Mini-map positioning for Virtual Reality environments in hyperbolic space

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Abstract
Navigation is a core aspect of exploring virtual environments. To assist players, a mini-map is a commonly used navigational tool. Navigation in an unknown space can be difficult. This difficulty is only increased when a player finds themselves in a non-Euclidean space. This paper explores the effect the mini-map's positioning has on the player's navigational performance in Virtual Reality using hyperbolic space. For this two positions are used: the first mini-map is positioned on the Heads-Up Display and the second is positioned on the player's right hand. Two player groups are randomly created to take part in a player experiment. Players get to read an information sheet and complete a small tutorial before having to complete 3 levels. Players are measured on how much time and how many steps it takes them to complete each level, how much their time and steps improve over the levels, their total time, and their total amount of steps. Combined these results indicate that there is no clear effect on the player's performance navigating a hyperbolic space in Virtual Reality.

1. Introduction

A Virtual Reality (VR) game is a game in which the player wears a head-mounted display and completes objectives in a virtual environment. A benefit of VR is that it allows players to explore spaces impossible in the real world. This paper will use a game that implements a hyperbolic space and asks players to navigate toward an objective. While navigation in an unknown real space can already be difficult, these impossible spaces are even harder to navigate. The player is provided with a mini-map on which their objective can be seen to help them navigate through this environment.

This mini-map can be positioned in a plethora of ways, most commonly in 3D video games it is found small in the corner of the screen [Zagata and Medyńska-Gulij, 2023]. The collection of information that is in a fixed position on the screen is usually referred to as the Heads-Up Display (HUD). For the purpose of this paper, the small mini-map will be referred to as *the mini-map on the HUD*. We use this definition as this paper will explore another option unique to VR, a small mini-map mounted to the player's right hand. This will be called *the player-fixed mini-map*.

This paper will explore how the position of the mini-map affects the player's performance to navigate the hyperbolic space in Virtual Reality. After presenting the background of our research, we will show the implementation and appearance of the two mini-maps. We will then delve into the setup of the experiments, the results gathered, and the insights gained from these results. How this research was done responsibly is then shown, followed by the conclusion and potential future work that can be done.

2. Background

This paper uses a game called "Holonomy" developed as a software project for the CSE2000 course at the TU Delft. [Yarar et al., 2022] documented their implementation of the game. In 2.1 the hyperbolic geometry and how a player moves through it within the game is explained. In 2.2 the related work and its connections to this research are shown.

2.1. Hyperbolic geometry

This hyperbolic space consists of square rooms. On the corners of each room, five square rooms come together. In other words, rooms are connected using the hyperbolic geometry. In the real world, a circle consists of 360 degrees. You could walk a circle and return

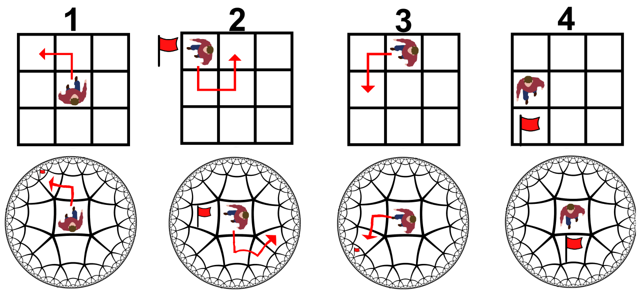


Figure 1: The top row indicates the movement of a player in the real world and what the player sees in the virtual world. The bottom row indicates how the player and the objective actually move within the virtual hyperbolic space. This image was made by Joris Rijsdijk.

to the original spot by taking four 90-degree turns around a pillar, however, in this game, a circle consists of 450 degrees. To walk a circle you will have to take five 90-degree turns around a pillar. The difference between the real world and the virtual space can be seen in figure 1. It is important to note that in both rows each turn is a 90-degree turn and each space is a square. You can see that from step 1 to step 3 the player walks a full circle in the virtual world while appearing to be one step further in the normal world. While having now walked a full circle in the virtual space you can also see that the player's orientation has changed by 90 degrees in both the real and virtual space. In 4.1 we will discuss in further detail how this orientation shift is used to navigate the virtual space.

2.2. Related work

[Kraus et al., 2020] found the mini-map to be one of the most useful navigational support tools. Similarly [Kotlarek et al., 2018] also found the mini-map to be helpful when navigating an unknown space. Both these studies however used a player-fixed mini-map and did not consider the HUD mini-map at all. [Johanson et al., 2017] and [Darken and Peterson, 2001] find that the mini-map can help players to learn to navigate the virtual environment. These studies, however, were not done in VR and therefore did not consider a player-fixed mini-map.

[Dominic and Robb, 2020] compared a screen-fixed mini-map against a world-fixed map, and found the world-fixed map to assist a player significantly better if applied correctly. The world-fixed map is, however, a different tool of navigation as it does not provide the player with an overhead view as a mini-map does. Thus this research is comparing different tools rather than comparing different positions. Therefore, we do not consider the world-fixed map within our research.

