University of Zurich[UZH]

Improving the Acquisition of Spatial Knowledge when Navigating with an Augmented Reality Navigation System.

GEO 511 Master's Thesis

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Table of Content

List of Figures

Unless stated differently, the figures are created by the author.

List of Tables

List of Abbreviations

ANCOVA	Analysis of Covariance
ANOVA	Analysis of Variance
AR	Augmented Reality
AV	Augmented Virtuality
FoV	Field of View
FRS	Fragebogen räumliche Strategien (Questionnaire on spatial strategies)
GIUZ	Geografisches Institut der Universität Zürich (Institute of Geography of University of Zurich)
HMD	Head-mounted Display
HDD	Head-down Display
HUD	Head-up Display
ISS	Irchel Spatial Self-evaluation
LM	Landmark
OST	Optical See-through
p	p-Value
ppi	Pixel per Inch
SAR	Spatial Augmented Reality
SBSOD	Santa Barbara Sense of Direction
UZH	University of Zurich
VR	Virtual Reality
VST	Video See-through

Key to Rooms

Rooms at UZH have a four-part name. The computer lab of GIUZ for example is located in Y25 J8. Y25 is building 25 of Irchel Campus (Y), J is the respective floor and 8 the room number on that floor. Note that floor G normally corresponds to the ground floor.

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Abstract

Navigation is a process humans use whenever they move. There are more complex tasks like finding our way in a new city and easier tasks like getting a cup of coffee. Daniel Montello (2005, p. 2) defines navigation as “the coordinated and goal-directed movement through the environment by organisms or intelligent machines”. When navigating in an unknown environment, humans often rely on assisted wayfinding by some sort of navigation aid. During the last years, the preferred navigation system shifted from printed maps to electronic and thus dynamic navigation systems on our smartphones. Recently, mixed reality and virtual reality approaches such as augmented reality (AR) have become an interesting alternative to the classical smartphone navigation. This although, the first attempts to AR were already made in the middle of the last century. The major advantages of AR navigation systems are that localisation and above all also tracking tasks are made by the system and that the navigation instructions are directly laid into the environment. The main drawback, on the other hand, is that the more tasks are made by the system, the less spatial learning is achieved by a human.

The goal of this thesis is to examine ways to improve the process of spatial learning on assisted wayfinding. An experiment where participants are guided through a test environment by an AR system is set up to test these ways. After completing the route, the participants had to fill out a questionnaire about landmarks and intersections, which they had encountered on the route. The concrete goals of the thesis are to find out (1) whether giving more spatial information will improve spatial learning, (2) whether the placement of navigation instructions has an influence (positive or negative) on spatial learning, (3) whether the type of landmark has an influence on how well it is recalled and (4) how well landmark and route knowledge is built after having completed the route once.

The results of the experiment suggest that giving background information to certain landmarks do not lead to a significantly different performance in spatial learning ($p = .691$). The result could also show that there is no difference whether a landmark is highlighted by a navigation instruction or not ($p = .330$). The analyses of landmark and route knowledge has shown that the participants have built less landmark knowledge than route knowledge after the run, as they have approx. 50 % of the landmarks correct but 67 % of the intersections. Interesting and in this case significant is the difference between the types of landmarks ($p = .018$). 3D objects are recalled much better than other landmarks. Also significant ($p = 6.14e-3$) but unfortunately not very robust is the influence of the age on the acquisition of route knowledge. As the age distribution is very unbalanced, these results have to be interpreted with caution.

Following the findings of this thesis, it is suggested to conduct a series of experiments with an eye tracker to learn more about how the visual focus of people using AR as a wayfinding assistance behaves.

Keywords

Navigation, Spatial Learning, Wayfinding, Mixed Reality, Augmented Reality, AR, Hololens 2

Zusammenfassung

Navigation ist ein Prozess, den Menschen ausführen, wann immer sie sich bewegen. Es gibt dabei komplexere Aufgaben, wie sich in einer fremden Stadt zurechtzufinden und einfachere Aufgaben, wie sich eine Tasse Kaffee zu holen. Daniel Montello (2005, p. 2) definiert Navigation als «koordinierte und zielgerichtete Bewegung von Menschen oder intelligenten Maschinen durch die Umgebung». Wenn wir uns in einer unbekannten Umgebung bewegen, greifen wir oft auf Hilfe von Navigationssystemen zurück. Währen der letzten Jahre haben Smartphones die analogen Navigationshilfen mehr und mehr abgelöst. In letzter Zeit haben sich zudem mixed reality und virtual reality Systeme wie zum Beispiel augmented reality (AR) als interessante Alternative zur klassischen Smartphonenavigation entwickelt. Das obwohl die ersten Versuche mit AR bereits Mitte des letzten Jahrhunderts gemacht wurden. Die grössten Vorteile eines AR-Systems sind, dass die Lokalisierung und die Ausrichtung vom System übernommen werden und dass die Instruktionen direkt in die Umgebung gelegt werden können. Der grösste Nachteil dabei ist, dass je mehr Aufgaben vom System übernommen werden, desto weniger räumliches Wissen bleibt dem Benutzer.

Das Ziel dieser Arbeit ist es, Wege zu untersuchen, wie trotz Navigationssystemen das Erwerben von räumlichem Wissen verbessert werden kann. Dafür wurde ein Experiment durchgeführt, bei welchem die Teilnehmenden mit einem AR-System durch eine Testumgebung geführt wurden. Nachdem sie dies abgeschlossen hatten, mussten sie einen Fragebogen zu Landmarken und Abzweigungen, welche sie auf der Route angetroffen hatte, ausfüllen. Die konkreten Ziele sind, herauszufinden, (1) ob das räumliche Lernen verbessert werden kann, wenn das System mehr Informationen zur Verfügung stellt, (2) ob die Position der Instruktionen einen Effekt (positiv oder negativ) auf das räumliche Lernen hat, (3) ob die Art der Landmarke einen Einfluss hat, wie gut man sich an sie erinnern kann und (4) wie gut das Landmarken- und Routenwissen bereits sind, nachdem die Teilnehmenden die Route einmal absolviert haben.

Die Resultate des Experiments legen nahe, dass das Erhöhen des Informationsgehalts nicht zu einem signifikanten Unterschied beim räumlichen Lernen führt ($p = .691$). Weiter zeigen die Resultate, dass es keinen Unterschied macht, ob eine Landmarke mit einem Navigationspfeil hervorgehoben wird ($p = .330$). Die Analyse von Landmarken- und Routenwissen zeigte, dass die Teilnehmenden weniger Landmarkenwissen als Routenwissen aufbauen konnten. Sie beantworteten ca. 50 % der Fragen zu Landmarken richtig und 67 % der Fragen zu den Abzweigungen. Interessant und auch signifikant ist der Unterschied, welcher bei den Arten von Landmarken besteht ($p = .018$). Die Teilnehmenden erinnerten sich besser an 3D Objekte als an andere Typen von Landmarken. Ebenfalls signifikant ($p = 6.14e\text{-}3$), aber leider nicht sehr aussagekräftig ist der Einfluss des Alters auf das Routenwissen. Die Verteilung des Alters der Teilnehmenden ist sehr einseitig, weswegen die Interpretation dieses Resultats mit Vorsicht zu geniessen ist.

Aufgrund der Resultate dieser Arbeit wird vorgeschlagen eine Serie von Experimenten mit einem Eye-Tracker durchzuführen, um mehr über den visuellen Fokus von Menschen, die AR als Navigationshilfe benutzen herauszufinden.

Schlagwörter

Navigation, Räumliches Lernen, Wegfindung, Mixed Reality, Augmented Reality, AR, Hololens 2

1. Introduction

1.1. Navigation

When we think about navigation, we may think about medieval explores who used rudimental maps and simple but effective navigation aids such as stars. Or we think about finding our way in a new city by using a map or rather a smartphone nowadays. But navigation is more. Only few of us would think about getting a cup of tea from the kitchen or going to the next store for groceries. In the end, all four examples are a form of navigation. Admittedly, some navigational tasks are more complex and require more cognitive workload than others.

The framework of Daniel Montello (2005) is one of the most cited work in this domain. Only Google Scholar alone lists over 500 articles in which it is referenced. Figure 1 shows a simplified schematic visualisation of this framework. According to him, navigation can be divided into two components. First, there is locomotion, which is defined as the movement around an environment, coordinated specifically to local or proximal surrounds. This includes both active and passive locomotion. There are two common perceptions of what is the separation between active and passive. For some researchers, the crucial point is whether the movement is self-directed or not. Self-directed movement would include all modes of locomotion from going by foot, riding a horse to flying a plane (Feldman & Acredolo, 1979). The other distinction between active and passive is the source of energy used to power the movement. Walking or riding a bicycle is then regarded as active while driving a car or flying a plane would be passive locomotion (Montello, 1997). Both ways have their advantages with respect to other aspects of navigation. Self-powered locomotion may result in a better judgement of distances and thus better dead-reckoning. A self-directed locomotion will lead to greater environmental learning which is important for landmark based wayfinding (Montello, 2005).

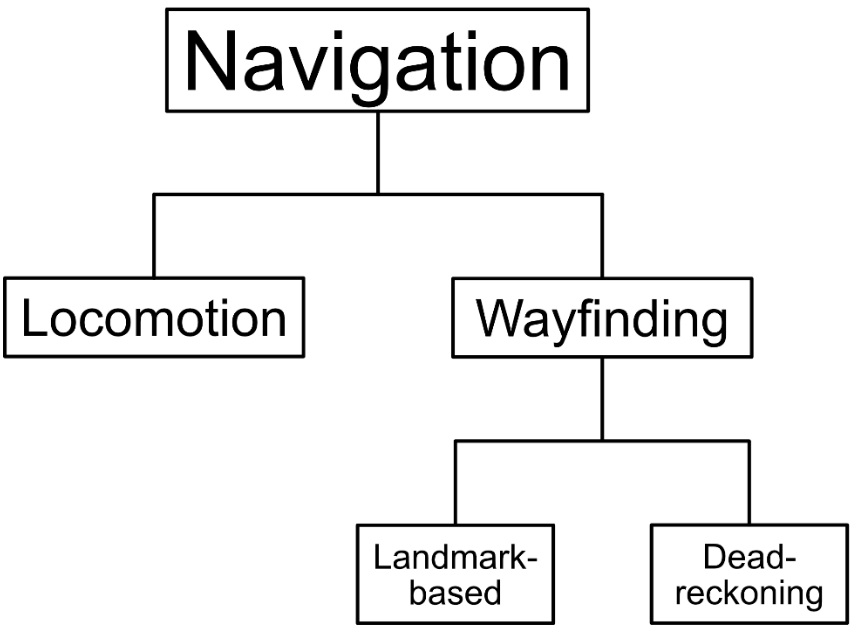


Figure 1 Simplified Navigation Framework after Montello (2005).

The other component of navigation is wayfinding. Montello (2005) defines wayfinding as the goal-directed movement around an environment in an efficient way. This sounds quite similar to locomotion at first, but the differences come clearer when thinking about examples in which one is done without the other. For example, imagine you are riding a bus. In this case, you are locomoting without any wayfinding. This is done by the bus driver for you. On the other hand, you can do wayfinding without locomoting. Take a bicyclist as an example who just blindly follows his navigation device and ends up driving on the motorway, as it happens from time to time (e.g., Unternährer (2019)). In such a case, the bicyclist did not move coordinated to local surrounds as he or she is not allowed to drive on the motorway. Furthermore, you can also do wayfinding without locomoting if you for example plan a route in advance by checking maps and/or images form a certain location.

For the process of wayfinding, humans and also animals need some sort of information to keep track of their location, orientation and direction. One possible way to gather information is landmark-based updating. The easiest way, and probably also the one that is done most, of landmark-based orientation is recognising a landmark (e.g., a house, a fountain or a statue) to which a direction is linked. This method requires an internal or external memory in which two things are saved. First, for identifying a blue house as relevant for your navigation, you need to know what a house is and which house is meant (the blue one in this example). The second thing that has to be memorised is the direction that is linked with the landmark, since only few landmarks indicate a direction themselves. For the example with the blue house this could mean that if I am coming from a certain direction, I have to turn left to go to the train station and right to go to stadium. The process of landmark-based orientation is not a discrete series of recognising landmarks and taking turns. Our brain starts to make paths continuous by linking landmarks of a route and making a map out of it. In our little fictional example, we know that if we turn right at the blue house, we eventually will approach an octagonal fountain where we have to go straight on. The here described way is the process if the information is coming from an internal map. Such a map is called cognitive map (Montello, 2005) or mental map (Brügger et al., 2019) and works well for environments we are familiar with. In case the environment is new (e.g., in a new city), we have to rely on external maps or cartographic maps, either printed or nowadays mostly on our smartphones.

Dead-reckoning is the other possible way to collect information. In contrast to landmark-based orientation, we gather the information from internal sources. This includes information about acceleration and velocity of our locomotion (i.e., how far we have been moving) and information about the direction of it (i.e., which direction we have been moving to). In practice, we often use a combination of landmark-based orientation and dead-reckoning while navigating. First, it is the most accurate way if we combine these two methods as we have internal and external sources which we can crosscheck and second there are some difficulties if we would only rely on dead-reckoning. We would not be able to start with dead-reckoning since we need a starting point (landmark) and direction and we would also face issues with error accumulation (Montello, 2005).

1.2. Spatial Learning

Spatial learning is a "side effect" (Münzer et al., 2006, p. 300) of wayfinding, but there is a number of reasons why this is not bad at all. The most obvious reason is that people eventually want to locomote without having to rely on help of any kind at some point. If we are in a new environment for the first time, we need some sort of help to find our way, but after a while and thanks to spatial learning we get used to the way and we know where we have to turn. Second, efficient route planning requires a minimum of spatial knowledge. Imagine being in a supermarket with a shopping list. Without knowing where the products are that you need, you might start at the top and work your way down the list. But if you know the location of the products you can plan your route in an efficient way that saves you a lot of time and shortens your way through. Third, you eventually want to be independent from any form of aid so that in case of a failure of technology you would still be able to find your way at least to the most important locations. And fourth, there are situations like driving a car in which wayfinding uses cognitive workload that can better be used for the actual task. In the example of driving, this means that if you do not have to have part of your focus on where you drive (even if most of the instructions are given orally, cf. Gardony et al. (2013)), you can use all your concentration on how you drive (Münzer et al., 2006).

It is important to point out that there are two types of navigational knowledge (Gardony et al., 2013; Münzer et al., 2006) and thus according to various researchers also two types of spatial learning (e.g., Taylor & Tversky (1992), Thorndyke & Hayes-Roth (1982) or Tversky (1996). The percipience from a first-person view along the route is called route perspective. For every entity, we memorise a first-person (egocentric) image and the corresponding direction(s) to it (Gillner & Mallot, 1998). In contrast, survey perspective is a mental map representation of the environment from a bird's eye view (allocentric) perspective. The gained survey knowledge is responsible for the understanding of spatial relationships between locations (Gardony et al., 2013; Münzer et al., 2006). Literature is discordant in terms of the order of how we gain information. Older literature like Siegel and White's (1975) "seminal work on spatial knowledge development" (Gardony et al., 2013, p. 321) suggest that we first gain landmark, then route and finally survey knowledge. More recent work like Ishikawa & Montello (2006) conclude that the gathering of these three types of information works in parallel. What is undisputed is that navigation experiences in new environments very quickly lead to route knowledge (Gardony et al., 2013).

Navigation aids, which we use a lot to navigate optimally in an unknown environment (Ludwig et al., 2014), interfere with the spatial learning described in the preceding paragraphs and it is broadly proven that the effect is negative (e.g., Brügger et al. (2019)). The first problem is that typical navigation aids provide turn-by-turn instructions. This means that at every point one has to take a decision they are assisted by the system (e.g., "turn left"). On one hand, this limits the user to the route perspective as the bigger spatial context is not relevant and on the other hand, the route knowledge is also be kept limited as the instructions are linked to the correct location by the system (Gardony et al., 2013). The second problem is that the selection of relevant environmental entities (for example landmarks) is made by the system, which leads again to a decreased attentiveness because one knows that the navigation system does the work for you (Taylor et al., 2008). Both cases conflict with the active learning hypothesis of Münzer et al. (2006) which states that the best spatial learning results are achieved if one has to process the information provided actively.

However, just saying that users of navigation aids are restricted in building spatial knowledge would only tell part of the story. There is a wide range of systems that differ in the information format (visual vs. verbal; Gardony et al. (2013)) or in their level of automatization. Parasuraman et al. (2000) have defined ten levels of human interaction with automation which can also be applied to automated navigation systems (Brügger et al., 2019). The levels (Figure 2) reach from level 1 where the system does not offer any assistance to level 10 where the system works autonomously and the human has no possibility to interact. The study of Brügger and colleagues (2019) compares four cases in which participants have to use four navigation systems, which differ in the level of automation in terms of self-localisation and allocation of attention. After guided through a route with the respective navigation systems, the participants had to find back to the starting point using the exact same way but without any help. The results show that participants of the groups with a less active participation made statistically significant more errors than participants with a more active participation (p = .034). Interestingly, members of the groups that made more errors did not rate the task to be more difficult than the other groups, but they seem to overestimate the difficulty of the task in advance (p = .289 before and p = .860 after walking back).

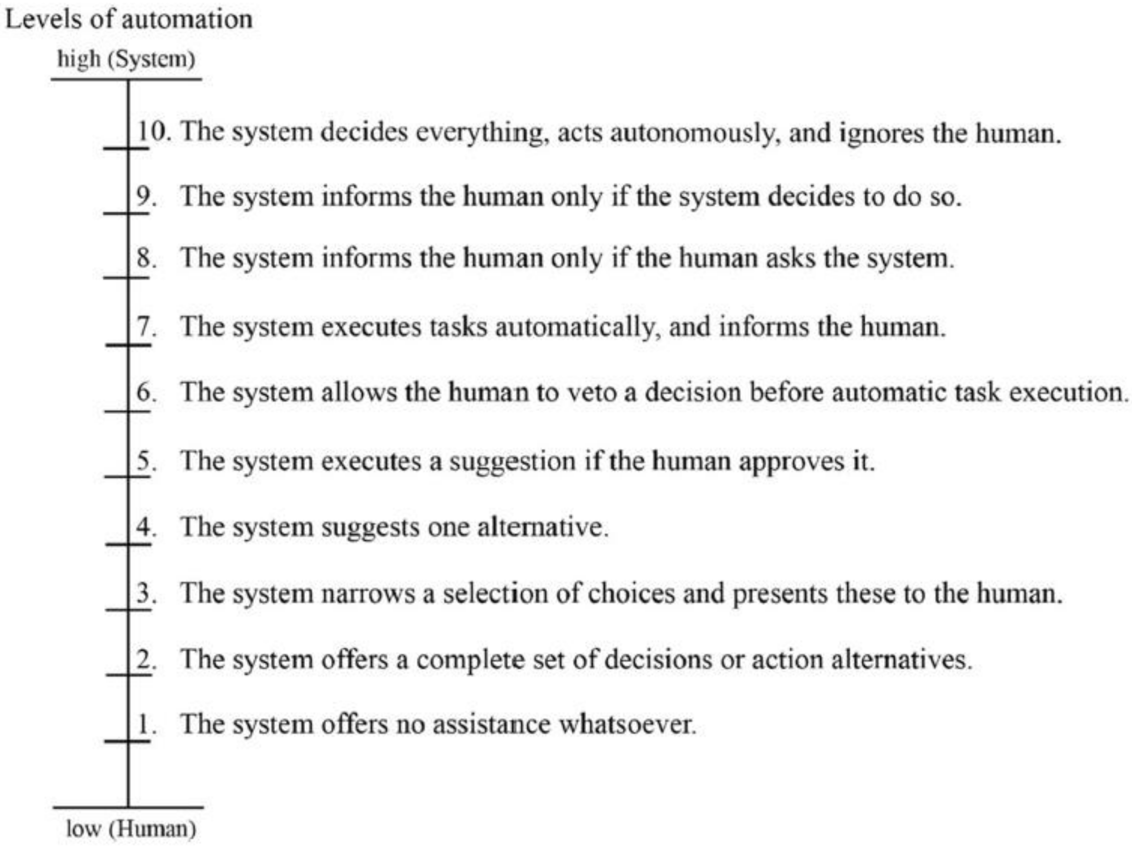


Figure 2 Levels of Automation. Figure from Brügger (2019) *adapted from Parasuraman* (2000).

1.3. Augmented Reality

1.3.1. History and Definition of Augmented Reality

The very first documented concept of augmented reality (AR) goes back to the novel "The Master Key – An Electrical Fairy Tale" by L. Frank Baum (1901), who is best known for his Wizard of Oz series. In the novel, Rob, an electricity-interested teenager, accidentally triggers the master key of electricity leading to the appearance of the Demon of Electricity. The demon gifts Rob electrical gadgets three times. The novel is not only vanguard in terms of AR. Among the gifts are an electric-shock tube for non-fatal self-defence (i.e., the first idea of a taser), a record of events that functions like a news service that is always available or an illimitable communicator that allows instant contact with anyone on the planet. The latter two are somehow possible by modern mobile phones. The AR device is described as a character marker that functions as follows: "[…] It consists of this pair of spectacles. While you wear them every one you meet will be marked upon the forehead with a letter indicating his or her character. The good will bear the letter 'G', the evil the letter 'E'. The wise will be marked with a 'W' and the foolish with an 'F'. The kind will show a 'K' upon their foreheads and the cruel a letter 'C'" (Baum, 1901, p. 45). However, the gadgets lead Rob more into problems – some people he meets even want to kill him to get one of the gadgets – than resolving any and he returns them to the demon. Saying that "it is no fun being a century ahead of the times" (Baum, 1901, p. 111)has been proven to be a quite accurate forecast. Using an electric-shock tube, a record of events or an illimitable communicator is nothing special a bit more than 100 years later.

The first scientific approach to AR was made by Morton Heilig in the 1950s. The American cinematographer described the cinema of the future in 1955 and built a prototype of it in 1962. The head-mounted display (HMD) was invented shortly afterwards in 1968. Heilig's Sensorama, as it was called, was a rather large fix-installed machine and AR devices became only dynamic with the invention of HMD. Again a few years later, it became possible for the first time to interact with virtual objects in 1975. The term AR as we know it nowadays did only emerge during this time from workers at the American aircraft manufacturer Boeing (Carmigniani & Furht, 2011). It took another 20 years until the mid-90s, until researchers came up with much of the theoretical basis of AR. These definitions and concepts were widely accepted and are still used today. Milgram et al. (1995) came up with the reality virtuality continuum (Figure 3). He defined it as a span between the real environment and a virtual environment. AR would then be virtual objects lain displayed over the reality, augmented virtuality (AV) the inversed case where real objects are displayed in the virtuality and a virtual environment is a display of fully virtual objects, i.e., there is nothing from reality visible anymore. Note, that virtual environment is more commonly referred as virtual reality (VR; Azuma (1997); Carmigniani & Furht (2011)).

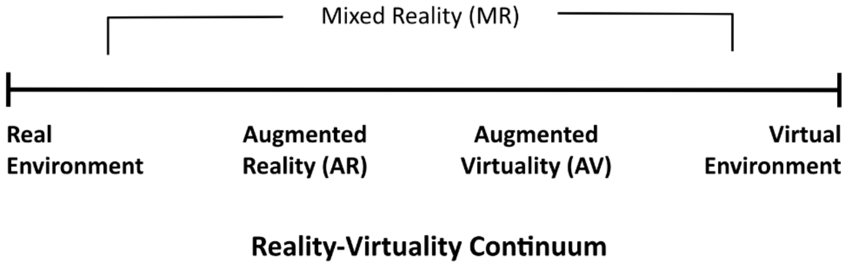


Figure 3 Reality-Virtuality Continuum. Figure by the Author after Milgram et al. (1995).

