Experimental Study on Verbal Indoor Wayfinding Support

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Abstract

Wayfinding in large indoor spaces is challenging for the limited views the wayfinder has. Verbal indoor wayfinding assistance converts the weakness into an advantage: This experimental study investigates whether such a conversation-based approach based on what is in view can lead to successful wayfinding in complex indoor environments. The findings of this experimental study indicate that by using verbal guidance people can arrive at their destination successfully without experiencing ambiguity of decisions and hesitation of decision-making time, nuanced by a set of environmental and personal attributes. These attributes are captured by variables including the route instruction grammar, familiarity with the environment, and configurational information.

1. Introduction

People often use symbolic representations (e.g., maps) to maintain orientation and find their destination in complex indoor environments such as shopping malls, airports, or office buildings. Traditional You-Are-Here maps (Levine, 1982), mounted at fix locations, help people orient themselves and navigate in such spaces. However, the interaction with these maps shows the well-known challenges of people with map reading, mental rotation, and spatial orientation (Klippel et al., 2006). An alternative are mobile You-Are-Here maps, which rely on some digital positioning infrastructure, such as WiFi access points, Bluetooth beacons, or RFID (Mendoza-Silva et al., 2019; Rüetschi and Timpf, 2005). However, indoor location-based services have their own challenges, prominently the lack of *universal* indoor positioning infrastructure and up-to-date maps (Basiri et al., 2017), which can often be attributed to the private nature of indoor environments (Winter et al., 2019).

Verbal indoor wayfinding (VIW) is a recent approach to identify the location of the wayfinders and guide them to their destination. *VIW* is independent of any technical localization infrastructure. This approach takes advantage of the ability of the wayfinder to describe their surroundings by what they see. Based on the wayfinder's description, their location can be derived and, consequently, verbal route instructions to their destination can be generated, referring to elements in the vista of the wayfinder (Amoozandeh et al., 2021, 2023). This paper, an experimental study of VIW, aims to answer the research question of how different personal and environmental variables can affect the wayfinding process, here the en-route retracings and delays, while following various forms of route instructions. The hypothesis is that depending on environmental variables and personal characteristics, people can be localized and guided to their destination using verbal indoor wayfinding.

The experimental study of the *VIW* approach is conducted in a computer-generated 3D environment. Participants interact with the computer using a mouse to control their viewing direction, and a keyboard to move around within the virtual environment. Participants and system communicate via text on localization and guidance to their destinations.

We investigate whether the *VIW* approach can lead to successful wayfinding. A key prerequisite for successful wayfinding is correctly localizing the wayfinder at the start. The time it takes for the person to be localized through a dialogue in the environment, known as *ToL*, is used to evaluate the localization procedure. After localization, people are being guided to their destinations. In the guidance process, two adverse factors can be observed: (1) when people go in the wrong direction and have to retrace (Montello and Sas, 2006); and (2) when people slow down or stop for orientation (O'Neill, 1992). Thus, the wayfinding can be evaluated by identifying the number of retracings en-route and quantifying the delays while following route instructions. Both factors can be the effect of different personal and environmental variables, and of the form of the route instructions themselves.

The findings of this study indicate that using the *VIW* approach, people can arrive at their destination successfully without significant errors and hesitation. The results also identify the effects of different influencing variables on the time of localization and delays in route instruction following. These variables include the route instruction grammar, the wayfinders' familiarity with the environment, their familiarity with video games, and configurational information.

The remainder of this paper is structured as follows: Section 2 reviews studies in applications of verbal interactions in wayfinding and the current state of research in indoor guidance systems. Section 3 introduces the types of mistakes that the wayfinder can make when following route instructions. Section 4 introduces the influencing variables that can affect the mistakes. Section 5 explains the conducted experimental study to evaluate *VIW*. Section 6 examines the observed effect of different personal and environmental variables on the delays and discusses the anomalies in results. Finally, Section 7 concludes the study.

2. Background

2.1 Verbal Interactions in Indoor Localization

Different applications of verbal interactions in wayfinding have been suggested prior to verbal indoor *wayfinding*.