There are many ways to represent a mini-map in VR. The mini-map in the current implementation can be defined as a 2D mini-map with a Forward-up orientation with an 'open and close' function. [Mahalil et al., 2019] used a Euclidean space to create this definition; however, that does not apply to the hyperbolic space of the game. The game world is set in a non-euclidean space while the mini-map is a 2D model. This game world can be seen as a sort of overlapping architecture. Research has been done into how to display overlapping architecture in VR [Epplée and Langbehn, 2022] [Auda et al., 2022]. To map the hyperbolic geometry to a 2D Euclidean space the game utilizes a Poincaré disk map [Kinsey et al., 2011].

3. Mini map alternatives

To assist the player with navigation, the mini-map displays a red dot on the border to show the direction of the objective. Additionally, the mini-map uses a hot-cold coloring, rooms closer to the objective show higher levels of red saturation, and rooms further away show more blue saturation. This hot-cold coloring can be seen in figure 3.

To make the mini-map intuitive to read, a north-fixed mini-map was implemented with an arrow indicating the direction the player is looking in. North fixed is not entirely feasible with the hyperbolic space as the implementation of the game rotates the player and the world along the cardinal directions. In figure 2 we see that when a player is in North-Right ("Nr") and goes right again they end up in the East-Left ("El") location. This will cause their orientation to turn, as the map is now shown from the East perspective. It is important to note that in this image, although the graph looks like 4 tree structures only connected at the root, they are actually connected to each other as well. As shown by the red arrow, moving between cardinal trees is possible if the nodes are adjacent, as indicated by the gray squares below, it will just change the orientation of the player. The black graph is visualized without these edges to show how the world coordinate system is built.

If the mini-map truly did not rotate, it would not correctly reflect the world and the player's orientation in it. To guarantee a correct mini-map it rotates with the world as the world rotates from the player's perspective. The following code shows the rotation calculation for the mini-map. Here, `nc` is the normalization correction of the player's position and `fd` is the direction the player came into the room. `flip` is used to position the mini-map correctly and `orientation` is then used to rotate the mini-map correctly.

```
Quaternion flip = Quaternion.Euler(-90, 0, 0);
float orientRot = ((nc + fd) % 4) * 90;
Quaternion orientation = Quaternion.Euler(0, -90 + orientRot, 0);
map.transform.rotation = flip * orientation;
```

Additionally, an arrow is added on top of the mini-map to show the player's orientation. This arrow does not follow the rotation

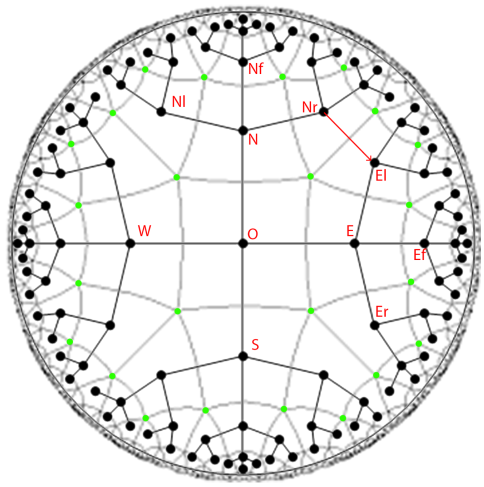


Figure 2: This image shows the graph on which the virtual world is based using the black lines. The rooms of the virtual world are indicated using gray lines. The center point is called the origin and from this point, all rooms are defined. The rooms are first defined by a cardinal direction and then the direction taken from that room (Left "l", Forward "f", Right "r"), as seen from the red letters. The red arrow indicates a step in which the player's orientation would turn. The green vertices indicate where a player would see pillars in the world.

of the mini-map as that correctly reflects the player's orientation. Because we rotate the mini-map and not the arrow when moving between rooms, there are no jumps in the arrow's orientation and it will not change direction unless the player turns their head. This creates an intuitive way of reading the mini-map as the arrow will always be oriented with the player's orientation. `main.transform.eulerAngles.y` represents the direction in which the player is currently looking. This is used to turn the arrow on the mini-map in that direction.

```
orientationArrow = Quaternion.Euler(0, main.transform.eulerAngles.y, 0);
arrow.transform.rotation = flip * orientationArrow;
```

