THE EFFECTS OF VISUAL SUPPORT BY A THREE-DIMENSIONAL STAIRCASE MODEL ON INDOOR NAVIGATION AND SPATIAL ORIENTATION DURING VERTICAL MOTION

Sofia Larsson, Pauline Mattsson
Abstract

Vertical structures in buildings have become very common and more complex, and thereby the importance of wayfinding increases. The aim of the present study was to investigate whether a three-dimensional model of a spiral staircase will improve spatial orientation when travelling in vertical motion via the corresponding real-world staircase. An experiment was conducted with 25 participants, 13 males and 12 females, between the ages of 18-29 (M= 23.12, SD= 2.93). They were divided into a test-group and a control-group. Both groups studied a map for 30 seconds and were instructed to walk to a goal on the top floor. The test-group was presented with a three-dimensional representation of the staircase as a visual aid before entering the stairs, the control-group was not presented with the aid. When the participants reached the top floor, they were instructed to point to the goal, the start and to the Universum building using a compass application. The pointing error was calculated and analyzed. The participants also filled in the Santa Barbara Sense of Direction scale to assess their spatial ability. Other aspects that was taken into consideration was to what extent the participants were familiar with the building the experiment took place in and differences in performance between men and women. Results show an indication of a smaller pointing error for the test-group than the control-group in all pointing tasks, however there were no statistically significant differences in the data. Alternative interpretations of the results and limitations of the study are discussed.

Keywords: indoor navigation, spatial ability, vertical motion, visual aid.

Abstrakt


Nyckelord: Inomhusnavigering, spatial förmåga, vertikal rörelse, visuellt hjälpmedel.
The effects of visual support by a three-dimensional staircase model on indoor navigation and spatial orientation during vertical motion

Wayfinding takes place on a daily basis in human life (Werner & Long, 2003). It could be to discover a new city, locating a grocery store or finding a room in a building you have never been in before. Even though it seems like a natural phenomenon, spatial orientation tasks can be more difficult than expected and some people might find themselves lost from time to time (Ishikawa & Yamazaki, 2009).

According to Golledge, Jacobsen, Kitchin and Blades (2000) humans’ spatial ability varies depending on individual differences, such as age and gender. There is evidence that human abilities undergo developmental change throughout life. Differences between preschoolers, preteens, teenagers and adults have been found when investigating abilities in learning environments and navigation. Previous research has shown that females and males acquire different knowledge methods in their wayfinding. For example, females tend to rely more on landmarks, while men use more orientation or frame-related processes (Self & Golledge, 2000, Chapter 12).

Furthermore, humans behave differently in environments depending on; their purpose, how familiar they are with the surroundings and their spatial abilities. Golledge, Jacobson, Kitchin and Blades (2000) refer to previous research that indicate when familiar with an environment, humans often recall environmental information by cognitive mapping rather than using supplementary aids. A cognitive map can be described as a representation in memory of an object and its location in space. It can be stored in either long-term memory or it can be stored more temporary depending on the extent of exposure to the environment, more exposure leads to more elaborated cognitive maps (Lloyd & Cammack, 1996, Chapter 9). In these cases, experience plays as a key role, and most people rely heavily on basic senses when building a representation of places. Thus, people obtain their knowledge by walking through different environments. However, human brains do not always store information correctly and therefore, errors in wayfinding are to some extent expected (Golledge, Jacobson, Kitchin & Blades, 2000).

There are three different categories of spatial knowledge; landmark, route and survey knowledge (He, McNamara, Bodenheimer & Klippel, 2018), first proposed by Siegel and White (1975). Landmark knowledge is knowledge about the objects that identify locations. Route knowledge is knowledge of a route from one location to another in relation and in association to landmarks. While survey knowledge refers to the overall layout of the location represented in an objective way, i.e. a map (He et al., 2018). However, the three categories have been criticized and recent research has shown that all three of them occur simultaneously, continuous and more flexible instead of stage-like (He et al., 2018).

A method developed to measure spatial ability in humans is The Santa Barbara Sense of Direction scale, which is a self-report scale developed by Hegarty, Richardson, Montello, Lovelace and Subbiah (2002) and consisting of 15 statements regarding a person's environmental spatial orientation. The scale of every statement starts from 1 representing “strongly agrees” to 7 representing “strongly disagrees”. Examples of statements are “I am very good at giving directions” and “I have a poor memory for where I left things”. The higher the score, the higher the perceived sense of direction. The present study uses the Santa Barbara Sense of Direction scale to assess the perceived spatial orientation of the participants and to investigate the correlation with their result on spatial orientation tests.