For example, de Vries et al. (2018) introduced a dialogue system that involves two agents, a *guide* and a *tourist*, who interact with each other via natural language to reach the place goal of the tourist. The guide has access to a map with a set of pre-selected landmarks and knows only the destination without information about the tourist's location; the tourist has a 360-degree view of the world but knows neither the target location on the map nor the way to it. The agents need to work together through verbal interactions to guide the tourist toward the place goal (de Vries et al., 2018).

From another point of view, Sernani et al. (2020) introduced a chatbot system based on voice and written interactions in museums to offer customized visits. In their approach, wearable sensors and a mobile map are required for localization with Ultra-Wide-Band radio technology.

None of those approaches are effective in indoor localization and wayfinding without technical infrastructure. To address this gap, this paper investigates whether an approach for wayfinding through verbal interactions without reliance on positioning infrastructure (Amoozandeh et al., 2021, 2023) can be successful and efficient.

2.2 Route Instructions

The wayfinder's decision is limited to the spatial objects that are visible or easily identifiable from their current location. As such, it is necessary to provide accurate directional instructions that represent the spatial relationships among the recognizable salient indoor objects in the environment. These directional instructions can be provided through photos, maps, or route instructions. Photos and maps are often visually rich and detailed, providing the wayfinder with a comprehensive view of the indoor environment. However, aligning the map with the physical environment requires spatial reasoning and is challenging in indoor environments with complex layouts.

On the other hand, route instructions induce less cognitive load on processing the visual information and thus allow the wayfinder to focus on the task at hand without being distracted by unnecessary details (Cock et al., 2022). In route instructions, the egocentric spatial relationships can be derived based on the view at the current position. Permissible combinations of these components that enable producing route instructions are called *route instruction grammars* (Klippel, 2003). For instance, route instructions can consist of direction actions (e.g., 'turn right'); or references to a landmark and its spatial relation to the wayfinder (e.g., 'pass shop X on your left') (Amoozandeh et al., 2023).

Using only the direction actions in a route instruction may lead to guiding in the opposite direction at the route's origin. On the other hand, references to landmarks in route instructions help to construct a cognitive map of the environment (Allen, 1997). Bailey (1995) shows that people are more successful in recognizing landmarks in *route-learning* task when they are provided instruction consisting of references to the landmarks than people who are restricted to directional information in the instructions. However, route instructions with adequate details can be misleading or overwhelming to remember (Padgitt and Hund, 2012) and lead to unsuccessful wayfinding. In this study, two different route instruction grammars are used to guide the wayfinders to a specific destination. The detail of these route instruction grammars is explained in Section 4.3.

3. Retracings and Delays

Wayfinding is successful when the wayfinder can move along the intended route without retracing and without delays (Montello, 2005). Retracings and delays are caused by a lack of appropriate information or the personal characteristic of the wayfinder, and occur at the decision-making stages of wayfinding (Schmid et al., 2010). Retracings and delays can have negative consequences, such as physical exhaustion, stress, and frustration (Cubukcu, 2003), but in any case, mean a loss of time.

O'Neill (1992) used different measurements to evaluate whether the wayfinding is successful: retracing a path in the opposite direction, wrong turns, and delays on the way (stopping and looking). Adopting these categorizations, in this paper wayfinding is assessed based on the following measures:

Retracing: the environments of this study were designed in a way that when a participant goes in the wrong direction, they need to retrace to arrive at their destination. Hence, observing the number of *retracings* along the routes, which occur when the wayfinder goes in a wrong direction and has to return, help us to identify whether the *VIW* approach can lead to successful wayfinding.

Delay: The *delay* is the difference between the actual travel time and the expected travel time of a pedestrian walking with average speed. It is measured using Equation 1 in which *TTT* refers to the actual time it takes the participant to travel between the origin and the destination, which is observed. *TTD* refers to the total distance that participant covered including any detours (erring and retracing), and v is the average walking speed. Δt tends to 0 if the wayfinder follows the route instruction without any pause or slowing down in search for further information or confirmation.

$$\Delta t = TTT - \frac{TTD}{v} \tag{1}$$

4. Influencing Variables

Delays and retracings are affected by a series of personal and environmental variables (Chen and Stanney, 1999). According to O'Neill (1992), wayfinding is affected by visual access to landmarks, the degree of architectural differentiation between different parts of a building, signage, and the overall configurational information of the building. Below, the influencing variables examined in this study are introduced.