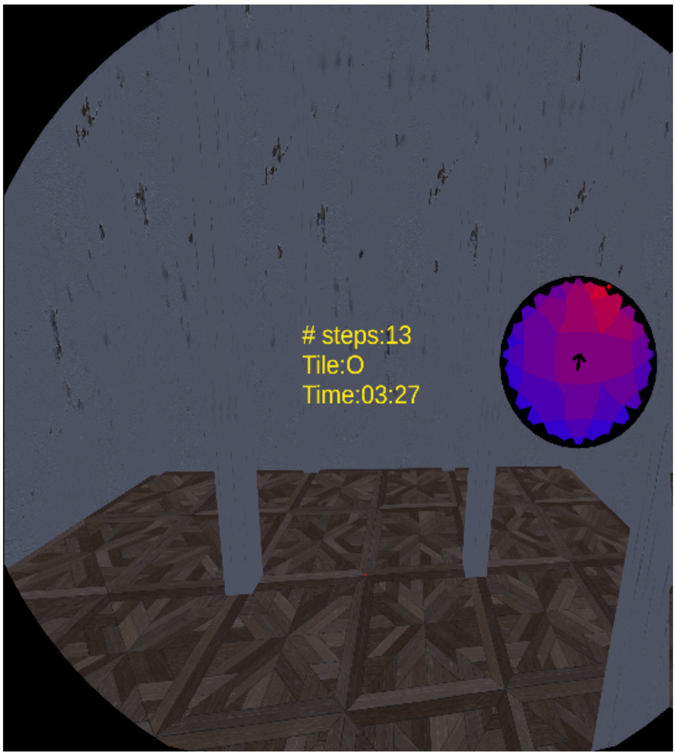


Figure 3: This image shows what the mini-map and the environment look like on the HUD as seen from the left eye

These rotations are consistent over both implementations of the mini-maps, the only difference between them is the position. In figure 3 the mini-map on the HUD can be seen. The other mini-map is positioned on the player's hand and the rotation of their hand is added to the rotation of the mini-map as shown in figure 4. This rotation was added so the mini-map feels more connected to the player's hand. Lastly, a setting is added to switch between the player-fixed mini-map or the mini-map on the HUD for ease of use.

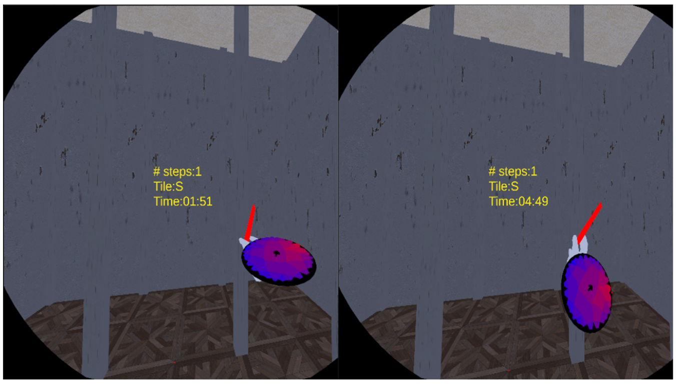


Figure 4: These images shows what the mini-map looks like on the hand and how the hand rotation affects the mini-map as seen from the left eye

4. Evaluation

To find how the position of the mini-map affects the player's performance navigating hyperbolic space in Virtual Reality, a player study has been set up with 30 participants. In 4.1 it is explained how experiments were set up and in 4.2 what data was collected is defined and shown. Lastly, in 4.3 the results are discussed and validated.

4.1. Methodology

When doing this player study it is imperative that players have the same experiment set-up with the only difference being the position of the mini-map. To achieve this the information that is shared with the player is prepared beforehand and no additional information is given. An information sheet and a tutorial were created to teach the player about the experiments, they can be found in appendix A and appendix B. To get an idea of the player group, a form was given to each player asking for some information about them. This form was structured in the following way:

- What is your age?
- What is your gender?
- What is your study?
- Are you right or left-handed?
- I am experienced with 3D video games.
- I am experienced with Virtual Reality (VR).
- I have a good understanding of hyperbolic geometry.

We ask for gender as it can be of influence on the navigational performance of a player [Astur et al., 2016]. For the last 3 points players were asked to fill in an answer on a scale from 1 to 6. 1 meaning strongly disagree and 6 meaning strongly agree. This scale avoids the tendency for a player to answer neutrally as they are forced to at least slightly agree or disagree.

After filling in the form they will read the information sheet. They then will do the tutorial in which they learn the basics of the game and get to see the mini-map for the first time. It is important to note that in this tutorial the player would already be using either the mini-map on the HUD or the player-fixed mini-map, depending on which group they were assigned. A part of the path a player walks in the tutorial can be seen in figure 1. In column 2 the player will see on their mini-map that the objective is straight ahead beyond a wall. After walking a circle around the pillar they now see the flag is within the walls as their orientation has shifted by 90 degrees. With the final step in column 4, they have now walked a circle in the hyperbolic space as well. In the bottom row, we can see how the flag is positioned within the hyperbolic space and how the player moves within the hyperbolic space. In figure 3 we can see the environment and how the rooms are visible to the player.

The player will then have to complete 3 levels. Between each level, they are positioned in the center in order for every player to start from the same position in the room and virtual space. Level 1 has the objective roughly straight ahead and requires the most steps, the optimal path is 13 steps. To complete this level, players have to learn the mechanics and look closely at the mini-map. Levels 2 and 3 require fewer steps to complete and are similar in difficulty, level 2 has an optimal path of 11 steps, and level 3 has an optimal path of

10 steps. Using the graph positioning as shown in figure 2, level 1 has the objective at "Nffrf", level 2 at "Elffr" and level 3 at "Srfrl". Note that even though all positions are at the same distance from the origin in the graph this does not mean they require the same amount of steps.