Nowadays, vertical structures such as shopping complexes, subways and towers have become very common. Therefore, wayfinding within buildings has become increasingly more important and relevant in today’s research (Werner & Long, 2003). Verticality can be a source
of disorientation since it is difficult to process (Fontaine, 2001) and causes a disruption of the spatial cognition. This seems to be a result of people's belief that the new floor should look similar to the previous floor (Soeda, Kushiyama & Ohno, 1999). Also, misalignment in general in buildings leads to an impairment of wayfinding (Werner & Schindler, 2004). Another argument is that the orientation of one’s position can be easier to comprehend if “access to global landmarks, reference directions, or coordinates is possible” (Werner & Long, 2003, p. 114), which one does not always have access to in indoor navigation or vertical motion.

A lot of research has been done on horizontal wayfinding, less has been done on vertical wayfinding (Soeda, Kushiyama & Ohno, 1999). Soeda et al. investigated vertical motion and concluded that it causes disruption in spatial orientation. In one part of the study the participants walked a path on three different levels. Three times on the path they were supposed to point to a specific mark. The result indicated that spatial orientation varies among individuals and that vertical motion causes disruption, but some people can recover using information from the environment.

Furthermore, vertical wayfinding has been studied in subway environments. Fontaine (2001) studied different aids that would help people navigate in the underground and concluded that a three-dimensional representation of the station was the most helpful when learning the relation of the different levels and thereby making it easier to navigate. The aim of the present study is to apply this research within a campus building by investigating whether a three-dimensional visual aid of a staircase will help when orienting during vertical motion. In line with Fontaine’s results, the hypothesis for this study is that a three-dimensional representation will help with navigation during vertical motion. Since the architecture of today’s world is getting more complex, the need for research in this area increases.

Method

Participants

This study examined in total 28 participants, however one participant was excluded due to invalid results. Another two participants were only considered as pilot tests. Thus, the final analysis is based on 25 participants, 13 males and 12 females (M= 23.12, SD= 2.93). The test-group consisted of 7 males and 6 females, while the control-group consisted of 6 men and 6 females. The participants were randomly selected into test-group or control-group.

To take part in the experiment, participants would preferably not have prior knowledge of the MIT-building at Umeå University. Solely because previous navigation in the building could lead to better results as they already have a cognitive map of the complex (Montello & Pick. Jr, 1993). However, participants were mostly recruited at the university and therefore, it was inevitable for some participants to have at least some previous understanding of the building. As compensation, the participants received a pastry.

Table 1. The age and gender of the participants.

<table>
<thead>
<tr>
<th></th>
<th>All</th>
<th>Test-group</th>
<th>Control-group</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>25</td>
<td>13</td>
<td>12</td>
</tr>
<tr>
<td>Age, M (SD)</td>
<td>23.12 (2.93)</td>
<td>23.23 (3.06)</td>
<td>23.00 (2.77)</td>
</tr>
</tbody>
</table>
Instruments and Materials

The study included the following instruments and materials:

**Map.** A map of the top floor of the MIT-building at Umeå university. A goal was marked on the map as a red cross. The map used was MazeMap\(^1\), which is a website for universities, hospitals, businesses and organizations to support visitors in wayfinding (MazeMap). The map was presented on a Samsung Galaxy Tap S4 tablet (see Figure 1).

**Three-dimensional model.** A visual three-dimensional model of the staircase, constructed in SketchUp\(^2\) by the authors and presented on the same tablet as the map, Samsung Galaxy Tap S4 (see Figure 2).

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\(^1\) [https://www.mazemap.com/](https://www.mazemap.com/)

\(^2\) [https://www.sketchup.com/](https://www.sketchup.com/)
**Pointer.** The pointer used in three different pointing tasks, the Apple compass application presented on an iPhone 8 (see Figure 3).

![Pointer Application](image)

*Figure 3. Screenshot of the pointer application used in the experiment.*

**Santa Barbara Sense-of-Direction Scale.** Used to measure the spatial ability of the participants. The scale was filled in on the same tablet, a Samsung Galaxy Tab S4 (see Appendix B).