4.1 Familiarity with Video Games

As the method for controlling the virtual movement within the environment is akin to playing a first-person video game, each participant's proficiency with such video games must be considered. Wayfinding in virtual environments is more difficult than in the physical environment (Goerger et al., 1998). When people are experienced in interacting with the computer and familiar with how to navigate in a virtual environment through a mouse and a keyboard, the time it takes to identify the location of the participant and delays decrease.

4.2 Familiarity with the Environment

We evaluate whether the wayfinding process is enhanced with experience, i.e., by gaining familiarity with the environment in subsequent wayfinding experiments (Chen and Stanney, 1999). A wayfinding task on an unfamiliar route is considered a resource-limited task that demands a high mental workload and may cause delays (O'Neill, 1992), in contrast to a wayfinding in a familiar environment. According to Golledge (1992), wayfinding in a familiar environment is the recall and recognition of turning directions and identification of an environmental cue for the next decision en route. To evaluate the effect of familiarity with the environment on retracings and delays in this experiment, each participant pass a route twice. When they pass the route for the first time, they are considered as unfamiliar with the environment, and when they pass the route for the second time, they are considered as familiar with the environment.

4.3 Route Instruction Grammars

In this experimental study, two route instruction grammars are chosen to guide the wayfinders to a specified destination: (1) the *8-section turns* grammar, and (2) a combination of 8-section turns and references to landmarks, the *pass-toward* grammar (Amoozandeh et al., 2023).

The *8-section turns* grammar represents the turning angles at each node on the route with seven possible directions such as 'veer right' (Amoozandeh et al., 2023). The eighth section – going back – is not needed in these wayfinding tasks and is thus excluded.

The *pass-toward* grammar represents the route based on the visible landmark on each node (Amoozandeh et al., 2023). Considering the numbers gaps on the boundary as the partial boundaries of landmarks (e.g., shops in a shopping mall), the visible landmarks on each node can be derived using the *visibility signature* of the regions calculated by visibility partitioning (Amoozandeh et al., 2021). Next, for each visible landmark, the clockwise angle between a line connecting the specified node as the current location of the wayfinder to the next route's node and a line connecting the node to the visible landmark will lead to the proper action for the landmark along with its direction to the wayfinder (e.g., 'pass shop X on the left'). Among the visible landmarks in front of the wayfinder along the route, the closest landmark will be chosen, and the instruction will be generated for the corresponding node.

According to Schmid et al. (2010), since wayfinders need to orient themselves at the origin to follow the instruction correctly, using the 8-section turns grammar may not be appropriate for some routes due to the lack of orientation and distance information. Route instructions based on directions but without distance information make it difficult for wayfinders to estimate how far they need to travel before reaching their destination. This grammar has been chosen to investigate how the lack of orientation and distance information can cause retracings and affect delays.

On the other hand, the pass-toward grammar represents the route based on visible landmarks at each decision point. While the orientation information in the 8-section turns grammar can be missed, route instructions with references to landmarks, i.e., pass-toward, allow reorientation. Reorientation is crucial to find the way successfully, improve spatial knowledge, and reduce retracings (Lovelace et al., 1999; Schmid et al., 2010). Moreover, referencing landmarks in route instructions help the wayfinder estimate the distance to the next landmark by visual cues.

However, Lovelace et al. (1999) show that the route instructions consisting of references to landmarks can lead to unsuccessful wayfinding due to the exceeding working memory capacity. Furthermore, excessive information in route instructions could move the route out of focus (Lorenz et al., 2013) and cause delays. Thus, delays while following route instructions can vary by route instruction grammar.

