The effect of the task locations on a pointing task performed in a VR spatial navigation study

by

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Declaration of Authorship

I hereby certify that the work presented here is, to the best of my knowledge and belief, original and the result of my own investigations, except as acknowledged, and has not been submitted, either in part or whole, for a degree at this or any other university.

City, Date

Signature

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Datum

Unterschrift

Abstract

Acknowledgements

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Imagine a long blackout, the eyes are closed and there is no sound. The consciousness is slowly coming back and the question arises: where am I?

1. Introduction

Spatial navigation entails the orientation and movement planing in an area. In the field of Cognitive neuroscience it is investigated how space, ”the abstract of all co-existence” (Spencer, 1867), is processed by the brain, memorized and retrieved for navigation.

Over the past centuries theories were developed about how space and the relation to its objects, thus distance, is represented in the brain, e.g., Cassirer (1955) categorized spatial knowledge in three different temporal levels, a close encounter with the objects and their spatial relation to one another allows for interaction with them. The second level contains a wider space that that allows for building the relation of routes and mental maps. The final step is realizing the relations of the places, routes, etc using the symbolic system to represent an space.

Performing a spatial navigation study in the real world has some known difficulties such as not being able to control the surrounding environment, thus having confounding variables, and not being able to or it being very hard to gather usable data for the analysis. VR is a reachable solution for these problems (Diersch & Wolbers, 2019). VR offers a range of advantages compared to conducting spatial navigation in real-world. From VR experiments in addition to the classical behavioral data, e.g., response times, a broader range of variables can be recorded, e.g., movement of the body, hands, head, eyes (Pan & Hamilton, 2018). Needless to say that these variables can be gathered in a controlled environment when utilizing VR as the method of measurement (McIlvenny, 2020). Apart from these VR is shown to offer ecological validity (Chicchi Giglioli et al., 2017; Pan & Hamilton, 2018) and reproducibility (Pan & Hamilton, 2018).

Human beings are born and grow up in social environments. They take the social aspects of their surroundings as their own (Berger & Luckman, 1967). They interact with the society and interpret the reality by what their culture is constructed of (Siegel & White, 1975). These aspects are also applicable in spatial navigation. Kuehn et al. (2018) shows that the social components can even be more powerful factors for encoding space when their participants perform consistently more accurate as they have to guess the position of the human agent as target in comparison to the position of an object.

Human-A, the present study, is a spatial navigation experiment built in a small European fictive VR city. The study conducted in this environment aims more at the social aspects and their affects on learning the space by using the functionality of some buildings, i.e., the social meaning of shops, e.g., bakery, bookstore, and adding human agents to the environment. The participants get the chance to explore and learn the city before the test session. Testing is a pointing task performed from different locations in the city, showing photos of buildings from the city and asking them to point towards them. The behavioral data gathered from the tasks consist of the angular deviation of participant's responded direction from the actual target location, and reaction times data.

The Human-A study leans toward the social factors of spatial navigation, hence it is essential for validity to check whether the other existing factors in the experiment could be confounding. One of those factors is the different locations from which the participant's perform the tasks, i.e., the different starting locations.

Investigating the effect of the social aspects of the environment entails having built a mental map and knowing the city, then it is hypothesized in this thesis that the change in starting locations has no effect on the angular deviation from the target building and as well has no effect on reaction times.

2. Methodology

2.1. Participants

A total number of 23 participants (12 male, mean age of 23.1 years, SD = 4.1) took part in the experiment. The participants were all students of the University of Osnabrück. Before the start of the first exploration session all participants were informed about the procedure of the experiment and gave their written consent for taking part in the study (see appx. D, Einverständniserklärung). The participation was voluntary and only students with no health issue were selected (see appx. D, Anamnese). The participants were compensated by test-subject hours and/or 5€ per hour.

Due to the Covid-19 pandemic sessions were conducted according to the laboratory hygiene regulations with a mask and under 3G rule.

3 participants were excluded due to not being able to comply with the experimental requirements, i.e., come in less than 3 days and more than 4 hours apart.

2.2. Experimental Design

2.2.1. City

This study is conducted in a virtual reality (VR) city with an area of about 1 km^2. The city (see figure 2.1) consisted of 284 buildings. 56 buildings were used in the experimental task from which 4 are global landmarks, 26 are `context meaningful` locations, e.g., shops, construction sites, and 26 are residential, `not context meaningful` buildings. These 56 buildings have human agents in front of them and an artwork on one of their walls. Human agents belonging to the meaningful areas took the pose of an act according to the functionality of that store `(meaningful)` (see figure 2.3a), e.g., has a book in the hand in front of a bookstore, or are just standing in front of the residential building `(standing human agent)` (see figure 2.3c).

A sun with a detectable origin is avoided in the city, no street is named and no building is numbered to implicitly direct the participants to prioritize their spatial learning. Furthermore, there are borders around the city so that the participants cannot exit the city area.

Figure 2.1.: the virtual city

2.2.2. Application and Technology

The experiment was implemented with unity version 2019.4.11f1. The assets of the city, e.g., buildings, streets were obtained from a previous study called SpaRe, made also at the university of Osnabrück. They were modified with blender version 2.83 LTS (Long Term Support), as were also the human agents picked from Adobe Mixamo collection. They were modified to interact with an object that underlined the meaningfulness of the area, i.e., holding a book in front a of a book store.
The experiment consisted of two separate parts, i.e., Exploration and Testing. Each section had the option to choose the language of the instructions, i.e., German and English. The experiment was conducted using a HTC Vive Pro Eye VR-Headset. For the virtual moving purposes inside the virtual city the participants were given an Index valve controller to navigate inside a city by moving its joystick. They had the option of choosing between right or left controller according to their handedness preference.

2.3. Experimental Procedure

Participants were seated on a backless rotating chair that enabled them to physically rotate in the virtual city. Any forward, backward and sideways movement were done utilizing the controllers.

2.3.1. Exploration

The exploration consisted of 5 sessions. The sessions had to be no more than 3 days and no less than 4 hours apart.
The total duration of each session was 30 minutes broke down into 10 minutes segments for breaks to reduce the possibility of motion sickness. Before starting each segment the built-in eye-tracker of the VR-Headset was calibrated and validated.

After inserting participant-ID and choosing the preferred language the exploration session started with a tutorial. The tutorial was held in a scene separate from the main city. The purpose of the tutorial was to allow the participant to move around, get acquainted with the controller and practice the possible movement options the experiment allowed for. After participants confirmed their confidence in using the controllers the experiment was continued to the exploration session. In the main city participants were advised to explore the city freely.

2.3.2. Testing

Testing comprised of one session of approximately 2 hours. The testing starts after inputting the participant-ID and choosing the language. There is then a tutorial scene outside of the main city used in the experiment for participants to get acquainted with how to use the controller for performing the tasks.

Testing was a pointing task comprised 336 trials performed from 28 different starting locations in the city (see figure figure 2.2). At each starting location 12 target buildings were randomly chosen from a pull of 112 targets (56 task buildings with and without human agents) for each participant individually. Some examples are shown in figure 2.3.