A broadly accepted definition of AR was published by Roland Azuma (1997) in a first survey about AR (Carmigniani & Furht, 2011). He states that AR is a variation of VR, but while VR users are completely immersed into a virtual world, AR users still see reality only with superimposed virtual objects. Thus, AR systems have the following three characteristics. First, the system combines real and virtual components. Second, it consists of interactive elements and third, it is registered in 3D. Some researchers (e.g., Milgram et al. (1995)) had defined AR in a way that it has to include an HMD, but Azuma left this part out on purpose not to be limited to one single technology. This idea is supported by the majority of scholars. Examples are Klopfer & Squire (2008) for whom reality is dynamically overlaid with virtual information, Dunleavy et al. (2009) for whom digital resources fuse with the real world or Wu et al. (2013) who state that AR should be conceptualised beyond technology.

The augmentation not necessarily has to be restricted to the visual component. There are possible applications that also include auditive or olfactory dimensions. However, this work will focus on the visual applications, as this is (1) the most common field of use, (2) the field used in the experiment of this work, (3) there are some issues combining it with point two and three of Azuma's (1997) definition and (4) humans gather the majority of information from visual sources (Chen et al., 2019). Generally, there are two types of AR available, optical and video technologies (Azuma, 1997; Bimber & Raskar, 2005; Carmigniani & Furht, 2011).

An optical see-through (OST) HMD allows the user to see the environment directly. The key part of such an HMD is a combiner which is partially transmissive and partially reflective. By being transmissive, it allows the user to see the real environment, the reflective part then projects the necessary virtual information onto reality. The amount of light, which is transmitted through the combiner, varies with the used hardware. Modern AR devices are even able to diversify the amount for different wavelengths. The used Hololens 2 (see Chapter 2.8.1) in this work is an example of this type of an HMD. On the other hand, there are video see-through (VST) HMD or closed-view HMD. In contrast to the OST HMD, it is not possible for a user to see the reality directly. One or two camera(s) is/are mounted on the HMD which record the environment. Normally, two cameras are used to be able to create a video in 3D. Before the user see these images, a scene generator combines the real world with the virtual graphics (Azuma, 1997). Figure 4 (OST) and Figure 5 (VST) illustrate the differences between the two types of HMDs graphically.

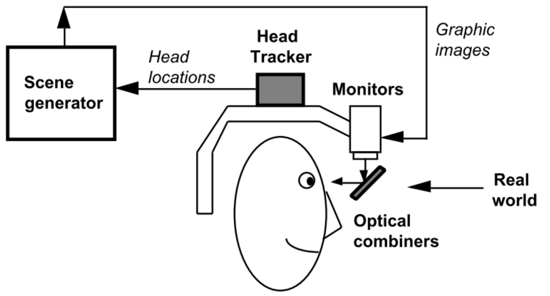


Figure 4 Schematic Image of an Optical See-through HMD. From Azuma (1997).

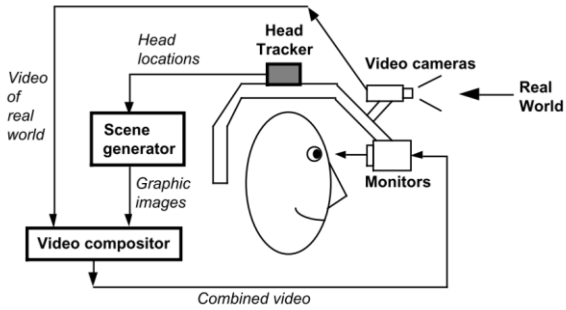


Figure 5 Schematic Image of a Video See-through HMD. From Azuma (1997).

Obviously, there are advantages a type of HDM has over the other. Azuma (1997) lists the following advantages for optical see-through HDM:

- **Simplicity**: The optical approach is simpler and also cheaper than the video approach, as only the virtual objects require processing and thus computational power. The real world can be seen directly without any manipulation.
- **Resolution**: Resolution is only an issue for the virtual objects but not for the reality, as the latter is seen directly. Note: Azuma argues that the resolution of displays is far less than the resolving power of the fovea. According to Serpengünzel & Poon (2011), a phone or tablet had to reach a resolution of 655 pixel per inch (ppi) to match the foveal resolution. The Nokia 3210 as an example for a mobile at the time of writing had a resolution of 64 ppi[1]. Modern smartphones have a much better resolution with 450 ppi (Huawei P50 Pro[2]), 476 ppi (Apple iPhone 13[3]) or 500 ppi (Samsung Galaxy S22 Ultra[4]). Therefore, the resolution gap could have been reduced by approximately 75% in the meantime and this is not the same issue as it was back in 1997.
- **Safety**: Wearing a VST HMD does not allow the user to see the environment directly. If for some reason the device stops working, the user is blind. This can be an issue for certain applications.
- **No eye offset**: The cameras of a VST HMD are usually not placed right in front of the users' eyes. This leads to a small difference between how the user would see the world directly or with an OST HMD and how he/she sees it with a VST HMD. OST HMDs provide therefore more intuitive sight on the environment.

And the following points for video see-through HMD:

- **Flexibility in composing:** Due to the mode of operation of an OST HMD (transmission and reflection at the same time), the virtual objects appear semi-transparent and a bit ghost-like. Having both the video and the virtual object digitally allows the compositor to calculate the optimal display characteristics pixel by pixel.
- **Wide field of view (FoV):** Features that are far away from the optical axis (direction of view) can appear distorted. The correction of such distortions requires indeed much computation power but is in a VST still much easier than in an OST HMD.

[1] https://en.wikipedia.org/wiki/Nokia_3210 (last retrieved on 29.09.2022)
[2] https://consumer.huawei.com/ch/phones/p50-pro/specs/ (last retrieved on 29.09.2022)
[3] https://www.apple.com/uk/iphone-13/specs/ (last retrieved on 29.09.2022)
[4] https://www.samsung.com/global/galaxy/galaxy-s22-ultra/specs/ (last retrieved on 29.09.2022)

- **Delays can be matched:** The diversion via the video compositor allows the VST HMD to correct the tiny difference that might be between the real and the virtual image. This is not possible for OST HMDs as the environment is seen directly.
- **Additional registration strategies:** While an OST HMD has only the head tracker as information source about the head's location, the video camera of a VST HMD acts as a second source for information.
- **Matching of the brightness of reality and virtuality:** In an optimal case, the brightness of the reality is more or less equal to the one of virtuality. This would allow to blend the best result possible in terms of sharpness of the objects.

Some of the advantages/drawbacks listed here could be observed in the experiment and are discussed in section 4 of this work. Carmigniani & Furght (2011) also list advantages for both options. The included points are mainly congruent with those of Azuma (1997). The only additional point they make is that with OST HMD the perception of the real environment is more natural compared to the blended perception in a VST HMD.

Besides the HMD, there are two further platforms for AR. One are handheld devices such as mobile phones or Tablets (Wagner & Schmalstieg, 2006). Since one looks through the screen into the environment, this can be classified as VST blending. Carmigniani & Furght (2011) list the widespread of the devices and powerful CPU and sensors as advantages. Both availability of handheld devices and their computational power have even further increased in the meantime.

The other type is Spatial Augmented Reality (SAR). Here, technology is detached from the user, meaning that one does not have to hold or wear any sort of device. There are three different approaches to SAR. The first are screen-based VST displays. In contrast to VST HMD, the output is displayed on a stationary device like a desktop computer. The main disadvantage of VST SAR is that it is mostly remote viewing, as the display is often not exactly in the optical axis when looking at the object. Second, there is OST SAR. Best examples for this are head-up displays (HUD). They work like HMDs, but the optical combiner is rather installed in front of the windscreen. The technology was first introduced in cockpits of aeroplanes (Coni et al., 2019), but can nowadays be found more and more also in cars (Pfannmüller, 2017). Major drawbacks are as for the first example the missing dynamic operation and that there is no direct interaction possible. The third approach is a projection-based spatial display. In this type of 3D rendering, the virtual objects are directly projected onto surfaces of real objects. Note that a combiner only does not count as an object in this definition. An example would be a sphere onto which boundaries and other information about countries is projected letting the sphere becoming an interactive globe. With this approach we encounter new problems that were no issue for the former two. However, many of these points are only problematic if there is only one projector. The 3D shape of the object that something is projected on possibly leads to shadowing. This problem can relatively easily be solved by using more than one projector. Furthermore, there is a limitation of the projectable surface to the object. It is not possible to display any further information beyond it. Using only one projector can also limit the geometries and colours of the desired projection. Again here, this problem can be solved by using more than just one projector (Bimber & Raskar, 2005).

1.3.2. State of the Art

Despite the cited literature in the previous section is over a decade old, the definitions, technologies and fields of application remain the same. Sure, there has been a technological advance in the meantime improving for example the resolution of the displays or the computational power of the processing units. But contemporary work like those of de Souza Cardoso and his colleagues (2020) or Scavarelli et al. (2021) still references Azuma (1997) for the definition of AR. Also the applications listed by the latter, including medicine, machinery industry, information visualisation, entertainment and (military) aviation, can be found in newer literature (e.g., Chen et al. (2019)). The following three examples are examples for state-of-the-art applications of a handheld device, a SAR and an HMD.

There are many applications for mobile phones and tablets that use AR technology to some extent. Google Maps’ Live View was chosen as an example. Live View is an additional feature of Google’s map and navigation system in which users can choose to be guided by arrows and other instructions (e.g., descend one floor at a staircase) on their phone screen. As with all handheld devices, the reality is augmented on a recording, making it a VST system. The localisation works with GPS as in normal operations and the tracking via Google Street View images. This makes Live View only work in environments that are available on Street View. These are mostly outdoor environments near roads and paths. But there are also a few indoor locations where Live View is available. Figure 6 shows assisted wayfinding in the buildings of Zurich Airport where it is available since last October (Zurich Airport, 2021).

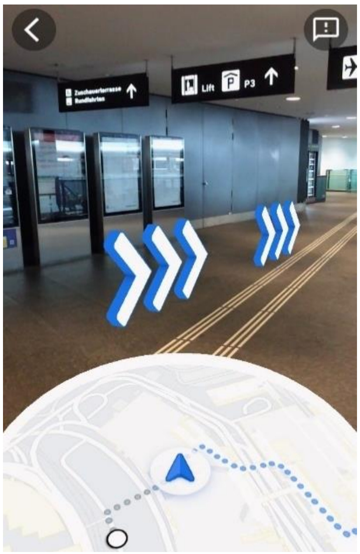


Figure 6 Screenshot from Google Live View.

Figure 7 shows a HUD in a car. The most common HUDs in cars are limited to relevant information for the driver including the current speed, navigation advices, driving assistance systems (e.g., speed control), warnings and recognised street signs such as speed limits (Pfannmüller, 2017). This is also what is included in this example. The “0” on the top right indicates the current speed, the “D” the selected gear. The and the distance next to it indicate to take a right turn after the given distance. The bar underneath acts as a tachometer. The main advantage of a HUD over a head-down display (HDD) in a car is the much shorter time a driver needs to check the speed for example. According to Miličić (2010), it takes a driver one second to check the speed. While driving 100 km/h, this results in a distance of 30 m that is covered. Including the turning of the head, checking the speed with a HUD is possible in 900 ms on average (Klocke, 2005). A further advantage is the missing readaptation to the outside light and contrast conditions what reduces fatigues and is especially

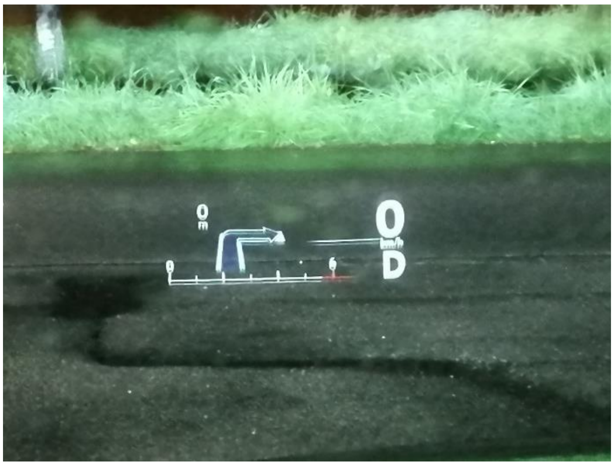


Figure 7 HUD Application in a Car.

a benefit for older drivers who have reduced adaptability capabilities (Kiefer, 1999; Miličić, 2010; Seitz, 2009).

Probably the most sophisticated HMD can be found in the cockpit of the F-35 Lightning II[5]. The jet fighter of the 5th generation is used in 13 countries and three further countries including Switzerland plan to purchase it (Lockheed Martin, 2022; N.N., 2022). With the visor of the helmet, which combines OST and VST approaches, the pilot has the possibility of switching between real-time video, thermal imagery and night vision. The aircraft is designed in such a way that six cameras allow the pilot to see through the airframe leading to an unlimited field of sight. The real-time frames are overlaid with all relevant flight and mission information. This includes the airspeed (625 kts to the left), the height (14000 ft to the right), the heading (290°) on the top and designated targets (circles) or possible targets (diamonds) in the centre of Figure 8 (Mola, 2017).

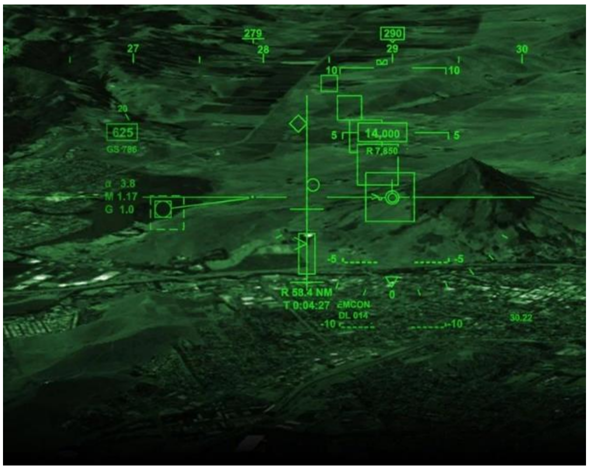


Figure 8 Augmented Night Vision Sight of a F-35 Helmet. From Mola (2017).

1.4. Augmented Reality in Indoor Navigation

Despite that AR in navigation was not included in Azuma's (1997) seminal work, a prototype of an AR navigation system was developed in the same year (Feiner et al., 1997). The users could augment the campus of Columbia University in New York. In addition to an HMD, the system also included a backpack in which the processing unit was carried and on which GPS and radio receivers were mounted as well as a power belt which acted as a link between the different components. The authors conclude that the technology is promising for the future but has serious issues with the quality of the display and of the tracking that have to be improved first. More and more researchers have taken up the experiences and the recommendations of Feiner et al. (1997) and developed AR navigation aids mostly for complex indoor environments such as airports, museums or libraries (Gerstweiler et al., 2015; Huang et al., 2016; Wang, 2019).

The use of an AR navigation system as a wayfinding aid offers various advantages over other aids. Before AR systems were available for general use, electronic 2D maps were most used for navigation (Dong et al., 2021). Münzer et al. (2006) found out that AR users make less mistakes and reach the destination faster than map users. In return, the latter acquired better route and survey knowledge. Rehman & Cao (2017) came to similar conclusions. Gardony et al. (2021) and Liu & Meng (2020) underline that navigation with AR is easier, since users do not have to recognise abstract map symbols, locate themselves and do route planning. They can just start and follow the automatically updated wayfinding instructions. Furthermore, AR systems normally follow a track-up display rather than a north-up display. This suits a significant majority of people who has problems if the alignment of a map does not correspond to their own orientation in the environment (Hickox & Wickens, 1999; Montello, 2005) and who

[5] https://www.f35.com/f35/index.html (last retrieved on 29.09.2022)

is in this case faster and more accurate in wayfinding with track-up instructions (Viita & Werner, 2006). But as previously observed, faster wayfinding leads to worse spatial learning if north-up and track-up systems are compared (Aretz, 1991). The reason of this drawback is that AR navigation aids have a higher level of automatization making most of the map manipulations like zooming, panning and rotating superfluous (Brügger et al., 2019; Dong et al., 2021).

In terms of research on indoor AR navigation, the very recent survey of Khan et al. (2022) provides an excellent overview over the current developments and the state of the art in this field. They reviewed 68 articles that were published between 2002 and 2021 with the majority of articles being released during the last decade. The authors of the survey classify the articles into four categories including robot navigation, wearable technologies, systems with AR visualisation only and mobile device systems. Robot navigation is very similar to human navigation. Scholars use approaches with different markers (Acuna et al., 2018; Garrido-Jurado et al., 2014) or cameras (Cheng et al., 2017; Diop et al., 2016) for localisation. Also researched are spatial knowledge and wayfinding (Ko et al., 2013; Yan et al., 2013). For wearable technologies, the most important sub-field is the evaluation of camera- and sensor-based systems as a help for visually impaired people (e.g., Bai et al. (2018) or Diáz-Toro et al. (2021)). One paper analyses such a system for non-impaired people (Rehman & Cao, 2016). Systems with AR visualisation only differ in a way that they do not use cameras and/or sensors for position tracking but they rely on AR technology for information visualisation nevertheless. Like in the previous category, the majority of articles evaluates systems addressed to seeing (Alnabhan & Tomaszewski, 2014; Landau & Ben-Moshe, 2020) and visually impaired people (Zhang et al., 2019). Further, Rehman & Cao (2017) compared handheld devices, Google Glass (an HMD from Google[6]) and paper maps and concluded that wearable devices are more accurate and that electronic aids are more effective and efficient but users showed worse route detentions. An interesting alternative to the presented approaches is presented by Möller et al. (2012), who suggest to use a combination of AR and VR for the interface. The last class, mobile and smartphone devices, is very similar to the field of wearable devices, but with a different device that is used. Khan et al. (2022) present studies that evaluate systems using different sensors of a smartphone for direct tracking (Al-Khalifa & Al-Razgan, 2016; Puertolas-Montañez et al., 2013) or for the detection of markers of any kind (Idrees et al., 2015; Poulose & Han, 2019).

1.5. Research Context, Goals and Hypotheses

There is a myriad of research in the field of (assisted) wayfinding of humans, some of the work has already been mentioned in the previous section of this thesis. The goal of this paragraph is to show the value that is added to research with this thesis. Like in every field, there is basis work that defines terms, concepts and technology. For navigation, this is the work of Montello (2005), Azuma (1997) is almost always cited for AR and Siegel & White (1975) for spatial knowledge. Constructive on the basic works, there is myriad of studies that researched navigational performances for the various types of navigation aids, either by evaluating the advantages and disadvantages of a system or by comparing different systems to each other. Then, there are numerous studies that aim at the improvement of these navigation systems. This is where this study adds value. As presented in the introduction, automated systems lead

[6] https://www.google.com/glass/start/ (last retrieved on 29.09.2022)

to a fast and efficient reaching of the desired destination but has the drawback of neglected spatial learning. The goal of the study is to present a way to improve this process when navigating with the help of an automated navigation system.

The study of Brügger et al. (2019) showed that spatial learning is dependent on the interaction of the user with the system. The experiment that is presented here goes one step deeper and analyses how the performance on a certain level can be improved without changing the level itself. It is assumed that with an increased amount of information given by the system, users will pay more attention to the environment what in the end will lead to better landmark and route knowledge. One study group gets information boxes, which describe certain landmarks, in addition to the actual instructions. Furthermore, this experiment examines the positioning of navigation instructions, information boxes and landmarks. The goal there is to find out where the ideal position for these features is and to which areas in our FoV we have our focus. We thus know which things are regarded anyways and which are not and have to be highlighted by the system if we want people to see them. The entire experiment uses an AR navigation system.

Based on these goals, four hypotheses have been set up for this work:

Hypothesis 1: Increasing the number of information given by the AR navigation system will lead to a better spatial learning of the users in terms of landmark and route knowledge.

Hypothesis 2: The position of the navigation instructions in form of arrows will influence the spatial learning process, as people are expected to have their focus mainly on the arrows.

Hypothesis 3: Landmarks that are augmented with further information are recalled better than landmarks which are not, since the users deal more deeply with the former.

Hypothesis 4: There are differences in the recall performance depending on the type of landmark.

2. Methods

2.1. Workflow of the Experiment

The experiment can roughly be divided into four phases. At first, participants who were willing to participate in the study were given the possibility to sign up for a suitable timeslot. This was done using the online scheduling tool Doodle[7]. Participants could sign up for 45 minutes slots starting every full hour. Test runs of the experiment had shown that it takes 30 to 40 minutes for the entire experiment. Walking speed and thoroughness of the general attention are the main drivers of this variance. It was made sure that there is enough time in case the setting had to be changed with a quarter hour break between the participant's slots. A detailed description of the participants is given in the following chapter 2.2.

After signing up for a slot, participants were sent the invitation to take the pre-test (cf. chapter 2.3) as well as final instructions for the actual experiment including the meeting point (Y25 J87 for people who are familiar with the rooms at GIUZ and Irchel Mensa for those who are not), further information about the AR equipment and the consent form. The English version of the latter is attached to this work in Appendix F, the German one in Appendix G. The invitation was normally sent 12 to 24 hours prior to the timeslot depending on the moment the participant signed up so that they were able to finish the pre-test six hours prior to the start latest. This allowed to change the experiment settings (i.e., the study group) in advance.

Upon arrival at the "base camp" of the study site (Y25 J87), which is not the starting point of the experiment, the participants were asked to sign the consent form. If needed, questions about any uncertainties were answered by the experimenter at this point. After that, the calibration of the AR equipment was started. In calibration mode, the Hololens 2 is adapted to a user's eyes to ensure the best results possible. After calibration, all of the preparatory work is done and the actual experiment starts. As mentioned, the starting point is at a different place which is reached by a short walk and a lift ride.

The route starts with a box containing the necessary information that is needed to complete the task and an example arrow to make the participants familiar (see first box of Appendix C). This is also the last opportunity for the participants to ask questions. If there are no questions and the participants stated that they were ready, the experiment starts. The Hololens 2 guides the participants with arrows (Figure 9) through the campus. Generally, there is no interaction between the experimenter and the participant in this phase. Only if a turn is missed, the experimenter would intervene and correct the path.

After completion of the route (for details see 2.4 and 2.5; for the respective box the last box of Appendix C) and a short walk back to Y25 J87, the final step of the experiment takes place. The participants are asked to fill out a questionnaire about the route. This questionnaire consisted of questions about landmarks (see chapter 2.6), intersections (2.7) and socio-demographic questions about the participants for the evaluation.

[7] https://doodle.com/en/ (last retrieved on 29.09.2022)

Figure 9 Example Arrow at a Right Turn.

2.2. Participants

In total, 38 interested people signed up for participating in the experiment. One person signed up but did not appear for the selected time slot for unknown reasons, which let the number of participants drop to 37 in the end. 15 of the participants were female and 22 were male. None of the participants indicated that they either prefer not to answer the question about their gender or that they would not identify with one of a binary gender. The vast majority of participants are either engaged at the GIUZ in some way or are friends and relatives of mine. Only one participant addressed us and volunteered spontaneously for a participation when he saw us walking by. The participants are on average 27.7 years old and the study cohort has a standard deviation of 9.7 years. The youngest participant was 20, the oldest 64 years old. Figure 10 shows the age distribution within the participants. The relatively low average and the left-skewness of the distribution (mode at 24/25) reflects the fact that mostly students and younger researchers could be recruited for the experiment.

There were no special requirements for potentially interested people to participate in the experiment. The only restriction was that a participant is able to locomote individually throughout the route. Since there are five staircases which were used on the route, people in wheelchairs would be excluded, but there was no such person interested in participating. Visual impairments are no problem either as long as a person is able to locomote individually. The Hololens 2 is suitable without difficulty for people wearing glasses or contact lenses.

