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Can You Find Your Way? Comparing Wayfinding Behaviour Between Reality and Virtual Reality

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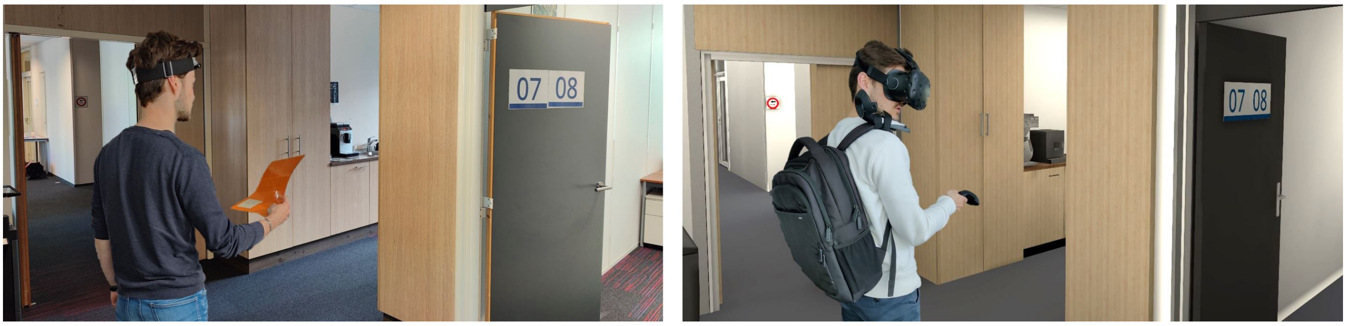

Figure 1: *Illustration of users executing a wayfinding task thanks to signage elements in real conditions and virtual conditions. (Left) A user in real conditions equipped with a head-mounted camera and an orange file in their hand. (Right) A user in virtual conditions equipped with a virtual reality Head-Mounted Display (HMD).*

Abstract

Signage is an essential element in finding one's way and avoiding getting lost in open and indoor environments. Yet, designing an effective signage system for a complex structure remains a challenge, as some buildings may need to communicate a lot of information in a minimum amount of space. Virtual reality (VR) provides a new way of studying human wayfinding behaviour, offering a flexible and cost-effective platform for assessing the efficiency of signage, especially during the design phase of a building. However, it is not yet clear whether wayfinding behaviour and signage interpretation differ between reality and virtual reality. We conducted a wayfinding experiment using signage with 20 participants who performed a series of tasks in virtual and real conditions. Participants were video-recorded in both conditions. In addition, oral feedback and post-experiment questionnaires were collected as supplementary data. The aim of this study was to investigate the wayfinding behaviour of a user using signs in an unfamiliar real and virtual environment. The results of the experiment showed a similarity in behaviour between both environments; regardless of the order of passage and the environment, participants required less time to complete the task during the second run by reducing their mistakes and learning from their first run

CCS Concepts

• ***Human-centered computing*** → ***Virtual reality;*** *User centered design;* • ***Computing methodologies*** → ***Virtual reality;***

1 Introduction

Signage is an essential support for wayfinding, contributing to the proper functioning of a complex building such as an airport or a hospital. The content of a sign and its placement are both equally important in order to convey effective information [RCT19]. There are recommendations and good practices for the signage design that require the integration of its environment and therefore of the architecture, as well as a graphic aspect [AP92; RCT19]. Unfortunately, the effectiveness of a signage system cannot be observed until it has already been implemented, in which case it is already too late to change the building design if it is not suitable. A full prototype of the designed signage system in a virtual mock-up of the building

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might be useful so as to anticipate poor signage designs.

Virtual reality can help with this validation, as we can create a full prototype of such a newly designed signage system in a virtual building, where multiple solutions can be assessed. VR technologies have evolved rapidly in recent years, leading to new experimental approaches to the study of wayfinding behaviour [GMES05; VRN14; ZZE14]. It allows us to more closely examine human behaviour, and more and more guidance studies are directly comparing VR to reality [EJ21; DQY*22]. However, VR with a Head-Mounted Display (HMD) has some limitations due to its limited field of view, which might impact the visual perception of the virtual environment and visual guidance.

Could we design and test signage during early stages of prototyping? This question would require the validation of signage in virtual reality to be as effective as in real-world conditions. For this purpose, we designed an experiment to compare wayfinding behaviour in a virtual environment versus a real environment. In this experiment, we evaluated participants wayfinding behaviour in an unfamiliar indoor environment. Each of these participants performed the same wayfinding task twice in a random order, once in a real office and once in a virtual copy, reproduced as closely as possible. We evaluated their wayfinding performance, studying the time it took to complete the different steps of the task, their choices of direction, and their learning of the environment and signage between the two runs.

The results of this study opens the door to virtual reality-assisted signage design, allowing for early testing during the building design, and limiting costs once actually implemented.

2 Related Works

This section reviews a number of works exploring the usage of virtual reality to study human behaviour, with a specific focus on wayfinding behaviour. We discuss works studying wayfinding in real and in virtual conditions, then studies comparing wayfinding behaviours in reality and virtual reality.