Each of the four conditions of the experiment, i.e., context meaningful with human agent present `(CmA)`, context meaningful with no human

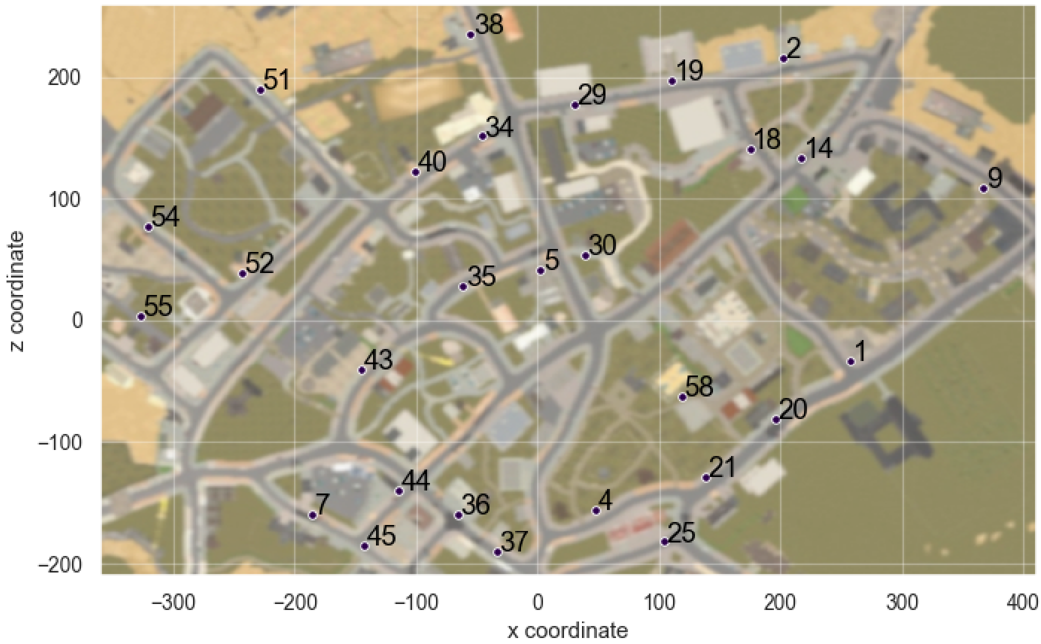


Figure 2.2.: distribution of the starting locations in the city with their IDs used in unity and for the analysis

agent present (CmANo), non-context meaningful with human agent present (Sa), non-context meaningful with no human agent present (SaNo) built up 25% of the trials. The starting locations themselves were consistent for all participants and their order of execution was randomized for each participant.
All movements except the rotation were blocked for the whole testing session to maintain the consistence of the participants' position in the starting locations between participants.

At each starting location the 12 consecutive trials were performed. Before the trial began a green circular loading bar (Go cue) was shown in the middle of the screen for 25ms (see figure 2.4). As soon as the bar was complete, it disappeared and a beep sound was played informing the participants of the start of a new trial.

In each trial a photo of one of the task buildings, with or without human agent in front of it (see figure 2.3) was presented at the top center of the screen (see figure 2.5a). The participants had the option to press the trigger button to bring the picture to the middle of the screen (see figure 2.5b). As soon as the button was released the photo moved back to the upper center part of the screen.

Since there was no visual virtual body, there was a green dashed laser beam (visible in figures 2.5b) attached to the virtual hand of the participants that

a) CmA

b) CmANo

c) Sa

d) SaNo

Figure 2.3.: Examples of photos shown in the pointing task as target buildings. A selection of all four experimental conditions. **CmA:** context meaningful with human agent present. **CmANo:** context meaningful without human agent present. **Sa:** not context meaningful with human agent present. **SaNo:** not context meaningful without human agent present.

a) go cue loaded at 30 %

b) go cue loaded at 80 %

c) go cue completely loaded

Figure 2.4.: The circular loading bar with the duration of 25ms showed as a cue of the start of a new trial

moved as they moved their hand. The purpose of the laser beam was to assist the participants with the visualization of the direction they are pointing at. The maximum duration of each trial was 30 seconds. If there was no answer given to the task after 20 seconds from the start of the trial, i.e., no direction was selected by the participant indicating in which direction the target building is located from their current location, a countdown timer appeared on the bottom center of the screen (see figure 2.6) and terminated the trial after 10 seconds if there was still no answer given.

a) default position, top

b) optional position, center

Figure 2.5.: The default (a) and the optional positioning (b) of target photos in each trial. The dashed green laser beam helped the participants to see where they are pointing at

Figure 2.6.: the countdown timer appears at the bottom of the screen after 20s has passed from the trial

Selecting an answer for the task, i.e., selecting the direction of the target building was possible with a button press. With once pressing the button it locked the laser beam onto a direction and detached it from the hand. The participants had the option to either confirm the chosen direction with the same button or cancel it with another. Moving on to the next trial was the result of either the participant confirming a direction or by running out of time. Behavioral and technical data, e.g., the chosen direction, participant position and rotation, reaction times were gathered during each trial. The human agents were present during the testing in the city at their exact designated positions and poses in the exploration sessions. A gray screen fade out and fade in occurred while transporting the participants from their current location to another starting location. This was to serve the purpose of decreasing the chance of motion sickness and also avoiding leaking environmental information while moving in the city.

2.4. Analysis method

The data of this experiment is gathered from unity in JSON [1] format. All the further processes for analysis were done in python (Van Rossum & Drake, 2009) v3.8. For the preprocessing the pandas (McKinney, 2010; pandas development team, 2022), numpy (Harris et al., 2020) and scipy (Virtanen et al., 2021) libraries, and for the analysis python's statmodels (Seabold & Perktold, 2010) module were utilized. Matplotlib (Hunter, 2007) and Seaborn (Waskom, 2021) were used for the visualizations.

After importing and converting the data into a pandas dataframe, the preprocessing is done to prepare the data for analysis. In this process the dependent variable `absolute_180_angle` is derived. The variable contains the absolute angular deviation of the participant's chosen direction from the actual target position.

2.4.1. Preprocessing

Different functions of pandas `(pd)` and numpy `(np)` used for the preprocessing. In all the calculations involving directions and positions, only the right direction (x) and the forward direction (z) are taken into account. The up direction (y) was excluded as it is not relevant for the analysis at hand.

The main preprocessing steps are as follow:

1. Removed trials in which the participants did not select any direction. These were the trials that were terminated due to timeout. Hence, only the trials where their respective TimeOut variable was False were kept for the analysis. a total of 20 trials were removed.

2. Calculated the participant's chosen direction's absolute angular deviation from the actual location of the target building.

    a) Translated the target building's center position `(Tpos)` by the participant's body position `(Ppos)` to be able to derive the translated building center position *Tpos_t* take the body position as the origin at the (0,0) coordinates.

[1] Introducing JSON: https://www.json.org/json-en.html

$$Tpos\_t_{x,z} = Tpos_{x,z} - Ppos_{x,z}$$

The direction vector of participant's chosen direction doesn't need to be translated because unity's output for a direction is a normalized vector and therefore it's origin lies already at (0,0).

b) Now that body position is at (0,0) with respect to the translated building center position, the angle difference between the participant's chosen direction `(Cdir)` to the positive x-axis and the translated building center position `(Tpos_t)` to the positive x-axis were calculated using numpy arctan2(z, x) [2] function. This function calculates the angle in radian between the positive x-axis and the vector given to the function as parameter.
Due to the translation done in step *a* the body position was implicitly translated to the origin (0,0), i.e., subtracting body position from body position results in (0,0), it was possible to pass the z and x coordinates of the `Tpos_t` and the `Cdir` to the arctan2 function separately to calculate the angle between the `Cdir` and the positive x-axis `(Cdir_to_x)` and the `Tpos_t` and the positive x-axis `(Tpos_to_x)`. The results are directly translated to degree utilizing numpy rad2deg() [3] function.

$$Tpos\_to\_x_\theta = np.rad2deg(np.arctan2(Tpos\_t_z, Tpos\_t_x))$$
$$Cdir\_to\_x_\theta = np.rad2deg(np.arctan2(Cdir_z, Cdir_x))$$

c) After creating `Tpos_to_x` and `Cdir_to_x` the angles were respectively converted to `Tpos_to_x_360` and `Cdir_to_x_360` in the 360 degree environment.

$$Tpos\_to\_x\_360_\theta =$$
$$if$$
$$Tpos\_to\_x_\theta < 180$$
$$then$$
$$360 + Tpos\_to\_x_\theta$$
$$else$$
$$Tpos\_to\_x_\theta$$

[2] Numpy arctan2: https://numpy.org/doc/stable/reference/generated/numpy.arctan2.html
[3] Numpy rad2deg: https://numpy.org/doc/stable/reference/generated/numpy.rad2deg.html

$$
\begin{aligned}
Cdir\_to\_x\_360_\theta = \\
& if \\
&& Cdir\_to\_x_\theta < 180 \\
& then \\
&& 360 + Cdir\_to\_x_\theta \\
& else \\
&& Cdir\_to\_x_\theta
\end{aligned}
$$

d) Calculated the angular difference between the selected direction `(Cdir_to_x_360)` and the target building `(Tpos_to_x_360)`. They were directly converted to the signed 2 quadrant environment.