Participating in the study was entirely voluntary and participants did not receive any financial compensation or profit from direct benefits. However, to show appreciation for their effort, every participant was given a bar of Toblerone Chocolate.

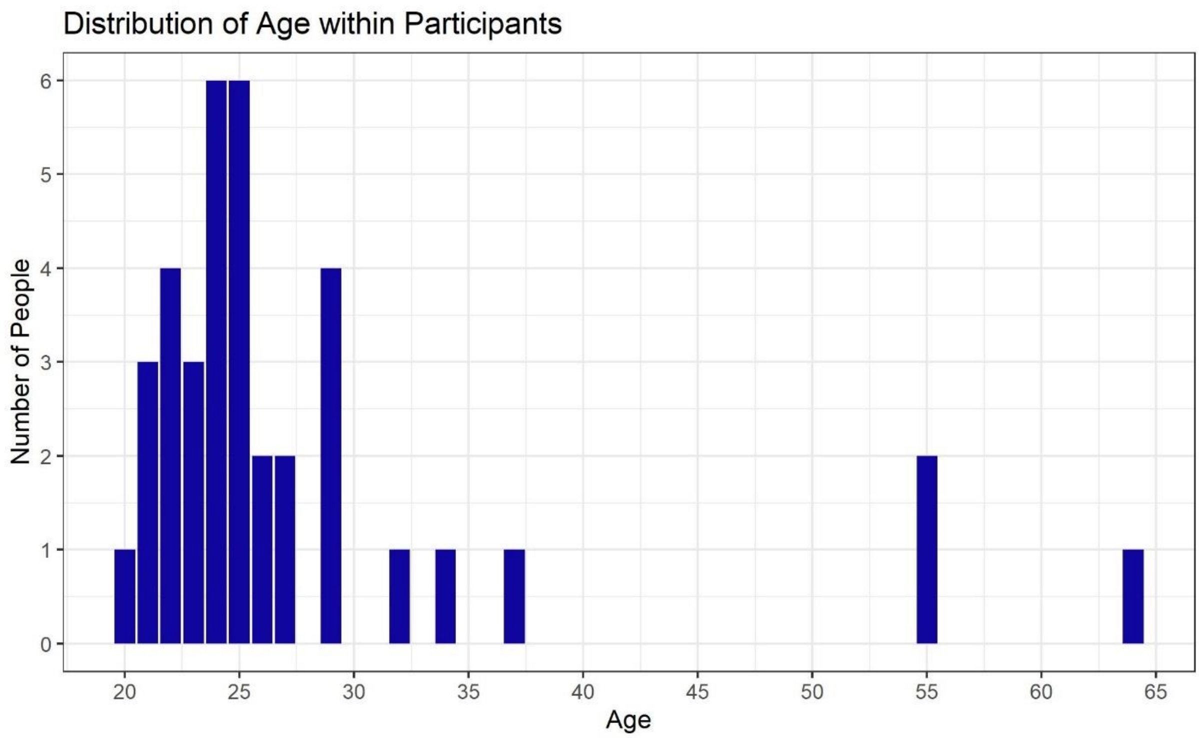


Figure 10 Age Distribution of the Participants.

2.3. Pre-Test

Prior to the actual experiment, the participants had to take a pre-test, in which they were asked about their spatial abilities. Having such a test is important for the formation of the two study groups, since it should be avoided that one group performs way better in spatial tasks than the other. This would distort the results as the group with significant better spatial abilities will most probably also perform better on the actual experiment (Hegarty et al., 2002). There are two spatial ability tests that can be found in comparable literature. English-speaking scholars often make use of the Santa Barbara Sense of Direction (SBSOD) Scale which goes back to the work of Hegarty et al. (2002). See Friedman et al. (2020), Ishikawa (2019) or He & Brown (2020) for examples of its application. The SBSOD questionnaire consists of 15 items from various fields of spatial abilities. Participants can answer each item with their level of agreement on a Likert scale from 1 to 7. 1 corresponds to strong agreement and 7 to strong disagreement while 4 would mean that they neither agree nor disagree.

The second spatial self-evaluation test is the *Fragebogen zur räumlichen Strategie* (FRS, questionnaire on spatial strategies). As the title suggests, this test was developed by Stefan Münzer and Christoph Hölscher (2011), who are two German-speaking researchers. The test is therefore usually used if an experiment is conducted in German. Examples of the application are Frei (2015), Ingold (2017) or Haig (2019). The FRS takes the SBSOD as a basis, translates the items to German and adds further items. The final questionnaire consists of 32 questions. Furthermore, the FRS items are classified into six strategies and six environments. The strategies are *Weg* (way), *Richtung* (direction), *Üb* (*Überblicksbasierte Strategie,* overview-based strategy), *LM* (*landmarkenbasierte Strategie,* landmark-based strategy) and *Him* (*Himmelsrichtungen,* cardinal directions) while the environments are *neutral*, *UnbSt* (*unbekannte Stadt,* unknown city), *KoGb* (*komplexes Gebäude,* complex building), *Natur* (nature) and *MeiSt* (*meine Stadt,* my city). The category global is both a strategy and an environment. Like the SBSOD, the FRS uses a Likert scale from 1 to 7 with the exact same meanings (Münzer & Hölscher, 2011).

For this experiment, a combination of the two tests, called Irchel Spatial Self-evaluation (ISS), has been used. The ISS uses the SBSOD as a base, since the experiment was set up in English. It uses all 15 items that were defined by Hegarty et al. (2002). Six items from the FRS were translated to English and added to the SBSDO. These are the items that were categorised into a complex building environment by Münzer & Hölscher (2011). The reason this was done is that the experiment takes place at Irchel Campus, which is a perfect example for a complex building (cf. chapters 2.4 and 2.5) and thus the combined questionnaire will represent the participant's spatial abilities in the given setting better than one single questionnaire.

Both Frei (2015) and Ingold (2017) have switched the scale of their spatial ability test when evaluating, as such a scale where 7 corresponds with full agreement is more sensible from a Swiss point of view. In addition to that, Münzer & Hölscher (2011) change their entire scale and Hegarty et al. (2002) a part of it prior to the respective analyses anyway. Due to this, the ISS uses also a scale in which 1 corresponds to full disagreement and 7 to full agreement. As it is a scale with an odd number of steps, a 4 would still correspond to neither agree- nor disagreement. Figure 11 shows the first three items of the ISS as an example.

	1 – I strongly disagree	2	3	4 - I neither agree nor disagree	5	6	7 – I strongly agree
I am good at giving directions	○	○	○	○	○	○	○
I have a poor memory where I left things	○	○	○	○	○	○	○
I am very good at judging distances	○	○	○	○	○	○	○

Figure 11 First Three Items of the ISS.

For the evaluation of the ISS, this means that not the results of the positively worded items are reversed, which the authors of the scale instruct to do, but the negatively worded ones. A list of all 21 items with a comment whether they had to be inverted before the analysis or not can be found in Appendix D. One could now argue that the negatively worded items could have been changed to a positive wording in advance to avoid a partial swich of the results. This is indeed true, but the initial idea of Hegarty et al. (2002) of having approximately half of the items positively and the other half negatively worded would then have been lost.

The pre-test and the assignment to groups were challenging, since the participants filled out the questionnaire continuously prior to their experiment slot. Assigning all the participants alternately like for example Frei (2015) did was therefore not possible. To tackle this issue, the following ranked criteria were defined to ensure that one study group is by coincidence better in terms of spatial tasks.

1. Same number of participants per group above and below the mean score
2. Alternating study group (i.e., that not the worst are in one group and the other in the second group, even if they would meet the first criteria)
3. Same number of participants in both study groups

Following these three criteria, the 37 participants were allocated to the two navigation system groups, according to Figure 12. In the end, there were 19 participants in the arrow group and 18 in the box group. Although the allocation was made continuously, the disequilibrium could be kept quite small.

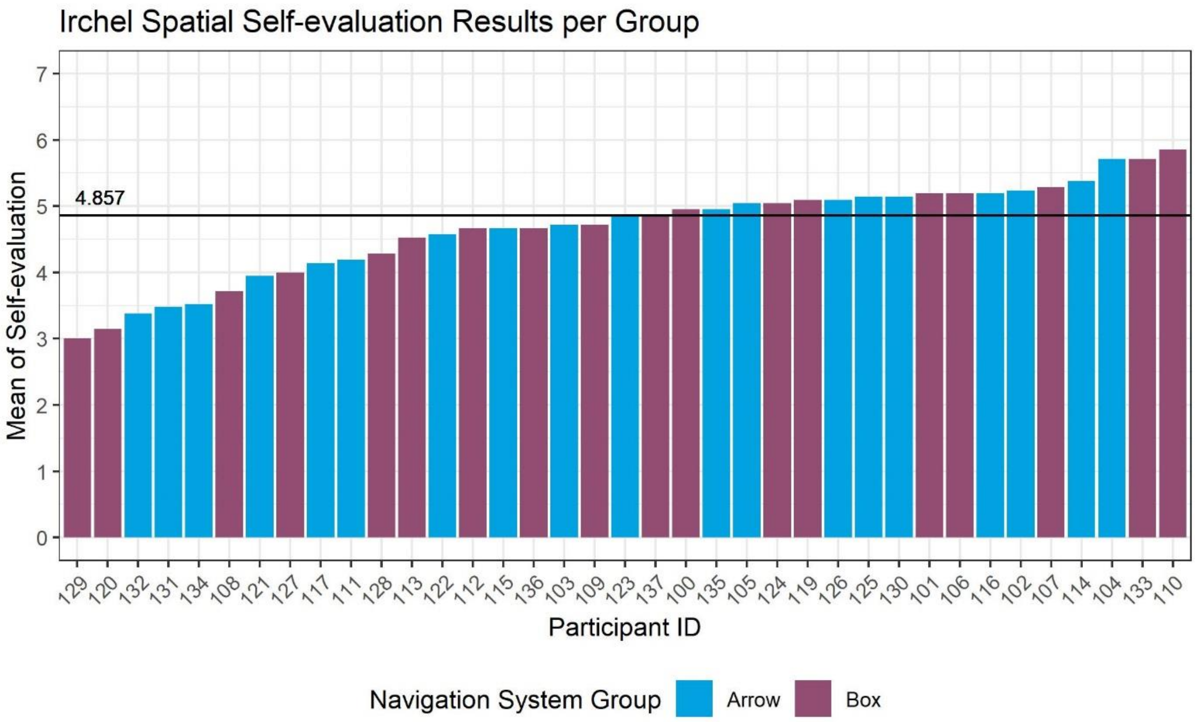


Figure 12 ISS Results with Allocation to Study Groups and Median Score.

2.4. Geographical Study Setting

The experiment took place at Irchel Campus of University of Zurich (UZH). Irchel Campus is one of the main facilities of UZH. It is located in the north-east of Zurich and is home to the faculties of medicine and science. This study site was chosen as it offers advantages in the following aspects. First, it is an indoor facility, which allows a flexible planning, since it is mostly not affected by external influences as the weather for example. Second, the proximity to the Institute of Geography (GIUZ) allows short distances in testing and possible problem solving. And third, there are 37 buildings[8] most of which are connected either above or below ground or even both. This offers various possibility to set up a route for the experiment.

Gärling et al. (1986) describe a way to characterise physical environments in three aspects. They are meant for designed/built environments, however they would also be applicable to natural and virtual environments but the latter were not very common when they were writing their article. The degree of differentiation is given by how much parts of an environment look alike. As stated by Montello (2005), more differentiated environments are easier to navigate in because the more different parts are the easier they are to recognise. Irchel Campus shows mixed differentiation. There are areas that are very similar to others while being designed completely different to again others. The area in which the experiment takes places has three different layout styles, therefore I would characterise it with a low differentiation.

[8] https://www.plaene.uzh.ch/campus/I (last retrieved on 29.09.2022)

The second aspect is the degree of visual access to the environment. An area with high visual access is visible from many other areas or points and favours quick wayfinding (Gärling et al., 1983; Zhu et al., 2020). Generally, Irchel Campus can be characterised with a poor degree of visual access. There are some areas that are clear but for a vast majority of the areas, one can only see the hallway or the very area they are currently in. The third facet is the complexity of the spatial layout. This includes the size of the environment, the number of possible routes and destinations and the number and layout (oblique vs. orthogonal) of the intersections. Irchel Campus has complex aspects (size, possible routes and destinations) but the layout is very clear (i.e., all turns are orthogonal).

According to the creators of the three aspects, we can expect a high to very high extend of spatial orientation and wayfinding problems in the experiment (Figure 13; Gärling et al. (1986)). Furthermore, the route through Irchel Campus was set in such a way that it runs to less known areas for geographers, expecting them to be the biggest group in the study cohort (cf. section 2.2).

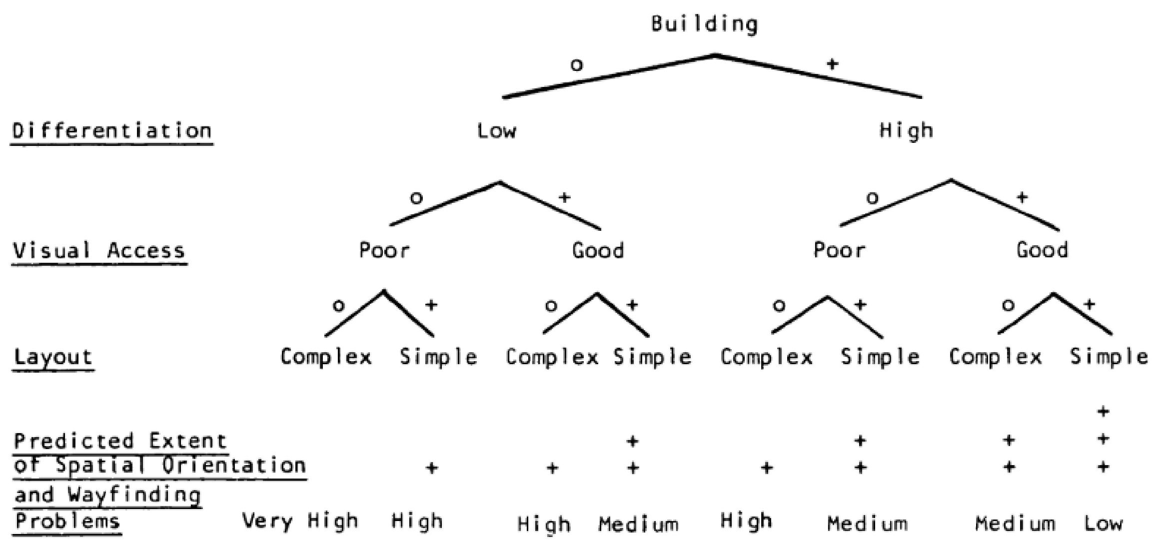


Figure 13 Environment Aspects and Expected Wayfinding Problems. From Gärling et al. (1983).

2.5. The Route of the Experiment

The route was set up through ten of the total 37 buildings. Since the buildings are connected so closely and since the borders of the buildings are sometimes not very clearly visible, the final questionnaire has a focus on the six buildings Y03, Y04, Y13, Y15, Y23 & Y25. The buildings that were left out are crossed only very shortly (e.g., Y44) or the border is not clear (e.g., Y16 whose border with Y15 is the hallway the route runs through. The route is 531 meters long and took course over five floors (F, G, H, J & K). Note that floor “I” does not exist. Figure 14 shows the course of the route through the campus while the sequential colour scheme represents the different floors. The route starts in front of the cargo lift and the recycling room at Y13 K04. Next, one heads to the round stairs where they descend one floor and turn right at the end of the stairs. Following the hallway passing letterboxes and a door frame, there is another round staircase to the left where, once again, one has to descend one floor and turn right. The next segment is a long leg straight on. On the right, there is the internal post office and to the left there are glass showcases from the Institute of Chemistry. Also on the right are round stairs on which the route descends two floors. On the intermediate floor there is a display of the periodic table of elements and Café Brunnenhof. Reaching the end of the stairs on floor F, the route turns right and follows the hallway almost to its end where there is another quite long hallway when turning right. The participants pass three door frames, the last of which has normally to be opened. After a right turn and reaching the end of another hallway, one can turn right and finds oneself in an atrium where the Irchel 2050 exhibition is located. Passing this exhibition, one can see lockers to the right, a glass door straight on and a wooden door to the left. The route continues through this wooden door and immediately turns left, passes an ice machine into a long hallway with rooms on both sides. At the end of the hallway, one turns right to the semi-round stairs on the left. Going up two floors, the participants are now on floor H of building Y23. The route turns right and passes lifts to the left, the statue of W.R. Hess to the right, a glass door which marks the transition to Y44. Right after the possibility to go into the courtyard on the left, there is a small hallway with a tap at the beginning. The route terminates at the end of this hallway which is marked by the door of Y25 H20a, a room which is also used for logistics. In total, there are eleven right and eight left turns. For evaluation purposes, landmarks and intersections along the route were chosen. Both are described in the following chapters 2.6 and 2.7.

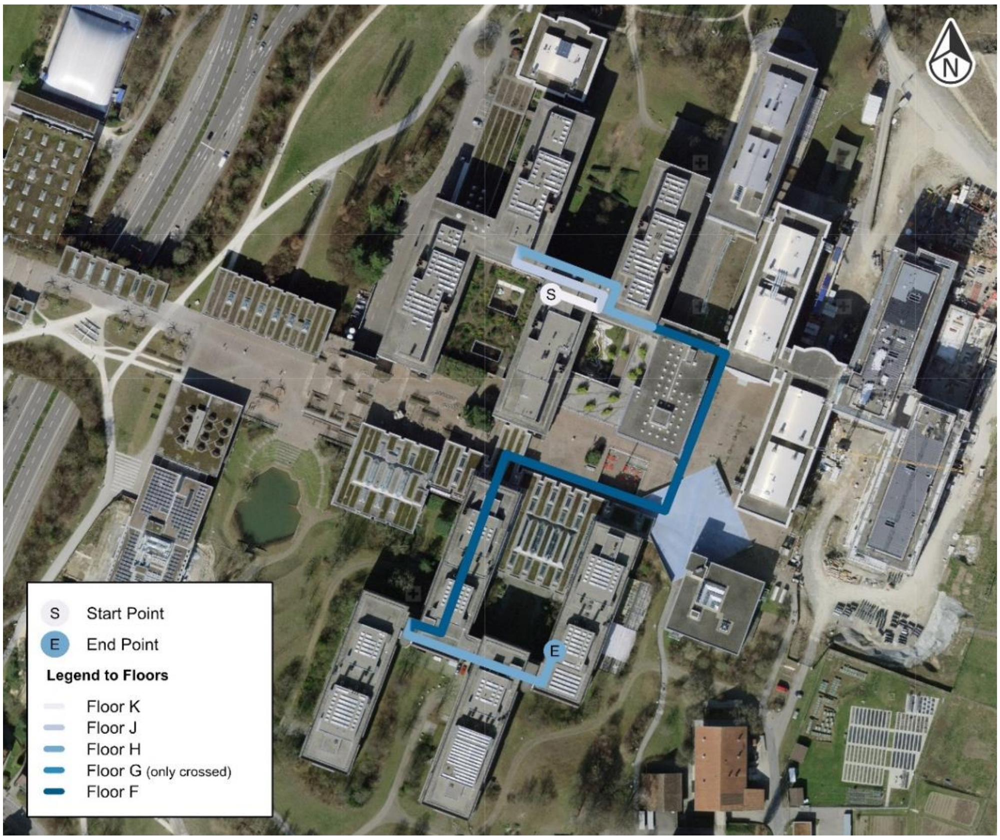


Figure 14 Overview of the Route through Irchel Campus. Orthoimage from map.geo.admin.ch.

2.6. Landmarks

A total of 16 landmarks throughout the route were chosen. To be able to test the participant's recording of these landmarks, 12 further landmarks that could not be seen were added. These 28 landmarks can be split into three groups, which are signs, 3D objects and wall features. 3D objects are defined as free-standing or hanging objects. Classified as wall installations are any objects that were mounted to the wall, such as photographs or information displays. Lastly, signs are also attached to walls but usually they are a lot smaller than wall installations and only in 2D. The landmark number was randomly assigned, i.e., LM 1 is not the first landmark on the route. Table 1 shows an overview over all landmarks and Figure 15 a map of them. A list of all landmarks including a photograph and a more detailed description can be found in Appendix A.

Table 1 List of Landmarks.

Landmark Number	Description	Group	Visible on Route
LM1	Ceiling mounted art installation	3D	No
LM2	Statue of W R Hess	3D	Yes
LM3	Fire extinguisher and sanitary material	Wall	Yes
LM4	Outdoor art installa-tion	3D	Yes
LM5	Periodic table of ele-ments	3D	Yes
LM6	Wardrobe	3D	No
LM7	Irchel 2050 exhibi-tion	3D	Yes
LM8	Lichthof	3D	No
LM9	Liquid nitrogen con-tainer	3D	Yes
LM10	Column outside	3D	No
LM11	Info display institute of biochemistry	Wall	Yes
LM12	Picture of Sil-vesterkläuse	Wall	No
LM13	Electron microscope	3D	Yes
LM14	Letterboxes	Wall	Yes
LM15	Lockers	Wall	Yes
LM16	Ice machine	3D	Yes
LM17	"Kursräume Bio", yellow	Sign	Yes
LM18	"Biochemisches Praktikum"	3D	Yes
LM19	"15F 59 – 90"	Sign	Yes
LM20	Internal post office	Wall	Yes
LM21	Model of Irchel Campus	3D	No
LM22	Mountain relief	3D	No
LM23	"TV"	Sign	Yes
LM24	"Bio-Kurse", white	Sign	No
LM25	Plotter	3D	No

Table 1 (continued)

LM26	"13G 22 – 24"	Sign	No
LM27	Info display institute of physiology	Wall	Yes
LM28	Info display general	Wall	No
			11 x No, 17 x Yes

The first part of the final questionnaire treated landmarks. The question participants had to answer was the same for all 28 landmarks. They were asked whether they "encountered the following landmark while navigating along the route". The options were "yes", "no" and "I don't know". The latter option was included to avoid having a fifty-fifty choice where there are reasonable chances to choose the right answer randomly if they did not know the answer. However, the decision for answering with yes or no lay at the participants as they were not given instructions on how sure they had to be about their answer. The questions of the final questionnaire can be found in Appendix E.

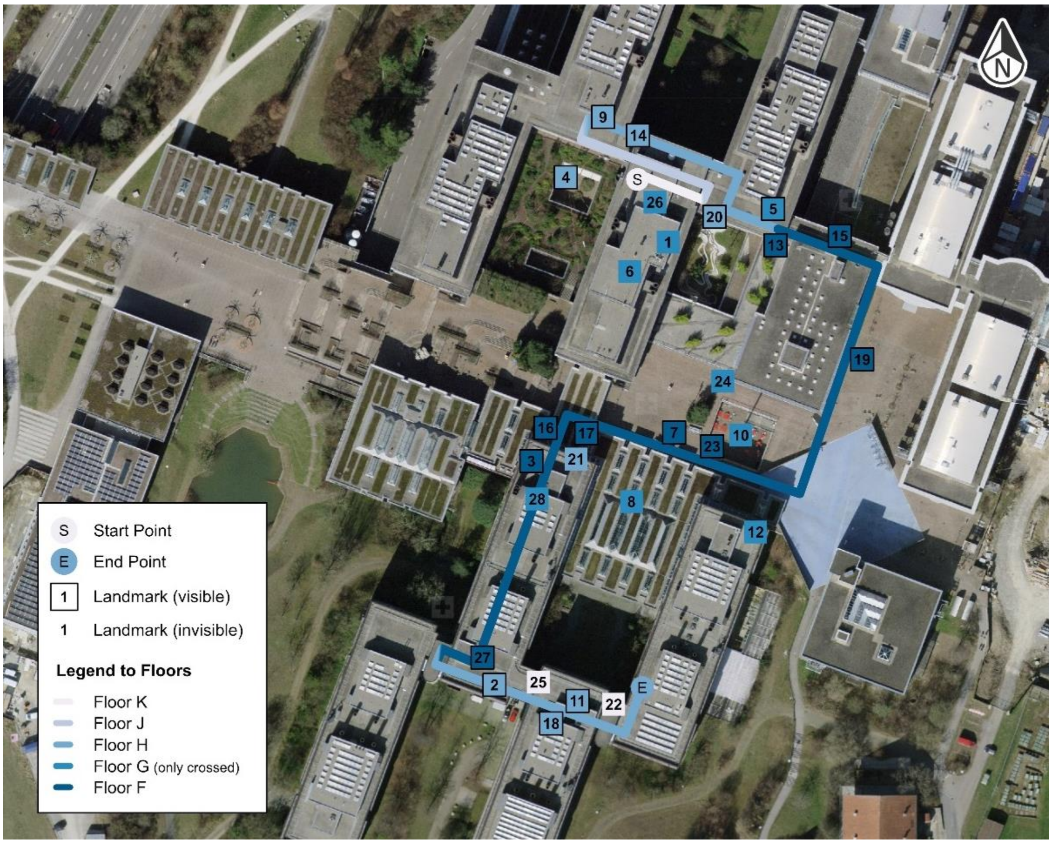


Figure 15 Locations of Landmarks on Campus Irchel. Orthoimage from map.geo.admin.ch.