2.1 Wayfinding

Finding our way around in a building is part of our daily lives. It is a cultural skill, acquired over years of experience. To better understand the use of buildings, new digital technologies could be more heavily used in the fields of navigation and orientation. According to the literature, there are different ways to study orientation under real conditions, focusing for example on wayfinding efficiency and wayfinding strategy [ZCZ*20; LK16], examining the effect of different levels of maps on spatial learning [SMG20] or on gaze behaviour [LDH*19], and using eye-tracking technologies to study visual landmarks and visual attention [KGRD17; LD17]. A recent study collected eye movement data in real conditions to compute landmark visual salience and semantic salience using a computer vision model [DQL*20]. The results demonstrated that we need to design important landmarks in complicated scenes to be more visually salient, at the risk of distracting the user from the real information. All methods can be complemented with questionnaires [AJF*14] and self-reports [ZCZ*20; LCZ96] to better include the user in the process.

Studying wayfinding in real conditions allows us to progress in a realistic environment. However, it is not easy to control external factors or to isolate the right features in complex environments, such as hospitals or museums, which still require further research on the wayfinding process [HHP05; RKT10]. Such studies are possible with the help of virtual reality, which offers a new way to examine this process. In a literature review, several studies have examined human wayfinding performance in virtual reality using different metrics of task performance [ISL21]. These studies have assessed the time required to complete a task [BJH99], the distance travelled to reach the destination, and the number of errors made during the task [RJ01]. Wayfinding behaviour has also been studied by measuring time and errors [BJH99] and by observing the route taken [DS96]. Using these key measures, wayfinding behaviour has been further examined by asking participants to justify their actions using post-experimental questionnaires and think-aloud protocols [MBW*00]. Virtual reality leads to new experimental approaches to the study of wayfinding behaviour [GMES05; ZZE14]. When it comes to studying human wayfinding behaviour, there are two main types of studies: experiments studying human behaviour in VR [TTTK18; LTHS19; LCL19], and experiments comparing the effects of different VR displays on wayfinding and spatial knowledge acquisition [RVB11; Egg16; SRV*19].

A number of wayfinding studies have been conducted using different scenarios and various environmental settings. A study carried out by Vilar *et al.* [VRN14], examines the performance of orientation in buildings using two different signage systems. The study was conducted in an immersive virtual environment, and participants were asked to navigate towards a given destination. The results showed that both horizontal and vertical signage improved wayfinding performance compared to no signage. The results showed no significant difference between the performances of the two signage systems. Another study, examining wayfinding performance and the effect of repeated exposure to indoor environments during a fire emergency [LCL19], showed that repeated exposure to the same space improved wayfinding performance. The fire emergency conditions negatively affected the wayfinding performance, but repeated exposure diminished the negative impact of said fire emergency.

2.2 Wayfinding studies between reality and virtual reality

Few works have compared the difference in wayfinding behaviour between real conditions and virtual conditions. In a study comparing real-world and virtual wayfinding [EJ21], Ewart *et al.* found a similarity in the paths taken by participants in both environments, and that participants showed less confusion and took the shorter path the second time, regardless of environments. A more recent study [DQY*22] used eye-tracking technology in both environments to examine participants' visual attention while they searched for directions. The eye-tracking system was physically connected to a laptop computer, which restricted users' movements especially in the real environment. Nevertheless, the wayfinding performance of the participants in VR was similar to that of the participants in the real environment, although the travel time was faster in the real environment. They also acquired the same directional knowledge in both environments. Another study from Savino *et al.*[SEK*19], aims to provide insights on how pedestrian navigation methods can be evaluated in virtual reality. This study also found that participants performed similarly in both virtual reality and real-life scenarios, regardless of the navigation method used. However, partic-

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ipants reported feeling more confident and comfortable using the mobile map application on a smartphone compared to a paper map. Although this study highlights the potential of virtual reality as a tool for evaluating navigation methods in a controlled environment, it does not focus on wayfinding signage. These previous studies do not focus on signage elements within unfamiliar buildings, although signage is the most important during first-time visits.

Several studies on wayfinding behaviour compare real and virtual conditions. However, none of these studies include signage as a parameter, where the participants are unfamiliar with the environment being studied and which therefore involves their learning of the path. Additionally, not all studies pay particular attention to the realism of the virtual environment in combination with a VR headset, and in some cases the participants were already familiar with the environment. Furthermore, we wanted to focus our study on wayfinding behaviour rather than visual attention. And we wanted the users in real conditions to have as much freedom as possible, to best reflect a genuine wayfinding situation.

3 Experimentation

The aim of this study was to investigate the wayfinding behaviour of a user using signs in an unfamiliar real and virtual environment. Half of the participants were invited to navigate the real environment and then the virtual environment, and the other half were invited to do the opposite. In order to perform this wayfinding task, participants were asked to bring several files to specific locations. Signage elements were designed and added to the environments, without which participants could not complete the task. We thus used an existing building that we modelled in 3D to produce a realistic copy, to which we added a signage system to guide the participants in the real and virtual environments. We then compared the same path in both conditions for each participant. In this experiment, we were particularly interested in the similarities and the differences in choices and behaviours between the real and virtual environments when faced with signage.