4.4 Configurational Information

According to Peponis et al. (1990), wayfinding performance depends on the configurational information of the built environment. When large parts of an object are visible across a large area in the environment, wayfinders rely less on existing spatial knowledge in route instructions and more on information directly available in their field of vision (Hölscher and Brösamle, 2007). In this experiment, the selected routes from the origins to the specified destination are crossing different parts of the built environment. Each route can represent partial configurational information of the environment. Hence, route identifiers can exert an influence on delays.

5. Experimental Settings

5.1 Virtual Environments

Researchers are already using virtual environments for the analysis of human behaviour (Meng and Zhang, 2014). In virtual environment experiments, participants are generally asked to perform different spatial tasks, such as moving and observing, similar to the real world (Chen and Stanney, 1999). Navigation in a virtual environment maintains the ability to control the lab experiment (Waller et al., 1998). This study generates a synthetic virtual indoor environment to examine the applicability of indoor localization and wayfinding through verbal interactions by measuring the wayfinding errors.

The VIW approach is applied to a 3D model of a synthetic shopping mall environment. The model was imported into the game engine Unity (Version 3.0.0-beta.6)[1] to enable the interactions between the participants and the system in the virtual environment. The shape of this synthetic environment is based on a combination of the shapes of selected capitalized Roman alphabet characters to generate a diverse indoor environment layout. This environment has been arbitrarily populated with shopping mall objects (e.g., shops, security, entrance, lifts) with recognizable parts of their surfaces.

Wayfinders can be localized within this environment through verbal descriptions containing references to objects. The environment is partitions based on Amoozandeh et al. (2021) such, that from each partition a unique set of objects is visible (i.e., the *visibility signature*). For instance, in the 2D floor plan of the synthetic shopping mall in Figure 2a, from the location identified as the blue dot, objects 19, 15, 16, and 22 are visible.

The wayfinder may, however, provide incomplete descriptions, resulting in an ambiguous specifications of their location in the environment. To resolve this ambiguity, Amoozandeh et al. (2022) proposed a dialogue-based localization approach in which the wayfinder initiates the dialogue with reference to the first set of visible objects. In case of an incomplete description, the visibility of another object will be asked about to reduce the

[1] `https://unity.com/`

ambiguity. The dialogue proceeds until an unambiguous match to a *visibility signature* of one of the regions is found. The number of interactions in the dialogue depends on the route instruction grammar that is being used for guiding the wayfinder through their destination (Amoozandeh et al., 2023). For instance, in the conversation shown in Table 1, it is assumed that the wayfinder is on the blue dot in Figure 2a, the destination is 28, and the route instruction is based on the *pass-toward* grammar.

G: What objects can you see?
W: Objects number 19 and 22
G: Can you see 15?
W: Yes.
G: Can you see 14?
W: No.
G: Can you see 17?
W: No.
G: Go toward 22 on your right, go toward 11 on your left.

Table 1. The destination is Object 28 in Figure 2a. The guide (G) interacts with the wayfinder (W) first to localize them, and then to guide them to their destination.

5.2 Ethics Approval

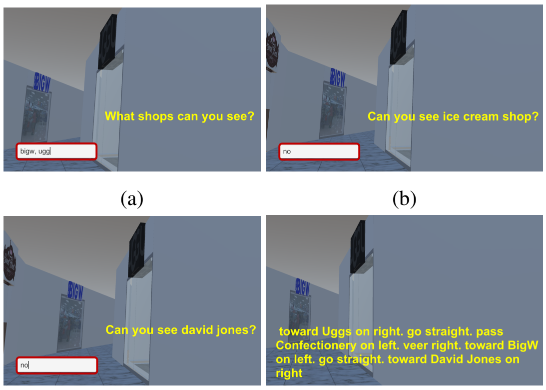
This study received ethics approval from the University of Melbourne's human ethics committee (Approval number 23695). All participants gave written informed consent prior to participating and were debriefed at the end of the experiment. Ethical consent to transferring data was incorporated into the experiment, and the collected dataset has been stored anonymously on the university cloud system.