2.7. Intersections

Intersections were chosen as a study subject as they are suitable to test the route knowledge of the participants. The initial idea of letting participants walk back to the start point after they have reached the endpoint was rejected mainly due to time reasons. Assuming that walking back would take longer as the route is not guided, one experiment run would most probably have exceeded one hour. To be able to test the participant's route knowledge anyway, a total of nine intersections were filmed and included in the final questionnaire. These films would always start with the approach to an intersection and stop at the decision point. The question was "Indicate the direction you were taking when passing the endpoint of the video" and the answer possibilities were left, straight on, right and I don't know. There are three intersections where there are only two directions possible. In this case, the number of answers were reduced to three.

If needed, it was possible to rewatch the film as many times as a participant wanted. As a further help, the end frame of each film was screenshotted and arrows with a direction indication were added. Figure 16 shows an example of such an end frame. Note that this is an example where a right turn is not possible and therefore is not indicated.

Figure 16 End Frame of Intersection 2.

As for the landmarks, the intersections were arranged in a random order to ensure that the participants could not reconstruct the route chronologically. Figure 17 and Table 2 show an overview of the intersections while a detailed list including images of them can be found in Appendix B.

Table 2 List of Intersections

Intersection Number	Location	Possible Directions
1	Between lift and stairway Y32, floor H	left, straight on, right
2	Right after LM15 (lockers) at Y15 F09	left, straight on
3	At the staircase of building Y25, floor H	left, straight on, right
4	At the internal post office (Y13 H01)	left, straight on, right
5	At the statue of W.R. Hess (Y23 H8/10)	left, straight on
6	In front of the Physiology information displays (Y23 F)	left, straight on, right

Table 2 (continued)

7	After the Irchel 2050 exhibition in the atrium behind Y04 F30	left, straight on, right
8	In front of the lifts in Y13 on floor J	left, straight on, right
9	After the stair next from LM5 to LM13 (Y34 F12)	left, right

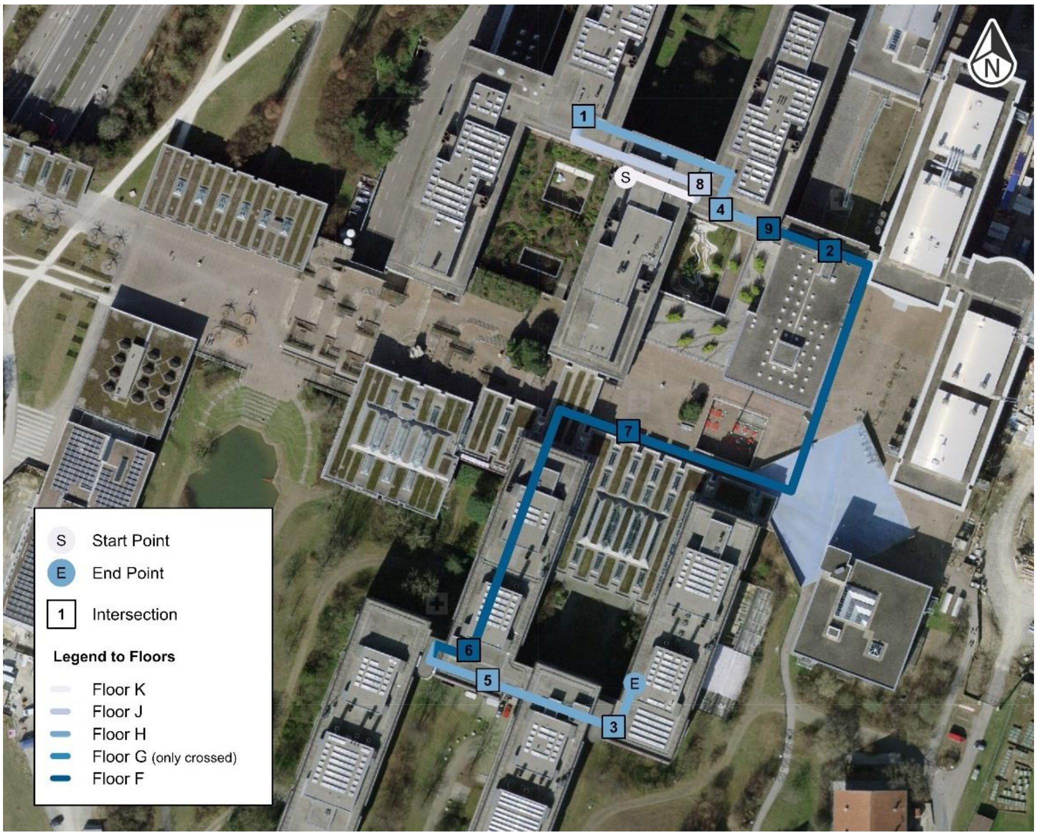


Figure 17 Location of the Intersections. Orthoimage from map.geo.admin.ch.

2.8. Technical Equipment

2.8.1. Experiment

The entire experiment is based on the Hololens 2 from Microsoft[9], which is equipped to be used in a myriad of possible applications. For this study, only the display features are used. It is able to display holograms in a resolution of 2k, which corresponds to 1920 x 1080 pixel on a TV, in an aspect ratio of 3:2. The holographic density is > 2'500 light points per radian. On the software side, the 3D viewer application is used to display the holograms (see further below in this chapter). Apart from the used hard- and software, the Hololens 2 has built in speakers, a microphone and various cameras for the environment and for eye- and head-tracking. The Windows Holographic Operation System has access to Dynamics 365 which supports interactive work with dynamic holograms (GIVA, 2022).

[9] https://www.microsoft.com/en-gb/hololens (last retrieved 29.09.2022)

The creation of 3D objects was done using 3D builder, which is a simple, free software from Microsoft to create and edit 3D objects[10]. These objects are saved in the 3mf-format and can be copied to the Hololens 2 via the explorer and accessed there in the 3D viewer application very easily. There is more sophisticated 3D software like for example the open-source software Blender[11], but its functions are way above what is needed for this experiment and the interoperability is possible but more complicated than with 3D builder. Therefore, using the latter is the easiest way to implement this experiment.

There are two possible ways to embed holograms in the environment. First, the cameras of the Hololens 2 are able to create kind of a "mental map" of the environment. This allows it to link the position of the hologram with this map. This landmark-based navigation (cf. Montello (2005)) has the advantage that the Hololens 2 works independently from any network connections. Thus, there is no need to plan the route along stable network connections. On the other hand, this approach has the drawback that it is dependent on the light conditions. The test runs have shown that the Hololens 2 is not able to display a hologram properly if there is too much light (e.g., against a window) or to less. In both occasions, there is not enough information to make the link with the mental map of the AR glasses. Second, information about the location could be retrieved by the built-in WLAN receiver, accelerometer, gyroscope, magnetometer or by radio frequency ranging (Gerstweiler et al., 2015). This would correspond to dead-reckoning in terms of navigation theory. This approach has the advantage that the light conditions only interfere with the quality of the displayed hologram but not with its positioning. Contrary to the first approach, the advantage of no required network connection can be seen as a disadvantage here. Due to the very unstable WLAN signal and the lack of radio frequency beacons in the buildings of Irchel Campus, a mobile router would have had to be used to ensure a stable connection or to set up a network of beacons. As these complexities prevail the drawbacks of the first approach, it was decided to rather follow the mental-map-approach.

2.8.2. Evaluation

Both pre-test and final questionnaire were created on LimeSurvey[12]. This tool is open-source and accessible via the webservices of UZH. The answers can be downloaded in various data types of which csv-files were chosen. The entire evaluation and the visualisation of the data was afterwards done using RStudio[13] (Version 2022.07.1+554 "Spotted Wake Robin") with the `car`, `dplyer`, `ez`, `ggplot2`, `psych`, `reshape2`, `rstatix` and `walrus` packages besides the functions of the `base` and `stats` package.

2.9. Hypothesis Testing

2.9.1. General

The data was tested on statistical significance in order to prove the hypotheses. The respective suitable tests are given by the data structure of the results. Field et al. (2013, p. 958) offer a decision tree which guides step by step to the correct test. In general, there are two categories

[10] https://apps.microsoft.com/store/detail/3d-builder/9WZDNCRFJ3T6?hl=en-gb&gl=GB (last retrieved 29.09.2022)
[11] https://www.blender.org/ (last retrieved 29.09.2022)
[12] https://www.limesurvey.org (last retrieved 29.09.2022)
[13] https://www.rstudio.com/ (last retrieved 29.09.2022)

of tests that can be used. For the first group, parametric tests, there is a list of assumptions that has to be fulfilled so that the results of a test are robust. If any of the assumption is not given, one should use the corresponding non-parametric test. These assumptions include the level of the data (i.e., nominal, ordinal, interval or ratio scale), its distribution (i.e., is the data normally distributed?), homoscedasticity (i.e., is there a homogeneity of variances?) and sphericity. Note that the latter one is only relevant if more than two groups are compared and homoscedasticity is normally neglected if there are equal group sizes (cf. Jane Superbrain 9.2 in ibid.).

2.9.2. Hypothesis 1

We deal with one continuous dependant variable with one categorical independent variable with different entities in two predictor categories. In this case, it is however more complicated than just following the decision tree. According to it, this leads to a dependant t-test if the assumptions are met or to a Wilcoxon test if they are not (Field et al., 2013, p. 958). But this would not consider the repeated measures that were made, since the participants had to answer questions about 27 landmarks and nine intersections. In such cases, repeated measures analyses of variances (ANOVA) are the better choice. A mixed design ANOVA would even allow to combine a repeated measures ANOVA with the possibility to combine two or more categorical independent variables.

R offers the `shapiro.test` function from the `stats` package to test for normal distribution and the `leveneTest` function from the `car` package to test for homoscedasticity. Both assumptions are met if the p-value is greater as the pre-defined significance level of .05. As Figure 18 and Figure 19 show, the data of the landmarks is normally distributed with a p-value of .257 and has homogeneous variances (p-value = .980). Therefore, a mixed design ANOVA was performed to test for significant differences. The function which is used here is the `ezANOVA` function from the `ez` package.

```
        Shapiro-Wilk normality test

data:  landmarks_result$abs_correct
W = 0.96334, p-value = 0.2573
```

Figure 18 R Output Shapiro-Wilk Test Landmarks.

```
Levene's Test for Homogeneity of Variance
      Df F value Pr(>F)
group  1   6e-04 0.9802
      35
```

Figure 19 R Output Levene's Test Landmarks.

Unlike the data of the landmarks, the data of the intersections does not meet the assumptions for parametric tests, namely the data is not normally distributed. See Figure 20 and Figure 21 for the respective R output. As the assumptions are not met, a robust mixed ANOVA was performed to test for significant differences. Robust mixed ANOVA are the non-parametric counterpart to "normal" mixed ANOVA. For such an ANOVA, a use of the `ezANOVA` function is not possible, as it is only constructed for the parametric ANOVA. The `walrus` package offers the `ranova` function which is used here instead.

```
        Shapiro-Wilk normality test

data:  intersections_result$abs_correct
W = 0.87571, p-value = 0.0006659
```

Figure 20 R Output Shapiro-Wilk Test Intersections.

```
Levene's Test for Homogeneity of Variance
      Df F value Pr(>F)
group  1  0.0778  0.782
      35
```

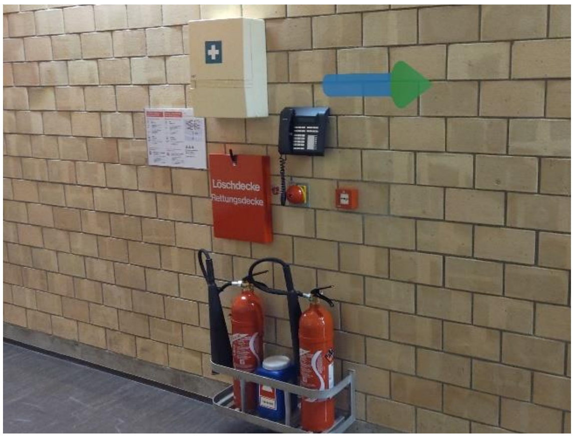
Figure 21 R Output Levene's Test Intersections.

The requirement of the data being at least at the interval level is fulfilled for both cases. Being a percentage, the variable would even be on ratio level.

2.9.3. Hypothesis 2

Out of the 17 landmarks in the questionnaire that could actually be seen on the route, there were five that had an arrow placed directly next to them. The rest of the landmarks has either no arrow close to it or no arrow at all. An arrow in the immediate vicinity is defined as an arrow that is visible if one focuses the landmark from the regular path without any diversions. Table 3 lists these six landmarks including a picture of the arrow.

Table 3 Landmarks with an Arrow in the Immediate Vicinity.

LM3	
LM9	
LM13	

(Table 3 continued)

LM17	
LM27	

Like for the previous hypothesis, a Shapiro-Wilk test is executed to test for normal distribution and a Levene's test to test for homogeneity of variances. The following figures show that the data is not normally distributed (Figure 22), but has homogenous variances (Figure 23). For both tests, a significance level of .05 is used. We can therefore not use a parametric repeated measures ANOVA to test for statistically significant differences but again have to conduct a robust ANOVA.

```
        Shapiro-Wilk normality test

data:  lm_w_arrow$corrects
W = 0.90336, p-value = 0.01373
```

Figure 22 R Output Shapiro-Wilk Test Immediate Arrows.

```
Levene's Test for Homogeneity of Variance
      Df F value  Pr(>F)
group  1   3.307 0.08053 .
      26
```

Figure 23 R Output Levene's Test Immediate Arrows.

2.9.4. Hypothesis 3

Five landmarks have an information box which tells the participants of the box group more about the respective landmark. These landmarks are LM2, LM5, LM7, LM13 & LM20. The information boxes and their exact location are listed in Appendix C. Before evaluated for significant differences between augmented and not augmented landmarks, the data is tested for normal distribution and homogeneity of variances. Figure 24 shows that the data is not normally distributed ($p < .05$) and Figure 25 that the two groups have homogenous variances ($p > .05$). The assumptions of a parametric test are thus not met and a robust ANOVA is used for the evaluation.

```
        Shapiro-Wilk normality test

data:  lm_w_box$corrects
W = 0.90336, p-value = 0.01373
```

Figure 24 R Output Shapiro-Wilk Test for Augmented Landmarks.

```
Levene's Test for Homogeneity of Variance
      Df F value Pr(>F)
group  1  0.2655 0.6107
      26
```

Figure 25 R Output Levene's Test for Augmented Landmarks.

2.9.5. Hypothesis 4

To find out whether people perform better on certain types of landmarks, the 28 landmarks in the questionnaire were divided into three groups 3D objects, wall installations and signs (see Table 1). Again here, the data requires an ANOVA as we deal with three groups of data. However, there are still repeated measures as there are more than one landmark per group. Therefore, a robuts mixed ANOVA was performed here. The data is not normally distributed (Figure 26) and has homogenous variances (Figure 27), so the assumptions of a parametric test are not met.

```
        Shapiro-Wilk normality test

data:  lm_type$corrects
W = 0.90336, p-value = 0.01373
```

Figure 26 R Output Shapiro-Wilk Test Landmark Groups.

```
Levene's Test for Homogeneity of Variance
      Df F value Pr(>F)
group  2  2.2579 0.1255
      25
```

Figure 27 R Output Levene's Test Landmark Groups.

3. Results

3.1. Irchel Spatial Self-evaluation

As mentioned in the previous sections, we can assume that the higher score a person gives itself the better is this person in spatial tasks. Or at least the better is the self-estimation of their performance. Figure 28 shows again the score of every participant.

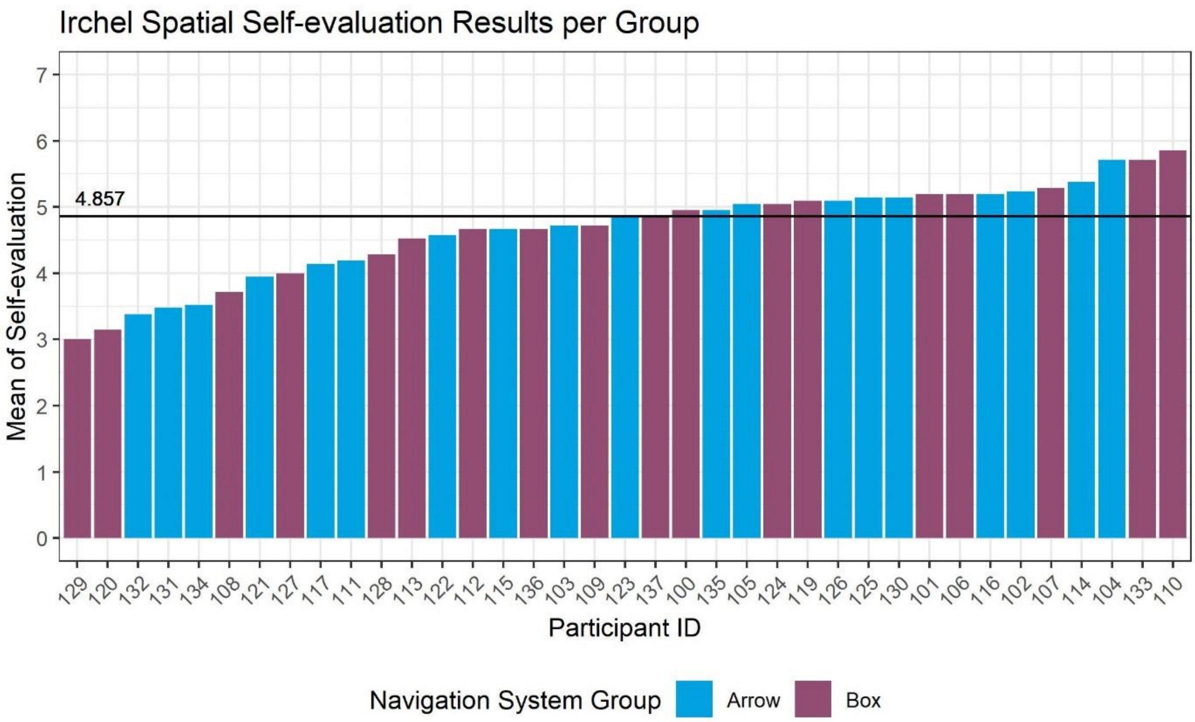


Figure 28 ISS Results per Group.

The ISS scores range from 3.00 to 5.86. The median, which was used as a threshold, is at 4.86, the mean at 4.66 and the standard deviation is .73. Table 4 shows the results of the ISS in table form and compares it to similar research. The range is comparably small, as the minimum value of 3.00 is the highest among the selection and the maximum value the second lowest. However, comparing only minima and maxima is not very meaningful as they only rely on one person. Neglecting the minimum or the maximum value could give a totally different picture. Mean, median and standard deviation are also similar though. Therefore, the study cohort used in this work can be seen as a representative sample and thus the presented results have a certain significance.

Table 4 Descriptive Statistics of ISS Results and Comparable Work.

Work	**Min**	**Max**	**Mean**	**Median**	**Standard Deviation**
Morf (2022)	3.00	5.86	4.66	4.86	.73
Dong et al. (2021)	*unknown*	*unknown*	3.89	*unknown*	1.08
Ingold (2017)	2.00	5.50	3.90	*unknown*	.90
Frei (2015)	2.95	6.21	4.56	*unknown*	.14
Weisberg et al. (2014)	2.30	6.50	4.46	*unknown*	.84
Wen et al. (2011)	*unknown*	*unknown*	*unknown*	*4.90*	*Unknown*

3.2. Hypothesis 1

Before having a closer look at the results of the statistical tests, a short analysis of the data is helpful to know what to expect from the tests and to be able to check the plausibility of its results. Figure 29 shows box plots of the correct answers by the study group (arrow or box) and by the navigation strategy (landmarks or intersections). In this boxplot, a black dot represents an outlier and a rhombus the mean of the respective data distribution.

Overall, the share of correct answers is medium to high. For all four combinations, the measures of centrality are well above the mathematical probability of getting something correct by chance (μ). Note that μ of the intersection strategy is slightly higher than 25%. This is due to the fact that for three intersections there were only three possible answers, as one option was spatially not possible. With both strategies, it is observable that the box group achieved higher percentages of correct answers than the arrow group (cf. Figure 29 and Table 5). The boxes of the landmark strategy are approximately equal. The 25 % and 75 % quartile of the box group is a bit lower than those of the arrow group, but in return, the measures of centrality are higher for the former. Also very similar are the upper whiskers which both reach up to 65 % of correct answers. The one of the box group is a bit longer due to the lower 75 % percentile. What is quite different, is the respective lower whisker. The whisker of the arrow group is almost twice as long as its counterpart and thus reaches further down. Based on these observations, one would not expect a significant difference for the landmarks.

The differences are more obvious at the intersections as they are at the landmarks. The most striking thing is that the size of the box (= interquartile range) is twice as big for the box group as it is for the arrow group. Mean and median are up to ten percentage points higher and box and whiskers cover much more of the plot. Unlike for the landmarks, there are three outliers (black dots), two for the arrow group and one for the box group which are partly responsible for the lower means. Overall, one could rather expect a statistically significant difference here.

