the third one for both interaction methods. This result aligns with the literature about the limited capacity of the WM. More precisely, users had reached higher values of PO in levels 1 (3 items) and 2 (5 items) than in level 3 (10 items) because, in the last level, the total number of the objects was over the upper bound of Miller's magic number [30], and thus users' WM might not have been capable of memorizing all the locations.

Considering H3, we expected that users would employ less TE to perform the task with the FGs than HCs because they could use the abilities already acquired during their lifetime to grab and move objects in the VE. Since results in terms of TE showed that HCs led participants to spend much less time performing the task, we rejected H3. The differences in the TE means were statistically significant in favor of the HCs for all levels. The HC interaction method took, in general, about 60% of the time to complete the OLSM task compared to the FGs.

Regarding H4, we expected a higher TE in the first level than the last two because of the need for familiarization with a new interaction method. The main effect of level supported our hypothesis. However, the significant interaction and the analysis of simple effects showed that the difference between the first and the second level was statistically significant for both HCs and FGs, and the difference between the first and the third was significant only when using the FGs.

A possible explanation for these results is that participants could not fully take advantage of the FG capability of providing users with haptic inputs about the shape of the objects over HCs because of the fatigue and discomfort of using those FGs, as shown by the DAQ results. In particular, it is possible that the fatigue from using the FGs could impede some users' movements, leading them to spend more effort for opening and closing their hands rather than simply clicking the "grip" or "trigger" button of the HCs. Furthermore, the statistically significant difference in the means for Item 2 of the DAQ questionnaire showed how the perceived smoothness of movements is greater for the HCs.

Interestingly, in an object identification task, the combined results of Kreimeier and Götzelmann [22] and Kreimeier et al. [23] showed that FGs significantly increased the execution time with respect to HCs, contradicting the authors' hypothesis as in our OLSM task. In [23], authors explained this discrepancy between hypothesis and results with the bulkiness of the HGs, which are the same that we used in our study.

Table 1. Mean, Standard Deviation, and paired t-Test results for IPQ scales and usability.

	HC		FG		Paired t-Test		
Measures	M	SD	M	SD	t	df	p bilateral
IPQ-G1P	4.50	1.14	4.92	1.02	-2.10	23	< .05
IPQ-SPP	4.48	1.06	4.85	0.51	-1.63	23	> .05
IPQ-INVP	3.96	1.19	4.14	1.09	-0.95	23	> .05
IPQ-REALP	2.66	0.97	3.05	0.85	-1.94	23	> .05
IPQ-TOTP	3.81	0.84	4.14	0.61	-1.85	23	> .05
SUS	83.54	11.28	83.13	11.23	0.14	23	> .05

Table 2. Mean, Standard Deviation, and Wilcoxon Signed-Ranks Test results for the items of the DAQ questionnaire.

		HC		FG		Wilcoxon Signed-Ranks Test	
	Item	M	SD	M	SD	Z	p
1	Required force	1.08	0.28	1.58	0.65	-2.97	< 0.005
2	Smoothness of movements	4.21	0.59	3.63	0.65	-2.73	< 0.01
3	Mental effort	2.25	0.99	1.96	1.00	-1.71	> 0.05
4	Physical effort	1.25	0.44	1.29	0.55	-0.33	> 0.05
5	Accuracy of the movements	2.25	0.85	2.46	0.93	-0.82	> 0.05
6	Speed of the movements	3.00	0.51	3.04	0.46	-0.33	> 0.05
7	Finger fatigue	1.13	0.34	1.79	0.88	-3.18	< 0.005
8	Wrists fatigue	1.08	0.28	1.54	0.93	-0.24	< 0.05
9	Arms fatigue	1.17	0.38	1.38	0.65	-1.51	> 0.05
10	Shoulder fatigue	1.13	0.34	1.33	0.70	-1.67	> 0.05
11	Neck fatigue	1.29	0.75	1.29	0.75	0.00	> 0.05
12	General comfort	4.33	0.70	3.92	0.72	-1.85	> 0.05
13	Overall ease of use	4.79	0.42	4.54	0.59	-1.90	> 0.05

The absence of differences between the interaction methods for the OLSM task regarding PO and the lower TE could also indicate that this type of OLSM task does not benefit from specialized FGs. A possible explanation is that participants remembered the items regardless of the haptic capabilities of the devices because they focused more on visual than haptic feedback to remember the shape of the objects to be placed at the different memorized locations. Even if the combination of visual and haptics are useful to build a representation of the near-body space [26], in our particular type of task with the employed FGs, the haptic input could not improve the spatial image of the environment in a significant way.