5.3 Participants

The experiment involved 24 participants. To counterbalance the effect of gender in the experiment, 12 women and 12 men were recruited. This ensured that any observed effects were not biased by gender. Six participants from each category (six women and six men) have been chosen among people who know how to navigate virtual environments to consider the effect of familiarity with video games. The rest have been chosen from people inexperienced in navigating virtual environments (six women and six men). Participants volunteered for the experiment and were incentivized by a voucher worth 20 Australian Dollars to participate.

5.4 Procedure

The experiment follows a complete within-subject design. Each participant performed six tasks in a pre-determined order in the virtual environment. The conversation started by asking about visible objects in the surrounding (the conversation is written on the screen in English, and answers are typed). The participant was then asked whether they can see further objects. The conversation continued until a unique location has been identified from the answers. Then instructions to a destination are provided to the participant in an egocentric way. The participant followed the instructions written on the screen in the virtual environment, guiding them to the destination. Participants saw the instructions until they arrived at the destination (See Figure 1 as an example).



(a) (b) (c) (d)

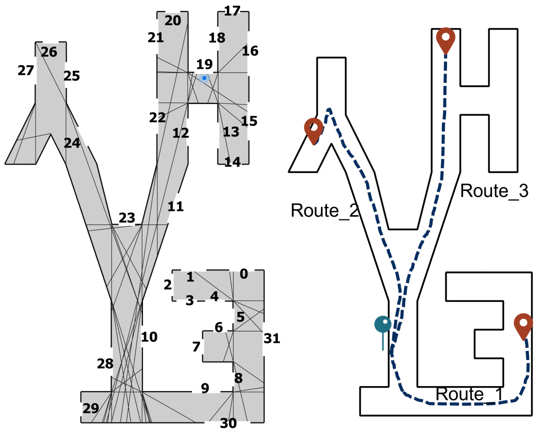
Figure 1. An example of *VIW* approach applied in this experimental study.

To overcome the sequence effect that arises from participants' growing experience with the procedures (practice effects) and the influence of initial conditions on later responses (carryover effects), the Latin Square method was used (Graziano and Raulin, 1993). Four different categories of participants were created to counterbalance the effect of gender and familiarity with navigating virtual environments. Each of these categories experienced the six tasks in an individually set order. As a consequence of the number of possible unique combinations, at least 24 participants were required for this experiment. The details of the tasks are shown in Section 5.6.

A training phase is formed in which participants get familiar with the virtual environment and the procedure they should follow. They could perform the main phase only after at least two successful training tasks.

5.5 Routes

Each participant follows three different routes from three different origins to a specified, single destination. They follow each of them twice (Figure 2b).



(a) (b)

Figure 2. (a) An example of partitioning: From each cell a distinct set of objects is visible. (b) The selected routes: Starts in red, destination in blue.

Following each route, the wayfinder reaches the destination after navigating along the route. Here, for each route considering all route instructions, i.e., total 48 route instructions (24 participants pass each route twice), the portion of the route from which the destination is visible is calculated using the visibility polygon of the destination. This visible portion of the route is calculated based on Equation 2 in which $route_i$ is the route passed by the participant, $visibility\_destination$ is the area in which at least one point of the destination is visible, and d_route_i is the total distance travelled for $route_i$. A number of routes followed by the wayfinders and the portion that the destination is visible from each are illustrated in Figure 5a.

$$visible\_portion_i = \frac{route_i \cap visibility\_destination}{d_{route_i}} \quad (2)$$

On average, the wayfinders could see the destination from 33% of the $Route1$, 35% of the $Route2$, and 78% of the $Route3$, excluding the outliers. Hence, the delays on route instruction following are expected to be less for $Route3$.

5.6 Order

To evaluate the effect of familiarity with the environment, the order of the routes was systematically assigned to each participant according to the Latin Square approach. It is important to note that each route order must be followed by one participant from each category. In Table 2, $Route1$ is from O_1 to D, $Route2$ is from O_2 to D, and $Route3$ is from O_3 to D according to Figure 2b. The participants are randomly assigned to each order set.