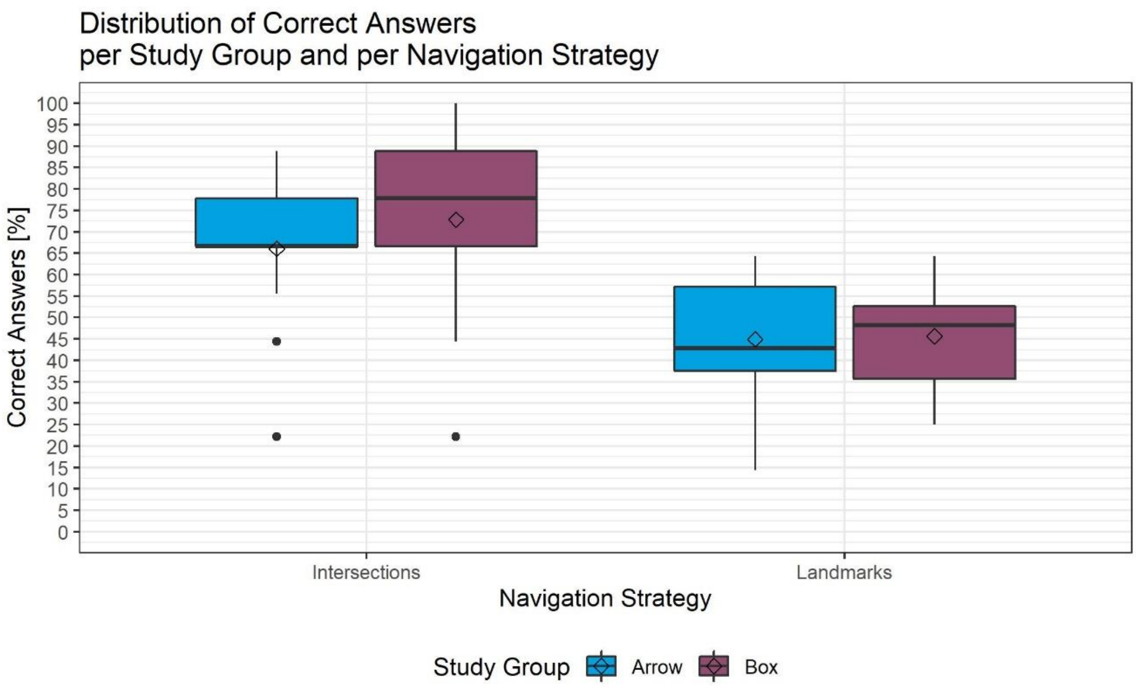


Figure 29 Distribution of Correct Answers per Group and per Strategy.

Table 5 Comparison of Correct Answers to Expected Value μ.

Group	Mean [%]	Median [%]	μ [%]
Intersection – Arrow	66.09	66.67	27.78
Intersection – Box	72.84	77.78	27.78
Landmark – Arrow	44.92	42.86	33
Landmark – Box	45.63	48.21	33

In terms of landmarks, there is a quite big difference between the single landmarks and there are all three answer options given for all landmarks but two (LM1 and LM10). There is no landmark for which all participants have given the same answer. The highest number of same answers can be observed for landmark 10 (n = 36), landmark 7 (n = 34) and landmark 12 (n = 31) which were of course correctly answered by the majority of people. The lowest number of correct answers can be found for LM23 (n = 2), LM19 & LM24 (n = 6), LM9 (n = 7) and LM11, LM13, LM15 & LM16 (n = 8). Also striking are landmarks 11, 19, 23, 24, 26 which have all close to or even above 50% of I don't know answers. Figure 30 and Table 6 summarise the answers graphically and in table form.

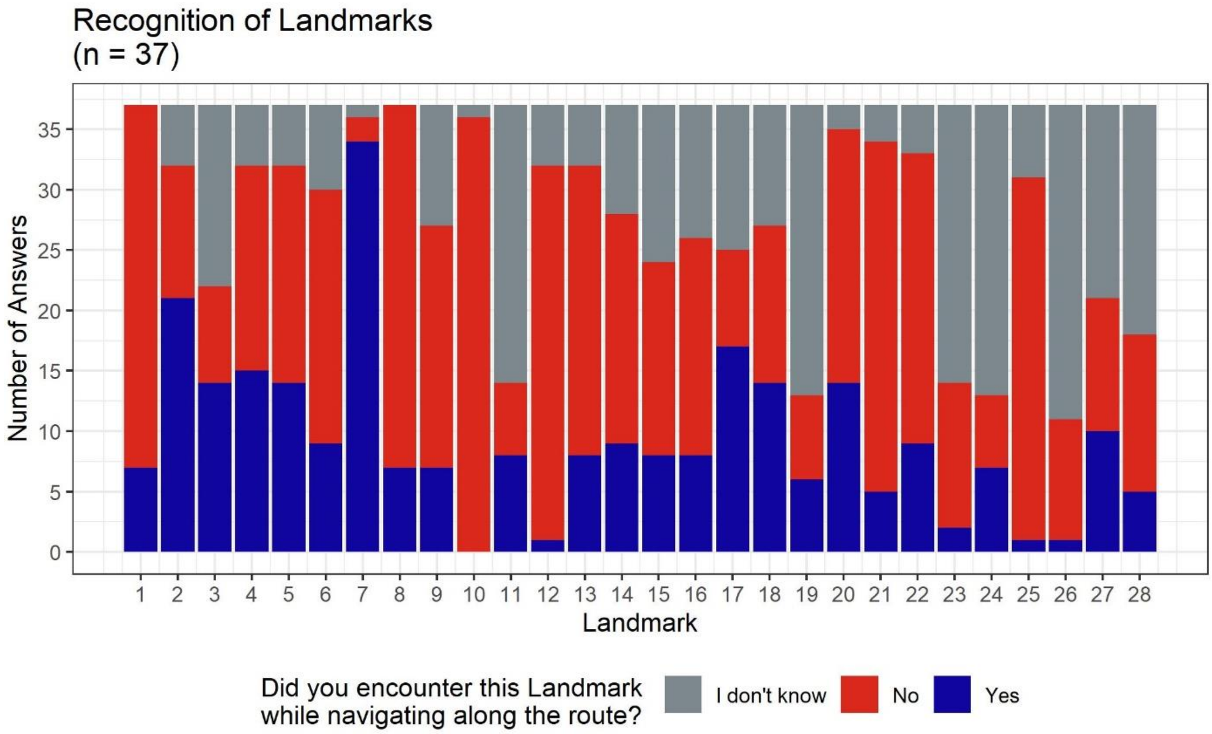


Figure 30 Number of Answers per Landmark.

Table 6 Landmarks with Corresponding Correct Answers and Number of It

Landmark	Correct Answer	Number of Correct Answers	Landmark Class
10	No	36	3D
7	Yes	34	3D
12	No	31	Wall
25	No	30	3D
8	No	30	3D

(Table 6 continued)

1	No	30	3D
21	No	29	3D
22	No	24	3D
6	No	21	3D
2	Yes	21	3D
18	Yes	18	3D
17	Yes	17	Sign
4	Yes	15	3D
20	Yes	14	Wall
5	Yes	14	3D
3	Yes	14	Wall
28	No	13	Wall
27	Yes	10	Wall
26	No	10	Sign
14	Yes	9	Wall
16	Yes	8	3D
15	Yes	8	Wall
13	Yes	8	3D
11	Yes	8	Wall
9	Yes	7	3D
24	No	6	Sign
19	Yes	6	Sign
23	Yes	2	Sign

Referring to the main statement of the hypothesis that people perform better on navigational tasks if the navigation system gives them more information, the output of the mixed design repeated measures ANOVA gives answers to it. Again, the significance level is .05. If we analyse the effect of the two groups on the result only, we get a p-value of .806, which is well above the significance level and we fail to reject the null-hypothesis that there is a difference between the two groups. However, analysing only the effect of the navigation system on the result would tell only a part of the story. Studies have shown that many other effects have an influence on navigational tasks. Kim et al. (2007) suggest gender differences in navigation, Hegarty et al. (2002) found out that scores of their spatial self-evaluation correlate strongly with the performance in navigational tasks, Rodgers et al. (2012) state that older adults navigate differently than younger ones, van der Ham & Claessen (2020) observed "clear functional dissociation[s]" in landmark and route knowledge among the age groups and the findings of Dijkstra et al. (2014) imply that also familiarity has an influence on people's performance in navigation. All of the mentioned influences were recorded in the experiment and can thus be analysed.

Table 7 Predictors and Corresponding p-Values for Landmarks.

Predictor	Test used	p-value	Significance (p < .05)
Study Group	ANOVA	.806	
Gender	ANOVA	.196	
ISS score	Pearson Correlation	.401	
Age	Pearson Correlation	.041	*
Building Familiarity	Pearson Correlation	.023	*
Route Familiarity	Pearson Correlation	.014	*

Table 7 shows that when we test the predictors isolated from each other, only age and familiarity with the buildings and route respectively differ significantly from each other. Significance for the other three predictors cannot be found within this data. However, to be able to make a statement about what generates differences overall, all predictors have to be analysed in one model. The analysis of covariances (ANCOVA) allows us to combine categorical (navigation system, gender) and continuous predictors (ISS score, age, building familiarity and route familiarity) (Field et al., 2013, p. 958). The output of the executed ANCOVA (Figure 31) shows quite a different result, as none of the predictors have a significant influence on the number of correct answers here.

```
Analysis of Deviance Table (Type III tests)

Response: abs_correct
                LR Chisq Df Pr(>Chisq)
group            0.15787  1     0.6911
gender           1.61738  1     0.2035
age              1.65126  1     0.1988
iss_score        0.55537  1     0.4561
mean_build_know  0.17492  1     0.6758
route_know       0.57395  1     0.4487
```

Figure 31 R Output ANCOVA for All Predictors.

The pattern of answers in terms of intersections is quite different from the one of the landmarks. As we have seen previously (Figure 29), the participants generally achieved a higher number of correct answers. This is obviously reflected in the number of correct answers per intersection (Figure 32). For all intersections but two (I6 & I8), a big to very big majority has the same answer which is correct in every case. Intersection 6 shows almost an even distribution (9 for left, 12 for right on and 16 for I don't know). The correct answer would be a right turn. Note that this is one of the intersections where there are only two possibilities. This explains why nobody indicated going straight on here. For Intersection 8, there are all four possibilities. A bit more than a third of all indicated that they turned right there, which is correct, and the rest is divided into almost perfect thirds (7 for left, 7 for straight, 15 for right, 8 for I don't know).

Table 8 Intersection with Corresponding Correct Answer and Number of It.

Intersection	Correct Answer	Number of Correct Answers
7	Left	34
2	Straight On	31
3	Left	31
5	Straight On	31
4	Straight On	29
9	Right	27
1	Right	25
8	Right	15
6	Right	12

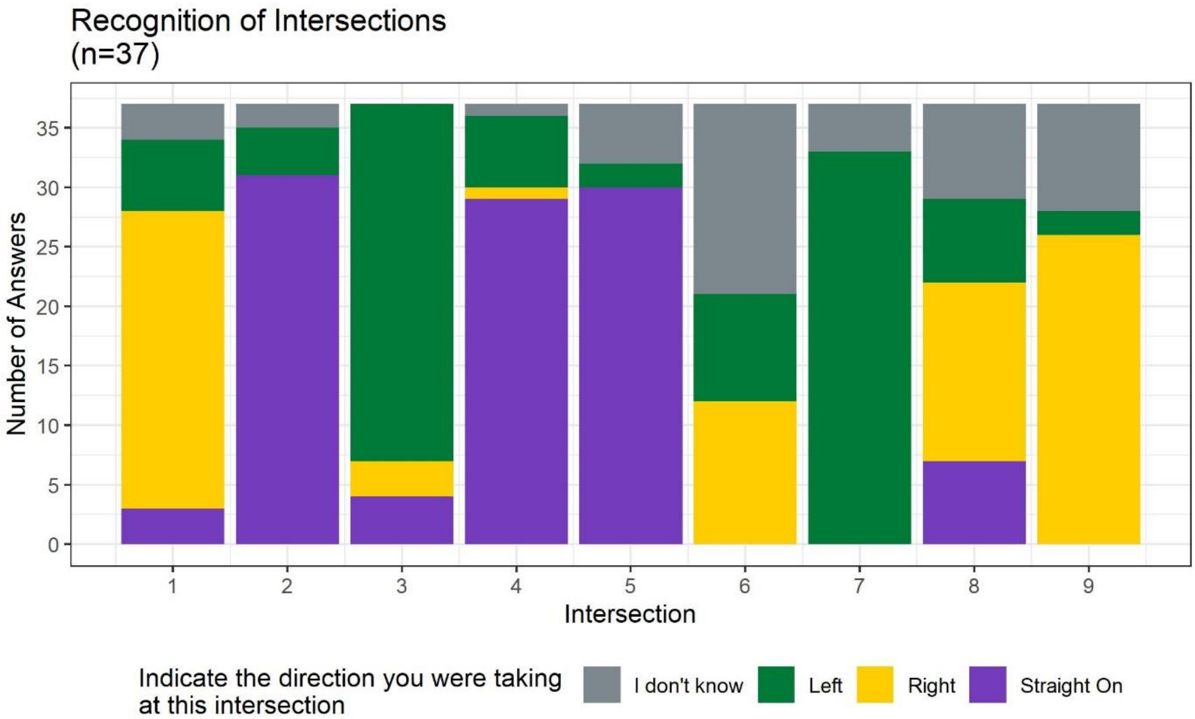


Figure 32 Number of Answers per Intersection.

With the same procedure as for the landmarks, the results of the intersections were tested for statistically significant differences among the predictors navigation system, gender, ISS score, age, building familiarity and route familiarity. The significance level is .05 for all of the tests. Table 9 summarises the p-values for every predictor. Testing the predictors isolated from each other, only the route familiarity (even though quite tight) shows significant differences between the groups.

Table 9 Predictors and Corresponding p-Values for Intersections.

Predictor	Test Used	p-Value	Significance (p < .05)
Navigation System	Robust ANOVA	.240	
Gender	ANOVA	.154	

Table 9 (continued)

ISS score	Kendall Correlation Tau	.077	
Age	Kendall Correlation Tau	.255	
Building Familiarity	Kendall Correlation Tau	.090	
Route Familiarity	Kendall Correlation Tau	.042	*

The result of a general model including all predictors (Figure 33) differs again very much to the one of an isolated analysis (Table 9). The navigation system group has not changed very much (from .240 to .239) and shows still no significant difference. The same is true for gender (.134 to .789), ISS score (.077 to .010) and building knowledge (.090 to .968), although the differences in p-values is greater. Significance has changed for route familiarity, whose difference is not significant anymore (p-value = .499) and the age which shows strongly significant differences now (p-value = .006).

```
Analysis of Deviance Table (Type III tests)

Response: abs_correct
                LR Chisq Df Pr(>Chisq)
group             1.3882  1   0.238709
gender            0.0717  1   0.788832
age               7.5080  1   0.006142 **
iss_score         2.7128  1   0.099549 .
mean_build_know   0.0016  1   0.967899
route_know        0.4572  1   0.498945
```

Figure 33 R Output ANCOVA for All Predictors.

3.3. Hypothesis 2

Figure 34 shows the distribution of correct answers disaggregated to whether there is an arrow in directly next to the landmark or not. The scattering is very high for both groups (cf. Table 10). Landmarks which do not have an arrow close by were recognised correctly between 5.41 % and 97.3 %, those who do between 18.92 % and 91.89 %. However, a closer look at the boxplot in Figure 34 shows that these 91.89 % of the yes group has to be treated as an outlier, that the interquartile range is much smaller than in the no group and that the scattering is much smaller than assumed. Interestingly, both groups have very similar standard deviations. Mean and median are also quite close with both groups having a greater mean than median.

Table 10 Descriptive Statistics for Immediate Arrows Groups.

Arrow in Immediate Vicinity	**Lowest Correct Answers [%]**	**Highest Correct Answers [%]**	**Mean [%] / Median [%]**	**Standard Deviation**
No	5.41	97.30	45.56 / 37.84	27.40
Yes	18.92	91.89	40.54 / 32.43	27.13

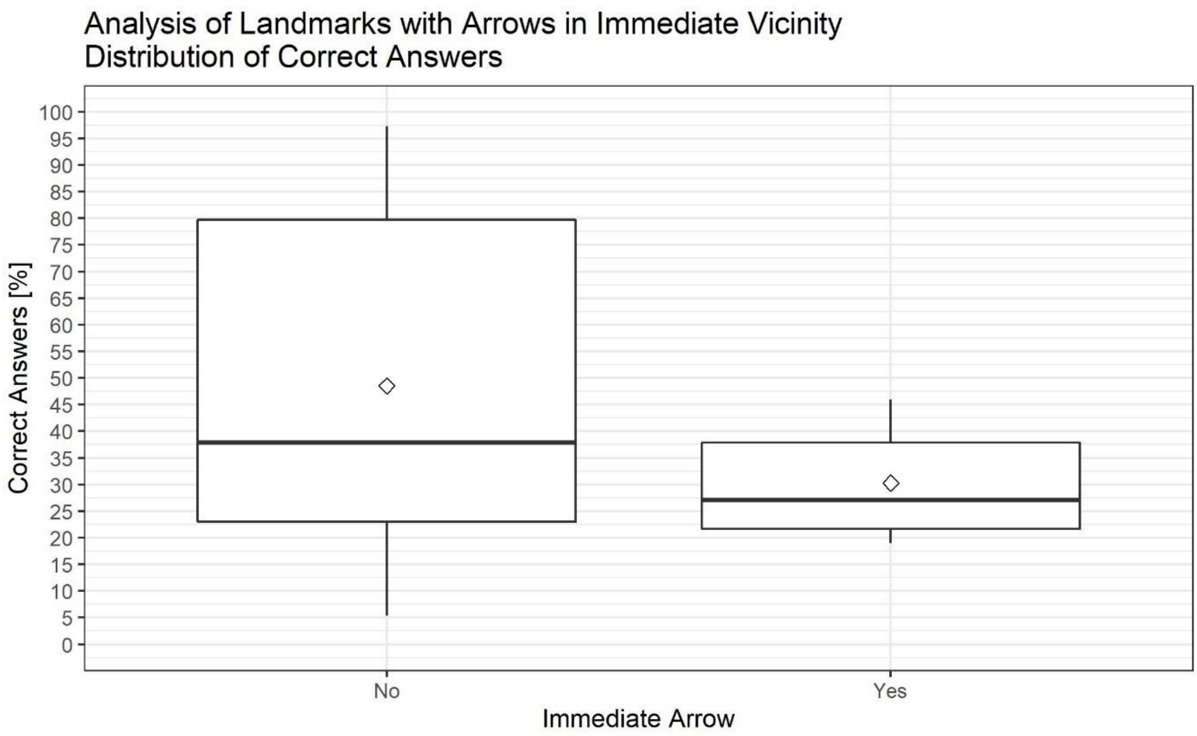


Figure 34 Distribution of Correct Answers with and without Arrows in Immediate Vicinity.

The robust ANOVA leads to the result that the difference between the landmarks which have an arrow in immediate vicinity and those which do not is statistically not significant ($p > .05$, see Figure 35). Note that there is no need for a post hoc test in this case, since there are only two groups in the data.

Robust ANOVA

	F	p
arrow	1.035797	0.3302139

Note. Method of trimmed means, trim level 0.2

Figure 35 R Output Robust ANOVA for Comparison of Landmarks with and without Arrows in Immediate Vicinity.

3.4. Hypothesis 3

The box plot of the results for this division of the landmarks (Figure 36) reveals that landmarks which have no information box for augmentation show a very big variance. The values range from 5 % to 97 %. The range of the values from the landmarks with an information box is a bit smaller, lasting from 22 % to 92 %. However, one has to be aware that the latter shows no upper whisker and the landmark that 92 % of the participants answered correctly is marked as an outlier. The 75 % percentile is at 56.76 % of correct answers.

Table 11 Descriptive Statistics for Augmented and Non-augmented Landmarks.

Information Box	Lowest Correct Answers [%]	Highest Correct Answers [%]	Mean [%] / Median [%]	Standard Deviation
No	5.41	97.30	44.42 / 37.84	27.49
Yes	21.62	91.89	49.19 / 37.84	26.92

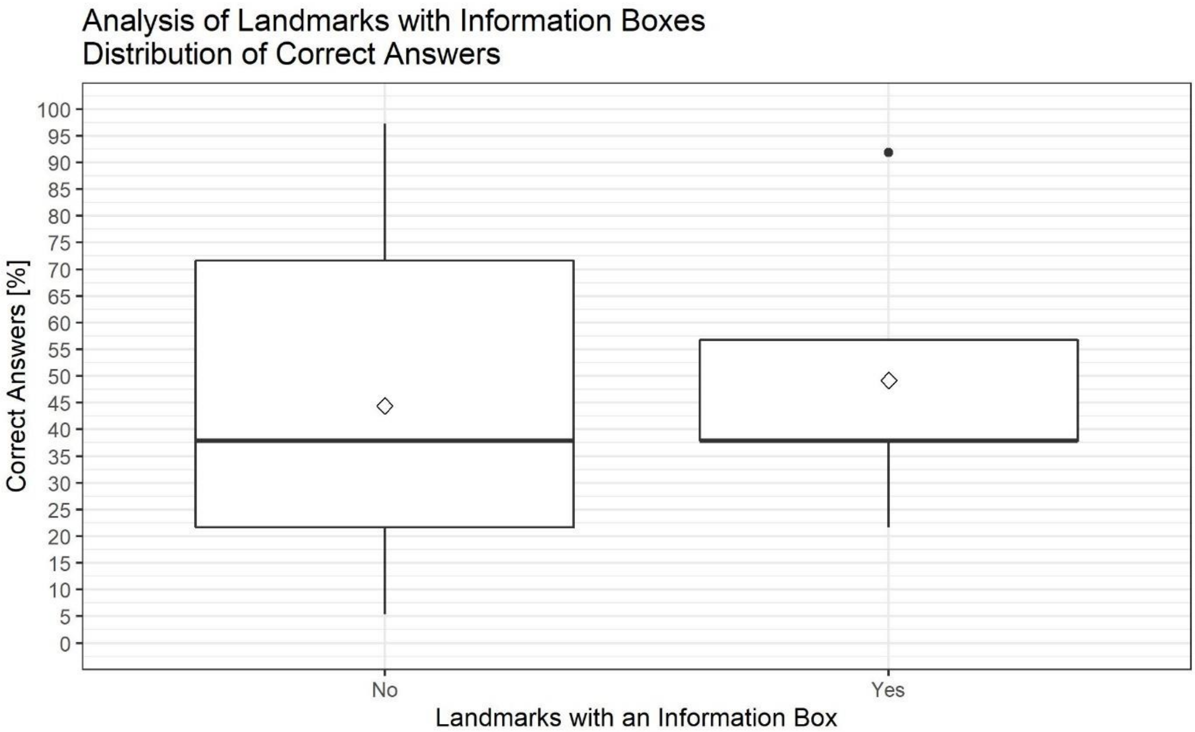


Figure 36 Distribution of Correct Answers for Landmarks with and without an Information Box.

The output of the robust ANOVA (Figure 37) shows a p-value of .823, which is above the significance level of .05. We therefore fail to reject the null-hypothesis that the two groups are equal. We cannot assume that the augmentation of a landmark by placing an information box leads to a better recall performance of these landmarks.

Robust ANOVA

	F	p
box	0.05418686	0.8232196

Note. Method of trimmed means, trim level 0.2

Figure 37 R Output Robust ANOVA for Augmented and Non-augmented Landmarks.

3.5. Hypothesis 4

Based on the box plot of the data (Figure 38), one would definitely expect a significant difference. The box of the 3D object covers almost the entire plot. The distribution of the other two groups is narrower and the interquartile range is approximately one fifth to one fourth. The exact measures are summarised in Table 12.