**Notebook.** A notebook was used for documentations of the raw data.

**Procedure**

The study was conducted as an experiment at Umeå University in the MIT building. First, all participants read and signed a consent form. Both the control- and the test-group received instructions to walk to a goal on the top floor of the building by taking the first stairs in the corridor (see Appendix A for full instructions). To know where the goal was, participants studied a map for 30 seconds, on which the goal was marked, before starting to walk (see Figure 4). The test-group was presented with a visual three-dimensional model of the staircase displayed on a tablet, representing the orientation of the entry and the exit of the spiral staircase. This was shown right before they entered the staircase. The control-group was not presented with a visual aid. The chosen staircase for the experiment was selected because of the lack of visual cues and its spiral construction, which makes orientation inside the staircase and coming out of it more difficult. When the participants exited the stairs on the top floor they were asked to point towards the goal that was presented to them on the map, the start, i.e., the place they were coming from, and to Universum (a building on the campus, also a well-known bus stop of the city) with a compass application. The participants then filled in the Santa Barbara Sense of Direction Scale to assess their spatial abilities (Hegarty, Richardson, Montello, Lovelace & Subbiah 2002), as well as a questionnaire containing some background information and a question about to what extent they are familiar with the MIT-building.

Using a printed map of the MIT-building and its surroundings the correct angles of the different directions were calculated, whereas a span of +10 degrees was considered correct. The span covers uncertainty in the measurements and also the fact that the locations are rather an area than a point. When considering the correct angle for Universum, the span was between
the beginning of the building and the end of the building. The angle of the pointing error was calculated by subtracting the correct degrees from the participants pointing degree and used as quantitative data.

A statistical analysis of the participants’ performance was conducted to see if the visual display of the staircase has a significant effect on the performance. To investigate if the data was normally distributed, SPSS and the Kolmogorov-Smirnov test were used. If the Kolmogorov-test showed normal distribution a t-test was performed using SPSS. If there was no normal distribution a Mann-Whitney U-Test was conducted, also using SPSS.

An additional aspect that was calculated was whether the results of the pointing tasks correlated with the participants’ spatial ability, where a score on the Santa Barbara Sense of Direction scale of 4 and below was considered low spatial ability and 5 and higher was considered as high ability. The spatial ability was measured by reversing some of the scores of the statements that contained negative statements (e.g., “I have a poor memory for where I left things”). In that way high scores on each statement represented high spatial ability. After reversing scoring, the sum of all the statements were calculated and divided by the number of statements, which was 15. This gives the average score, a number between 1 and 7.

Whether they were familiar with the MIT-building or not was also an aspect that was considered in correlation with the results of the pointing tasks. People who filled in that they visit the building every day, more than once a week and once a week were considered to be familiar with the building. Participants who filled in visit a few times a month, been there once or twice and never were considered not familiar with the building. The difference between men and women were considered in the analysis.

Figure 4. The path to the staircase.

**Results**

The main result of the study is that the test-group have a lower average pointing error in all three pointing tasks compared to the control group. The significance level set in the statistical analysis was 0.05. The analysis shows no statistical differences for any of the pointing tasks. The result of the Kolmogorov-Smirnov test suggest that the pointing error to
the goal follows a normal distribution for both the test-group, \( D(13)=0.15, p=0.200 \), and the control-group, \( D(12)=0.16, p=0.200 \). The test-group have a smaller pointing error to the goal (\( M=47.00°, SD=40.71° \)), than the control-group (\( M=54.33°, SD=33.18° \)), although the difference is not statistically significant; \( t(23)=0.49, p=0.628 \).

A Kolmogorov-Smirnov test indicates that the pointing error to the start for the test-group does not follow a normal distribution, \( D(13)=0.34, p=0.000 \). Neither does the pointing error to the start for the control-group follow a normal distribution, \( D(12)=0.32, p=0.001 \). When performing a Mann-Whitney U-test, it indicates that the pointing error is greater for the control-group (\( Mdn=7.00° \)) than for the test-group (\( Mdn=0.00° \)); \( U=52.00, p=0.139 \). Due to that the p-value is higher than 0.05 there is no statistically significant difference.

Concerning the pointing task to Universum, the Kolmogorov-Smirnov test shows that the pointing error of the test-group does not follow a normal distribution, \( D(13)=0.27, p=0.009 \). While the pointing error of the control group follows a normal distribution, \( D(12)=0.23, p=0.084 \). The Mann-Whitney U-test implies that the pointing-error to Universum was smaller for the test-group (\( Mdn=5.00° \)) than for the control-group (\( Mdn=12.00° \)), although it shows no statistically significant difference; \( U=76.00, p=0.913 \) (see Table 2).