$$signed\_180\_angles_\theta = ((Tpos\_to\_x\_360_\theta - Cdir\_to\_x\_360_\theta) + 180)\%360 - 180$$

e) The final step was to create `absolute_180_angles`, the dependant variable for the main analysis in LMM. This variable stores the absolute value of the angular differences contained in `signed_180_angles`. The reason for using absolute values is that the direction of the deviation is not a deciding factor in how accurate the participants performed the pointing task. Taking the absolute values is done with numpy abs() [4] function.

$$absolute\_180\_angles_\theta = np.abs(signed\_180\_angles_\theta)$$

3. Calculated the Euclidean distance from the participant's body position to the target building for each trial. This was done using the Euclidean distance function [5] of scipy spatial.

$$body\_to\_target_{dis} = Euclidean\_distance((Ppos_x, Ppos_z), (Tpos_x, Tpos_z))$$

2.4.2. Analysis

Due to the hierarchical structure of the data, Linear Mixed Models (LMM) were chosen as the method of analysis. For that the MixedLM function [6] from

[4] Numpy absolute: https://numpy.org/doc/stable/reference/generated/numpy.absolute.html

[5] Scipy spatial Euclidean distance: https://docs.scipy.org/doc/scipy-1.8.0/reference/generated/scipy.spatial.distance.euclidean.html#scipy.spatial.distance.euclidean

[6] Statsmodels function for linear mixed effects model: https://www.statsmodels.org/dev/generated/statsmodels.regression.mixed_linear_model.MixedLM.html

python's statmodels module were used. Participants' ID is the grouping component of all the models.

Independent variables

1. **Starting locations:** the 28 different starting locations spread out through the city. See the full list of the locations in appx. A.

2. **Distance to the target:** this variable is the distance of the participant to the target building at each starting location.

Dependent variables

1. **Absolute angular deviation** (`absolute_180_angles`): the absolute value of the angular deviation of the direction chosen by the participant from the actual location of the target building shown at each trial. Two models are used to predict this dependent variable.

   a)
   $$\textit{absolute angular error} \sim \textit{starting locations} + (1|\textit{subject})$$

   b)
   $$\begin{aligned}\textit{absolute angular error} \sim & \textit{starting locations} + \textit{distance to target} \\ & + \textit{starting locations} * \textit{distance to target} + (1|\textit{subject})\end{aligned}$$

2. **Reaction times** (`RT`): this variable stores the duration between start of each trial and the time the participants confirmed a direction as their respond. The begin timestamp of the trial is directly after the go cue is completed and the end timestamp instantly after the response is given. Calculating the duration is done in unity.

   $$RT = end\_timestamp - begin\_timestamp$$

   For the analysis two models are used to predict this dependent variable.

   a)
   $$\textit{reaction times} \sim \textit{starting locations} + (1|\textit{subject})$$

   b)
   $$\begin{aligned}\textit{reaction times} \sim & \textit{starting locations} + \textit{distance to target} \\ & + \textit{starting locations} * \textit{distance to target} + (1|\textit{subject})\end{aligned}$$

3. Results

The data from a total of 23 participants with the average of 335 and a total of 7708 trials were used for the analysis. The starting location IDs were identical with the building-IDs inside the unity environment and were not replaced with new numbers for the analysis.

3.1. Summary statistics of dependent variables

3.1.1. Absolute angular deviation

This variable has the mean of 48.08 with the standard deviation of 44.30, and median of 33.70. (See figure 3.1)

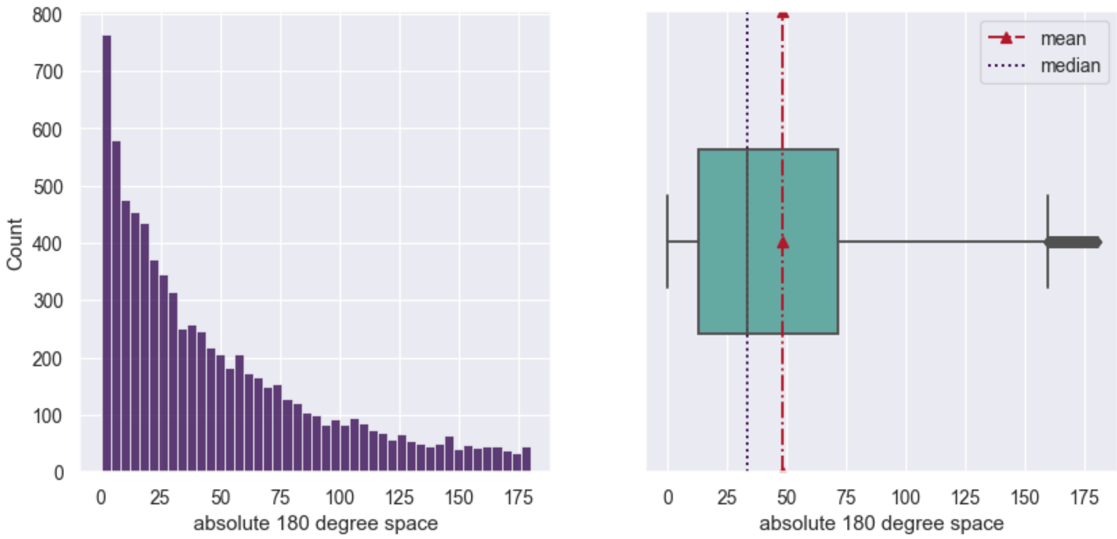


Figure 3.1.: distribution of the absolute angular deviation

3.1.2. Reaction times

This variable has the mean of 7.77 with the standard deviation of 5.56, and median of 6.06. (See figure 3.2)