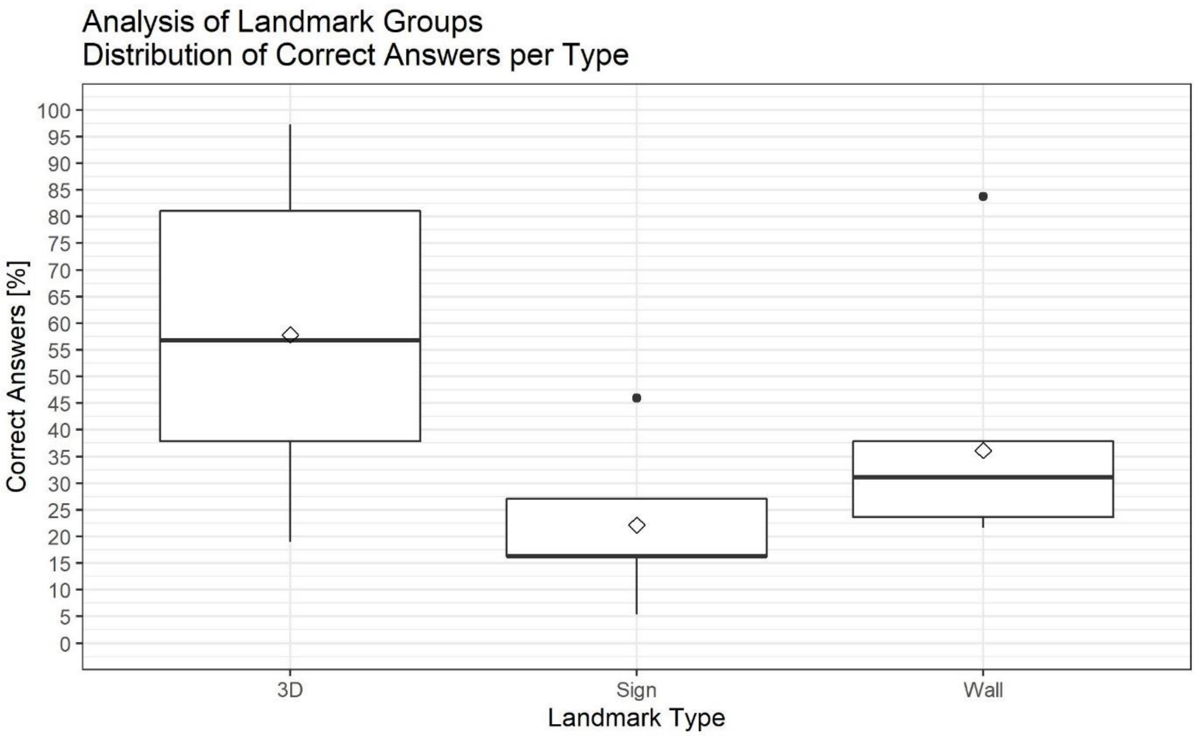


Figure 38 Distribution of Correct Answers per Landmark Type.

Table 12 Distribution of Correct Answers per Landmark Type.

Landmark Group	Median [%]	Mean [%]	Standard Deviation
3D	56.76	57.84	26.79
Sign	16.22	22.16	15.34
Wall	31.08	36.15	20.43

As one could expect based on the boxplot, the output of the robust ANOVA (Figure 39) shows a significant result. The p-value is .018 and thus below .05, which means that we can reject the null-hypothesis an take the correct answers of the three groups as unequal. In this case, there is a need for a post hoc test. Unlike for hypothesis 1, there are three groups and with the output of the robust ANOVA we cannot tell where the differences are. The `ranova` function in R automatically computes this post hoc test when the argument $\mathrm{ph} = \mathrm{T}$ is used. The relevant output is included in this work in Figure 40. The post hoc test has the same significance level (α = .05) as the actual ANOVA. The p-value confirms the observation made in the box plot (Figure 38). The p-value of the comparison of the 3D type with the signs (7.8e-3) and the wall installation (.023) is significant but not the sign-wall-difference (.142).

Robust ANOVA

	F	p
group	7.310825	0.0181745

Note. Method of trimmed means, trim level 0.2

Figure 39 R Output Robust ANOVA for Landmark Groups.

Post Hoc Tests - group

		psi-hat	p
3D	Sign	14.666667	0.0078444
3D	Wall	10.666667	0.0226560
Sign	Wall	-4.000000	0.1423908

Figure 40 R Output Robust ANOVA Post Hoc Test.

4. Discussion

4.1. Hypothesis 1

Generally, the results show that the participants performed better on recalling directions at intersections than recognising landmarks that were visible along the route. This is at odds with the findings of Siegel & White (1975) who stated that humans first gain landmark and then route knowledge. If this was the case, the number of correct answers should be higher for the landmarks' questions. This is not true and in fact the results of these questions are actually quite poor. The mean of correct answers is only nine (arrow group) and 15 percentage points (box group) respectively higher than the expected value. The majority of participants can be considered to be in early stages of spatial learning, as they stated not to know the buildings and the route very well. The following figures show how well the buildings (Figure 41 to Figure 46) and the route (Figure 47) are known by the participants. Unsurprisingly, building Y25 is best known by the participants, since this building is home to the Institute of Geography and approximately two thirds of the participants are geographers. In contrast, the other third does not know the building at all, leading the mean familiarity be at 3.6. The other buildings have means of familiarity between 1.73 and 2.87. This is reflected in the results of the route familiarity where only two people indicated that they are very familiar with at least one part of the route. Based on these findings, the author would suggest to follow Ishikawa & Montello (2006) that landmark, route and survey knowledge is built up simultaneously and one could even presume that creating landmark knowledge is easier in the beginning

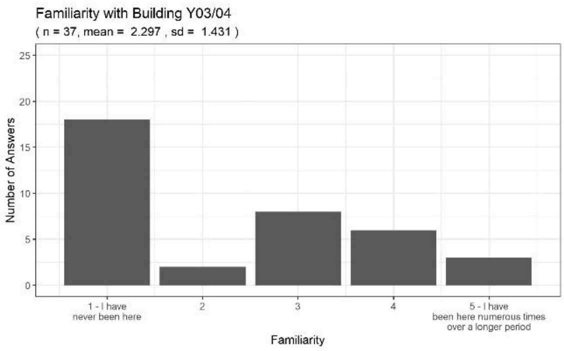


Figure 41 Familiarity with Building Y03/04.

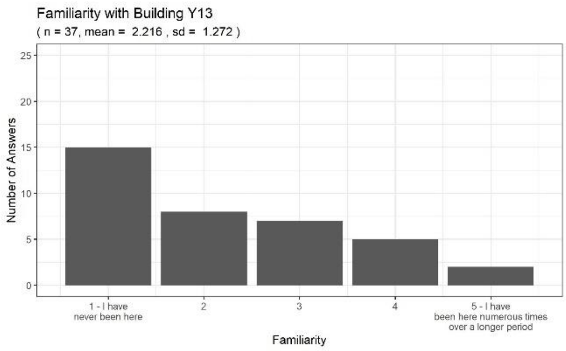


Figure 43 Familiarity with Building Y13.

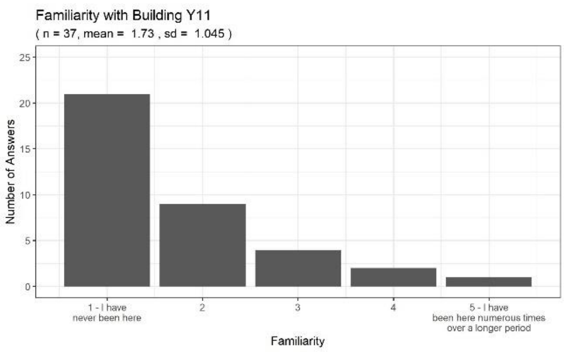


Figure 42 Familiarity with Building Y11.

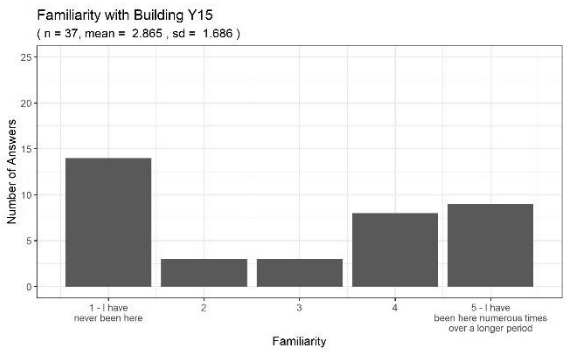


Figure 44 Familiarity with Building Y15.

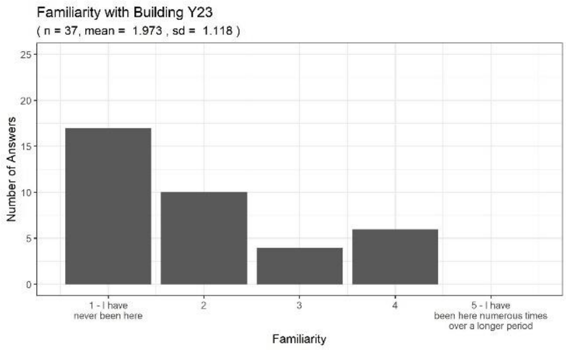


Figure 45 Familiarity with Building Y23.

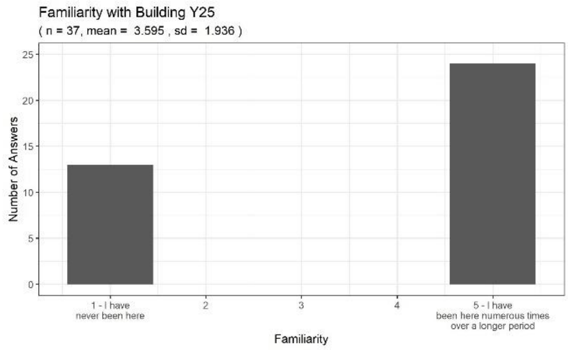


Figure 46 Familiarity with Building Y25.

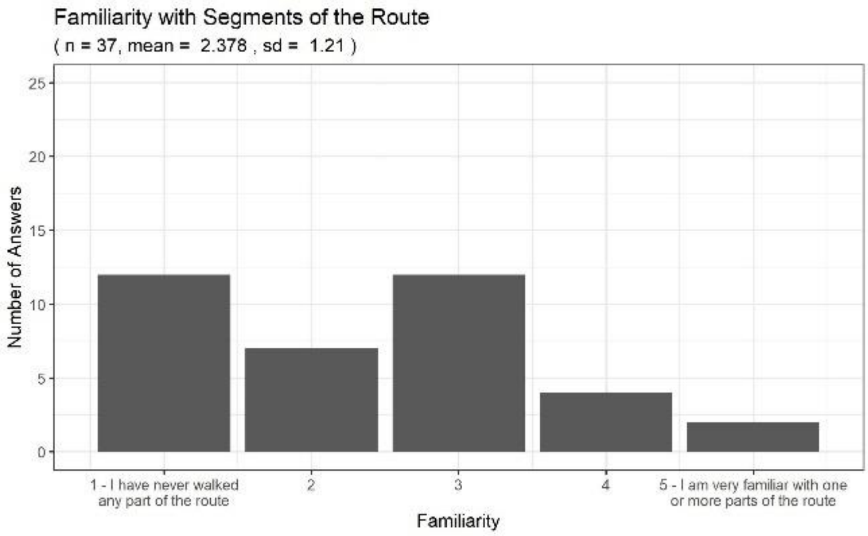


Figure 47 Familiarity with Segments of the Route.

One of the difficulties with such an experiment is that navigational performance can be influenced by a myriad of factors. Strictly following the first hypothesis, a simple ANOVA between the two study groups would be enough to tell whether there is a difference or not. However, if we take a closer look into the two groups, it becomes obvious that this would not be enough. Comparing the arrow and the box group on the other predictor variables, we get the following result (Table 13).

Table 13 Differences between the Two Study Groups on the Other Predictors.

Predictor	Mean Arrow Group	Mean Box Group	p-Value	Significance (p < .05)
ISS Score	4.65	4.66	.968	
Age	27.84	28.00	.962	
Building Knowledge	2.28	2.62	.369	
Route Knowledge	2.37	2.39	.959	

Based on the calculated p-values gathered in Table 13, we can conclude that the two study groups divided by the navigation system they used are very equal. The p-values for the ISS Score, the age and the route knowledge are all above .95, which means that the two groups are almost the same. Only the p-value of the building knowledge is compared to the others relatively small (.369), but still far above the significance level of .05. The only predictor that is not included in Table 13 is gender. This due to the fact that it is not possible to compare the number of men/women with a statistical test. Figure 48 shows the number of males and females in the two respective groups. There is a certain disequilibrium in the box group where there are two females and 13 males. However, this can be neglected to a certain extent, since there is no difference in spatial abilities (p-value = .405) and since the results show no significant difference between the two genders in an isolated analysis (Table 7) and in the complete model (Figure 31).

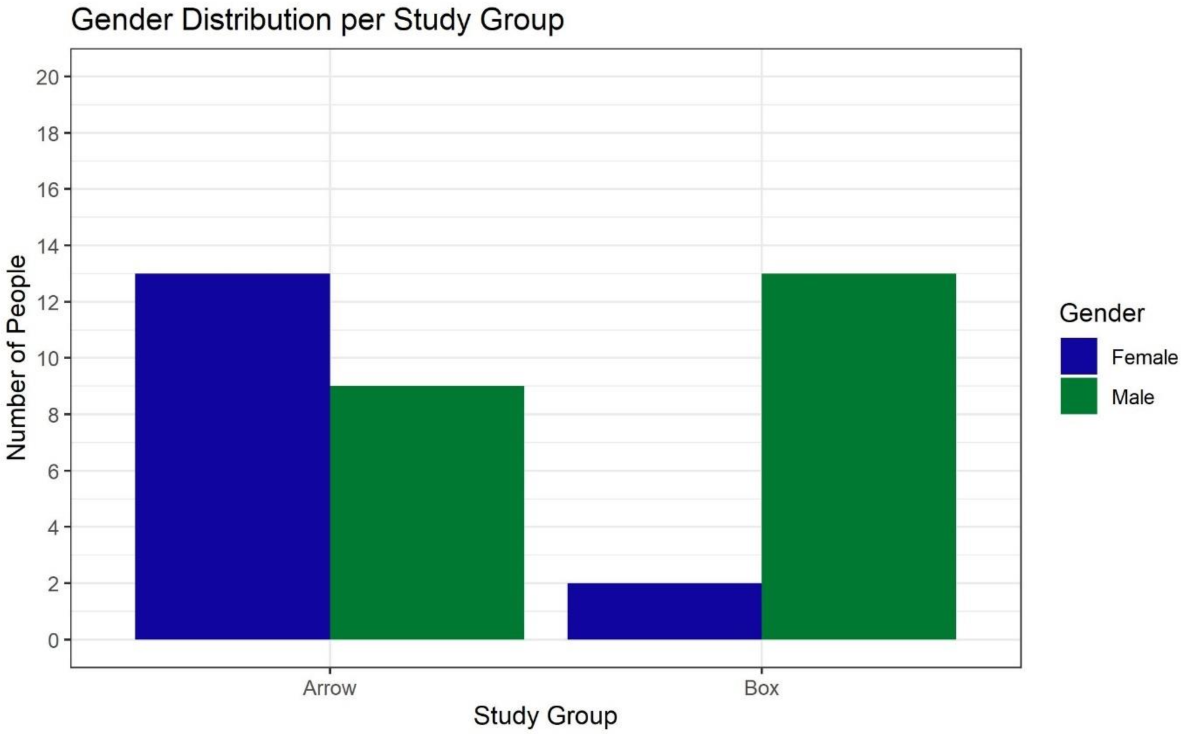


Figure 48 Gender Distribution per Study Group.

The primary goal of hypothesis 1 was to find out whether spatial learning can be improved if the AR navigation system provides more spatial information to the user or if more information would even distract the user. For landmark knowledge, no difference could be detected, neither an improvement nor a decline. The same can be concluded for the route knowledge. As a side effect, also the influence of other predictors (gender, age, spatial abilities, route and building knowledge) was evaluated. Only the age seems responsible for a significant difference, namely for landmark knowledge. This finding, however, has to be considered with caution as the age distribution is very uneven. A very vast majority is aged between 20 and 30, only three people are in their 30s and another three people are 55 and over (cf. Figure 10).

The easiest way to explain this would be just to say that the recall performance becomes worse with age, which would be in line with the findings of Rodgers et al. (2012). This could be proven by leaving out the oldest three participants, who are all older then 50. By doing so, the mean age drops from 27.7 (σ = 9.7) to 25.3 (σ = 3.8) and indeed the p-value of a robust ANCOVA is now .942 and the effect thus strongly not significant. Figure 49 supports these findings, since the performance of those aged 55 and over is obviously worse than the performance of those under 55. However, Figure 49 underlines also that the age of the participants is very unevenly distributed and the results are therefore not very robust.

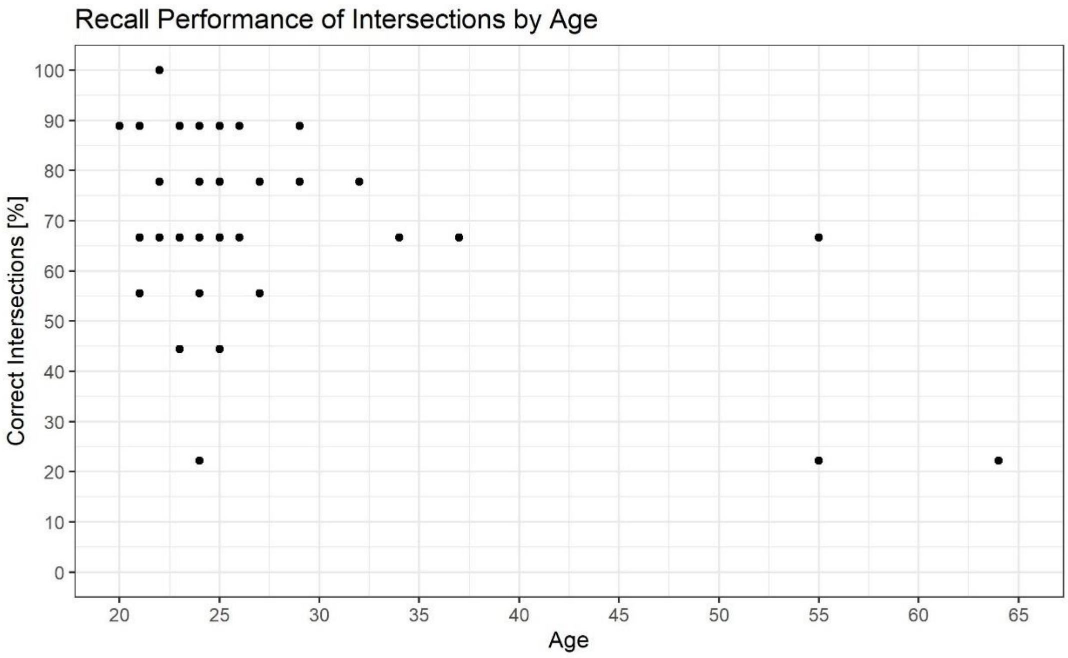


Figure 49 Recall Performance of Intersections by Age.

According to the environment aspects and the resulting wayfinding problems of Gärling et al. (1986), we would expect the participants to have a high to very high extent of problems. With respect to the findings of this work, the expectation is only partially met. The participants showed very few problems on acquiring route knowledge which is reflected by a rather high percentage of correct answered intersection questions. On the other hand, landmark knowledge seems a bit harder to gather and participants showed more problems answering the questions about encountered landmarks. This could mean that either the environment is not as complex as assumed or the AR navigation system supports the spatial learning process in an ideal way.

Table 6 leads to the assumption that people remember better what they did not see than what they did see. This hypothesis can be tested using a Mann-Whitney test since the groups have homogeneous variances but the data is not normally distributed (Field et al., 2013, p. 958). The test results in a p-value of .012 which is smaller than the significance level ($\alpha = .05$). We can therefore reject the null-hypothesis that the groups are equal. Observed on its own, it is effectively easier for the participants to remember what they did not see in terms of landmarks. Table 6 also leads to the assumption that 3D objects are recalled better than wall features or signs. This question is equal to hypothesis 4 and therefore treated in section 3.5 and 4.4.

4.2. Hypothesis 2

As the robust ANOVA showed, there is no statistically significant difference between the landmarks which have an arrow close by and those which do not. This means that the participants recalled the landmarks equally well. Or actually equally bad, since the average for both groups is below 50 %. For the further use of AR navigation systems, we can conclude that by placing arrows or navigation instructions in general in the immediate vicinity of a feature which we want to highlight does not have the desired effect. It seems that humans indeed notice the arrows but their focus is not influenced. It could also not be proven that the navigation instructions would absorb the user's attention and landmarks are even recognised worse. Mean and median are a bit lower for landmarks with an arrow but the effect is not significant as mentioned. It can be assumed that this difference is coincidental and caused by the disequilibrium between the number of landmarks in the two groups. This would also be supported by the interquartile range which is much smaller for the yes group than for the no group. We thus probably even have to acknowledge that it is possible that only landmarks which are poorly recognised anyway have an arrow in the vicinity. This issue, which is also applicable for the following hypothesis, is further discussed in the Technical and Conceptual Limitations section (4.5).

4.3. Hypothesis 3

Like the previous two hypotheses, hypothesis 3 also cannot be proven, as the participants of the study did not recognise the landmarks that had been augmented with an information box significantly better. Again here, the much smaller variance of the yes group can possibly be explained with the very unbalanced number of landmarks. Interestingly, the degrees of centrality are very similar, which is something one would at least in this case not expect. It can be explained with the attention towards these information boxes. There was no systematic recording of who has seen which information boxes, but it is striking that only one participant of the 18 has effectively noticed all five boxes. Everyone else has missed at least one, most of the people even more. Therefore, the inexistent difference can be explained with the fact that there is no difference in the predictor variable for this hypothesis.

For further research projects, this could mean two things. First, the participants of the box group were not told that there are information boxes along the route. We can now hypothesise that if they were informed about the boxes they had cared more. It was deliberately decided not to do so, since in the regular use of a navigation system, there is no introduction of what can be expected on the guided trip. One could now even argue that the participants had seen the information boxes but thought that these were irrelevant. However, from the author's point of view this would not make any sense, since on one hand why should there be irrelevant holograms in such a situation and on the other hand were the information boxes held in the same style as the instruction boxes at the beginning and in the end. And these boxes were not missed by anybody. The second recommendation for further work with the Hololens 2 is that a good positioning of non-core holograms is even more important than holograms people will expect.

4.4. Hypothesis 4

The goal of hypothesis 4 was to focus on which type of landmark is recalled best in spatial learning. Keep in mind that overall landmarks were not recalled very well as hypothesis 1 showed. The result is quite clear as signs and wall installations are recalled very poorly. Remembering 3D objects seems easier, in which the variance is very big. This corresponds well to the immediate feedback of the participants right after they filled out the final questionnaire. Very many of them said things like "I had no clue about these landmarks, the intersections went way better" or "I was sure I haven't seen a landmark which suddenly appeared in one of the intersection videos". One possible explanation for this phenomenon could be that signs and wall installations are usually mounted to a wall which does not necessarily attract our attention while navigating. We are rather focused on our way which runs through the space between walls. This is also where 3D objects are placed. Furthermore, even if an object is sited at a wall or in a corner, it is better cognisable due to its structure.

The modus operandi of the AR navigation system supports this effect in some way. Knowing that navigation instructions will probably appear along the path one locomotes, we will keep our focus on this path and neglect the periphery even more. One landmark that would support this theory is LM4 the outside art installation in the courtyard. Nearly half of the participants (17) were sure that they had not seen this landmark on the route. This sets the percentage of correct answers of landmark 10 into relation. 97.3 % indicated that they had not seen this landmark which is a LM outside like LM4, but in contrast this landmark could effectively not be seen and we could easily come to the conclusion that (at least some of) those 17 people got LM4 correct only by coincidence. Whether this theory can be supported is discussed in the following two hypotheses.

4.5. Technical and Conceptual Limitations

There are some limitations on the technical side which influenced the outcome of this experiment in some way or which should be considered for further research. First, there is a problem with the interaction with the holograms. The 3D viewer was used for the display. This application allows an easy placement and interaction (moving, scaling & rotating). As soon as the Hololens 2 detects a hand, it is possible to change a hologram (Figure 50). The experiment showed that people easily get excited when seeing a hologram and many want to touch it. To prevent participants from accidentally changing the setup of the experiment, they were told to keep their hands away from the holograms (cf. Instructions in Appendix H). For such simple applications as this navigation experiment was, this works fine even though there is still a remaining risk to some extent. However, if the complexity of the application is increased, be it for example when people actually have to interact with the holograms, this issue can cause trouble.