3.1 Virtual and real environments

The chosen environment for this experiment was a corporate office consisting of 25 individual offices, a reception, a cafeteria, and two meeting rooms (Figure 2).

A 3D rendering of the office and entrance was modelled in Autodesk Revit based on the building plans, with additional on-site measurements. The aim was to recreate a sufficiently realistic virtual environment (see the Annexes for comparisons between the real and virtual environments). Some of the furniture was also modelled, such as storage spaces, tables, chairs, and certain objects to enhance the scene.

3.2 Signage and wayfinding

Signs are a key aspect of this experiment. We created a signage system that would guide the participants through the building (Figure 3). According to Smitshuijzen [Smi07], traditional guidance techniques can be summarised in two main ways: 1) the grouping and repetition of destinations, with an arrow; and 2) the creation of a more or less continuous line, connecting the starting point to the final destination. For the purpose of this study, only guidance methods of the former category were evaluated. The signage also takes into consideration the recommendations of Rodrigues [RCT19]. Signage should always consider the eye level of users, with a recommended height of between 1.40 and 1.70 m. Signs that can be approached from two angles should be double-sided. Furthermore, the signage elements are in compliance with Arthur and Passini's recommendations on the choice of colours [AP92]. In keeping with the calculation of contrast, and retaining the company's own colour code in order to remain consistent, we opted for white and blue signage (Figure 3).

This signage system consists of a set of rectangular signs to identify offices from 1 to 25, floor signs to identify meeting rooms (Figure 10), ceiling signs to identify the cafeteria and reception(Figure 11), and directional signs to guide users(Figure 12). Floor and ceiling signs were added to study the impact on the field of vision and consistency compared with eye-level signage. Signs identifying the toilets were already there, so we reproduced them in the virtual environment. Although they were not useful for the orientation task, we kept them and took them into account for our directional signs in order to keep the overall coherence of the environment.

This signage system has been designed to be recognisable, adapted to the building, and consistent throughout the wayfinding task. As the layout of the offices cannot be modified, the wayfinding process was designed through the creation of the signage, the elements of the environment, and the layout of the offices themselves. Figure 2 provides the distribution of the numbering of the offices and the different named rooms. We also added deliberate difficulties to reduce any ceiling effects and to better characterise the learning process of the environment:

- Signs whose location is less adapted to the environment, such as directional signs that cannot be seen at first glance (see the Annexes, Figure 9 and Figure 12);
- Missing sign for office 23;
- Confusing order of office numbers such as offices 06 to 09 beyond the cafeteria (View 2 of Figure 2) and offices 13 to 17 (View 3 of Figure 2).

We also took into account a point of interest referred to as the "blue totem", whose importance is revealed once it has already been passed by, as its location must be recalled. The blue totem is placed in front of office 22, visible in View 1 of Figure 2. There is a door just before the totem, partially obstructing the view from the entrance to the corridor. The interesting idea behind this door frame is that the blue totem cannot be seen unless the participants first pass through the door frame.

3.3 Real and virtual interactions

Reality Participants could walk freely within the environment and use their hands to interact with the files.

Virtual Reality A navigation system were design and develop to provide freedom of hand and head movements to allow the participants to explore the environment when navigating. Each participant had to be standing, so that the height of the field of vision was as similar as possible to real conditions. Given the limited space for the virtual reality component of the experiment (3 meters by 3 meters), we envisaged a virtual steering technique in which the direction of motion was defined by the torso, whereby users could rotate in place to alter their direction. This allows us to decouple the rotation of the head with the direction of the participants' advance-

Figure 2: *Top view of the office space, with office numbers (from “01” to “25”), reception (“R”), meeting rooms (“M 01” and “M 02”), and cafeteria “C”). Orange files and their designated destinations are also indicated on the plan. Three points of interest for the experiment are also numbered and displayed: 1) the blue totem, 2) the cafeteria, and 3) offices 13 to 17.*

Figure 3: *Signage samples created and used for the experiment. (Left) The numbers used for the offices. (Centre) A directional sign used at the entrance. (Right) Identification signs used to identify the cafeteria and the reception.*

ment, which is essential when looking for directional information. We selected the torso-steering technique both by its simplicity and its ability to provide similar motor behavior as walking[BPK*19]. To limit the effects of cybersickness, we opted for progressive acceleration and deceleration to limit abrupt changes of speed. After a number of tests, we set the max. speed at 1 metre per second, with an acceleration (time from 0 m/s to max. speed) of 1.7 s, and a deceleration (time from max. speed to 0 m/s) of 0.8 s. Finally, each participant could steer within the environment thanks to the direction of their torso, and interact with the virtual files using the second controller, clicking once to grip and again to release.