The routes

Grammar	$Route1$	$Route2$	$Route3$
8-section turns	Round 1	Round 3	Round 5
pass-toward	Round 2	Round 4	Round 6

The orders

Order name	Round series
A	6,2,3,1,5,4
B	1,3,4,2,6,5
C	3,5,6,4,2,1
D	5,1,2,6,4,3
E	2,4,5,3,1,6
F	4,6,1,5,3,2

Table 2. Introducing the routes and the orders

5.7 Localization

The localization approach in *VIW* is evaluated based on the time it takes to identify the location of the wayfinder, i.e., *ToL*. *ToL* can be influenced by familiarity with video games. People who have less experience in video games may need more time to type their answers in the dialogue. Moreover, when the participant is familiar with the environment, they may need less time to answer the questions since they know the surrounding objects.

5.8 Dataset

For each participant, the following data is collected:

- The order in which the participant follows the routes to take familiarity with the route into account.
- The *ToL* for each task, which is the time it takes to be localized in the conversation.
- The *TTT* which the time it takes for the wayfinder to find the destination. This observation will help to identify the lapses while wayfinding.
- The trajectory of the wayfinder, defined as a sequence of time-stamped locations, which helps to identify whether the wayfinder deviated from the intended route to the destination while following route instructions. Using the trajectory, *TTD* is calculated which is used to derive the delays while following a route instruction.

6. Discussion

6.1 Influences on Time of Localization

As mentioned in Section 5.7, it is expected that the variables *familiarity with video games* and *familiarity with the environment* influence the *ToL*. Our findings confirm that when people are familiar with video games, they can be localized in the environment based on verbal interactions in the dialogue faster than those less experienced with video games (Figure 3).

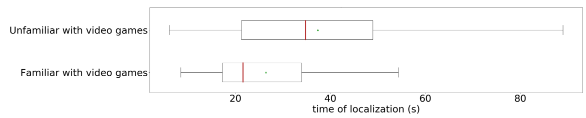


Figure 3. The effect of familiarity with video games on the time of localization.

We also show that *familiarity with the environment* can decrease *ToL*. This means that the wayfinders who have previously been in the same environment and have thus gained familiarity with it are able to localize themselves more quickly than those who are experiencing the environment for the first time (Figure 4).

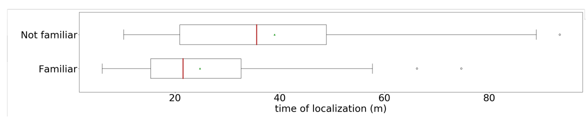
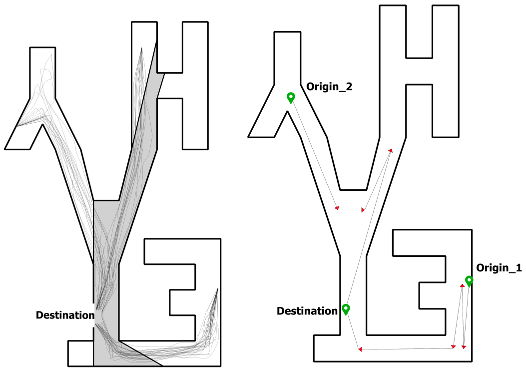


Figure 4. The effect of familiarity with the environment on the time of localization.

6.2 Retracings

In order to assess whether the *VIW* approach can lead to successful wayfinding, the number of retraces among all followed route instructions is analysed. Navigating in the wrong direction always leads to retracing in our environment. For instance, in Figure 5b, retracings occurred on $Route1$ and $Route2$.



(a) (b)

Figure 5. (a) Wayfinders can see the destination when they reach the gray shaded area. (b) Examples of retracings: On Route 1 (from Origin_1 to Destination) a retracing occurred, and on Route 2 a wrong turn occurred.

The percentage of the route instruction following without retracings in this experimental study is 91%. This shows that regardless of influencing factors, the majority of wayfinders could find the destination without going in the wrong direction. Table 3 shows the percentage of route following without retracings for each route considering the grammar of the route instruction.

The highest number of retracings belongs to $Route1$ when following instructions specified following the 8-section turn grammar (Table 3). However, this does not necessarily mean that in general the 8-section turns grammar is inferior and leads to retracings. For instance, the backtracking percentage for $Route3$ following route instructions with the 8-section turns grammar is 0%. This is attributed to the destination visibility from 77% of the route.