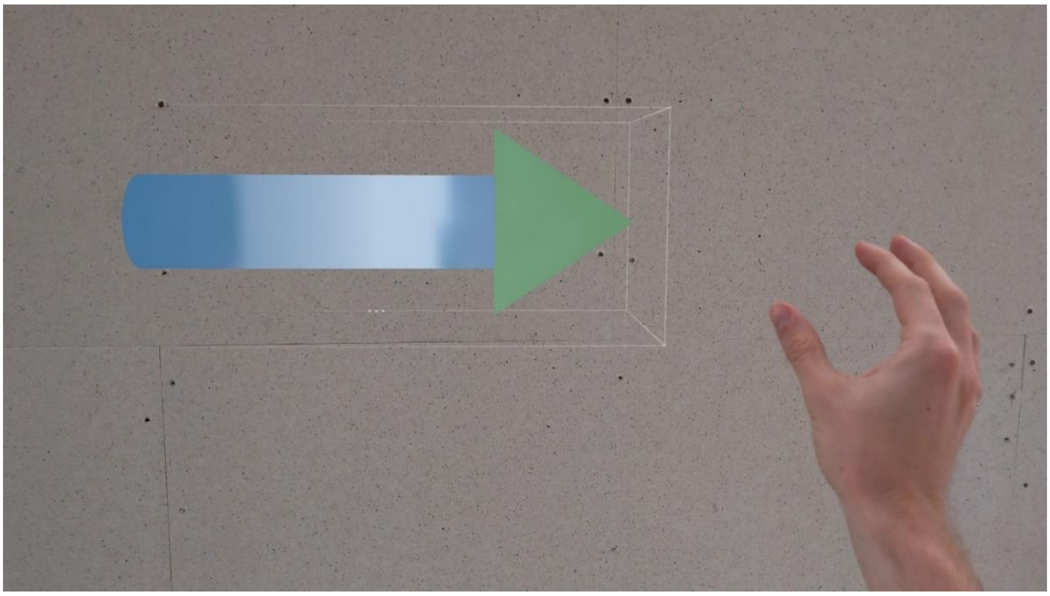


Figure 50 Editing Mode of the Holograms.

Second, the visible angle of the Hololens 2 is challenging. The AR device has a field of view (FoV) of 43° horizontally and 29° vertically. This is already a big improvement to the Hololens 1, whose FoV is 30° x 17.5° (Heaney, 2019). However, this is still quite a bit below the FoV of the human eye, which is able to see up to 200° horizontally and 135° vertically (Dey, 2013). For a static application, when the user knows where to look, this FoV is surly sufficient. In an open environment, like this navigation experiment, this creates challenges for the placement of the holograms, as the users are very likely to miss them if they are not placed in the direct line of vision. The experiment has shown that this is generally only a problem on the horizontal axis. The arrows were placed approximately on the height of my eyes (≅ 170 cm above ground) and none of the participants reported that they are either too tall or too short to see the hologram. The second point is even more an issue if we take the next limitation into account. Third, the optical recognition of the environment is very limited to the light conditions. Both a too dark and a too bright vicinity causes problems. Either the Hololens 2 is not able to detect its position and its direction at all or a detection is possible but the holograms show a jittering. Therefore, the Hololens 2 can only be used in certain conditions and the placement of the holograms has to be deliberate.

The fourth point is the issue that was observed most while following the experiment. Like humans, the Hololens 2 eventually starts building up route and survey knowledge. This means it can calculate the position of a hologram in advance even if it has not yet reached the exact environment where the hologram would belong to. This is a problem if for example the route takes course on two superposed floors. The computer assumes that we can see the position of a hologram even if there is a floor or a ceiling in between (see Figure 51). Although the participants were told that the relevant holograms are placed roughly on the height of their head, five participants detected an arrow from a floor below and four of them actually followed it, leading the participants to proceed wrongly.

Figure 51 Hologram Shimmering through the Floor.

On the conceptual side, the age distribution of the participants is surely something that can be improved. The study cohort has a size that is more than enough. The statistical power analysis software G*Power[14] calculates a sample size of 12 if there are 28 measurements (landmarks) and 22 if there are nine (intersections). The cohort is also very balanced in terms of spatial abilities and previous knowledge about the buildings of Campus Irchel and the route of the experiment, while the gender distribution can be seen as a minor problem. From the total 37 participants, 22 or 60 % were male. However, very problematic is the age distribution of the participants. A vast majority is between 20 and 30 and only a few are aged 30 and over and even less 50 and over. This makes it quite hard to make a statement about the meaningfulness of the result. Yes, the data shows a significant difference in route knowledge with respect to the age, but as there are only so few older people, this effect could easily have its origin in a coincidence.

A further limitation of this work is the unbalanced number of observations in certain groups. This is particularly a problem for the landmarks with an arrow in the immediate vicinity and those with an information box. The ratio for both cases in hypotheses 2 and 3 is 5:23 which is very unbalanced. In addition to the number of landmarks only, the findings of hypothesis 4 underline the importance of a balanced distribution not only in terms of their number even more. Table 14 shows that landmarks with an arrow close by are recognised a bit worse than landmarks which do not have an arrow even if the former only have one landmark of the sign group which is the group whose landmarks are recalled significantly worse than those of the other two groups. The same is applicable for the landmarks where in the yes group are only landmarks of the 3D and the wall group. Further work into this direction should make sure that there is an equal number of landmarks and an equal number of landmarks types in both groups.

Table 14 Landmarks with Arrows in Immediate Vicinity and Information Boxes.

	LM2	LM3	LM5	LM7	LM9	LM13	LM17	LM20	LM27
Immediate Arrow	No	Yes	No	No	Yes	Yes	Yes	No	Yes
Information Box	Yes	No	Yes	Yes	No	Yes	No	Yes	No
LM Type	3D	Wall	Wall	3D	3D	3D	Sign	Wall	Wall

4.6. Suggestion for Further Work

The most interesting point for further work is the positioning of holograms to support the user in wayfinding. The results of the experiment show that there is no difference in the recognition of landmarks if the level of information that is given by the navigation system varies. But the experiment showed also that almost all participants missed at least one information box. An optimal positioning of the holograms is therefore crucial. The first suggestion for further work based on the findings of this work is to analyse where the visual attention of AR users lies and how much attention areas in the FoV generally get. This can be achieved by using the built-in eye tracker of the Hololens 2 whose recordings are able to give answers to these two issues.

[14] https://www.psychologie.hhu.de/arbeitsgruppen/allgemeine-psychologie-und-arbeitspsychologie/gpower (last retrieved on 09.09.2022)

Somewhat related to the optimal positioning of holograms is the user’s ability to recall landmarks. This work has shown that it differs depending on what type of landmark it is. 3D objects are recalled much better than signs, whose purpose would actually be to assist wayfinding, and wall installations. Again, with making use of the eye tracker, it can be analysed whether this difference simply comes from the place where these landmarks are or whether the attention for the different groups does not differ very much but we can remember 3D objects better. The findings of this experiment could add value to AR assisted wayfinding in the sense that we have a hint which landmarks are recognised anyway, which landmarks are worth augmenting by further information and which landmarks have to be highlighted.

A third suggestion, which is likewise linked to the previous two, is the number of arrows that are placed along the route, as it is not only important where the navigation instructions are place but also how many. The more instructions there are, the less attention is paid to the environment. Subsequent research could find out where the upper and lower limits are and what the ideal number (i.e., where is an arrow really necessary) is.

5. Conclusion

The goal of this work was to elaborate ways with different approaches to improve the process of spatial learning when being assisted by an automated navigation system. The first approach was to vary the amount of information given by the system. In this case, there were additional information boxes showed to the participants of one study group. The results show that with the described study setting and parameters there is no statistically significant difference between the two study groups and we have to conclude that increasing the amount of information does not have the desired effect on spatial learning. Even when only focusing on the landmarks with an information box, there could no significant difference be observed.

The second approach was to focus on the placement of navigation instructions. It was analysed whether an arrow in immediate vicinity of a landmark has an influence on how well the participants recall this landmark. Again, there are minor differences but none of them are statistically significant. This is valid for both directions. Thus, an arrow does neither improve the attention towards the landmark by highlighting it nor does it reduce the attention by absorbing all the attention.

Finally, the third approach was to find out which landmarks are recalled how well. For that, all landmarks were classified into three groups, 3D objects, wall installations and signs. The results of the experiment show that there is a significant difference between the three types. 3D objects are recalled best, followed by wall installations and signs interestingly worst. The difference can be observed overall (i.e., comparing all types together) and when comparing 3D objects and wall installations and 3D objects and signs, but not if we compare wall installations and signs.

Furthermore, the acquisition of spatial knowledge with a focus on landmark and route knowledge is observed in this work. It can be concluded that the participants gained better route knowledge than landmark knowledge after one walk along the route. The participants recognised approximately one out of two landmarks correctly while for two out of three intersections the participants remembered the direction they were taking correctly. It can also be concluded that most of the participants have a good self-estimation about their spatial learning as many indicated that they had more problems answering the questions about the landmarks. However, this was not recorded systematically and is therefore not further analysed.

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Appendices

A. List of Landmarks

Figure 52 Landmark 1.

Landmark 1

Landmark 1 is an art installation from Franco Fornasier located in building Y13. It is 26.4 meters long, 3.6 meters wide and mounted on the ceiling.

Landmark 1 is part of the 3D objects group and not visible on the route. However, it can be seen on the way to the starting point and some participants have probably spotted it there which led to confusion in the questionnaire.

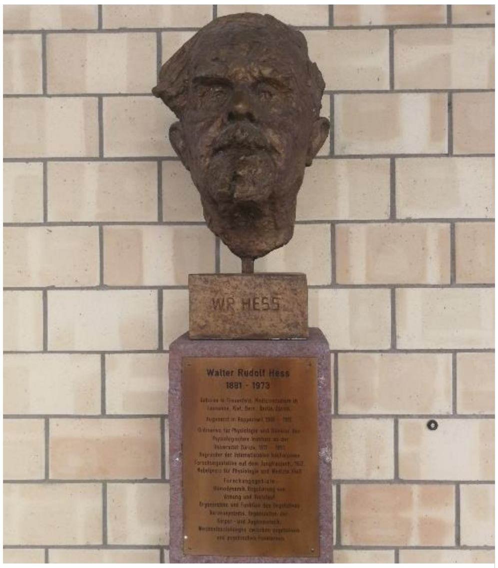


Figure 53 Landmark 2.

Landmark 2

Landmark 2 is a statue of W. R. Hess, a former researcher at the Institute of Physiology and one of UZH's Nobel Prize winners. The statue consists of an effigy of his head and an information plate in German about important achievements in his life. It can be found in building Y23 in front of rooms H8 and H10.

Landmark 2 is part of the 3D objects group and visible on the route.

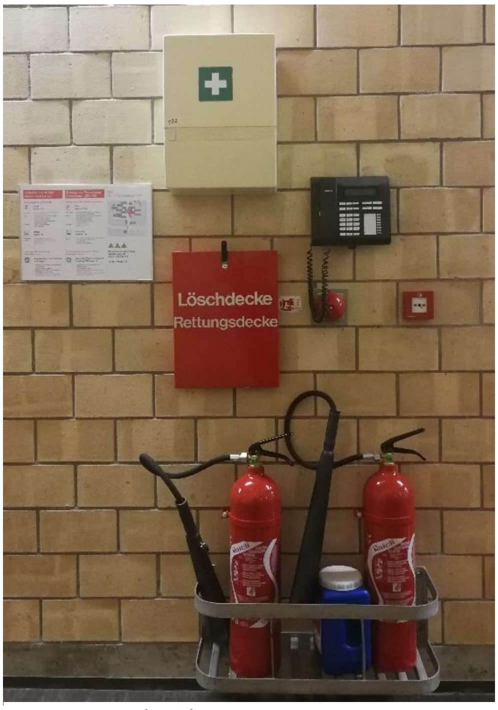


Figure 54 Landmark 3.

Landmark 3

Landmark 3 is an emergency point. It is formed of two fire extinguishers, a fire blanked, two alarm buttons, a telephone and a first-aid-kit. There are numerous points as this one distributed over the campus, but there is only one on the route and on the way to the start and back from the end. It is located in building Y23 next to the entrance of room F64.

Landmark 3 is part of the wall installation group and visible on the route.

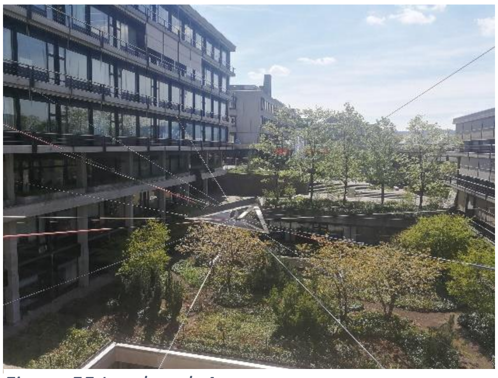


Figure 55 Landmark 4.

Landmark 4

Landmark 4 is an outdoor art installation located in the courtyard between buildings Y11, Y13 and Y32. It is approximately 30 x 50 meters large and can be seen through the windows in the respective building.

Landmark 4 is part of the 3D group and visible the route.

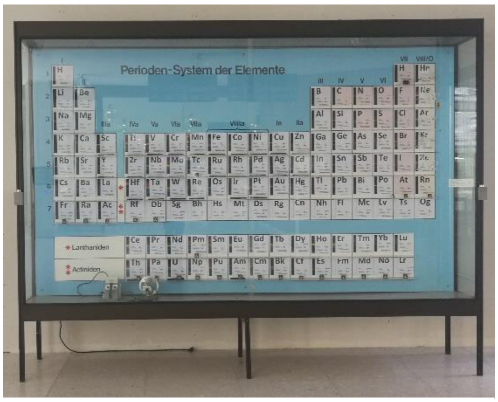


Figure 56 Landmark 5.

Landmark 5

Landmark 5 is a periodic table of elements, located next to Café Brunnenhof on floor G of building Y15. It is 3 meters wide and 2.4 meters high.

Landmark 5 is part of the 3D group and visible on the route.

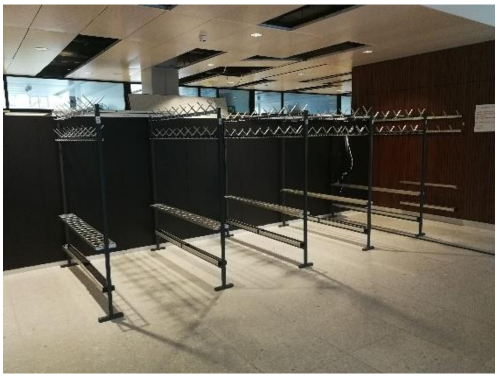


Figure 57 Landmark 6.

Landmark 6

Landmark 6 is a wardrobe, located on floor G of building 13. It is 6.6 meters long and 1.8 meters high.

Landmark 6 is part of the 3D group and not visible on the route.

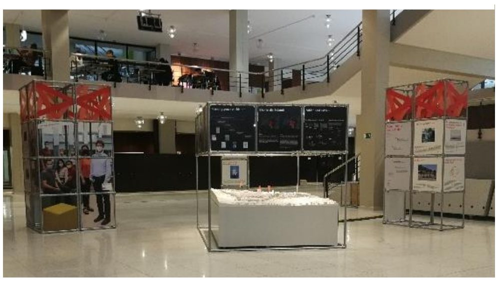


Figure 58 Landmark 7.

Landmark 7

Landmark 7 is an exhibition about the future of Irchel Campus in the year 2050. It is located on the F floor of building Y04 in the “courtyard” behind F30. All elements together cover an area of approx. 6 x 6 m.

Landmark 7 is part of the 3D group and visible on the route.


Figure 59 Landmark 8.

Landmark 8

Landmark 8 is the Lichthof. It is a small square located in building Y04 where it is possible to enter the adjacent buildings Y13, Y15, Y22, Y23 and Y25.

Landmark 8 is part of the 3D group and not visible on the route.


Figure 60 Landmark 9.

Landmark 9

Landmark 9 is a tank for liquid nitrogen, where researchers can collect nitrogen if needed. It is located next to the elevator on floor H of building Y32. There are other tanks at Irchel Campus, but this is the only one that is visible on the route.

Landmark 9 is part of the 3D group and visible on the route


Figure 61 Landmark 10.

Landmark 10

Landmark 10 is a yellow column located in the courtyard of building Y15. The column is approximately XY meters tall.

Landmark 10 is part of the 3D group and not visible on the route.

Figure 62 Landmark 11.

Landmark 11

Landmark 11 are two information displays of the Institute of Biochemistry. They are located on H floor in building Y23 right at the passage to building Y25.

Landmark 11 is part of the wall installation group and visible on the route.

Figure 63 Landmark 12.

Landmark 12

Landmark 12 is a landscape picture of a Silvesterklaus in a snow environment. Silversterklausen is a tradition in the Swiss cantons of Appenzell Inner- and Ausserrhoden on New Year's Eve[15]. The photography is 8 meters long and 1.2 meters tall and can be found in the passage between Y05 and Y27 (floor G).
Landmark 12 is part of the wall installation group and not visible on the route.

Figure 64 Landmark 13.

Landmark 13

Landmark 13 is an old electron microscope built in 1949 from Philips. It is located in building Y34 on floor F next to the staircase and room 12.

Landmark 13 is part of the 3D group and visible on the route.

Figure 65 Landmark 14.

Landmark 14

Landmark 14 are letterboxes for internal and external letters. If can be found on floor H in the passage between Y32 and Y13.

Landmark 14 is part of the wall installation group and visible on the route.

Figure 66 Landmark 15.

Landmark 15

Landmark 15 are lockers that can be rented by students and can be found on floor F in building Y15 on the opposite wall of room 09. There is a myriad of lockers at Irchel Campus, but they all differ in size, style, colour, etc. so that there are no lockers looking alike on the route.

Landmark 15 is part of the wall installation group and visible on the route.

[15] https://appenzellerland.ch/de/informieren/typisch/braeuche-tradition/silvesterchlausen.html (last retrieved 29.09.2022, in German)

Figure 67 Landmark 16.

Landmark 16

Landmark 16 is an ice machine from the Institute of Biology. Like for the liquid nitrogen in Landmark 9, researchers can get ice here if needed. The machine is located on floor F in building Y03.

Landmark 16 is part of the 3D group and visible on the route.

Figure 68 Landmark 17.

Landmark 17

Landmark 17 is a sign for course rooms of the Institute of Biology. The sign is yellow with white and blue writing on it and can be found on floor F in building Y04 in the same courtyard as LM7.

Landmark 17 is part of the sign group and visible on the route.

Figure 69 Landmark 18.

Landmark 18

Landmark 18 is a sign for laboratories of the Institute of Biochemistry. It can be found at the entrance to building 44 at floor H next to the room 11.

As it stands freely, Landmark 18 is part of the 3D group and not regarded as a sign. It is visible on the route.

Figure 70 Landmark 19.

Landmark 19

Landmark 19 is a sign for rooms 59 – 90 on floor F in building Y15. It is located in the corridor behind lecture halls G19, G20, G40 and G60.

Landmark 19 is part of the sign group and visible on the route.

Figure 71 Landmark 20.

Landmark 20

Landmark 20 is the internal post office of Irchel Campus. It is located at Y13 H01.

As the visible part of the post office is only a counter, landmark 20 is regarded as part of the wall installation group and not as a 3D object. It is visible on the route.


Figure 72 Landmark 21.

Landmark 21

Landmark 21 is a model of Irchel Campus. It is 2 meters wide and 2 meters long and can be found by the entrance to building Y23 on floor H. There is no scale indicated, but based on its size, we can assume that it is around 1:500.

Landmark 21 is part of the 3D group and not visible on the route.

Figure 73 Landmark 22.

Landmark 22

Landmark 22 is a model of Aguille Vertes in the Mont Blanc area in the scale 1:5000. The location is at room Y25 L04

Landmark 22 is part of the 3D group and not visible on the route.

Figure 74 Landmark 23.

Landmark 23

Landmark 23 is a sign for the TV recording rooms at Irchel. It is a white sign with blue writing on it and can be found in the courtyard behind Y04 F30.

Landmark 23 is part of the sign group and visible on the route.

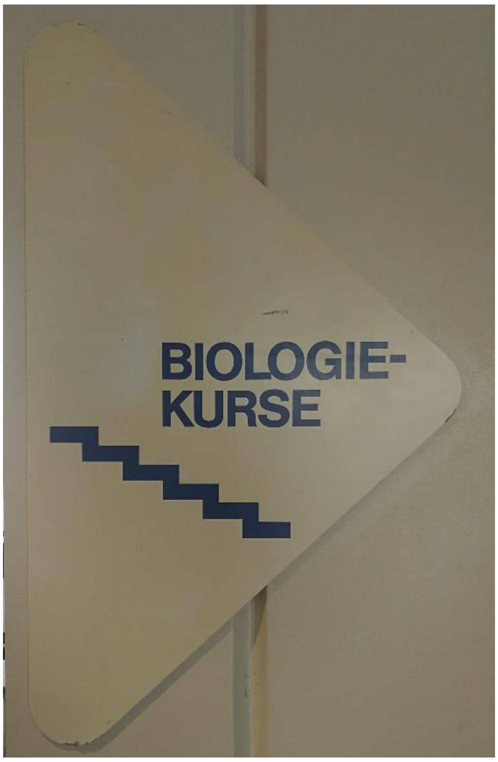


Figure 75 Landmark 24.

Landmark 24

Landmark 24 is a sign for course rooms of the Institute of Biology. It is a white sign with blue writing on it and can be found at the staircase opposite of lecture hall G60. Landmark 24 and landmark 17 belong together as the former leads the way to the latter which then leads to the rooms.

Landmark 24 is part of the sign group and not visible on the route.

Figure 76 Landmark 25.

Landmark 25

Landmark 25 is a plotter located at room 09 on floor L of building 44. Note that it has been removed in the meantime.

Landmark 25 is part of the 3D group and not visible on the route.

Figure 77 Landmark 26.

Landmark 26

Landmark 26 is a sign for rooms 22 – 44 on floor G of building 13. It can be found right to the lifts opposite of Café Brunnenhof.

Landmark 26 is part of the sign group and not visible on the route. However, these lifts were used to get to the starting point and some participants have probably spotted it there which led to confusion in the questionnaire.

Figure 78 Landmark 27.

Landmark 27

Landmark 27 are two information displays of the Institute of Physiology. They are located on F floor in building Y23.

Landmark 27 is part of the wall installation group and visible on the route.

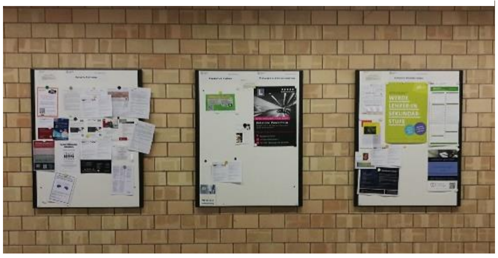


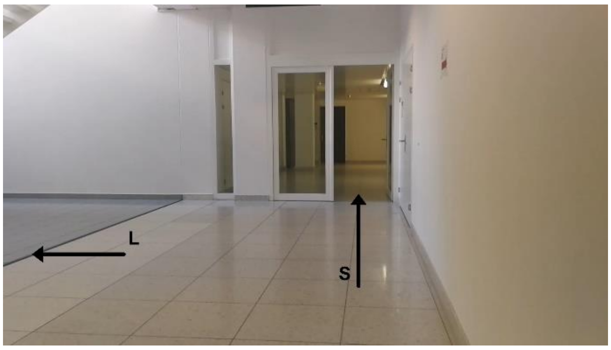
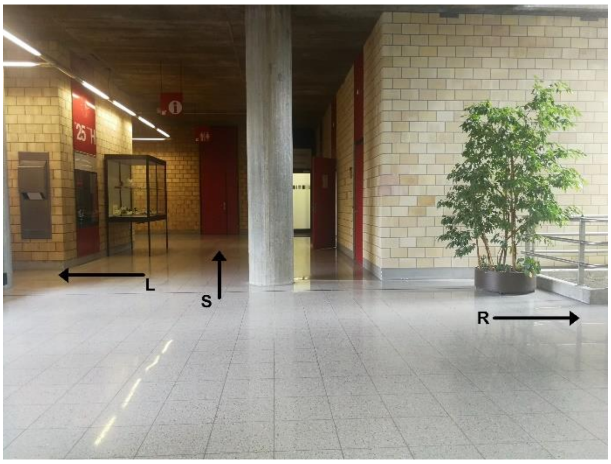
Figure 79 Landmark 28.