After playing the game the players are asked to fill in another form, rating their experience. The format of this form and the results can be found in 4.2.3.

4.2. Results

In this section, the results for the three measured steps are presented. The results were gathered from 30 participants split into two equal-size groups, one HUD group, and one player group. They would run the experiments with the HUD mini-map and player-fixed mini-map respectively. Firstly, the results derived from the pre-test form are provided in 4.2.1. Subsequently in 4.2.2 the results measured during the experiment are given. Lastly, in 4.2.3 the results from the evaluation form are shown.

4.2.1. Pre-test form

The following 3 tables show some base data of the player groups gathered with the pre-test form:

Mini-map position	Percentage male	Percentage female	Percentage other
HUD	80	20	0
Player	66.67	20	13.33

Mini-map position	Percentage Computer Science and Engineering	Percentage Mathematics	Percentage other
HUD	73.33	20	6.67
Player	73.33	6.67	20

Mini-map position	Average experience 3D video game	Average experience VR	Average understanding hyperbolic geometry
HUD	4.6	2.733	2.2
Player	5	3.733	2.133

From the HUD group, 1 person was left-handed and from the player-fixed group 3 people were left-handed, all others were right-handed. The HUD group had a mean age of 22.3 and the player-fixed group had a mean age of 21.87.

4.2.2. Measurement results

For every player, we measure the time and number of steps it takes them to complete each level. This data is used to analyze the following additional metrics with which we define the navigational performance of a player:

- The total time
- The total steps
- The time improvement of a player over each level in percentage
- The step improvement of a player over each level in percentage

Improvement is calculated using the following formula:

$$V = \frac{V_{old} - V_{new}}{V_{old}} * 100 \quad (1)$$

In this formula V_{old} is the value from the previous level, V_{new} is the value from the new level and V is the improvement represented in a percentage.

After these results were gathered, an ANOVA test was run for each. The ANOVA test returns a p-value, if this value is below 0.05 the null hypothesis is rejected. This means that the difference in the mean for both positions is significant. After running the ANOVA, the outliers were identified and removed from their specific category. This means that if someone was an outlier in "Level 1 time", they would be removed from that category. If they were not an outlier for "Level 2 time", they would be included again in that evaluation. Another ANOVA was then run on the categories without the outliers.

In figure 5, 6 and 7, the three most interesting categories are shown. A full list of all results can be found in appendix C.

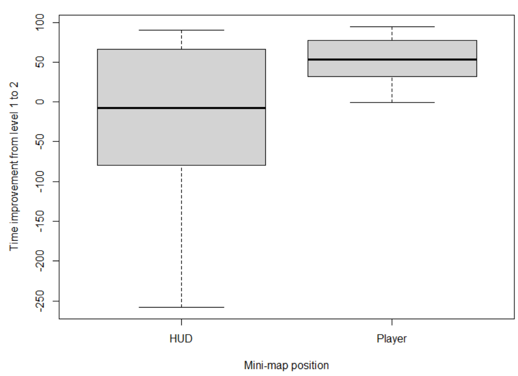
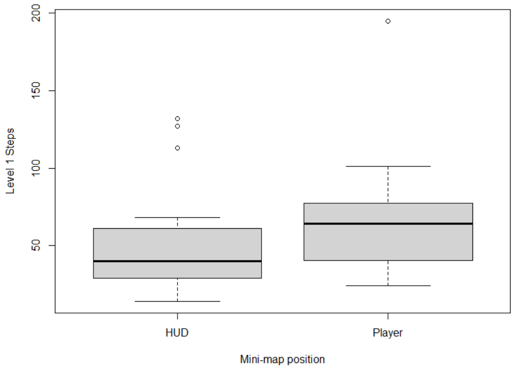
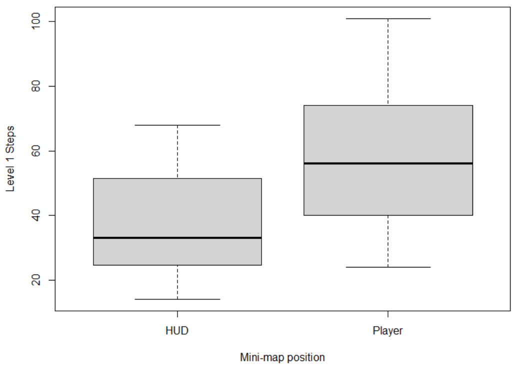


Figure 5: The time improvement of players from level 1 to level 2. F(1, 28) = 6.7913, p = 0.01451

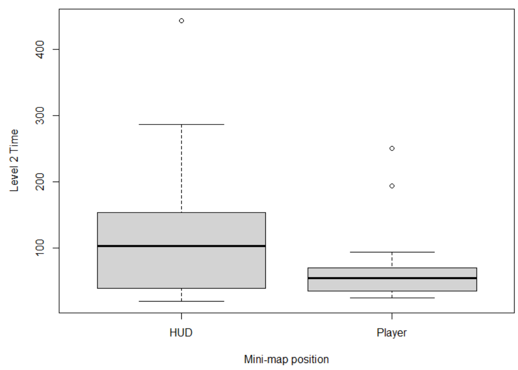


(a) A boxplot of the original data for the level 1 steps. F(1, 28) = 0.7702, p = 0.3876