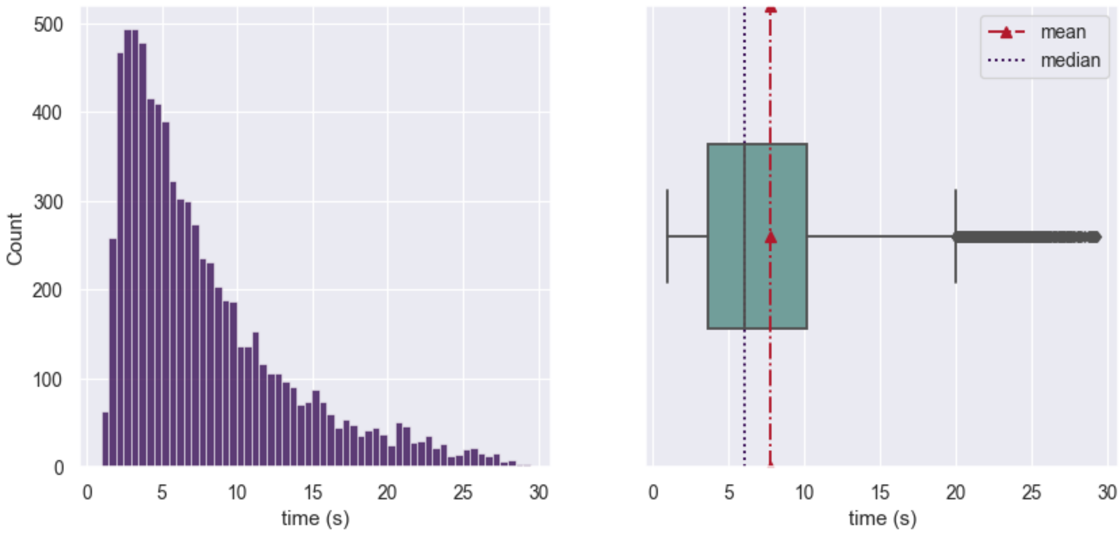


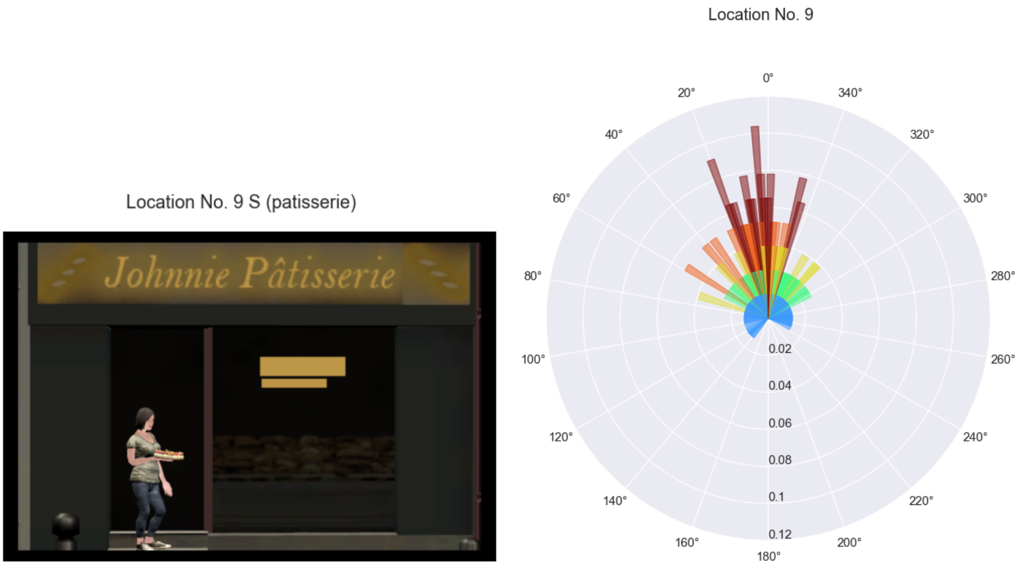
Figure 3.2.: distribution of the reaction times in the pointing task

3.2. Extremes at starting locations

3.2.1. Absolute angular deviation

In order to find out which of the 28 starting locations were the best and worst in performance with respect to the angular deviation from the target, the minimum and maximum medians of angular deviation grouped by the starting locations were taken.
As a result the starting location with the ID 9 which is a patisserie shop, therefore a context meaningful location, with the median of 19.18 degree deviation from the targets and the difference of 16.03 degree from the overall median (35.21) is the best location, i.e., has the lowest degree deviation from the target. See figure 3.3a.

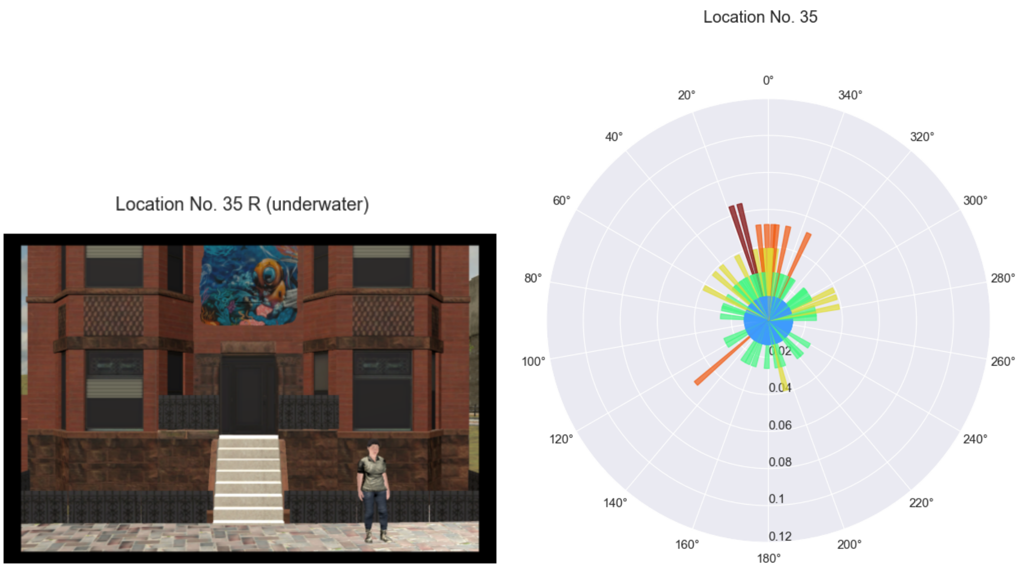
Furthermore, the starting location with the ID 35, one of the residential, thus not context meaningful buildings, with the angular deviation median of 52.49 degree away from the target and overall distance of 17.28 degree from the overall median (35.21) was the worst location of performing the task with regard to the angular deviation. See figure 3.4a.



a) best starting location

b) angular deviation at location 9 (%)

Figure 3.3.: the best starting location is chosen by taking the least median angular deviation among all starting locations.



a) worst starting location

b) angular deviation at location 35 (%)

Figure 3.4.: the worst starting location is chosen by taking the highest median angular deviation among all starting locations.

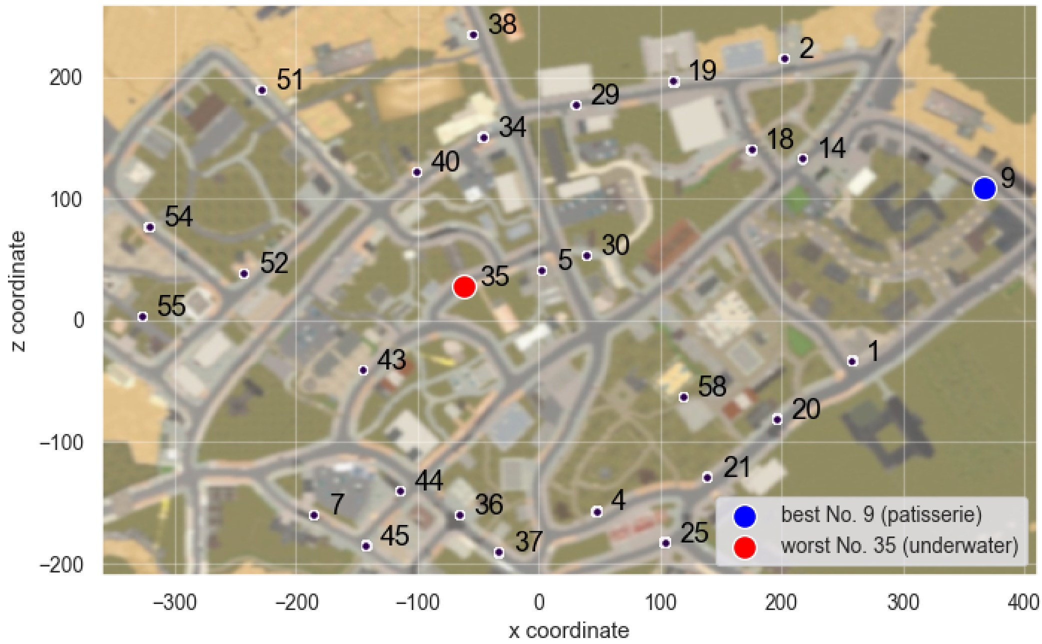


Figure 3.5.: the locations of the best and worst starting locations inside the city coordinates.

3.2.2. Reaction times

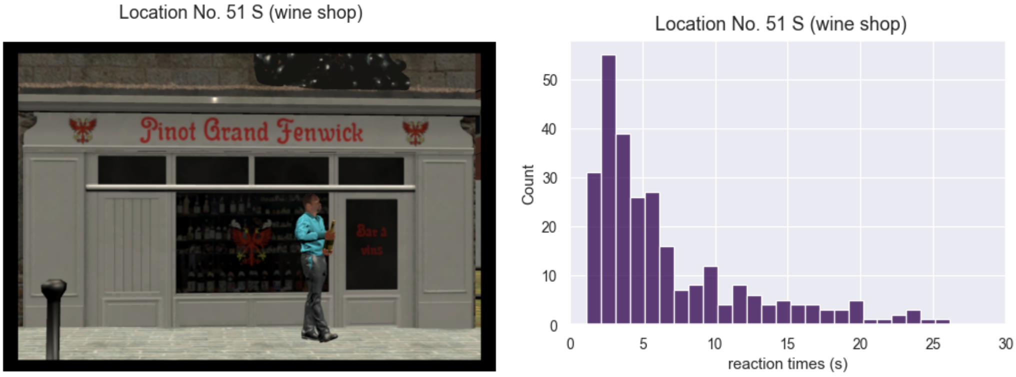
For finding the fastest and the slowest performance among the 28 starting locations, the medians of reaction times grouped by the starting locations were Calculated.
The starting location number 51 which was a wine shop, hence a context meaningful location, with the median of 4.63s and the difference of 1.38s from the overall median (6.01) was the fastest location. See figure 3.6a.