3.4 Participants and apparatus

Twenty participants took part in the experiment (10 females and 10 males), aged from 18 to 50 years old (25% 18-25, 55% 26-35, 15% 36-45, and 5% 46-50). All participants were recruited with zero knowledge regarding the environment. They did not receive any financial compensation for their participation. They all had normal or corrected vision.

Reality Participants were equipped with a GoPro Hero4 camera. It was placed on the forehead with the help of an elastic strap, in order to have the closest possible field of view to the participant’s eyes and line of sight.

Virtual Reality Participants were equipped with an HTC VIVE Pro HMD with a wireless communication system. One HTC VIVE Pro controller held in the right hand, is used to accelerate in the direction provided by the first controller, and interact with files in the environment. Another on the right shoulder to monitor the direction of the user’s torso. We used a desktop computer ensuring a minimum of 90 fps under all conditions and developed under Unity 2020.3.16f1.

This experiment was approved by the local ethics committee.

3.5 Experimental tasks

During the experiment, all participants performed the same wayfinding task in real conditions and in virtual reality conditions at seven-day apart (for organisational reasons, two participants performed the second run nine days after the first). Participants were split into two groups. The first group (Group 1) started with the virtual reality iteration, while the second (Group 2) started with the real-world iteration.

During the task, users were required to carry orange files from one location to another, placing them on their designated destinations (Figure 4). Yellow Post-it notes provided destination information throughout the process, to help participants to complete the task. Post-it notes were placed either on the files or next to a designated destination, indicating the next destination (Figure 4).

Path sequence The first and only indication provided to the participants before starting was “Retrieve File A from the reception”. Participants then had to complete seven steps: **Step 1** - Retrieve File A from the reception and bring it to office 15; **Step 2** - Retrieve File B from meeting room 2 and bring it to office 23; **Step 3** - Retrieve File C from the cafeteria and bring it to office 08; **Step 4** - Retrieve File D from office 14 and bring it to office 17; **Step 5** Retrieve File E and bring it to the office in front of the blue totem (a picture of the blue totem is present on File E). Users had to determine that this was office 22; **Step 6** - Retrieve File F and bring it to office 03; **Step 7** - Exit through the reception door.

Figure 4: *(Left) Orange File with a Post-it note designating its destination. (Right) File destination and a Post-it note indicating the next destination.*

3.6 Experimental protocol and design

For their first run, participants were asked to read and sign the consent form and to fill in a questionnaire to gather demographic information. They were then briefed regarding the purpose of the experiment, depending on the condition concerned (Real or VR). With regards to the task in real-world conditions, participants were asked to sign the consent form for recording sound and video, then equipped with the GoPro. As for the task in VR conditions, participants filled in a Simulator Sickness Questionnaire and were fitted with the VR equipment. Participants then performed the wayfinding task. They were autonomous throughout the entire task, until all the steps of the wayfinding task were completed. The experiment followed a mix design, with the environment condition (Real vs. VR) as a within-subject variable, and the order (VR-Real, Real-VR) as a between-subject condition. The order was counterbalanced. Participants were informed that they could stop whenever they wished. They were immersed in the virtual environment for approximately 15 minutes.

3.7 Objective measures

For the task in real conditions, we recorded each participant's point of view with the GoPro camera on their head. For the virtual reality iteration, we recorded the HMD view. For each condition, we made note of the time required to complete the entire task as well as the time to complete each step of the task.

Each video was viewed at least twice for each condition, corresponding to 113 minutes for the real condition and 163 minutes for the virtual condition. This enabled us to check that the participants had completed the course without error, as they were completely autonomous throughout. In addition, a table was produced listing the key decisions made by the participants, with a specific commentary for each one. The table includes a number of indications, such as whether the participant made the right orientation decision, a comment in the event of notable hesitation or particular behaviour. Using this decision table, we were able to compare the times between steps and the participants' progress between the two conditions. We were also able to categorise the orientation and navigation phases.

3.8 Subjective measures

After each run (Real and VR), we asked participants to complete a questionnaire about signage systems and wayfinding. First, we asked the participants how they felt about the implemented signage. Four questions were graded from (1) Not at all suitable to (5) Very suitable, asking what they thought of the proposed directional signs, the general legibility of the signage, the legibility of the text, and the colour contrast. We then asked them to give their order of preference for floor, wall, and ceiling signs. Regarding the wayfinding-specific questions, we asked them if they had noticed specific elements of the environment (directional signs, cafeteria, blue totem, meeting room 2) and if they could locate them within the space, and if they could describe the general shape of the building with a letter ('U', 'L', etc.).

After their second run, we asked participants to complete a questionnaire about their learning process with 10 questions graded from (1) Strongly disagree to (5) Strongly agree, using the statements in Figure 5.