Considering hypothesis H5 regarding presence, we expected that users would feel a greater sense of presence with the FGs because of the more natural interaction with the VE, in line with the results seen in [32]. Indeed, we found a statistically significant difference in favor of the FGs for the general item about the sense of "being there" (G1P). However, we could not confirm our hypothesis about the sense of presence for the global value (IPQ-TOTP) and the subscales of IPQ. The differences suggested that using the FGs could increase presence, but the data collected did not reach statistical significance.

Regarding hypothesis H6 about system usability, both interaction methods received high mean SUS scores with a negligible difference between the two. Therefore, we rejected the hypothesis about the greater usability of the FGs compared to HCs. This contrasts with the results in [32]. Interestingly, compared to the usability results in [34] for the same commercial FGs, users in our study reported higher usability values. A possible interpretation is that our task consisted of remembering the object locations rather than performing different actions that could lead users to focus more on grabbing and moving the objects in the VE.

Results confirmed hypothesis H7: the participants felt more fatigue in the fingers and wrists with FGs, as suggested by [34]. Statistically significant results concerning Item 1, 7, and 8 of the DAQ questionnaire showed that using FGs required participants to use more force to interact with the system and caused participants more fatigue in their wrists and fingers. In addition, despite statistical significance was not reached, the difference between the means for fatigue of the other body parts (Item 9 and 10) might suggest that FGs could increase the fatigue also of the arms and the shoulders. However, for both interaction methods, it must be noted that the average reported values for fatigue were very low.

6 LIMITATIONS

This user study is a preliminary evaluation of a system for OLSM training conducted with young people with no history of Alzheimer's disease. This evaluation serves as a preliminary step to identify which characteristics of the system could affect OLSM training.

Therefore, future work with patients is needed to assess the effectiveness of the system on the target users.

7 CONCLUSION

In this paper, we investigated the influence of haptic feedback on an OLSM task in iVR by comparing a pair of FGs and a pair of HCs to perform the same OLSM task. Regarding presence, statistically significant differences were found in favor of interacting with FGs for the general item about the sense of being there. Regarding usability, participants judged the system almost equally usable when interacting with HGs and FGs. There was a statistically significant difference in the fatigue experienced after the task with the FGs, possibly because of the position of the weight of the gloves. The fatigue and discomfort of the FGs could have influenced the OLSM task results, in which there were no statistically significant differences about PO and participants employed less time to do the task with the HCs. This opens the possibility that other, more comfortable, and lighter FGs may lead to different results.

We plan to carry out a study on a OLSM task using a different, new model of FGs to check if it could lead to better results. If new studies would instead confirm the lack of differences between the FGs and HCs, we could conclude that a basic commercial VR kit may be sufficient to perform this type of OLSM tasks without requiring specialized hardware. The absence of a requirement for specialized hardware could be helpful in the rehabilitation context, where patients, especially those with locomotion disabilities, would be able to do the rehabilitation at home without necessarily needing costly special hardware that could be available only in specialized clinics.

Another important aspect that needs to be evaluated in rehabilitation is the transfer of the improved spatial skills from the VE to the real world. In this direction, we plan to develop an OLSM task for rehabilitation in iVR concerning an everyday activity to investigate if the training in the VE improves spatial memory in the physical world.

A final aspect that could be evaluated for rehabilitation is the influence of performing the OLSM task in a multi-user setting, where users could collaborate or compete with each other. Indeed, the results of [24] showed different behaviors for single and pairs of users in an OLSM task not concerning rehabilitation, so it would be interesting to explore if rehabilitation could be more effective in a multi-user setting than doing the rehabilitation exercises individually.

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