### Table 2.

The mean pointing error and the standard deviation of the test- and control-group for all three pointing tasks as well as the median and result of t-test and Mann-Whitney test.

<table>
<thead>
<tr>
<th>Pointing task</th>
<th>Group</th>
<th>M</th>
<th>SD</th>
<th>Mdn</th>
<th>t</th>
<th>U</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goal</td>
<td>Test-group</td>
<td>47°</td>
<td>40.71°</td>
<td></td>
<td>0.49</td>
<td></td>
<td>0.628</td>
</tr>
<tr>
<td></td>
<td>Control-group</td>
<td>54.33°</td>
<td>33.18°</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Start</td>
<td>Test-group</td>
<td>0.00°</td>
<td></td>
<td></td>
<td></td>
<td>52.00</td>
<td>0.139</td>
</tr>
<tr>
<td></td>
<td>Control-group</td>
<td>7.00°</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Universum</td>
<td>Test-group</td>
<td>5.00°</td>
<td></td>
<td></td>
<td></td>
<td>76.00</td>
<td>0.913</td>
</tr>
<tr>
<td></td>
<td>Control-group</td>
<td>12.00°</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Evaluating the Santa Barbara Sense of Direction questionnaire for spatial ability resulted in 9 participants with low spatial ability in the test-group and 11 participants in the control-group, in total 20 participants with low spatial ability. 4 participants in the test group have high spatial ability and 1 participant in the control-group, i.e., 5 participants in total. Of the total number of participants, those with high spatial ability have a smaller pointing error to the goal (\( M=41.40°, SD=35.46° \)) than those with low spatial ability (\( M=52.80°, SD=37.55° \)). The pointing error to the start was bigger for the group with high spatial ability (\( M=12.80°, SD=13.68° \)) than the group with low spatial ability (\( M=9.15°, SD=17.99° \)). When it comes to the pointing error to Universum the participants with high spatial ability have a smaller pointing error (\( M=8.60°, SD=9.15° \)) than the participants with low spatial ability (\( M=21.70°, SD=25.98° \)), (see Table 3).

### Table 3.

The mean and standard deviation of the group with low spatial ability and the group with high spatial ability for all three pointing tasks.

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Note: The exact values for t and Mann-Whitney U are not provided in the tables presented in the image, but they should be included in the actual context of the analysis.
3 participants of the test-group and 2 participants of the control-group indicates to be familiar with the MIT-building, in total 5 participants. Whilst 10 participants from the test-group as well as from the control-group indicates not to be familiar with the MIT-building, in total 20 participants.

In all pointing tasks the group that was not familiar with the building performed better, with smaller pointing error than the familiar group. When pointing to the goal, the average pointing error of the participants who were not familiar with the MIT-building was smaller (M=46.15°, SD=37.17°) than those who were familiar with the building (M=60.00°, SD=37.17°). In the pointing task to the start the average pointing error among the participants that were not familiar with the building was smaller (M=9.15°, SD=15.11°) than the participants that were familiar with the building (M=11.40°, SD=25.49°). In the pointing tasks towards Universum the average pointing error was smaller for the group that were not familiar with the MIT-building (M=17.80°, SD=24.21°), than those who were familiar (M=24.20°, SD=25.22°), (see Table 4). No statistical analysis was conducted on the findings of familiarity of the MIT-building nor the spatial ability findings because of the uneven size of the groups and the resulting small sample size.

Table 4. The mean and standard deviation of the group that are not familiar with the MIT-building and the group that are familiar with the MIT-building for all three pointing tasks.