Learning questionnaire	
1	"I recognised the environment well"
2	"The path seemed more familiar to me"
3	"I found the path more easily"
4	"I knew the directions better"
5	"I was able to anticipate the time it would take"
6	"I had a better knowledge of the site"
7	"I felt less apprehensive"
8	"I found the blue totem more easily"
9	"I knew better where to find the directional information"
10	"I paid more attention to the signs"

Figure 5: *Questions about the learning process of the participants.*

3.9 Hypotheses

Based on our experimental design, we had three main hypotheses:
[H1]: Users will perform the task faster during the second iteration. Participants should learn from their first path and reduce their path time in the second run, regardless of the order of virtual and real conditions or vice versa.
[H2]: Users will perform the task faster in real conditions. We expected that participants would walk faster in real conditions than in VR conditions, as the virtual speed was limited to 1 metre per second.
[H3]: Users will demonstrate similar wayfinding behaviour regardless of the environmental conditions. We expected to observe the same decision-making and errors in both conditions.

4 Results

4.1 Objective results

Some of the hypotheses required us to study the travel times of the participants. This allowed us to identify two different phases across the seven steps of the task. The Wayfinding phase, tasks that required participants to seek out more directional information; The Navigation phase, tasks that mainly required navigating within the environment, as the target location was known or obvious.

The analysis was performed using the full-factorial repeated-measures ANOVA procedure. Only significant effects are discussed here. The statistical analysis was performed using R with the Afex and ARTool Packages. When needed, Bonferroni correction was applied to account for multiple comparisons.

We will first discuss the travel times of the participants as a

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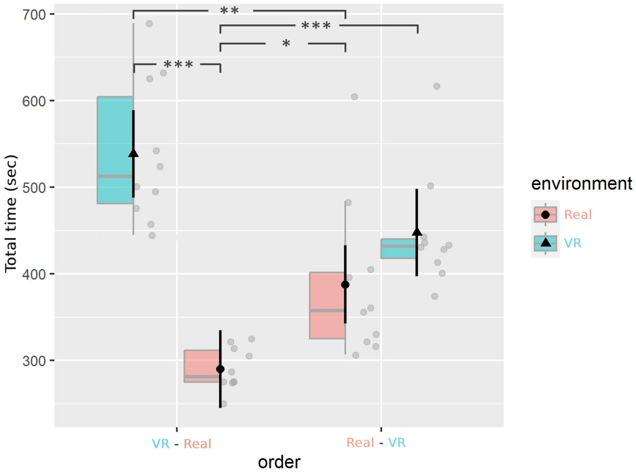

Figure 6: *Boxplot for the total task completion time for each condition and order.*

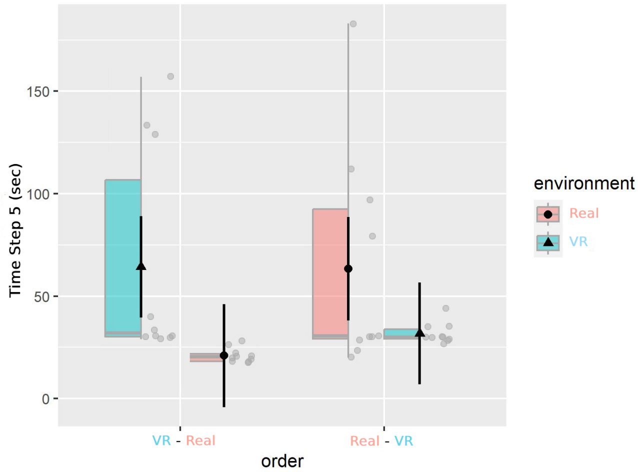

Figure 7: *The ANOVA analysis showing a significant interaction effect between order and environment for Step 5.*

whole, before specifying the two identified phases of wayfinding and navigation, and finally, focusing on a special case that we wanted to discuss in more detail.

4.1.1 Total time

The ANOVA analysis showed a significant interaction effect between order and environment (Figure 6):

Totaltime	$F(1,18) = 15.284$	$p < .001$	$\eta_p^2 = 0.459$

VR1	R1	R2	VR2
$M = 538.4$	$M = 290.2$	$M = 387.8$	$M = 447.6$
$SD = 83.23$	$SD = 24.72$	$SD = 92.42$	$SD = 67.41$

The interaction order and environment can be explained by the fact that VR runs were always slower compared to the real runs disregarding the order (all $p < .05$), which supports **H2**. Thus, when users start with the real run, the second run (in VR) required significantly more time to be completed ($p < .05$). In contrast, when users performed the VR run first, they significantly reduced the time required in the second real run ($p < .05$). Although these results do not support **H1**, when comparing the VR and real runs between subjects, the second run was always significantly faster (both $p < .05$).

4.1.2 Wayfinding phases

The ANOVA analysis showed a significant main effect on environment :

Step 1	$F(1,18) = 32.538$	$p < .0001$	$\eta_p^2 = 0.643$
Step 2	$F(1,18) = 11.625$	$p < .001$	$\eta_p^2 = 0.392$

The ANOVA analysis also showed a significant main effect on the order-environment interaction :

Step 1	$F(1,18) = 20.516$	$p < .001$	$\eta_p^2 = 0.532$
Step 2	$F(1,18) = 10.249$	$p < .001$	$\eta_p^2 = 0.362$

Regarding the Step 1 post-hoc tests, it showed significant differences between VR times ($p < .05$) but not for real times ($p = .1484$). Post-hoc tests of Step 2 showed non-significant differences between the two conditions.