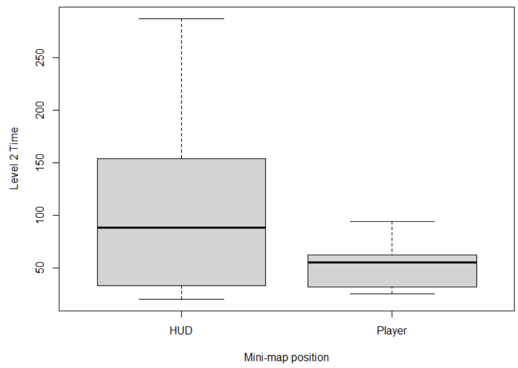


(b) A boxplot of the reduced data for level 1 steps. F(1, 24) = 6.5707, p = 0.01706

Figure 6: Boxplots showing the difference for the level 1 steps.



(a) A boxplot of the original data for the level 2 time. F(1, 28) = 2.6631, p = 0.1139



(b) A boxplot of the reduced data for level 2 time. F(1, 25) = 5.4311, p = 0.02815

Figure 7: Boxplots showing the difference for the level 2 time.

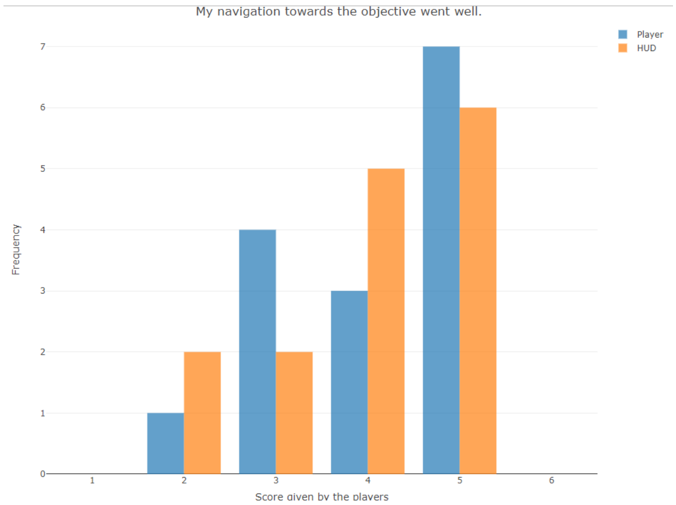


Figure 8: "My navigation toward the objective went well" answers. W = 116.5, p-value = 0.8778

4.2.3. Evaluation form

Three statements are made in the evaluation form for which players grade how much they agree on a scale of 1 to 6:

- My navigation toward the objective went well.
- The minimap was very helpful with finding the objective.
- The minimap was easy to read and understand.

A Wilcoxon rank sum test was run on each question. The result from the form and the test can be found in figures 8, 9, and 10.

4.3. Discussion

This section focuses on the discussion and evaluation of the obtained results. The influence of the player's pre-test knowledge on the final results will be discussed in 4.3.1. Afterward, in 4.3.2 the measured results will be evaluated and lastly, in 4.3.3 the player's evaluation of the experience will be discussed.

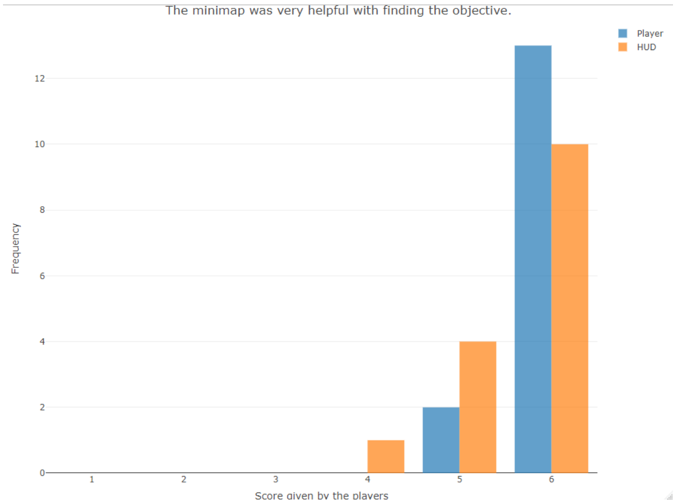


Figure 9: "The minimap was very helpful with finding the objective" answers. W = 136, p-value = 0.195

