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# Wayfinding search strategies and matching familiarity in the built environment through virtual navigation

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**Abstract**

There is an underestimation of the conscious and unconscious wayfinding search strategies in a virtual built environment without signage information. Wayfinding is the process of determining and following a path or route between an origin and destination. This is the base of the experiment discussed in this paper. Herein, the assignment was to find the destination and then return to origin in a virtual maze-like building. Subjects perform three different assignments given different locations for the destination and the start; each assignment was repeated two times subsequently. Each of the routes was recorded. Analysis of the recorded data shows a significant increasing familiarity of wayfinding. Furthermore, the increase of the number of subjects, who had chooses a route with minimal links for performing subsequent routes, is striking. That indicates whether or not consciously applying a search strategy. This paper reports about the results of analysis of familiarity and search strategies.



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*Keywords:* wayfinding; virtual navigation; virtual environment; matching familiarity; orientation; search strategy

## 1. Introduction

Wayfinding is an everyday activity when we go somewhere, e.g. from our home to our work, or from the train station to the city center, etc. When finding our way we know where we are and where we want to go to (destination). The destination is our goal location and various situations may occur; we visited regularly our destination before and, therefore know this destination; or we visited the destination before, but irregular and with

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medium to large intervals. In the last case, we have familiarity with the environment to certain extent and should probably reorient using our cognitive map. If we have no idea where the destination is, we need verbal, signage and/or map information.

Wayfinding is defined by Golledge (1999) as the process of determining and following a path or route between origin and destination. One can assume that orientation mechanisms affect this process of determining and following a path; we can distinguish reorientation (to know where one is) and wayfinding (how one can get from here to a certain destination). Wang and Spelke (2002) distinguish three processes relevant for orientation, namely path integration, viewpoint-dependent place recognition and reorientation.

Meilinger (2008) defines reorientation as trying to regain one's position, i.e. location and heading, in relation to an internal and external representation of an environment. The cues for this reorientation can be divided into geometric layout of an environment (e.g. shape of a room) and features of a geometric layout; in order to find a location again, geometry is considered more important than landmarks.

Montello (2005) pointed out that, in contrast to reorientation, path integration does not involve the recognition of external features such as geometry or landmarks. In path integration, sensory inputs indicating locomotion are integrated over time to keep track of one or more locations in the environment. Working memory is seen as sufficient to do that, without the need for long-term memory. Apparently, no internal or long term representation of an environment is needed. Path integration is more difficult during imagined movement compared to physical movement (Meilinger (2008)). Especially, interference could occur from a conflict between the awareness of one's physical position in an environment and the discrepant position one has adopt in imagination.

As mentioned before, orientation mechanisms include reorientation as well as wayfinding. A wayfinding process encompasses route navigation, which assumes a process enabling us to reach a known location in an environmental space. It includes route knowledge: identification a location and from that location navigation towards a target location.

What we can see from the above literature are is the importance of geometric layout features of an environment and the conception that working memory satisfies keeping track of locations while navigating in the environment. In our approach of unconscious wayfinding, this is of interest to know. Worth mentioning in this approach are notions about cognitive map related to working memory and virtual navigation related to location navigation.

Tolman (1948) introduced the term "cognitive map" to illustrate the necessity of assuming a memory content in order to explain spatial behavior in rats and men. A cognitive map is an efficient way to represent spatial representations. In this context, Kaplan (1973a) distinguishes four types of knowledge in perception and thought, namely *where one is* (perceptual process), *what is likely to happen next* (essence of prediction), *what it will be good or bad* (payoff), and *some possible courses of actions* (activation). He extends the concept of cognitive maps to the area of environmental preference (1973b). Gunzelman (2007) provides a framework for understanding how human spatial abilities are applied to naturalistic spatial tasks with maps; he distinguishes the identification of a target on a map or within an egocentric view of a space. In his study, participants were able to tailor a general strategy to the requirements of particular tasks. In a neural/cognitive approach, Nadel (1990) shows, in the development of a relational spatial system, its susceptibility to variation as function of early experiences of each individual organism.

It has already been common practice to conduct experiments with virtual reality (e.g. Bailenson et al. (2001) Stanton et al. (1996), Wilson et al. (1997)) as well as navigation through virtual environments. In this context, experiments were performed on wayfinding behavior and spatial knowledge (e.g. Jansen-Osmann et al. (2007)), learning processes (e.g. Buchner et al. (2008)), and VR-based simulators for urban environments in applied contexts (e.g. Sun (2009), Ishikawa et al. ( 2006)).