With regards to the wayfinding phases, we observed that there was no order effect, which means that regardless of the environment, participants could learn from their first run. We also observed a significant difference between environments; real conditions lead to a faster time than virtual conditions, which supports **H2**.

4.1.3 Navigation phases

The ANOVA analysis showed a significant main effect on the environment :

Step 3	$F(1,18) = 214.052$	$p < .0001$	$\eta_p^2 = 0.922$
Step 4	$F(1,18) = 42.37$	$p < .0001$	$\eta_p^2 = 0.701$
Step 6	$F(1,18) = 129.40$	$p < .0001$	$\eta_p^2 = 0.877$
Step 7	$F(1,18) = 97.384$	$p < .0001$	$\eta_p^2 = 0.844$

For all navigation phases, only the time difference between real and virtual conditions is significant. The main point of note is that there is no significant interaction effect between order and environment. We simply observe a similar time difference between the two groups where the real conditions lead to a faster time than the virtual conditions, which supports **H2**.

4.1.4 Special case: Blue totem

There was a significant main effect on the order-environment interaction (Figure 7) :

Step 5	$F(1,18) = 9.63$	$p < .01$	$\eta_p^2 = 0.348$

With Step 5, pertaining to the blue totem, we found that 100% of the participants in both groups performed flawlessly on the second pass.

The results showed that regardless of the order between the real and the virtual iterations, there is as much error and time reduction for all participants when it comes to finding the blue totem. Post-hoc tests showed no significant differences between the two environments.

4.1.5 Participant decision-making

The success rates of the participants' decision-making in steps 1 to 5 are shown in the table in Figure 8.

We observed similar rates between the two groups, which supports **H3**, and this also applies to the two decisions "Turn left when leaving the cafeteria towards offices 08" and "Go directly to office 14" in Figure 8, where the success rate is very low and where we expect a clear improvement during the second passage. However, the improvement in Group 2 is noteworthy.

4.2 Subjective results

4.2.1 Questionnaires

Post-experiment Concerning the signage, the participants found that the signage displayed good general legibility: direction, font, colour, contrast ($M = 4.39, SD = 0.83$) in both conditions. Almost all participants rated the signs on the walls and doors as more visible (37 out of 40 runs, 100% of Group 1 and 85% of Group 2). All participants indicated that the directional sign "Offices 13-25" was useful to them in both runs. On 92.5% of the runs, the participants knew how to place the office number in front of the blue totem in the correct number range (21-25). One participant in Group 1 and one in Group 2 placed the office in the 16-20 range, but gave the correct answer on their second pass. Concerning the directional sign in the corridor at the corner of the entrance (Centre of Figure 3), seven participants from Group 1 could correctly place the sign after the first run, and after the second run, only two could not place it. In Group 2, six participants could correctly place it after the first run, but after the second run, five participants could not place it correctly, with three participants who were correct during the first run making a mistake during the second. Concerning the the general shape of the building, 100% of group 1 choose 'U' or added alternative response as 'L' or 'J' that we consider not wrong. In group 2, One participant choose "I don't know" in both runs and another choose 'U' the first run and 'S' the second run, which we consider wrong. From both groups, 3 participants proposed another letter 'h' and 'b' that we consider more precise than 'U'.

Learning If we consider the entire questionnaire, we obtain a score of ($M = 4.57$, $SD = 0.87$). Through this questionnaire, participants expressed that they remembered the environment of their first run independently of the order between both conditions. If we look at the questions regarding their memory of their first run, participants better recognised their environment, better found their way and the directions to take, and better knew where to look for direction-related information ($M = 4,84$, $SD = 0,43$). Among all these answers, one participant stated that they did not seem to have found the blue totem any better during the second run. Finally, participants were less attentive to the signage after the first run ($M = 3.25$, $SD = 1.45$), and 26 out of 40 (65%) gave a score less than or equal to 3. This means that they remembered the signage on their second run.

4.2.2 User feedback

We also collected a number of voluntary testimonies from the participants after completing the first or second run. For some participants, the virtual scene was more uncluttered than the real one, and the signage seemed more visible to them than in real conditions. There was more detail in real conditions than in virtual conditions, and they differentiated the offices from the other rooms more rapidly. Some participants found that office 14 was not logically placed in relation to the other offices around it. Some also confirmed orally that they had less need for the signage on their second run, regardless of the environment. Some participants expressed that they recognised the cafeteria in the real environment by the smell of coffee before visually recognising it. Many participants after the first run stated that they did not see ceiling and floor signs once they were faced with the question about their signage preferences, where they were asked to sort floor, ceiling, and wall signs in order of visibility. Finally, participants who were comfortable with VR wanted to go faster (max. speed = 1 m/s) and none of them expressed having any cybersickness.