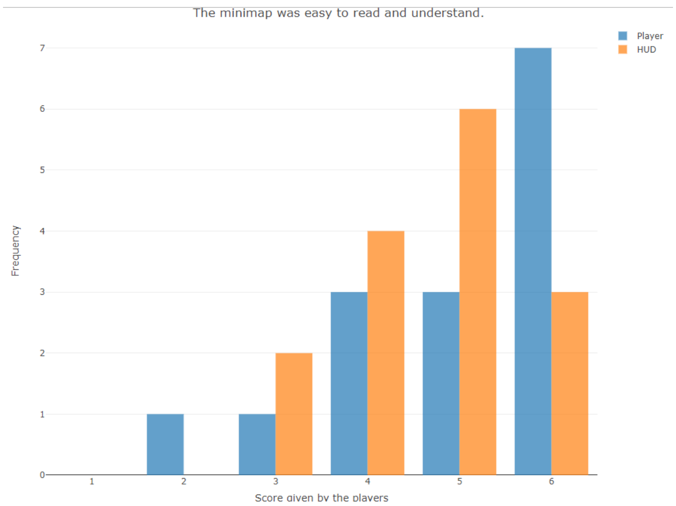


Figure 10: "The minimap was easy to read and understand" answers. W = 134.5, p-value = 0.3534

4.3.1. Pre-test influence

The pre-test form and the results show that players who were already experienced in VR had an easier time navigating the hyperbolic world, as can be seen from figure 11, while players that said to understand hyperbolic geometry did not display any significant changes. Similarly, experience with 3D video games does not seem to affect the player's performance. Being left-handed did not influence a player's performance navigating the hyperbolic space.

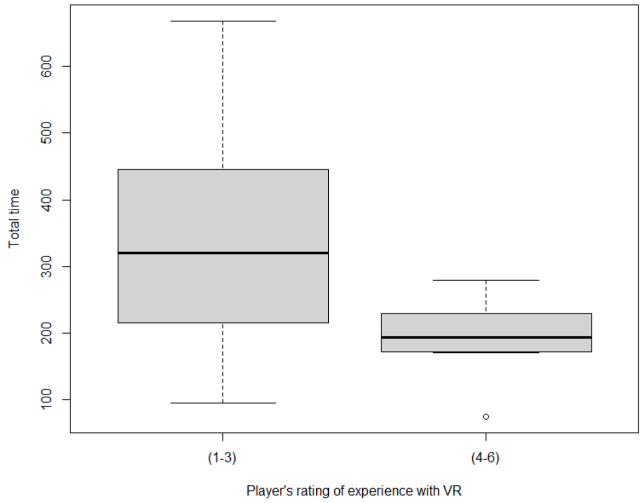


Figure 11: A boxplot comparing the total time of a player to how much experience they claim to have with VR after the removal of the outliers. $F(1, 25) = 5.7599$, $p = 0.02417$

4.3.2. Measurement results

Before outlier removal, we can see only one significant difference as shown in figure 5. The means, shown by the black bar in the box plot, are significantly far apart as indicated by the p-value being smaller than 0.05. This figure also shows no outliers which leaves the results for this category unchanged after the removal of the outliers. Another interesting observation taken from this figure is that the mean for the HUD mini-map seems to be around 0. As mentioned in 4.1 the levels get easier and thus it would be expected that the improvement is always positive. This does seem to be the case for the player-fixed mini-map but not for the HUD mini-map. Lastly, before the removal of the outliers, no other category showed a significant difference.

After the removal of the outliers, some additional categories now show a significant difference, see figures 6b and 7b. The interesting thing here is that the "level 1 steps" is better for the HUD mini-map but the "level 2 time" is better for the player-fixed mini-map. An important note to make is that, while we would expect that if the mean for steps is significantly different then the time is also significantly different. However, this is not the case.

Level 1 steps being better for level 1 indicates a natural understanding of the HUD mini-map while the player-fixed mini-map required players to learn its use first. This also logically leads to the player-fixed mini-map having a greater improvement in steps from level 1 to level 2.

A third significant difference can be found in the step improvement from level 1 to level 3. This logically follows from the previous results. In level 1 the player-fixed mini-map group performs significantly worse, but they are better in levels 2 and 3, which then combined gives a significant improvement.

Interestingly, the total time and total steps do not show a significant difference. Overall, no position can be stated to be the most useful when helping a player navigate based on our results.

Lastly, we can see that in most box plots the player box has less variance than the HUD box. This indicates that the player-fixed mini-map is more versatile when it comes to the player's preference. How experiments can be set up to determine the player's preference, is shown in 6.

4.3.3. Evaluation results

From the Wilcoxon rank sum test, no significant difference can be found. From the three histograms, we see that all results are close together. The mini-map was the only tool that players had to navigate the world. Therefore, figure 9, which asks the player how helpful the mini-map was, having more than half the data points at 6 comes as no surprise.

5. Responsible research

When involving humans with your research it is important to take the ethical considerations of all humans into account, this is shown in 5.1. To make the results of this research valid any reader must be able to reproduce this research and get similar results. How the research was made reproducible is shown in 5.2.

5.1. Ethical considerations

One of the most important aspects to consider when working with people is how to handle their sensitive data. To ensure data privacy no names or emails were collected for the evaluation of the results. All players are only visible by participant number and can have their data removed if requested to do so. All participants were informed beforehand about what data would be collected and what steps to take when they wanted their data removed.