In this paper, the term "egress" refers to a linkage between two rooms or a linkage between a corridor and room; it has nothing to do with an exit or egress in emergency situations. Therefore, in this paper, literature about this research domain (e.g. Kobes et al. (2010)) isn't under discussion. The focus is on unconscious wayfinding in a virtual built environment without signage. The basis for the described experiment and the provided data is provided by Chen (2012).

This paper gives in section 2 a description about the design of the experiment. Section 3 provides the approach about the used method and the data collection, and section 4 presents the results of the experiment. A discussion about the conclusions and future directions will conclude this paper.

## 2. Design of the experiment

An experiment was designed so data can be collected to explain the potential familiarity with the unfamiliar environment. The experiment was carried out by using a desktop VR-based application aiming navigation through a virtual environment.

The layout of the built environment will be explained as well as the perceivable information. Note that '*egress*' mentioned in this paper is specified as a linkage between rooms, or a linkage between a room and a corridor, rather than the linkage between the built environment and the outside environment.

### *2.1. Design of the virtual built environment*

For designing a maze-like built environment, we keep at the back of one's mind that the size of the built environment (i.e. the number of rooms), actually determine to what extent the potential familiarity of the environment could reflect people's decision in wayfinding. If the size of the designed built environment is too big, subjects may find it too difficult to complete their task. Also, a larger size of the built environment indicates a higher complexity of the built environment and consequently more data should be collected for analysis. On the other hand, if the size of the designed built environment is too small, data to be collected may be insufficient for the intended analysis.

Chen (2012) pointed out that for this type of experiment; a number of 18 rooms for the virtual built environment is plausible. We limited the size of rooms to medium (9 m * 12 m) and large (15 m * 20 m) to restrict the variety. Rooms are connected by doors and corridors.

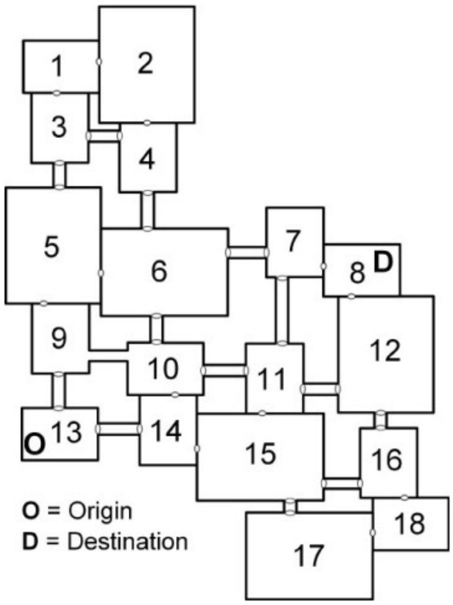


Fig. 1. Lay-out of the maze-like virtual built environment.

Figure 1 shows the layout of the designed maze-like virtual built environment; the number in the middle of each room indicates the 'room ID'. Two kinds of egresses, namely door and corridor, connect these 18 rooms. In this figure, small ellipses are the connections of the egresses and the rooms. Each door has one connection, which links two rooms. Furthermore, each corridor contains two connections that are located at each end of the corridor, and each connection links a room and this corridor.

In this experiment, subjects were given three tasks in the same layout of the virtual built environment. Each task had a unique *origin* (start position; a red circle on the ground), a *destination* (goal position; a yellow box in the middle), and sometimes an *object room* (a green table in the middle). For each task, subjects were asked to find their way from origin to destination (O-D), and then return to origin (D-O). Also, each subject was asked to repeat the same task two or three times. Table 1 shows the tasks that were assigned to the subjects.

Table 1 All three tasks.

| TASK 1 | Start room (O) | Destination room (D) | Object room |
|---|---|---|---|
| 1 | 13 | 8 | 0[1)] |
| 2 | 1 | 11 | 6 |
| 3 | 2 | 12 | 15 |

[1)] 0 indicates: there is no object room

## *2.2. Perceivable information*

A grey level of the egress is used to indicate the brightness of the grey egresses in the room. The grey level of an egress was computationally defined, ranging from 0 as brightest to 100 as darkest, indicating the brightness of the grey of the egress. Changing room illumination in the virtual environment would affect the grey level of the egresses. The higher grey level an egress was, the brighter of the egress's grey would be (Dijkstra et al. (2012)).