5 Discussion

The aim of this study was to investigate the wayfinding behaviour of a user using signs in an unfamiliar environment in both real and virtual conditions. Following this experiment, we have collected objective and subjective data that we will discuss in the order of our hypotheses. Finally, we will discuss the limitations of this experiment.

5.1 Participants learnt from the first run

The results and the visual inspection of the video recordings show that, regardless of the environment and order, the participants were able to learn from their first run. They made fewer mistakes and had less hesitation overall. For both groups and both conditions, 53 mistakes for the first run, then 31 for the second run. However, as reported in Section 4.1.1, when participants started with the real condition, task completion time significantly increased in the second VR run, which do not fully supports **H1**. However, the results also show that the second VR run required significantly less time as the first VR run, and the second real run required significantly less time that the first real run. These results suggest that the knowledge gained in the first run allowed participants to perform more efficiently in the second run. This is consistent with participant feedback, both in the questionnaire and orally, participants expressed that they had less need for the signs.

Finally, we observed two particular cases for Group 2: One participant had difficulty finding their bearings during the first run in the real conditions (603 s with $M = 387.8, SD = 92.42$) but performed well on the second run in virtual reality (431 s with $M = 447.6, SD = 67.41$). We assume that this participant either had difficulties with orientation or was anxious in an unknown environment. On the other hand, one participant did well on the first run in real conditions (323 s with $M = 387.8, SD = 92.42$) but had difficulties with VR on the second run (616 s with $M = 447.6, SD = 67.41$). Nevertheless, both cases remain anecdotal, but highlight the possibility of outlier behaviours in such experiments.

5.2 Real conditions produce faster times

In both conditions, participants were instructed to perform the task at their normal speed. However, when comparing the average walking speed in real life (≈ 1.4 m/s [ZPPD09]) and the considered virtual speed (1 m/s), we hypothesised that participants would require more time in virtual conditions to achieve the task. All participants from the Group 1 produce faster times in real conditions. About the Group 2, a participant had more difficulties in real conditions during steps 2 and 5, producing a slower time in real conditions (603 s) than in virtual conditions (431 s). We determined this speed of 1

	STEP 1		STEP 2				STEP 3		STEP 4				STEP 5	
	Turn right at sign 13-25		Turn right towards Meeting 2		Turn right after office 15		Turn left out of the cafeteria to office 08		Go directly to office 14		Turn left towards office 17		Turn left towards the blue totem	
GROUP 1	VR	REAL	VR	REAL	VR	REAL	VR	REAL	VR	REAL	VR	REAL	VR	REAL
	50%	100%	70%	90%	80%	90%	10%	20%	20%	20%	70%	80%	70%	100%
GROUP 2	REAL	VR	REAL	VR	REAL	VR	REAL	VR	REAL	VR	REAL	VR	REAL	VR
	60%	100%	60%	80%	60%	90%	0%	20%	0%	30%	60%	60%	60%	100%

Figure 8: *Decision-making success rate table in steps 1 to 5*

m/s based on several trials with users who were not familiar with VR. By opting for this speed, they were able to master the controls better and faster. A higher speed increased the probability of users running into walls. Additional effects might have been due to their unfamiliarity with VR. The obtained results support **H2**. We suspect that multiple repetitions in VR conditions would further decrease the time, as we expect that participants would learn more about the virtual wayfinding process as well as the actual means of movement therein.

5.3 Similar wayfinding behaviour regardless of the environmental conditions

Based on the observations and feedback from the participants, regardless of the environmental conditions and the order, participants displayed a similar behaviour. They made similar mistakes during the same phases of the task, presented similar visual exploration behaviours, and demonstrate the same hesitations, which supports **H3**. For example, when participants hesitate at a connecting passage between corridors, they will stop and turn their head from left to right before making a decision. However, participants tend to make their directional decisions quicker in reality than in a virtual environment. Participants in reality reduce their speed before taking a decision, when in virtual conditions they tend to stop before. Furthermore, when looking at the videos and the time data, no significant effect of gender was found, participants' behaviour and performance were similar.

Regarding the placement of the signs. We expected that ceiling and floor signs would be less useful in virtual reality due to the limited field of view of the VR HMD. However, the experiment did not show any differences. Whether in VR or in reality, participants did not notice the floor signs or ceiling signs, which support **H3**. However, there were only two ceiling signs, designating the cafeteria and the reception area, which can be recognised without signs. Concerning the floor sign “Meeting 02”, based on our observations and on users' feedback, the sign was not easy to see during the first run, regardless of the environment. Seven participants (35%) took the wrong turn during the first run, against three (15%) during the second run, with two (10%) who took the wrong turn in both runs. Some participants who took the wrong turn went to the “Meeting 01” sign and turned around; we surmise that they probably used this sign to find their bearings within the space.