<table>
<thead>
<tr>
<th>Pointing task</th>
<th>Familiar with MIT-building</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Goal</strong></td>
<td>no</td>
<td>48.15°</td>
<td>37.17°</td>
</tr>
<tr>
<td></td>
<td>yes</td>
<td>60°</td>
<td>37.17°</td>
</tr>
<tr>
<td><strong>Start</strong></td>
<td>no</td>
<td>9.15°</td>
<td>15.11°</td>
</tr>
<tr>
<td></td>
<td>yes</td>
<td>11.40°</td>
<td>25.49°</td>
</tr>
<tr>
<td><strong>Universum</strong></td>
<td>no</td>
<td>17.80°</td>
<td>24.21°</td>
</tr>
<tr>
<td></td>
<td>yes</td>
<td>24.20°</td>
<td>25.22°</td>
</tr>
</tbody>
</table>

Regarding the difference between genders, women performed better in all pointing tasks. In the statistical analysis, the Kolmogorov-Smirnov test indicate that the pointing error to the goal follow a normal distribution for both men, D(13)=0.17, p=0.20, and women, D(12)=0.15, p=0.20. Women pointed with a smaller pointing error (M=42.33°, SD=26.85°) than the men (M=58.08°, SD=43.65°). Although, the difference is not statistically significant; t(23)=1.08, p=0.294.

In the pointing task to the start, the Kolmogorov-Smirnov test shows that the pointing error does not follow a normal distribution neither for men, D(13)=0.28, p=0.006, or women,
D(12)=0.44, p=0.000. A Mann-Whitney U-test indicate that the women have a smaller pointing error (Mdn= 0.00°) than the men (Mdn=8.00°), but no statistical significant difference; U=49.00, p=0.099.

A Kolmogorov-Smirnov test suggest that the pointing error to Universum does not follow a normal distribution for women, D(12)=0.25, p=0.044, nor men D(13)=0.24, p=0.038. The pointing error is smaller for women (Mdn=8.50°) than men (Mdn=9.00°). However, the difference is not statistically significant; U=70.50, p=0.681.

Table 5. The mean pointing error and the standard deviation of men and women for all three pointing tasks as well as the median and result of t-test and Mann-Whitney test.

<table>
<thead>
<tr>
<th>Pointing task</th>
<th>Group</th>
<th>M</th>
<th>SD</th>
<th>Mdn</th>
<th>t</th>
<th>U</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goal</td>
<td>Men</td>
<td>58.08°</td>
<td>43.64°</td>
<td></td>
<td>1.08</td>
<td>0.294</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Women</td>
<td>42.33°</td>
<td>26.°</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Start</td>
<td>Men</td>
<td>8.00°</td>
<td></td>
<td></td>
<td></td>
<td>49.00</td>
<td>0.099</td>
</tr>
<tr>
<td></td>
<td>Women</td>
<td>0.00°</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Universum</td>
<td>Men</td>
<td>9.00°</td>
<td></td>
<td></td>
<td></td>
<td>70.50</td>
<td>0.681</td>
</tr>
<tr>
<td></td>
<td>Women</td>
<td>8.50°</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Discussion**

The purpose of this study was to investigate whether a three-dimensional visual aid would help when orienting during vertical motion in buildings. The choice of method was based on the fact that the three-dimensional model of the staircase had to be tested, in order to see if it had any impact on the participants’ performance. The reason to have three different pointing tasks was to test different aspects of spatial knowledge. Pointing to the goal demonstrates orientation towards an unknown location (survey knowledge), pointing back to the start shows how well participants are oriented towards a previously visited location and how much they are affected by vertical motion (route knowledge), and pointing to Universum shows how well participants know where they are in relation to other buildings (survey knowledge). The hypothesis was that the participants who received the visual support would perform better than those who did not. The results of the present study did somewhat correspond to the initial hypothesis. However, the results only showed a small indication of a better performance of the test-group than the control-group with no statistical significance. The means and standard deviations in the different tasks for the test-group were lower than those for the control-group. However, the standard deviation was nearly the same as the mean within both groups, which indicated a wide distribution.

Hence, similar to Fontaine’s (2001) findings, the results also provided some indication that the three-dimensional visual model of the staircase may have helped the performance of the participants in the test-group. On the contrary, Lloyd and Cammack (1996, Chapter 9) found in their study about cognitive maps that participants who studied information from a three-dimensional display had longer reaction time in an identification task than participants who studied information from a two-dimensional display. This contradicts Fontaine’s view and
the indication in the present study that a three-dimensional representation helps in orientation. However, in the study by Lloyd and Cammack (1996, Chapter 9), the participants learned the environment via a three-dimensional representation, as well as five other learning processes. This might be more difficult than the task in Fontaine’s study and the present study, where the participants were in the actual environment, and received additional support from the three-dimensional presentation.