In this experiment, the grey level of the egresses was fixed at 50, and the grey level of the room was either 25 or 75. As a result, the grey level contrast between the egresses and the rooms could be -25 or 25, indicating the egresses could be brighter, or darker than the background. This limits the variability so the focus is geometrical features and unconscious wayfinding without other environmental conditions. Figure 2 shows two designed rooms with grey level contrast.

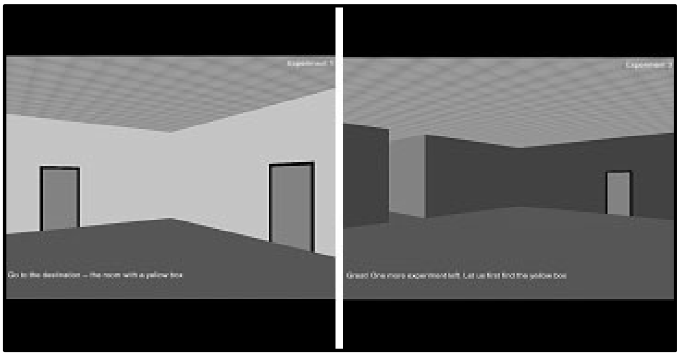

Fig. 2. Some shoots showing designed rooms in the experiment

This grey level is one type of the perceivable information in each designed room. Other types of perceivable information are: the size of the room, and the number of egresses in the room.

## 3. Approach method

When a subject navigates through the maze-like built environment, the subject takes a route that includes a number of visited rooms. The rooms are linked together; therefore one can say that this route includes a number of links. We assume that with an increasing familiarity with the environment, the number of visited rooms decreases and thus the decrease of the number of links. In this section, successively the statistical method and data collection will be discussed.

### *3.1. Data collection from experiment*

In this experiment, 59 subjects (students from Eindhoven University of Technology and from Tongji University in Shanghai) took part and had performed their tasks. This group of subjects consisted of 38 males and 21 females. All subjects repeated each task twice and most of them repeated each task three times. Once the subject ran the VR-application, the following introductory information popped up on the monitor screen (Chen (2012)):

*"You will go through three experiments in the same virtual environment. In each experiment your task is to find a destination (a room with a yellow box in the middle) from the start (a room with a red circle on the ground), and then return to the start. Each time you touch the red circle or the yellow box, you can find a short note in the left lower corner of the screen. You will repeat the same task three times for each experiment and try to find a route from the start to the destination for each experiment. You can use the mouse or arrow keys to navigate in the experiments. If you are unable to finish all tasks in current experiment, you can move on to the next experiment by pressing a corresponding number button (2 or 3). You cannot return to a previous experiment."*

In conscious wayfinding, people's egress choice depends on factors that are influenced by specific situations (Sagun et al. (2013)). Regarding unconscious wayfinding without signage and confounding environmental conditions, this number of factors is limited.

The data collected from this experiment could be categorized into several types, such as subject's personal characteristics, features of the egress in the current room. For these features, we can think of distance to egress, egress width, grey contrast between the rooms and the egress, position of the egress in the current room, number of egresses, etc.

In this paper, the focus is on (increasing) familiarity with the environment when performing tasks. Therefore, we are most interested in task information, because this type of information gave the subject's familiarity of the current environment and current task (Table 2).

Table 2. Task information.

| Feature | Variable | Values |
|---|---|---|
| TASK | Task-ID | {1, 2, 3} |
| ROUND | Round-ID | {1, 2, 3} |
| RETURN | Return (from destination to start) | {0, 1} |

Task-ID showed the performed task. Round-ID showed how many times the subject had repeated the same task. Return indicates that the subject was on the way from the origin to destination (Return=0) or on the way from destination to origin (Return=1).

### *3.2. Statistical method*

We have used the *sign test*, which is a nonparametric statistic that makes no assumption about the distribution. The *sign test* is often used when comparing paired observations. The test counts how often there is increase (+) in the second measurement, or decrease (-).