Regarding previous works, Dong et al.[DQY*22] found a similarity in the paths taken by participants in both environments, and that participants showed less confusion and took the shorter path the second time, regardless of environments. We also found similar results with Ewart et al.[EJ21] where the wayfinding performance of the participants in VR was similar to that of the participants in the real environment, although the travel time was faster in the real environment. Our results are also consistent with the study of Savino *et al.*[SEK*19]. We observed similar results to these previous studies with participants who were not already familiar with the environment and with a focus on signage and learning.

5.4 Poor signage design decreases wayfinding performance

This experiment showed that poor signage design and office layout had a negative impact on wayfinding performances. Regardless of the conditions, when navigating in a poorly designed environment, participants had to make an additional effort to reach their destination, even after a first run, whereas this was not the case for other destinations. We made this observation for two cases in particular. These two observations can be seen in Figure 8 ("Turn left out of the cafeteria towards offices 07-08" and "Go directly to office 14"), where the success rate is very low and improves very little, if at all, on the second run, whatever the condition and order, which validates **H3**. In addition, concerning the directional sign in the corridor at the corner of the entrance (Centre of Figure 3), we can see that a sign whose placement is not adapted to its environment and to the potential direction of traffic does not allow for an optimal transmission of information to the users. In contrast, we observed that the blue totem (View 1 of Figure 2) is an important element for orientation. All participants, regardless of the environment, reduced their hesitations and errors to zero during the second run in both conditions, validating **H3**. This confirms the recommendations set forth by Dong [DQL*20]. The results express the need to design important or noticeable landmarks in complicated scenes to be more visually salient.

5.5 Limitations

Firstly, this experiment was carried out in a single environment and one of relatively small size at that. The results may be different in a larger or outdoor environment. Experimental validation in this type of experiment remains complex. Further studies in which the same procedure is carried out in a different environment, of a different size and with different signs, could help to generalise the procedure and adapt it to all indoor environments.

The degree of resemblance between the real and virtual environments is relatively high. However, the representation of details is weaker in virtual reality than in reality. We did not model all the office equipment present in the offices. There is no simple solution, although there are various alternatives. An additional experiment, with varying degrees of clutter, might be interesting, but it remains uncertain which elements of the environment might help or hinder the wayfinding process.

This study mainly focuses on the time required to complete the run, video recordings, and questionnaires. Additional studies are to be encouraged in order to further investigate the comparability of the real and virtual environments with the above-mentioned parameters as well as other parameters, such as a map of pauses and hesitations or participants' track records.

Finally, we had to defer to the availability of the participants and the building, so it took several weeks to finalise the experiment, and not all participants had the same lighting conditions in the real condition. This being said, we could not determine if these differences in light conditions had any impact on the results. However, the experiment considered various signage elements (including landmarks), which show that the results may be generalisable in other scenarios.

6 Conclusion

In this paper, we assessed and compared human behaviour during a wayfinding task in both a real and virtual environment. In the described experiment, we explored the impact of signage and learning between real and virtual environments. The aim was to evaluate the comparability of wayfinding behaviour between real and virtual signage, where the use of virtual signage should ideally be comparable to the use of real signage. Overall, the results show that all participants were able to learn from their first run, regardless of the condition, resulting in a reduction in the time required to complete the run, faster decision-making, a decrease in the number of errors made, and a reduced need to make use of the signage. Interestingly, we did not observe any major differences between both conditions regarding wayfinding behaviour in similar situations. This suggests that in an information-seeking situation, participants react in the same way under both conditions and independently of the order. Furthermore, the results demonstrated that a poor or confusing signage design slows down the participants' ability to learn the environment between both conditions. Overall, in these situations, the participants were not able to reduce their number of wayfinding errors as much as they would when faced with a good signage design.

The results of this experiment demonstrate that virtual reality indeed represents a viable means of assessing signage, thus paving the way for the integration and use of virtual reality in the signage design process.

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7 Annexes

The following images show multiple views from the office space concerned by this experiment, offering a comparison between the real environment (Left) and the virtual environment (Right).

Figure 9: *The entrance to the office space, at the reception.*

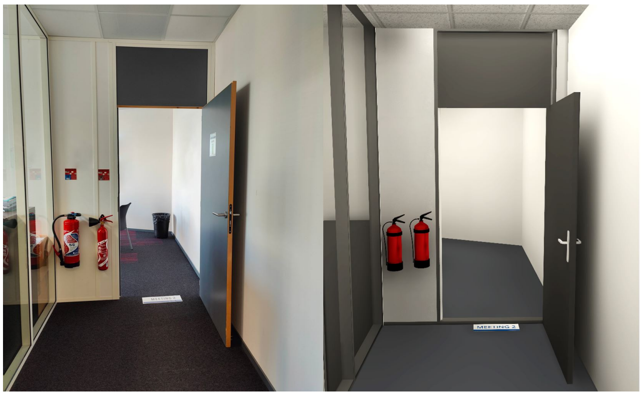

Figure 10: *The entrance to meeting room 02, with the sign on the floor.*

Figure 11: *The entrance to the cafeteria and offices 07 and 08.*

Figure 12: *The corridor between offices 10 and 13, with the sign directing to offices 13 through 25.*