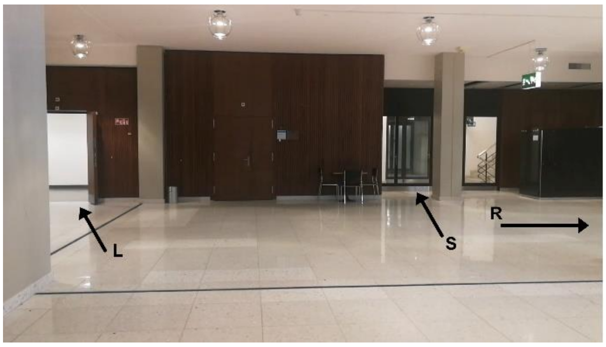
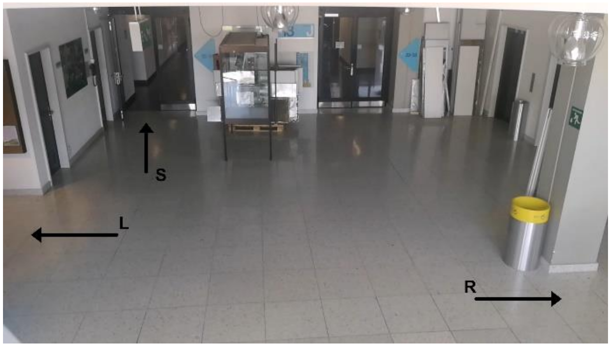
Landmark 28

Landmark 28 are three information displays used for general information. They can be found next to Y23 G35.

Landmark 28 is part of the wall installation group and not visible on the route.

B. List of Intersections

Intersection	Location	End Frame
I1	Between lift and stairway Y32, floor H	 *Figure 80 Intersection 1.*
I2	Right after LM15 (lockers) at Y15 F09	 *Figure 81 Intersection 2.*
I3	At the staircase of building Y25, floor H	 *Figure 82 Intersection 3.*
I4	At the internal post office (Y13 H01)	 *Figure 83 Intersection 4.*

I5	At the statue of W.R. Hess (Y23 H8/10)	 *Figure 84 Intersection 5.*
I6	In front of the Physiology information displays (Y23 F)	 *Figure 85 Intersection 6.*
I7	After the Irchel 2050 exhibition in the atrium behind Y04 F30	 *Figure 86 Intersection 7.*
I8	In front of the lifts in Y13 on floor J	 *Figure 87 Intersection 8.*

I9	After the stair next from LM5 to LM13 (Y34 F12)	 *Figure 88 Intersection 9.*

C. Information Boxes

The following information boxes were placed along the route. For participants that were part of the arrow group, only the first and the last box (Figure 89 and Figure 101) were visible, while the participants of the box group could see all boxes.

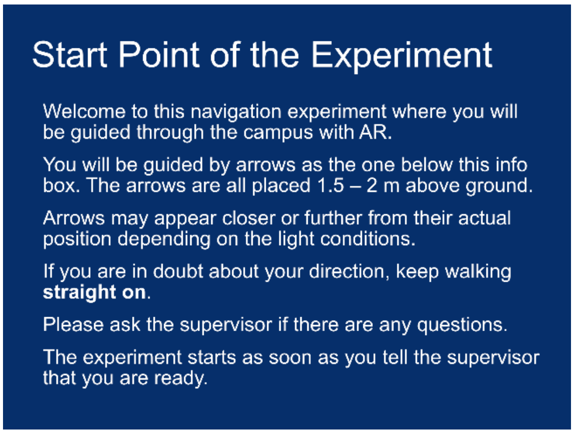


Figure 89 Start Instructions Information Box.

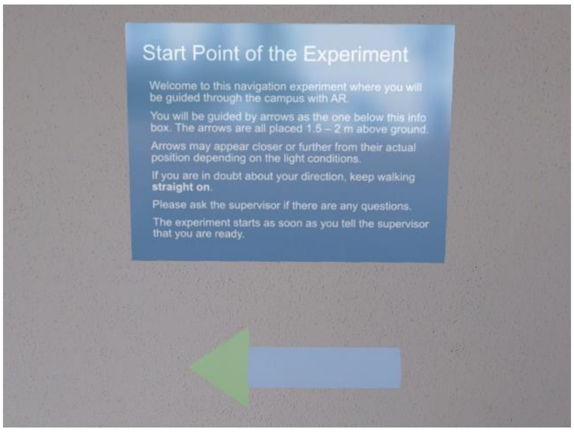


Figure 90 Position of Figure 89 Information Box.

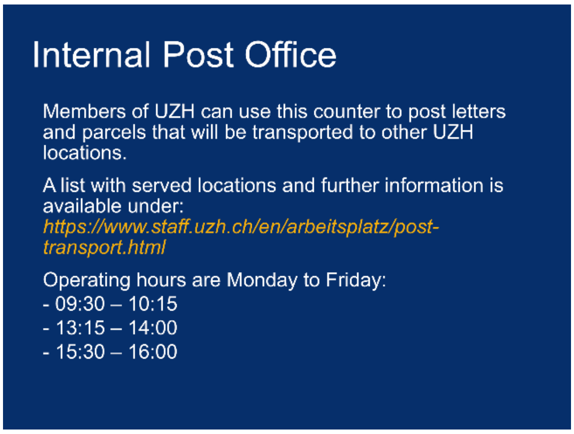


Figure 91 Internal Post Office Information Box.

Figure 92 Position of Figure 91 Information Box.

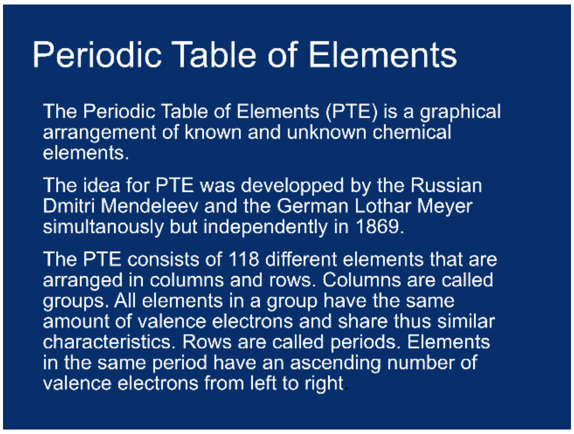


Figure 93 Periodic Table of Elements Information Box.

Figure 94 Position of Figure 93 Information Box.

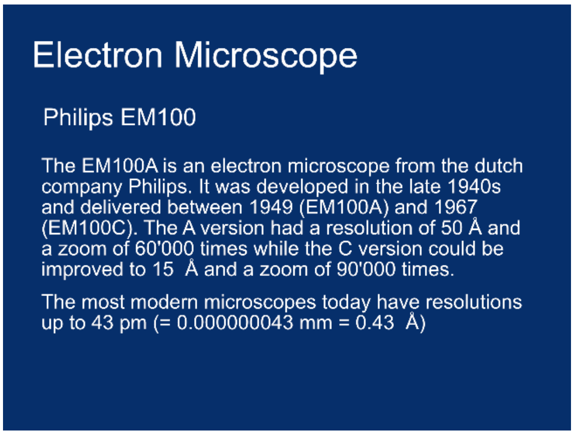


Figure 95 Electron Microscope Information Box.

Figure 96 Position of Figure 95 Information Box.

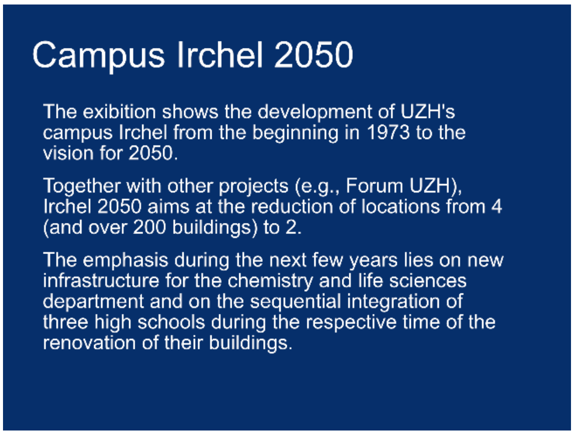


Figure 97 Irchel 2050 Information Box.

Figure 98 Position of Figure 97 Information Box.

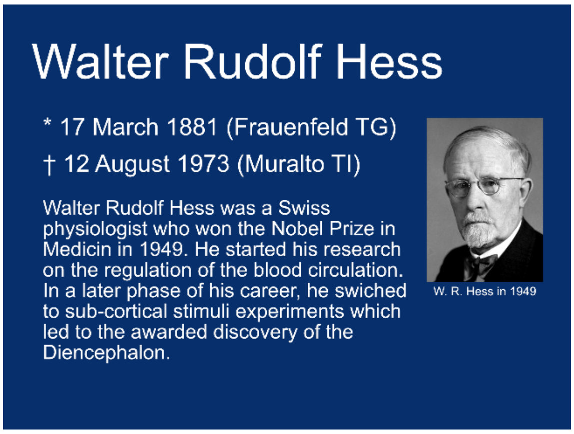


Figure 99 W.R. Hess Information Box.

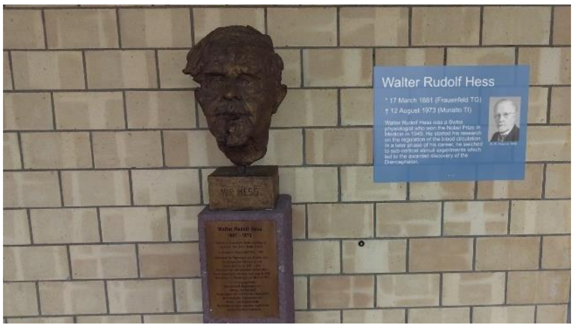


Figure 100 Position of Figure 99 Information Box.

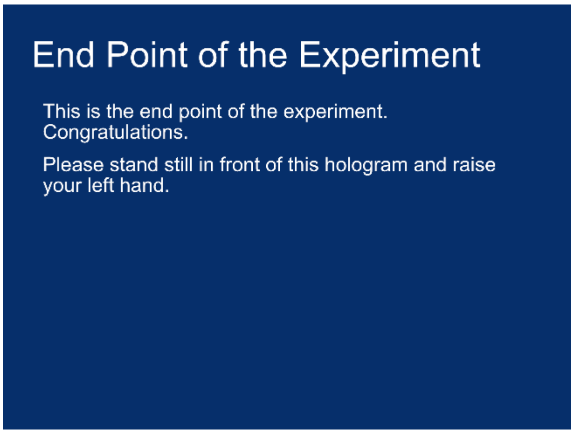


Figure 101 End Instructions Information Box.

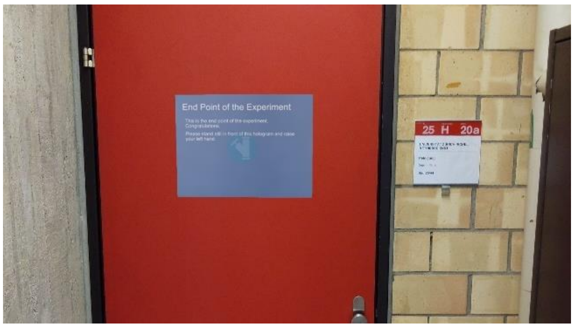


Figure 102 Position of Figure 101 Information Box.

D. Irchel Spatial Self-evaluation Questionnaire

Item Number	Item Text	Inversion Necessary
1	I am good at giving directions	No
2	I have a poor memory where I left things	Yes
3	I am very good at judging distances	No
4	My sense of direction is very good	No
5	When moving through a big building, I imagine a plan or a footprint of it	No
6	I tend to think of my environment in terms of cardinal directions (N, S, E, W)	No
7	I very easily get lost in a new city	Yes
8	In a complex building (e.g., airport), I always take the exact way back that I took before to the destination	No
9	I enjoy reading maps	No
10	I have trouble understanding directions	Yes
11	I am very good at reading maps	No
12	I look out for striking structures or eye-catching objects in complex buildings	No
13	I do not remember routes very well while riding as a passenger in a car	Yes
14	I do not enjoy giving directions	Yes
15	In a big building, I can tell spontaneously where the entrance is	No
16	It is not important to me to know where I am	Yes
17	I usually let someone else do the navigational planning for long trips	No
18	When moving through a complex building, I memorise striking places and turns to eventually find my way again	No
19	I can usually remember a new route after I have travelled it only once	No

20	I do not have a very good "mental map" of my environment	Yes
21	I do not have a very good "mental map" of my environment	Yes

E. Final Questionnaire

The final questionnaire consisted of three parts. In the first part, there are questions about the landmarks participants have encountered while navigation along the route.

Question No.	Question	Answer Possibilities
1 – 28	Have you encountered this landmark while navigating along the route?	Yes No I don't know
29	Was there an eye-catching landmark that you would see as a good navigation help and that has not been included in this questionnaire?	Yes No
30 (only shown if 29 was answered with yes)	Please list the eye-catching landmark(s).	Open question

The second part, questions about the intersections had to be answered.

Question No.	Question	Answer Possibilities
31, 33, 34, 36, 37, 38	Please indicate the direction you were taking when passing the end point of the video.	Left Straight on Right I don't know
32, 35	Please indicate the direction you were taking when passing the end point of the video.	Left Straight on I don't know
39	Please indicate the direction you were taking when passing the end point of the video.	Left Right I don't know

The third part were socio-demographic questions.

Question No.	Question	Answer Possibilities
40	Please indicate your participant's number.	Numerical Input
41	Please indicate the participant group you are part of.	Arrow Box
42	Please indicate your gender.	Female Male No Answer
43a	Please indicate your general familiarity with the following buildings of Irchel Campus. Y11	1 – I have never been here 2 3 4

		5 – I have been here numerous times over a longer period
43b	Please indicate your general familiarity with the following buildings of Irchel Campus. Y13	Same as 43a
43c	Please indicate your general familiarity with the following buildings of Irchel Campus. Y15	Same as 43a
43d	Please indicate your general familiarity with the following buildings of Irchel Campus. Y03/04	Same as 43a
43e	Please indicate your general familiarity with the following buildings of Irchel Campus. Y23	Same as 43a
43f	Please indicate your general familiarity with the following buildings of Irchel Campus. Y25	Same as 43a
44	Please indicate your familiarity with the route or segments of it.	1 – I have never walked any part of the route. 2 3 4 5 – I am very familiar with one or more parts of the route
45 (only shown if 44 was answered with 5)	Please name segements of the route or landmarks that you are very familiar with.	Open question

F. Consent Form (English)

Dear participant

You agreed in participating in a study conducted by Nicolas Morf for his master's thesis at the Institute of Geography at University of Zurich.

Contact Details Study Supervisor

Nicolas Morf, E-Mail: nicolas.morf@uzh.ch, Tel: +41798605118

Aim of the Study

The aim of the study is to investigate the influence of augmented reality (AR) navigation systems on the spatial knowledge of the participants. The focus lies on the different amount of information given to the participants.

Test Procedure

The study consists of three parts. In the first part, participants are asked to fill out a questionnaire where they evaluate themselves with respect to spatial information. This part takes place prior to the actual study and serves the forming of equal groups to obtain significant results.

In the second part, participants have to follow a route with the help of an AR navigation system. Afterwards, they will be asked to fill out a questionnaire about their acquired spatial knowledge. The study is being evaluated with the results of the latter questionnaire. The answers to both questionnaires will be collected and stored anonymously.

Voluntary Participation

Your Participation in this study is entirely voluntary. You may withdraw your consent to participate in this study at any time without providing notice or reason. You may always ask questions to the experiment at all time.

Benefits for the Participants

This study offers no direct benefit to the participant.

Data Confidentiality

This study involves recording your personal information. All data are coded by replacing the names with a code and are made anonymous. Furthermore, your name will never be used in any reports or publications. All collected data will be kept encrypted and stored on secure media protected by a password only known to researchers listed above.

The personal information provided here is stored for a period of 10 years due to a legal obligation. A local ethics committee may examine the information during this period. All the information is stored in a locked laboratory space and on a highly secure server at the Department of Geography of the University of Zurich.

Costs

The entire study will not incur any direct costs to the participants

Compensation

The participants will not receive any financial compensation for participating in this study.

Termination of Participation

Your participation will be cancelled if you

- are not able (anymore) to understand or adhere to the instructions of the supervisor.
- withdraw your participation. Should you wish to do so after completion, your data will be deleted.

The participant confirms that they have read and understood the information provided here. Upon request, the information can also be explained orally.

Place/Date___________________________ Signature____________________________

Declaration of the experimenter: I certify that I have explained the nature of the study and how the data will be used from this experiment to the participant. If there are any changes through the course of the experiment that affect the participant, I shall inform them immediately and seek approval. I certify that this study adheres to all legal obligations and is compliant with the national rules and international guidelines on human experimentation.

Place/Date___________________________ Signature____________________________

G. Consent Form (German)

Sehr geehrte Studienteilnehmerin, sehr geehrter Studienteilnehmer

Sie haben sich dazu bereit erklärt, an einer Studie teilzunehmen, die von Nicolas Morf im Rahmen seiner Masterarbeit am Geografischen Institut der Universität Zürich durchgeführt wird.

Kontakt Studienleiter

Nicolas Morf, E-Mail: nicolas.morf@uzh.ch, Tel: +41798605118

Zweck der Studie

Der Zweck dieser Studie besteht darin, herauszufinden, welchen Einfluss der Einsatz von augmented reality (AR) Navigationshilfen auf das Raumwissen der Teilnehmenden hat. Der Fokus dabei liegt auf dem unterschiedlichen Ausmass der verfügbaren Informationen.

Studienablauf

Die Studie besteht aus drei Teilen. Im ersten Teil wird mittels eines Fragebogens festgestellt, wie sich ein Teilnehmer/eine Teilnehmerin sich in Bezug auf räumliche Informationen einschätzt. Dieser Teil findet vorgängig statt und dient dazu, die Teilnehmenden in gleiche Gruppen aufzuteilen, damit ein aussagekräftiges Resultat erreicht werden kann.
Der zweite Teil besteht darin, mit einer AR Navigationshilfe einen Parcours zu absolvieren. Anschliessend werden Sie gebeten, einen Fragebogen zu Ihrem erworbenen Raumwissen auszufüllen. Die Studie wird anhand der Resultate aus diesem Fragebogen evaluiert. Ihre Antworten auf beide Fragebogen werden anonymisiert erfasst und gespeichert.

Freiwillige Teilnahme

Ihre Teilnahme an dieser Studie ist freiwillig. Sie können Ihre Einwilligung zur Teilnahme an dieser Studie jederzeit ohne Angabe von Gründen widerrufen. Sie können auch jederzeit Fragen zur Studie stellen.

Vorteile für Studienteilnehmende

Diese Studie bietet keine direkten Vorteile für die Studienteilnehmenden.

Vertraulichkeit der Daten

Diese Studie beinhaltet die Erfassung Ihrer persönlichen Daten. Alle Daten werden durch das Ersetzen Ihres Namens mit einem Code verschlüsselt und anonymisiert. Darüber hinaus wird Ihr Name nicht in der Arbeit verwendet. Alle gesammelten Daten werden verschlüsselt aufbewahrt und auf sicheren Datenträgern gespeichert. Ihre Daten können in anonymisierter Form in der wissenschaftlichen Community publiziert werden.

Die erfassten personenbezogenen Daten werden aufgrund einer gesetzlichen Verpflichtung für einen Zeitraum von 10 Jahren gespeichert. Eine lokale Ethikkommission kann die Informationen in diesem Zeitraum prüfen. Alle Informationen werden in einem abgeschlossenen Archivschrank sowie auf einem sicheren Server am Geographischen Institut der Universität Zürich gespeichert.

Kosten für Studienteilnehmende

Die Studie verursacht keine direkten Kosten für die Studienteilnehmenden.

Entschädigung der Studienteilnehmenden

Die Teilnehmenden erhalten für ihre Teilnahme keine finanzielle Entschädigung.

Abbruch der Teilnahme

Ihre Teilnahme an der Studie wird abgebrochen, wenn Sie

- nicht (mehr) in der Lage sind, die Anweisungen des Versuchsleiters zu verstehen oder diese umzusetzen.
- Die Teilnahme an der Studie widerrufen. Sollten Sie dies nach Beendigung tun, werden Ihre Daten gelöscht.

Der Studienteilnehmer/die Studienteilnehmerin bestätigt, dass er oder sie diese Informationen gelesen und verstanden hat. Diese werden auf Wusch auch mündlich erläutert.

Ort/Datum__________________________ Unterschrift__________________________

Erklärung des Versuchsleiters: Ich bestätige, dass ich die Studie sowie die Verwendung der Daten der Teilnehmenden erklärt habe. Sollten sich im Laufe des Versuchs Änderungen ergeben, die die Teilnehmenden betreffen, werde ich sie unverzüglich informieren und um Zustimmung bitten. Ich bestätige, dass diese Studie alle gesetzlichen Verpflichtungen erfüllt und mit den nationalen Regeln und internationalen Richtlinien für Humanexperimente übereinstimmt.

Ort/Datum__________________________ Unterschrift__________________________

H. Instructions for Experiment

Arrival at Base	• Tasche, etc. deponieren • Dauer Experiment: 45 Minuten -> WC, etwas trinken • Kalibrierung Hololens • Ablauf erklären: Route, Fragebogen zu Raumwissen • Einverständniserklärung unterschreiben lassen	• Leave bags, etc. • Duration of the experiment: 45 minutes -> toilet, drink something • Calibration hololens • Explain Experiment: Route, questionnaire about spatial knowledge • Signature on consent form
Walk to Start	• Small Talk	• Small Talk
Start point	• Position vor Lift • Hololens übergeben • Anweisungen lesen lassen • Nachfrage Unklarheiten • Hologramme nicht berühren • Erster Pfeil bei Pflanze • Keine Interaktion mit Studienleiter	• Position in front of lift • Hand over Hololens • Let them read the instructions • Ask for questions • No touching of holograms • First arrow next to plant • No interaction with experimenter
Enroute	• Etwa 10 Meter dahinter laufen • Korrektur bei falschem Weg	• Walk approx. 10 m behind • Correct after a wrong turn
End point	• Hololens zurücknehmen • Weg zurück zu base	• Take back hololens • Return to base
Questionnaire	• Fragebogen erklären • Videos nicht durcheinanderbringen • Fragebogen starten • Aufenthalt während Fragebogen ausserhalb des Sichtfelds • Bedanken für Teilnahme, Übergabe Schokolade	• Explain the questionnaire • Do not mix up videos • Start the questionnaire • Stay out of sight while participant is filling out the questionnaire • Thank participant for participation, hand over chocolate

I. Personal Declaration

I hereby declare that the submitted Thesis is the result of my own, independent work. All external sources are explicitly acknowledged in the Thesis.

Ich erkläre hiermit, dass ich die vorliegende Arbeit selbständig verfasst und die den verwendeten Quellen wörtlich oder inhaltlich entnommenen Stellen als solche kenntlich gemacht habe.

Date: 30.09.2022 Signature: ____________