In our experiment, we count the increase of number of links (+) (*plus*-links) or the decrease of number of links (-) (*min*-links) between two subsequent rounds. The test statistic $T$ is the number of *min*-links. The null hypotheses ($H_0$) states: there is no statistic significant difference of scores of *min*-links between two consecutive rounds. The test statistic $T$ is derived from a binomial distribution $B(n,p)$ with probability $p = 0.5$, and $n$ is the number of observations. For example (taken from Table 3), if test statistic $T = 41$ and $n = 59$ then $p\_value$ from $B(59,0.5)$ results in:

$$p\_value = P(T \geq 41; n = 59, p = 0.5) = .0007 \quad (1)$$

This *p_value* is much less than 0.05, which results in rejecting $H_0$. That means an increasing familiarity with the maze-like built environment.

## 4. Estimation results

From the tasks, the estimation results and corresponding significance are listed in successive tables (Tables 3-4).

Table 3. Estimation results of paired rounds.

| | | Paired Round 1 – Round 2 | | Paired Round 2 – Round 3 | |
|---|---|---|---|---|---|
| | | To Destination | From Destination | To Destination | From Destination |
| TASK 1 | # observations | 58 | 58 | 58 | 58 |
| | # -1 links | 38 | 43 | 41 | 39 |
| | # +1 links | 20 | 15 | 17 | 19 |
| | *p-value* | .0064* | .0001* | .0007* | .0033* |
| TASK 2 | # observations | 58 | 58 | 25 | 25 |
| | # -1 links | 38 | 44 | 19 | 19 |
| | # +1 links | 20 | 14 | 6 | 6 |
| | *p-value* | .0064* | .0000* | .005* | .005* |
| TASK 3 | # observations | 58 | 58 | 26[1)] | 26[1)] |
| | # -1 links | 41 | 35 | 16 | 19 |
| | # +1 links | 17 | 23 | 10 | 7 |
| | *p-value* | .0007* | .0305* | .079** | .010* |

* Significant at 0.05

** Significant at 0.10

1) no participation of students from Tongji university

Table 3 shows significant *p-value's*, which indicates an increase of familiarity of the maze-like environment from round to round. This applies both to 'O-D task' and to 'D-O task'. Following these results, it is interesting to examine the impact of the 'O-D task' and 'D-O task' on familiarity.

Table 4 also shows significant *p-value*'s. In other words, there is also an increase of familiarity in the same round when the task is carried out in reverse order.

Apparently, people have already soon a sense of orientation in an unfamiliar environment that contains no further clues.

Table 4. Estimation results of paired 'To Destination'- 'From Destination' in the same round..

| | | Paired 'To Destination'- 'From Destination' | | |
|---|---|---|---|---|
| | | Round 1 | Round 2 | Round 3 |
| TASK 1 | # observations | 58 | 58 | 58 |
| | # -1 links | 38 | 41 | 40 |
| | # +1 links | 20 | 17 | 18 |
| | *p-value* | .0064* | .0007* | .0016* |
| TASK 2 | # observations | 58 | 58 | 25 1) |
| | # -1 links | 45 | 46 | 17 |
| | # +1 links | 13 | 12 | 8 |
| | *p-value* | .0000* | .0000* | .003* |
| TASK 3 | # observations | 58 | 58 | 26 1) |
| | # -1 links | .36 | 32 | 41 |
| | # +1 links | 22 | 26 | 17 |
| | *p-value* | .0195* | .0768** | .023* |

* Significant at 0.05
** Significant at 0.10
1) no participation of students from Tongji university

## 5. Discussion

In this paper, we have discussed unconscious wayfinding in a virtual environment. Thereby, the focus was on wayfinding navigation tasks to reach a goal in an unfamiliar environment without obvious clues., and the influence of repeating tasks under the same conditions on the familiarity of the environment. To this end, an experiment was set up to examine this influence. Subjects performed their tasks by navigating through a virtual environment provide by a VR-based application. Data was collected and analyzed. From the analysis one can conclude that there is a growing familiarity with an unfamiliar environment that has only geometrical clues by repeating navigating tasks under same conditions. It seems that people are soon familiar with their environment and can orientate themselves quite quickly.

In this paper, the influences of geometric visual clues are not discussed. Further exploration of geometric features, like distance from one's position to an egress, number of egresses, and the angle from current position to the egresses, and the impact of these features on the influence of the navigation tasks is in progress.