Furthermore, the starting location 35, the residential not context meaningful location with the worst angular deviation performance with the median of 7.75s and overall distance of 1.74s from the overall median (6.01) was the slowest location among the 28. See figure 3.7a.

3.3. Linear mixed effects model

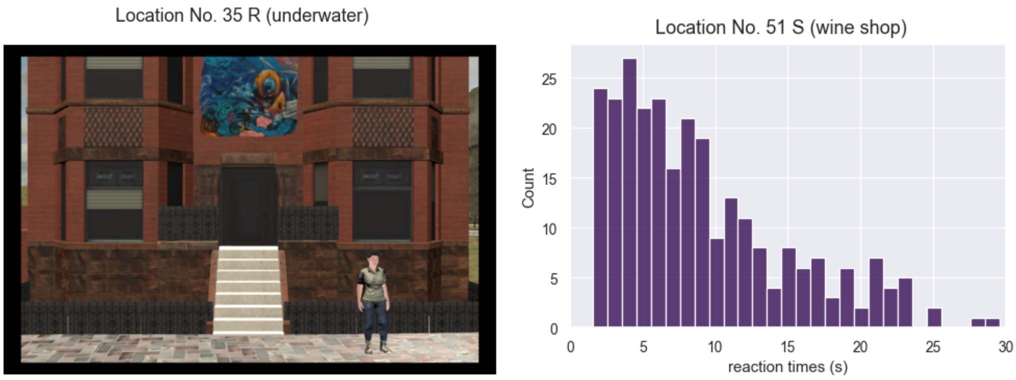
3.3.1. Absolute angular deviation

For choosing the intercept for the model the overall mean of absolute angular deviation, 48.09 degree, was taken into account. The starting location No. 20



a) fastest starting location b) reaction times at location 51 (%)

Figure 3.6.: the fastest starting location is chosen by taking the least median reaction time among all starting locations.



a) slowest starting location b) distribution of reaction times at location 35 (%)

Figure 3.7.: the slowest starting location is chosen by taking the highest median of reaction times among all starting locations.

(fast food) which is a meaningful location with the mean absolute angular deviation 48.07 was chosen since its mean absolute angular deviation was the closest to the overall mean among starting locations by 0.02 degree absolute difference.

The LMM model was fitted using that reference location No. 20. The results (see table 3.1) show a significant effect of 12 starting locations listed in the table 3.2 on the dependent variable. From the 12 locations with a significant effect, 7 are meaningful locations and from the 15 non-significant locations, 6 are meaningful (see figure 3.9). The variance between subjects is 174.867.

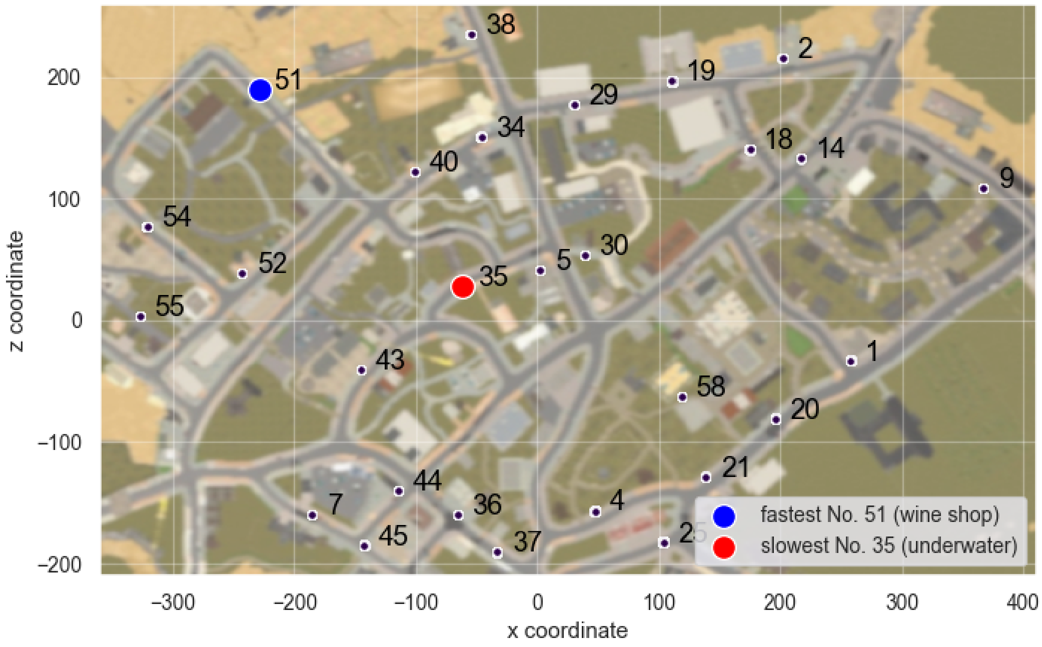


Figure 3.8.: the locations of the fastest and the slowest starting locations inside the city coordinates.

Table 3.1.: The results of the model absolute angular deviation by starting locations. "Loc" stands for location. z-score($=\beta/SE(\beta)$)

Predictor	Coef. β	SE (β)	z-score	P$>|z|$
Intercept	48.066	3.717	12.933	**<.001**
[Loc.1]	-1.335	3.524	-0.379	0.705
[Loc.2]	**-14.540**	**3.524**	**-4.126**	**<.001**
[Loc.4]	-2.269	3.524	-0.644	0.520
[Loc.5]	**14.709**	**3.524**	**4.174**	**<.001**
[Loc.7]	**-9.310**	**3.531**	**-2.637**	**0.008**
[Loc.9]	**-20.563**	**3.524**	**-5.835**	**<.001**
[Loc.14]	-6.695	3.524	-1.900	0.057
[Loc.18]	3.932	3.531	1.114	0.265
[Loc.19]	-5.040	3.524	-1.430	0.153
[Loc.21]	-2.832	3.531	-0.802	0.423

[Loc.25]	**-8.855**	**3.524**	**-2.513**	**0.012**
[Loc.29]	**8.787**	**3.524**	**2.493**	**0.013**
[Loc.30]	**11.587**	**3.527**	**3.285**	**0.001**
[Loc.34]	-1.073	3.527	-0.304	0.761
[Loc.35]	**17.333**	**3.537**	**4.900**	**<.001**
[Loc.36]	0.918	3.524	0.261	0.794
[Loc.37]	-0.949	3.524	-0.269	0.788
[Loc.38]	**-8.841**	**3.524**	**-2.509**	**0.012**
[Loc.40]	3.126	3.524	0.887	0.375
[Loc.43]	3.882	3.524	1.101	0.271
[Loc.44]	-2.338	3.524	-0.663	0.507
[Loc.45]	-2.755	3.527	-0.781	0.435
[Loc.51]	0.365	3.524	0.104	0.917
[Loc.52]	**12.917**	**3.531**	**3.658**	**<.001**
[Loc.54]	**-12.374**	**3.534**	**-3.502**	**<.001**
[Loc.55]	4.253	3.527	1.206	0.228
[Loc.58]	**18.807**	**3.527**	**5.332**	**<.001**
subject_id Var	174.867	1.311		

In comparison to the starting location No. 20 (fast food restaurant) ,the reference point, the starting location No. 51 (wine shop) has the least difference in angular error degree to the reference and the starting location No. 9 (patisserie) the most. All three locations are meaningful locations.