Another point of consideration is that not everybody is comfortable with sharing their gender, therefore an option was added in the pre-test form where participants could fill in "prefer not to say" when asked for their gender.

An application was used to allow players to book their preferred time slots. This application required a name and email to book time slots. When signing up players were informed this data was collected and that it would be deleted as soon as the experimentation was done. When the experiments finished this data was deleted.

5.2. Reproducible research

To ensure this research is reproducible all information that players were given when experimenting was prepared beforehand and all experiments were conducted in the same manner, as described in 4.1. No additional information or help was given to any player. The full documents used to inform players can be found in the appendix.

6. Conclusion and Future work

In conclusion, our research suggests that the position of a mini-map in a VR game using hyperbolic space does not affect a player's navigational performance. Small differences can be observed, while people naturally know the HUD mini-map better, in some cases the player-fixed mini-map performs better. The best position might rather depend on the choice of the player. The variance difference indicates that the player-fixed mini-map is the most likely to align with the average player's preference.

A variant of this study can randomize the order in which levels 1, 2, and 3 are given to the player. This would eliminate the effect that the difficulty of the levels has on the player's performance.

To test the player's preference a within-player test can be held. Two groups would be made, one group plays with the HUD mini-map first, and then after some time they play with the player-fixed mini-map and give their opinion on both. The other group would play with the player-fixed mini-map first and the HUD mini-map later.

Another situation in which the mini-map's effect can be tested is when it is used in combination with the environment. The environment can be populated with landmarks which can then be shown on the mini-map as well. This will allow players to navigate using the virtual environment alongside the mini-map.

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Appendix A: Information sheet

Information sheet

Welcome participant to the holonomy vr experimentation. This sheet will provide you with the necessary information to get started as well as some useful hints. Please read all the information carefully.

The game

In this game you will be presented with a 3x3 of rooms. Outside of this 3x3 area are walls you can not/should not walk through. Your mini map will show you the direction of your objective, a flag. Get to this flag as quickly as possible.

The catch

This game utilizes hyperbolic geometry. What does this mean? In the real world a circle consists of 360 degrees. So you could walk a circle and return to the original spot by taking 4 90 degree turns. In this game a circle consists of 450 degrees. To walk a circle you will have to take 5 90 degree turns. The image below shows the difference between the real world and the virtual world that has 450 degrees. It is important to note that in both rows each turn is a 90 degree turn and each space is a square. The top row shows the movement of the player in the real world and the bottom row shows the movement in the virtual world. As you see in step 5 the player has returned to their original square in the real world but not yet in the virtual world.

This hyperbolic geometry only applies to the connection of the rooms. Walking a circle within a room will not behave differently from the real world.

*hint: if the objective is straight beyond a wall try taking 4 90 degree turns and check what direction the objective is now.

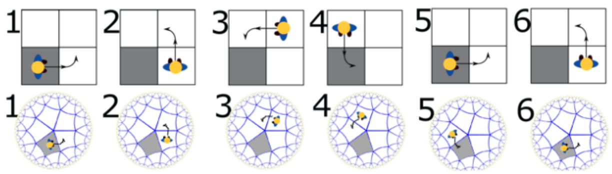

Figure 12: page 1 of the information sheet

The controls

You can walk in the virtual world by walking in the real world. The virtual world size of 3x3 will prevent you from hitting any walls or objects in the real world. The button on top of the controller will open/close the minimap that guides you to your objective.

The experiment

We will begin with a short tutorial in which we will walk you through every step you should take and explain the basics of the game to you. It is important that during this tutorial you only move when told to do so. Afterwards you will play 3 levels where you have to get to an objective for which you will not receive any help from others.

The evaluation

Try to be as fast as possible.

After playing you will be asked to fill in a form. Please fill this form in truthfully. Both negative and positive feedback are of equal importance to our research.

Data storage

The data is anonymized and will be stored under a participant number. This participant number can not be led back to you. You will be informed of your participant number. If at any point you want your data deleted send an email to [redacted]
This email should contain your participant number. You will receive an email with confirmation when your data has been deleted.

Figure 13: page 2 of the information sheet

Appendix B: Tutorial script

Tutorial script

Make sure the player is centered and facing the menu before they begin.
Make clear the player is not allowed to take any steps unless told to do so.

Mini map explanation

Use the trigger button to open or close the minimap for the purposes of this tutorial keep the minimap open at all times. You will see colors on the mini map. This is a hot cold coloring red tiles are closer to the objective and blue tiles are further away. When far away the objective will appear as a red dot on the edge of the mini map when close enough the objective room will appear striped.

Path

Take one step forward, now turn to the left and take one step. You will see on the mini map that the objective is straight ahead of you behind this wall. To get to it we will use the hyperbolic geometry.
Face the objective and turn left and take one step, turn left again and step towards the middle tile. another left turn and step forward and one more left turn and step forward bringing you back into the corner.
You will now see the objective on your minimap towards the left if you look left you will see the flag. Don't grab it yet. As you see, walking a circle in the real world has shifted the game world by 90 degrees.
Take one step closer but don't walk into the room with the flag. Now turn left and step into the middle tile. Now don't walk, just look. If you look left around the pillar you will see an empty room. If you look right around the pillar you will see the flag. This is because at each corner there are actually 5 squares touching, meaning that going left around a pillar or right gives you different rooms. Using the minimap you can see which room you are looking at.
Go to the corner tile moving along the left side of the pillar. You will now see the flag on your right go ahead and grab it.