In further research, we will examine search strategies that subjects have used in their navigation task. Here, we can think of *features based* strategy, *boundary based* strategy, *minimum rooms* based strategy, and *orientation based* strategy. Features based strategy includes the previous mentioned geometric features, boundary based strategy implies the influence of boundary rooms on the search strategy, minimum rooms based has to do with a short path between origin and destination of the given task, and orientation based strategy has to do with one's build-in "compass": as long as one knows the orientation of the destination, one will simply choose an egress which will lead a closer direction orientating the destination. From the findings of the "familiarity impact", it seems that important strategies are minimum rooms strategy and orientation strategy. Further analysis of the data of the experiment should give an answer about that. We hope to report on the results of this analysis in the near future.

## References

Bailenson, J., Blascovich, J., Beall, J., Loomis, J., 2001. Equilibrium theory revisited: mutual gaze and personal space in virtual environments. Presence: Teleoperators and Virtual Environments 10(6), 583-598.

Buchner, A., Jansen-Osmann, P., 2008. Is route learning more than serial learning? Spatial Cognition & Computation 8, 289-305.

Chen, Q., 2012. A vision driven wayfinding simulation system based on the architectural features perceived in the office environment. Thesis. Eindhoven University of Technology.

Dijkstra, J., Chen, Q., de Vries, B., Jessurun, J., 2012. Measuring individual's egress preference in wayfinding through virtual navigation experiments. In: Weidmann, U., Kirsch, U., Schreckenberg, M. (Eds.), Pedestrian and Evacuation Dynamics 2012. Springer, Heidelberg, pp. 371-383

Golledge, R., 1999. Human wayfinding and cognitive maps, in *"Wayfinding behavior: cognitive mapping and other spatial processes"*. In: Golledge, R. (Ed.). The John Hopkins University Press, pp. 5-45.

Gunzelmann, G., 2007. Strategy generalization across orientation tasks: testing a computational cognitive model. Cognitive Science 32, 835-861.

Ishikawa, T., Montello, D., 2006. Spatial knowledge acquisition from direct experience in the environment: individual differences in the development of metric knowledge and the integration of separately learned spaces. Cognitive Psychology 52(2), 93-129.

Jansen-Osmann, P., Schmid, J., Heil, M., 2007. Spatial knowledge of adults and children in a virtual environment: the role of environmental structure. European Journal of Developmental Psychology 4(3), 251-272.

Kaplan, S., 1973[a]. Cognitive maps in perception and thought. In: Downs, R., Stea, D. (Eds.), Image and environment. Chicage, IL: Aldine, pp. 63-78.

Kaplan, S., 1973[b].Cognitive maps, human needs and the designed environment. In: Preiser, W. (Ed.), Environmental design research. Stroudsburg, PA: Dowden, Hutchinson and Ross, pp. 275-283.

Kobes, M., Helsoot, I., de Vries, B., Post, J., Oberijé, N., 2010. Way finding during fire evacuation; an analysis of announced fire drills in a hotel at night. Building and Environment 45, 537-548.99

Meilinger, T., 2008. MPI Series in Biological Cybernetics No. 22. Max-Planck-Gesellschaft.

Nadel, L., 1990. Varieties of spatial cognition: psychological considerations. Annals of the New York Academy of Sciences. 608(1), 616-636.

Montello, D., 2005. Navigation. In: Shah, P., Miyake, A. (Eds.), The Cambridge Handbook of Visuospatial Thinking. Cambridge, Cambridge University Press, pp. 257-294.

Sagun, A., Anumba, C.J., Bouchlaghem, D., 2013. Designing buildings to cope with emergencies: findings from case studies on exit preferences. Buildings 3, 442-461.

Stanton, D., Wilson, P., Foreman, N., 1996. Using virtual reality environments to aid spatial awareness in disabled children. Proceedings 1st European Conference on Disability, Virtual Reality and Associated Technology. Maidenhead, UK, pp. 93-101.

Sun, C., 2009. Architectural cue model in evacuation simulation for underground space design. Thesis, Eindhoven University of Technology.

Tolman, E., 1948. Cognitive maps in rats and men. Psychological Review 55, 189-208.

Wang, R., Spelke, E., 2002. Human spatial representation: insights from animals. TRENDS in Cognitive Science 6(9), 376-381.

Wilson, P., Foreman, N., Gillett, R., Stanton, D., 1997. Active versus passive processing of spatial information in a computer-simulated environment. Ecological Psychology 9(3), 207-222.