It could be discussed whether the improved performance with the visual aid was a matter of spatial ability in the test-group or if the physical spiral staircase used in the experiment was too basic in its construction, meaning its lack of complexity. The initial desire was to have a staircase with different orientations of the entry and the exit, however the availability of different staircases was limited at campus and the best option was chosen. Another interpretation is that it is possible that the control-group performed worse because all participants except one, was measured with low spatial ability. However, the test-group consisted of only 4 participants with high spatial ability and 9 participants with low spatial ability. Thus, it is arguably a matter of randomness rather than an obvious difference. A question arises whether a more difficult staircase would result in worse results in the control-group and if the three-dimensional visual aid of that staircase would have helped to improve the performance of the test-group in a significant way. To get a valid result of this aspect it would be necessary to control the number of participants with high- and low spatial ability in each group and have them evenly distributed according to that. However, this is hard to control because then the assessment of spatial ability would have to happen before the test in order to actively place each person in the desired group.

It is possible that the printed map was presented in a difficult way. It can be argued whether the map would have been easier to comprehend if it provided more helpful indications, such as a “You are here” symbol or which staircase participants were going to use. To not include a “You are here” symbol on the map made it more difficult for the participants to properly align the map with the environment. This is supported by previous research by Darken (1996) which suggests that survey knowledge, often obtained by maps, is orientation-specific. Meaning that one’s orientation in relation to the map is important in wayfinding. Also, Levine (1982) argues that such alignment produces better map use and fewer errors. However, the created map was chosen to avoid a ceiling effect and was therefore intended to be rather difficult. Nevertheless, it is unknown whether the map was simply too difficult to read, or whether observed difficulties are due to the low spatial ability among the participants.

Another aspect is that 5 participants had previous knowledge of the building and, thus, may have had a cognitive map of the area used in the experiment. This may have affected their perception of the printed map, which made it easier to interpret. Nevertheless, the results showed that the participants with previous knowledge of the building performed worse than those who were not familiar with the building. It is difficult to determine the cause of this result since the groups were very uneven and therefore a statistical analysis would be less reliable. In the previous study by Fontaine (2001), participants were divided into groups after familiarity, which in the present study did not happen. Such division may result in more obvious data and, thus, is something to consider when designing future experiments.

Another interesting result indicates that participants in both groups found it easier to locate where they came from, in comparison to the goal and Universum. Research by Golledge, Jacobson, Kitchin and Blades (2000) suggests that people gain general knowledge about the environment of a route by walking through it, which implicates a bottom-up process (Golledge, Dougherty & Bell, 1993). The mental representation of the route is thereby based upon the person's senses, such as vision, sensory-motor or proprioceptive experiences (Golledge, Jacobson, Kitchin & Blades, 2000). Also, the participants may have created a temporary
cognitive map of the area while they performed the experiment (Lloyd & Cammack, 1996, Chapter 9). This may be an explanation why participants in the present study performed better in pointing back to the start.

Furthermore, pointing to Universum showed results that were second best of all the pointing tasks, not far from the correct answer. Most of the participants were familiar with Universum, since they were students and residents in Umeå. Therefore, according to Lloyd and Cammack (1996, Chapter 9), it could be discussed whether participants had established a long-term cognitive map of the campus area and thus the results were positively affected. Regarding the reasoning about the start and Universum, it appears that different spatial abilities were used, such as route knowledge and survey knowledge for the different tasks. However, recent research by He, McNamara, Bodenheimer & Klippel (2018) describes that these processes works in collaboration with each other, rather than separately.

How well the participants performed in the experiment on all pointing tasks correlates with their spatial ability. High spatial ability resulted in better performance, while low spatial ability showed worse performance. However, the groups of high- versus low spatial ability were very uneven, making an analysis less reliable. Another aspect to consider is the reliability of the Santa Barbara Sense of Direction scale, i.e., how well it estimates spatial ability. According to the researchers behind the scale (Hegarty, Richardson, Montello, Lovelace & Subbiah, 2002), the scale is concluded to have high test-retest reliability.

Previous research suggests that gender matters in spatial tasks, were girls and women tend to perform at lower levels than boys and men (Golledge, Jacobson, Kitchin & Blades, 2000; Liben, Kastens & Stevenson, 2002). However, a study by Montello, Lovelace, Golledge and Self (1999) argues that previous research has been focusing on targeting single spatial tasks and therefore the analysis of gender differences has been overgeneralized. The present study shows that women overall performed better than the men in the experiment. It should be mentioned that the gender groups were evenly distributed. However, the difference is not significant and the standard deviation for both men and women were almost as high as the mean. More participants would be needed in order to generalize these results.