Contrary to previous studies claiming that referencing landmarks in route instructions minimizes backtracking, the results in Table 3 suggest otherwise. Table 3 shows that following route instructions with references to the landmarks does not necessarily lead to a low percentage of retracings. For instance, comparing the route instruction grammar for $Route2$, following route instructions with the pass-toward grammar led to a higher number of retracings.

The results show that pass-toward grammars might offer more ambiguous or imprecise instructions compared to other route instruction grammar. Landmark references in pass-toward instructions, could introduce cognitive complexity, potentially leading to misinterpretation or uncertainty among wayfinders. The pass-toward instructions might emphasize certain visual cues or landmarks more strongly than others. This could prompt wayfinders to prioritize specific landmarks, causing them to retrace when they realize they have overemphasized one landmark. Finally, the presence of multiple landmarks referenced in pass-toward grammars might create a form of cognitive overload. When participants attempt to simultaneously process and align their visual observations with multiple landmarks, it could lead to decision-making difficulties and spatial disorientation.

Routes	Grammar	Retracing (%)
1	8-section turns	21%
1	pass-toward	4%
2	8-section turns	8%
2	pass-toward	16%
3	8-section turns	0%
3	pass-toward	8%

Table 3. The percentage of route instruction following without major disorientation for each route.

6.3 Influences on Delays

This section investigates the influences of the variables introduced in Section 4 on the delays introduced in Section 3.

6.3.1 Familiarity with Video Games Influence A comparison of delays based on familiarity with video games variable shows that, on average, individuals who are unfamiliar with video games exhibit delays ranging from 1.01 s to 102.36 s, while those who are familiar with navigating virtual environments experience delays ranging from 0.66 s to 58.58 s (Figure 6). These observations confirm that people who are unfamiliar with video games, i.e., without experience walking in virtual environments, stop more frequently on the way to decide and perform the actions about the direction to take, compared to those who are more experienced and familiar with video games.

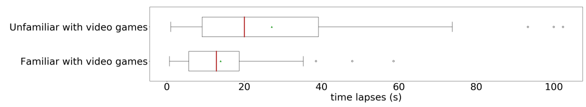


Figure 6. The effect of familiarity with video games on delays.

6.3.2 Familiarity with the Environment Influence As explained in Section 4, wayfinders who have previously passed a specific route and thus gained familiarity with it may follow route instruction without hesitation and stops on the way to find their destination. Figure 7 confirms that when people are unfamiliar with the environment, they need more time to decide which way to take while following route instructions. Delays for people who pass the routes for the first time range from 2.25 s to 102.35 s. However, this range for people passing the routes for the second time is from 0.66 s to 93.25 s.

As shown in Figure 7, the medians of the delays for people who are familiar with the environment and who are not familiar with it are similar. This similarity can be due to the simplicity of the environment. Since most parts of this environment consist of corridors, even when people are unfamiliar with the environment, they can find their way without high delays.

The delays for some cases can be considered as outliers Figure 7 due to the effect of other influencing factors. For instance, the person may be familiar with the environment but has difficulty understanding the route instructions.

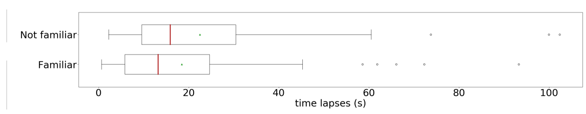


Figure 7. The effect of familiarity with environment on delays.

6.3.3 Route Instruction Grammar Influence As argued in Section 4, excessive information in route instructions could move the route out of focus and cause delays (Lorenz et al., 2013). Here, it is illustrated that when people follow route instructions with references to landmarks, i.e., the pass-toward grammar, they are delayed more while matching the instruction with the environment compared when they follow instructions with the 8-section turns grammar (Figure 8).

Figure 8 shows that when people are unfamiliar with the environment and are provided with a route instruction with the pass-toward grammar, they tend to delay and stop on the way while following route instructions. In this study, the reason that people do not delay while following route instructions with the 8-section turns grammar can be due to the simplicity of the environment. This matter needs more investigation in real-world environments.