3.3.2. Reaction times

The starting location No. 7 (bear) which is a non-meaningful location was chosen as the intercept for the model RT predicted by starting locations. This decision was made based on the comparison of medians of RT from each starting location to the overall median of 6.01s. Here the median was

Table 3.2.: Significant locations in absolute angular deviation predicted by starting location

	Location ID-name	mean	meaningfulness
1	2 (boulangerie)	33.53	meaningful
2	5 (Maraz cafe)	62.77	meaningful
3	7 (bear)	38.73	non-meaningful
4	9 (patisserie)	27.50	meaningful
5	25 (alligator)	39.21	non-meaningful
6	29 (restaurant)	56.85	meaningful
7	30 (purpul bat)	59.63	non-meaningful
8	35 (underwater)	65.28	non-meaningful
9	38 (bike shop)	39.22	meaningful
10	52 (la cantine)	60.93	meaningful
11	54 (tree)	35.77	non-meaningful
12	58 (basketball court)	66.85	meaningful

considered as the measure of central tendency because the medians were more normally distributed than means. The location No. 7 had median of 6.02s and the difference of 0.01s from the overall median. However, the starting location No. 29 (restaurant) had also the same difference from the overall median. Hence their mean difference to the overall mean of RT was also secondarily taken into account for the final choice. Location No. 7 had the smaller difference of 0.03s compared to the location No. 29 with the difference to mean of 0.55s.

The LMM model was fitted using that reference location No. 7. The results (see table 3.3) show a significant effect of 7 starting locations (listed in the table 3.4) on the dependent variable. From the 7 locations with a significant effect, 2 are meaningful locations and from the 20 non-significant locations, 12 are meaningful (see figure 3.10). The subject variance of the reaction times is 3.762.

Table 3.3.: The results of the model RT predicted by starting locations

Predictor	Coef. β	SE (β)	z-score	P> $\lvert z\rvert$
Intercept	7.736	0.512	15.116	0.000
[Loc.1]	-0.335	0.443	-0.757	0.449
[Loc.2]	-0.676	0.443	-1.526	0.127
[Loc.4]	**-1.047**	**0.443**	**-2.365**	**0.018**
[Loc.5]	0.821	0.443	1.854	0.064
[Loc.9]	-0.287	0.443	-0.649	0.516
[Loc.14]	0.542	0.443	1.224	0.221
[Loc.18]	0.863	0.444	1.946	0.052
[Loc.19]	**-1.220**	**0.443**	**-2.755**	**0.006**
[Loc.20]	**-1.078**	**0.443**	**-2.435**	**0.015**
[Loc.21]	-0.314	0.444	-0.708	0.479
[Loc.25]	-0.434	0.443	-0.979	0.327
[Loc.29]	-0.516	0.443	-1.165	0.244
[Loc.30]	0.733	0.443	1.654	0.098
[Loc.34]	0.446	0.443	1.006	0.315
[Loc.35]	**1.323**	**0.444**	**2.978**	**0.003**
[Loc.36]	-0.207	0.443	-0.468	0.640
[Loc.37]	**0.945**	**0.443**	**2.134**	**0.033**
[Loc.38]	-0.128	0.443	-0.290	0.772
[Loc.40]	0.780	0.443	1.762	0.078
[Loc.43]	**0.929**	**0.443**	**2.098**	**0.036**
[Loc.44]	-0.312	0.443	-0.704	0.482
[Loc.45]	0.470	0.443	1.060	0.289
[Loc.51]	**-1.042**	**0.443**	**-2.353**	**0.019**
[Loc.52]	0.340	0.444	0.766	0.444
[Loc.54]	0.438	0.444	0.987	0.323
[Loc.55]	0.128	0.443	0.289	0.772

[Loc.58]	-0.290	0.443	-0.655	0.512
subject_id Var	3.762	0.223		

Table 3.4.: Significant locations in RT predicted by starting location

	Location ID-name	mean	median	meaningfulness
1	4 (gorilla)	6.69	5.62	non-meaningful
2	19 (bottle spray)	6.52	5.28	non-meaningful
3	20 (fast food)	6.66	5.80	meaningful
4	35 (underwater)	9.08	7.75	non-meaningful
5	37 (house)	8.68	6.69	non-meaningful
6	43 (daisy)	8.66	6.89	non-meaningful
7	51 (wine shop)	6.69	4.63	meaningful

In comparison to the starting location No. 7 (the reference point), the starting location No. 55 has the least difference in RT to the reference and the starting location No. 35 the most. All three locations are residential buildings.

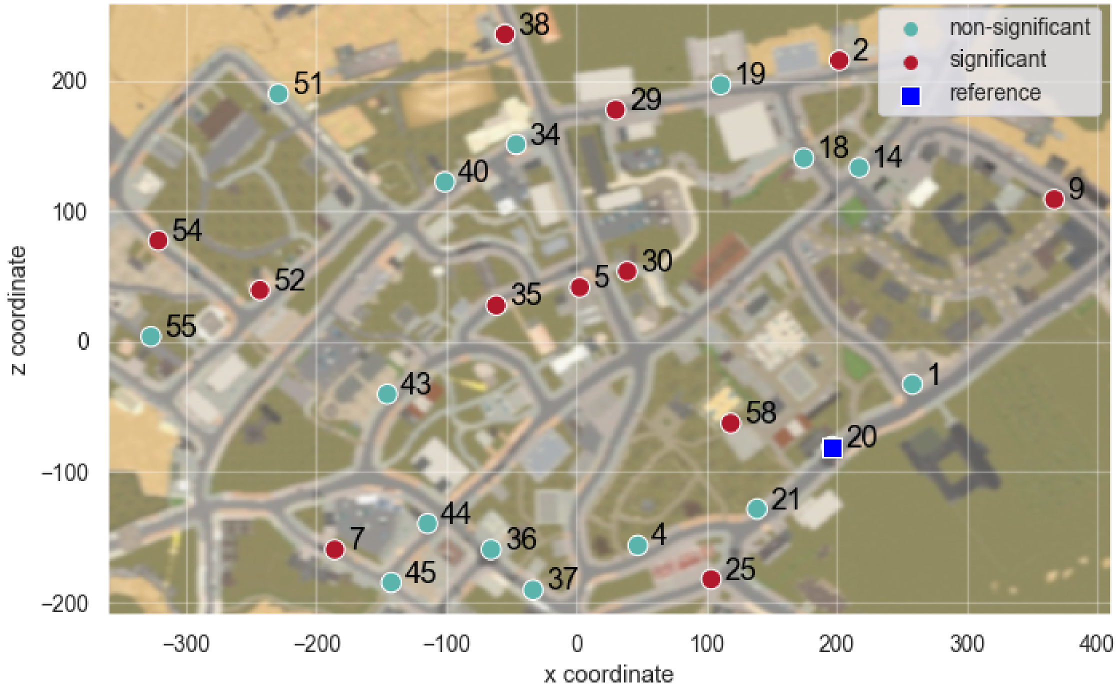


Figure 3.9.: Significance and meaningfulness of LMM results of absolute angular deviation predicted by starting location

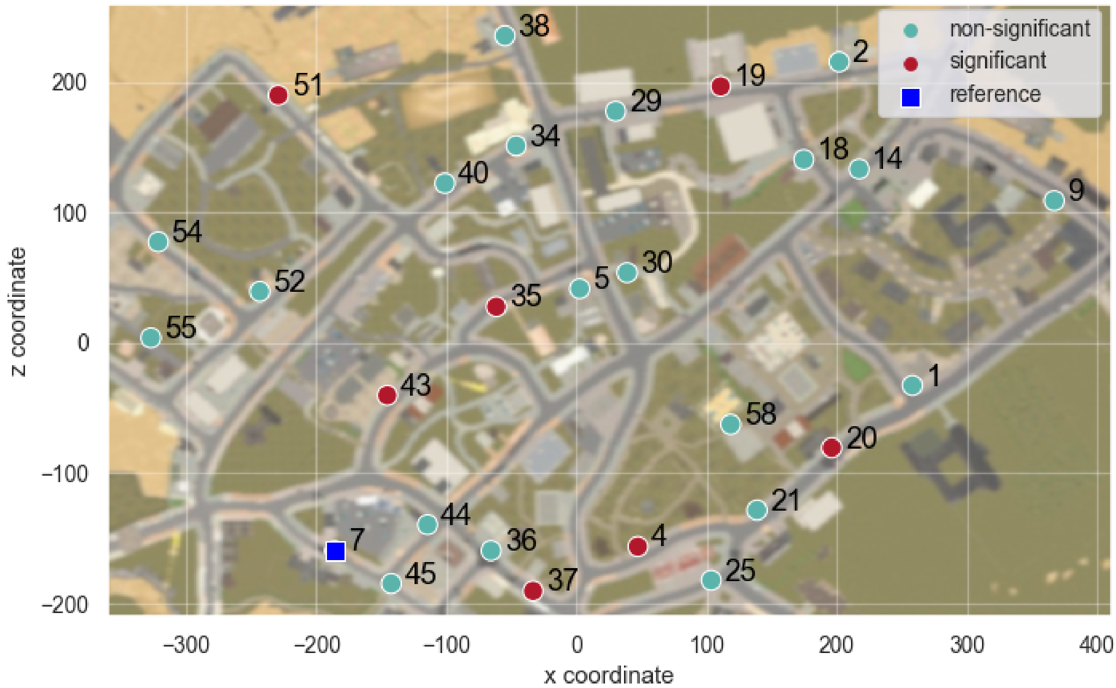


Figure 3.10.: Significance and meaningfulness of LMM results of RT predicted by starting location

4. Conclusion

Work of this thesis was based on the question whether or not the task's starting locations effect the two dependent variables targeted at this analysis, i.e., the absolute angular deviation and the reaction times.