The validity of the present study is considered inadequate because the results are based on a rather small sample size of participants. This could be the reason why the study did not reach statistical significance. Due to lack of time the quantity of participants was constraint, which suggests that the results cannot be generalized. At least double the participants would most likely be needed, i.e., the initial aim of 30 participants would not have been enough neither. Thus, 26 participants were considered acceptable in the context of this project. It should also be mentioned that the experiment took place in a real-life setting and therefore, not all variables could be controlled for. Variables, such as people moving and noise, may have affected the performance of the participants. However, the chosen method for the experiment was well implemented and gave the desired data.

In conclusion, the three-dimensional model did, to some extent, provide the participants with useful information and therefore, it can be speculated whether it is possible that similar visual aids may lead to a better understanding and mental representation. However, further research in this area is highly recommended since the results shown in this study are not of statistical significance. Therefore, future research in this area could replicate this research and address if a three-dimensional visual aid actually helps with vertical navigation in buildings and if the results could be generalized. Thereby it would be useful to have more participants in the study, with a more controlled setting. Also, dividing the groups into low and high spatial ability as well as familiar and not familiar with the building from the beginning, i.e., before tasks are executed, would contribute to more even group sizes, which would make it more reliable to draw conclusions from statistical analyses.
Reference list


Appendix A
Instructions

Control-group:
You will be presented with a map of the top floor of the MIT-building in the beginning of the experiment (on a tablet). The map will show an X somewhere in the building and your task is to walk towards this goal. You have 30 seconds to study the map. Your first task is to walk to the top floor by locating the first red staircase in the corridor that you see.

Please let us know if there is something that you don’t understand.

Test-group:
You will be presented with a map of the top floor of the MIT-building in the beginning of the experiment (on a tablet). The map will show an X somewhere in the building and your task is to walk towards this goal. You have 30 seconds to study the map. Your first task is to walk to the top floor by locating the first red staircase in the corridor that you see. Before entering the staircase, you will be provided with a visual 3D representation of the staircase.

Please let us know if there is something that you don’t understand.
Appendix B
Santa Barbara Sense of Direction Scale

Sex: F M  
Today's Date: ____________________  
Age: ______  
V. 2

This questionnaire consists of several statements about your spatial and navigational abilities, preferences, and experiences. After each statement, you should circle a number to indicate your level of agreement with the statement. Circle "1" if you strongly agree that the statement applies to you, "7" if you strongly disagree, or some number in between if your agreement is intermediate. Circle "4" if you neither agree nor disagree.

Questions to reverse code in bold.

1. I am very good at giving directions.  
   strongly agree 1 2 3 4 5 6 7 strongly disagree

2. I have a poor memory for where I left things.  
   strongly agree 1 2 3 4 5 6 7 strongly disagree

3. I am very good at judging distances.  
   strongly agree 1 2 3 4 5 6 7 strongly disagree

4. My "sense of direction" is very good.  
   strongly agree 1 2 3 4 5 6 7 strongly disagree

5. I tend to think of my environment in terms of cardinal directions (N, S, E, W).  
   strongly agree 1 2 3 4 5 6 7 strongly disagree

6. I very easily get lost in a new city.  
   strongly agree 1 2 3 4 5 6 7 strongly disagree

7. I enjoy reading maps.  
   strongly agree 1 2 3 4 5 6 7 strongly disagree

8. I have trouble understanding directions.  
   strongly agree 1 2 3 4 5 6 7 strongly disagree

9. I am very good at reading maps.  
   strongly agree 1 2 3 4 5 6 7 strongly disagree

10. I don't remember routes very well while riding as a passenger in a car.  
   strongly agree 1 2 3 4 5 6 7 strongly disagree

11. I don't enjoy giving directions.  
   strongly agree 1 2 3 4 5 6 7 strongly disagree

12. It's not important to me to know where I am.  
   strongly agree 1 2 3 4 5 6 7 strongly disagree
13. I usually let someone else do the navigational planning for long trips.  
strongly agree 1 2 3 4 5 6 7 strongly disagree

14. I can usually remember a new route after I have traveled it only once.  
strongly agree 1 2 3 4 5 6 7 strongly disagree

15. I don't have a very good "mental map" of my environment.  
strongly agree 1 2 3 4 5 6 7 strongly disagree