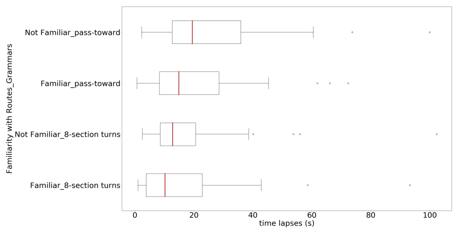


Figure 8. The effect of the route instruction grammar and the familiarity with environment on delays.

6.3.4 Configurational Information Influence As explained in Section 4, when large parts of an indoor environment are immediately visible from different parts, wayfinders rely less on route instructions and more on the destination itself when it becomes visible. Section 5.5 shows that the wayfinders could see the destination from a portion of the route (33% of $Route1$, 35% of $Route2$, and 78% of $Route3$).

Since the wayfinders can see their destination from about 78% of $Route3$, they keep walking without delay toward the destination. However, on $Route1$ and $Route2$, the wayfinder on the route's origin may need time to match the route instruction to their current view (Figure 9).

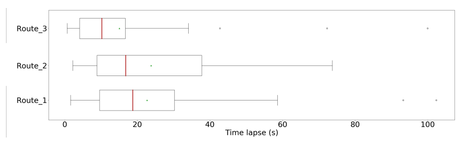


Figure 9. Delays are different in different parts of the environment

7. Conclusion

This paper assesses whether the *VIW* approach can lead to successful wayfinding. For this, an experimental study has been conducted to investigate the influences of different variables on the time it takes to identify the location of the wayfinder, the number of retraces, and the delays while route following. These influencing variables include familiarity with video games, familiarity with the environment, the chosen route instruction grammar, and configurational information of the environment. By investigating the effects of different influencing variables, this paper shows that depending on environmental variables and personal characteristics, people can be localized and guided to their destination using verbal indoor wayfinding.

The following findings of this experimental study identify the effects of different personal and environmental variables on the retracings en route and delays while following a route instruction.

- The observations indicate that people without experience with video games tend to delay more frequently on their way to a destination in a virtual 3D environment than those who are more familiar with video games.
- When people are familiar with the environment, they need less time to decide which way to take while following route instructions compared to those who see the environment for the first time.
- When people follow route instructions formed with pass-toward grammar, they delay more than when they follow instructions with 8-section turns grammar.
- When people see the destination on the way toward the destination, they keep walking without delay toward the destination.

Overall, the research hypothesis – that depending on environmental variables and personal characteristics, people can be localized and guided to their destination successfully using verbal indoor wayfinding – has been supported by the collected evidence. Both chosen grammars are underspecified, allowing errors, and more specific grammars can only improve the results. Fundamentally, this experiment supports the applicability of localization by dialogue, based on objects in the current vista space (Amoozandeh et al., 2022), and also the applicability of route guidance based on the objects in vista space along the route (Amoozandeh et al., 2023).

Although this experimental study has contributed insights into indoor localization and wayfinding, we recognize its limitations. First, the study is implemented in a computer-generated 3D environment, which may not fully replicate the complexities of a real-world indoor environment. Second, in this study, the environment is designed in a way that when a wayfinder goes in the wrong direction, they need to retrace to arrive at their destination. In fact, circular environments, such as around atriums are excluded in this designed environment. People may arrive at their destination from different directions when there is a void in an indoor environment. As a result, the findings of the study may not be entirely transferable to real-world scenarios.

Finally, there are other variables that were not considered here and could play a significant role in the *VIW* approach. These variables include saliency of landmarks in the environment, distribution of the landmarks, and other factors related to environmental complexity. This experimental study is only tested on one environment with a limited set of landmarks. To gain a more comprehensive understanding of the effects of environmental variables on the time of localization and delays in route instruction following, future research need to (1) examine different characteristics of landmarks to investigate the effect of landmark saliency, and (2) conduct the experiment in multiple environments with different geometric characteristics to investigate the effect of geometric information on wayfinding performance.

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