As for the best and worst locations, No. 9 and No. 35 respectively, it seems that maybe being located inside or on the edges of the city could be a factor of this outcome. At the location No. 9, it is possible that a very large portion of the angular possibilities are eliminated due to the fact that if the participant sees that there is no part of the city on one side of where they are, it will be highly unlikely to point there.

Furthermore, due to this elimination, there would be also a higher likelihood of pointing by chance and making small errors. Likely for the starting location No. 35, due to it being about the center of the city, it is more likely to get widely located targets around the starting location and therefore the error rate could rise. This could also be one of the explanation for location 35 being the slowest starting location. The spread of the targets could cause the participants the need to think more accurately about the target.

The results of the LMM, absolute angular deviation as a function of starting location, seems to show that almost half of the starting locations effect the outcome significantly. There are some factors that should be taken into consideration for this outcome. There seems to be a slight trend of having a better performance by the starting locations that lie on the edge of the city and their view is not blocked by buildings. Looking at the results of predicting RT by starting locations, clearly the minority of the starting locations affect the reaction times significantly. From those it is also possible that the locations being located on the edges of the city or inside make the difference.

Moreover, the results of LMM were not able to explain the variance of the data finely. It appears that other factors existing in the experiment should also be taken into account to find the best model for explaining the variance. Factors such as distance to target and meaningfulness of the location should be also investigated to maybe be able to answer the outcome. Furthermore, the independent variables trial id per starting location which contains the 12 consecutive trials performed from each starting location can be also a factor to investigate.

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Appendix

Appendix A.

List of starting locations

add the table of starting locations with their id and names, human agent id and meaningfulness

Appendix B.

Additional plots

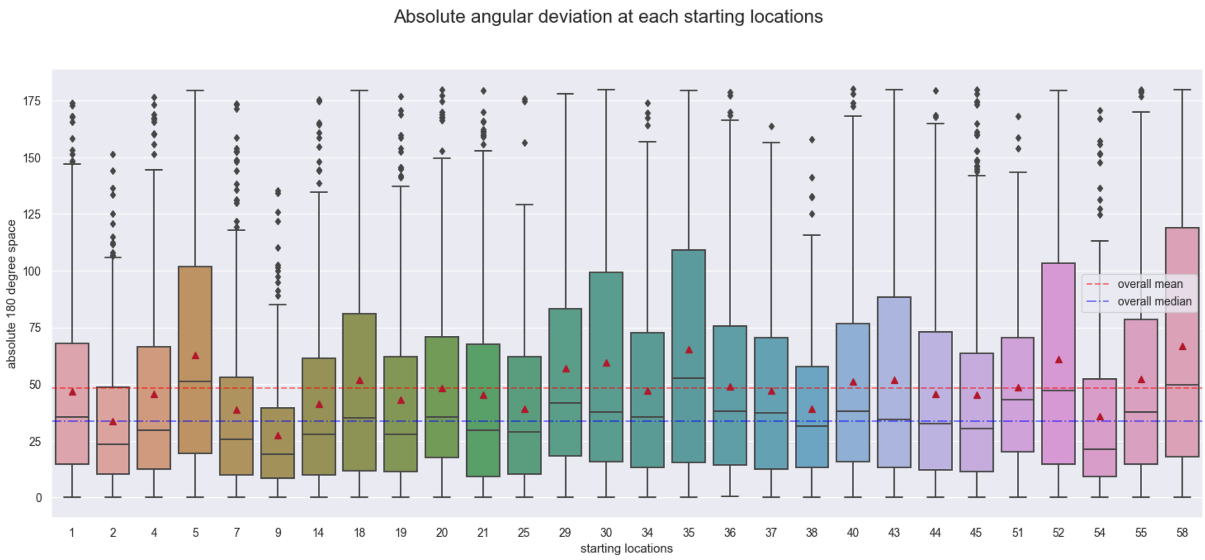

Figure B.1.: Absolute angular deviation at each starting location

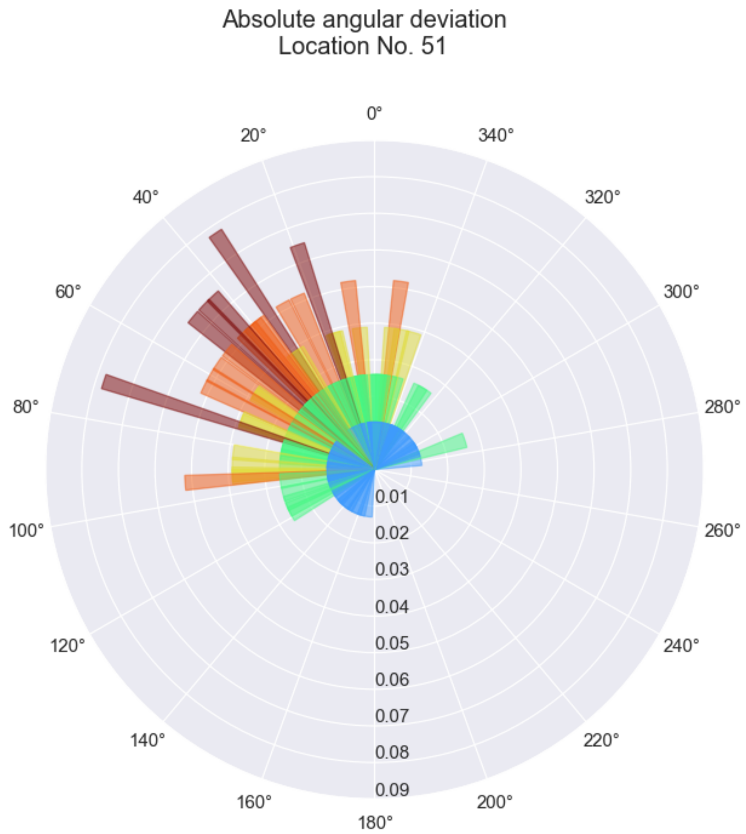

Figure B.2.: Absolute angular deviation of the fastest starting location

Appendix C.

Experimental protocol

the complete experimental protocol

Appendix D.

Forms

Einverständniserklärung

Titel der Studie: Untersuchung des Effektes von menschlichen Avataren auf räumliches Lernen und räumliche Navigation in einer virtuellen Stadt unter Einbeziehung des Blickverhaltens

Zweck der Studie: Das Ziel des vorliegenden Forschungsprojekts ist es, den Effekt von menschlichen Avataren auf das Lernen durch aktive Navigation in einer virtuellen Stadt zu untersuchen. Zu diesem Zweck werden wir menschliche Avatare strategisch neben Gebäuden innerhalb einer virtuellen Stadt platzieren. Auf Basis der erhobenen Daten werden wir evaluieren, ob die Teilnehmer sich die Teile der Stadt, in denen wir Avatare platziert haben, besser merken konnten.