Info for real runs

You have now completed the tutorial. You will now try to complete 3 levels on your own, I will not help you anymore. Use the minimap and the trick of walking circles you just learned to navigate towards your objective good luck.

Figure 14: Tutorial script

Appendix C: All measurement results

Mini map positio	Level 1 time	Level 2 time	Level 3 time	Level 1 steps	Level 2 steps	Level 3 steps	Level 1-2 time imp	Level 2-3 time imp	Level 1-3 time imp	Level 1-2 step imp	Level 2-3 step imp	Level 1-3 step imp	Total time	Total steps
Screen	45	20	10	22	12	12	55.55555556	50	77.77777778	45.45454545	0	45.45454545	75	46
Screen	290	28	44	127	13	24	90.34482759	-57.14285714	84.82758621	89.76377953	-84.61538462	81.1023622	362	164
Screen	101	273	39	50	120	20	-170.2970297	85.71428571	61.38613861	-140	83.33333333	60	413	190
Screen	132	142	185	40	46	62	-7.575757576	-30.28169014	-40.15151515	-15	-34.7826087	-55	459	148
Screen	78	59	35	35	37	28	24.35897436	40.6779661	55.12820513	-5.714285714	24.32432432	20	172	100
Screen	66	73	55	19	24	20	-10.60606061	24.65753425	16.66666667	-26.31578947	16.66666667	-5.263157895	194	63
Screen	25	46	25	14	24	17	-84	45.65217391	0	-71.42857143	29.16666667	-21.42857143	96	55
Screen	256	33	36	68	14	17	87.109375	-9.090909091	85.9375	79.41176471	-21.42857143	75	325	99
Screen	116	287	30	31	118	12	-147.4137931	89.54703833	74.13793103	-280.6451613	89.83050847	61.29032258	433	161
Screen	88	154	34	31	49	10	-75	77.92207792	61.36363636	-58.06451613	79.59183673	67.74193548	276	90
Screen	319	154	76	113	57	37	51.72413793	50.64935065	76.17554859	49.55752212	35.0877193	67.25663717	549	207
Screen	120	28	76	53	16	43	76.66666667	-171.4285714	36.66666667	69.81132075	-168.75	18.86792453	224	112
Screen	434	104	89	132	38	31	76.03686636	14.42307692	79.49308756	71.21212121	18.42105263	76.51515152	627	201
Screen	124	444	100	54	194	40	-258.0645161	77.47747748	19.35483871	-259.2592593	79.3814433	25.92592593	668	288
Screen	103	137	425	27	44	147	-33.00970874	-210.2189781	-312.6213592	-62.96296296	-234.0909091	-444.4444444	665	218
Hand	87	51	68	34	28	28	41.37931034	-33.33333333	21.83908046	17.64705882	0	17.64705882	206	90
Hand	169	39	27	74	25	19	76.92307692	30.76923077	84.02366864	66.21621622	24	74.32432432	235	118
Hand	72	25	74	40	12	40	65.27777778	-196	-2.777777778	70	-233.3333333	0	171	92
Hand	211	64	41	64	30	20	69.66824645	35.9375	80.56872038	53.125	33.33333333	68.75	316	114
Hand	192	194	36	96	93	24	-1.041666667	81.44329897	81.25	3.125	74.19354839	75	422	213
Hand	298	55	19	101	23	11	81.54362416	65.45454545	93.62416107	77.22772277	52.17391304	89.10891089	372	135
Hand	307	251	93	69	83	31	18.24104235	62.94820717	69.70684039	-20.28985507	62.65060241	55.07246377	651	183
Hand	107	94	37	44	41	15	12.14953271	60.63829787	65.42056075	6.818181818	63.41463415	65.90909091	238	100
Hand	100	78	27	30	30	10	22	65.38461538	73	0	66.66666667	66.66666667	205	70
Hand	118	55	60	48	21	24	53.38983051	-9.090909091	49.15254237	56.25	-14.28571429	50	233	93
Hand	122	60	26	41	21	10	50.81967213	56.66666667	78.68852459	48.7804878	52.38095238	75.6097561	208	72
Hand	607	32	307	195	12	82	94.72817133	-859.375	49.42339374	93.84615385	-625	57.94871795	946	289
Hand	165	28	28	81	18	23	83.03030303	0	83.03030303	77.77777778	-27.77777778	71.60493827	221	122
Hand	109	62	109	24	25	40	43.11926606	-75.80645161	0	-4.166666667	-60	-66.66666667	280	89
Hand	139	32	23	71	22	18	76.97841727	28.125	83.45323741	69.01408451	18.18181818	74.64788732	194	111

Figure 15: All measurement results gathered during experimentation