Projektleitung: Prof. Dr. Peter König, Dr. med. Sabine König, Prof. Dr. Gordon Pipa, Tracy Sánchez (Lic.), Institut für Kognitionswissenschaften, Wachsbleiche 27, 49082 Osnabrück

Sehr geehrte Studienteilnehmerin, sehr geehrter Studienteilnehmer, hiermit bitten wir Sie um Ihre Einwilligung zur Teilnahme an dem oben genannten Forschungsvorhaben und zur Nutzung Ihrer personenbezogenen Daten, wie sie Ihnen in der Probandeninformation und der Aufklärung näher erläutert worden sind.

I. Allgemeines

Hiermit erkläre ich, __________, geboren am ________, dass ich durch die Projektleitung mündlich und schriftlich über das Wesen, die Bedeutung, die Risiken und Folgen der wissenschaftlichen Untersuchungen im Rahmen der o.g. Studie informiert und aufgeklärt wurde und ausreichend Gelegenheit hatte, meine Fragen mit der Projektleitung zu klären.

Mir ist bekannt, dass ich das Recht habe, meine Einwilligung jederzeit ohne Angabe von Gründen und ohne nachteilige Folgen für mich zurückzuziehen. Mir ist bekannt, dass meine Daten nach Abschluss der Datenerhebung nur in anonymisierter Form gespeichert, analysiert und veröffentlicht werden. Dies führt dazu, dass ein späteres Löschen meiner Daten nicht mehr möglich ist, da die Daten nicht mehr meiner Person zugeordnet werden können.

Ich habe eine Kopie der schriftlichen Studieninformation und der Einwilligungserklärung erhalten.

Ich erkläre, dass ich freiwillig bereit bin, an der wissenschaftlichen Studie, die für mich aus 5 wiederholten Erkundungen in der virtuellen Stadt „Westbrück", die jeweils 45 Minuten dauern werden und einer Testsession in der virtuellen Umgebung, die ungefähr 120 Minuten dauern wird, teilzunehmen. Die Erkundungs- und Testsessions finden jeweils an unterschiedlichen Tagen statt.

Insbesondere erkläre ich mich damit einverstanden,

1. dass die in der Studie aufgenommenen Daten in anonymisierter Form gespeichert und analysiert werden, auch auf elektronischen Datenträgern;
_______ (Initialen Proband)

2. dass meine persönlichen Daten zu Zwecken der Vergütung und Dokumentation gespeichert werden. Diese persönlichen Daten werden nur in Papierform und nicht mit den experimentellen Daten verbunden aufgehoben.
_______ (Initialen Proband)

3. dass an dieser Studie folgende beteiligte Wissenschaftler Zugang zu den erhobenen anonymisierten experimentellen Daten zum Zweck der Durchführung und wissenschaftlichen Verwertung der Studie haben: Prof. Dr. Peter König, Dr. med. Sabine König, Prof. Dr. Gordon Pipa, Tracy

Sánchez, Institut für Kognitionswissenschaften, Universität Osnabrück;
________ (Initialen Proband)

4. dass die Studienergebnisse und die Studiendaten in anonymisierter Form, die nach heutigem Stand der Technik keinen Rückschluss auf meine Person zulässt, veröffentlicht werden; die Veröffentlichung kann zum Beispiel in einer wissenschaftlichen Zeitschrift oder im Internet erfolgen;
________ (Initialen Proband)

5. dass meine Daten, im Sinne der guten wissenschaftlichen Praxis, in anonymisierter Form der Öffentlichkeit über eine Creative Commons Lizenz (CC0) zugänglich gemacht werden;
________ (Initialen Proband)

6. dass ich aktiv eine virtuelle Stadt erkunde. Anschließend werde ich Orientierungstests in der virtuellen Stadt durchführen. Während des Navigationstrainings werde ich eine virtuelle Realitätsbrille tragen. Die Messungen finden in einem Labor des Instituts für Neurobiopsychologie der Universität Osnabrück statt
________ (Initialen Proband)

7. dass die in der Studie aufgenommenen Daten entsprechend der Empfehlung durch die DFG mindestens 10 Jahre lang aufbewahrt werden.
________ (Initialen Proband)

II. Ausschlusskriterien, Verhaltensregeln

II.1 Ausschlusskriterien

Ich versichere, den mir vorgelegten Anamnesebogen wahrheitsgemäß ausgefüllt zu haben. Mir ist bewusst, dass während des Trainings in der virtuellen Stadt „Seekrankheits-“ ähnliche Symptome („Bewegungsübelkeit“) wie Schwindel und Übelkeit auftreten können. Des Weiteren ist mir bewusst, dass das Tragen der virtuellen Brille ein Druckgefühl bis hin zu leichten Kopfschmerzen und ein Verspannungsgefühl im Nacken auslösen kann.

II.2 Zustimmung zur Einhaltung von Verhaltensregeln

Ich wurde vor der Durchführung der Studie darauf hingewiesen, dass ich vor oder während der Untersuchung auftretendes körperliches oder psychisches Unwohlsein der Projektleitung unverzüglich mitzuteilen habe. Ich wurde zusätzlich informiert, dass ich jederzeit während des Experimentes eine Pause einlegen darf.

III. Datenschutzrechtliche Einwilligungserklärung

Einblick in die anonymisierten Daten durch Dritte findet statt:

Ich bin damit einverstanden, dass die erhobenen Daten in anonymisierter Form in wissenschaftlichen Zeitschriften und über eine Creative Commons Lizens (CC0) im Internet veröffentlicht werden. Dies bedeutet, dass die Daten frei zugänglich sind und frei analysiert und veröffentlicht werden dürfen.

IV. Aufwandsentschädigung

Ich bin damit einverstanden, dass ich für die Teilnahme an der Studie mit 5€ pro Stunde für die Zeit der Exploration und Messungen in VR vergütet werde. Alternativ, wird mir auf Wunsch ein Teil der Zeit entsprechend in Versuchspersonenstunden bestätigt. Weitere Vorteile wurden nicht zugesagt.

V. Unterschrift

Ich erkläre hiermit, dass ich freiwillig und unter Kenntnis der oben genannten Punkte an der Studie „Untersuchung des Effektes von taktiler Wahrnehmungserweiterung auf räumliches Lernen und räumliche Navigation in einer virtuellen Stadt unter Einbeziehung des Blickverhaltens“ teilnehme.

Osnabrück, den ______________ ____________________________ (Unterschrift Proband)

Osnabrück, den ______________ ____________________________ (Unterschrift Projektleitung)

ALLGEMEINE ANAMNESE (A1)

Bei Problemen mit dem Ausfüllen wenden Sie sich bitte an die studienbegleitenden Mitarbeiterinnen und Mitarbeiter!

VP-Nummer			
Geschlecht:	□ m □ w □ andere	**Datum**:	

Nervensystem

Bewusstseinsstörungen □ ja □ nein

Krampfanfälle (Epilepsie) □ ja □ nein

Schwindel/Gleichgewichtsstörung □ ja □ nein

Seekrankheit/"Bewegungsübelkeit" z.B. beim Autofahren □ ja □ nein

Tinnitus □ ja □ nein

Kopfschmerz □ gelegentlich □ oft □ nein

Migräne □ gelegentlich □ oft □ nein

Tremor (Zittern) □ ja □ nein

Gedächtnisprobleme □ ja □ nein

Sprach- oder Sprechbeschwerden □ ja □ nein

Verhaltensstörungen □ ja □ nein

Halluzinationen/Wahnvorstellungen □ ja □ nein

Weiteres: □ ja □ nein
Wenn „ja", welche:

Psychopharmaka □ ja □ nein
Wenn „ja", welche:

Augen

Sehstörung □ ja □ nein
Wenn „ja", welche:

Seheinschränkung □ ja □ nein
Wenn „ja", welche:

Art der Sehhilfe

Stärke der Sehhilfe

Doppelbilder □ ja □ nein

Lichtempfindlichkeit/-scheuheit □ ja □ nein

Weiteres:
Wenn „ja“, welche:

Bewegungsapparat
Schmerzen □ ja □ nein
Wenn „ja“, welche:

Schwäche □ ja □ nein

Steifigkeit □ ja □ nein

Rückenprobleme □ ja □ nein

Weiteres (auch Verlust von Körperteilen):

Bei Problemen mit dem Ausfüllen wenden Sie sich bitte an die studienbegleitenden Mitarbeiterinnen und Mitarbeiter!