Wayfinding Abilities and Gamer Skills in *Portal 2*

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Abstract

Spatial and wayfinding abilities and video game playing abilities seem to be linked somehow. Video game players are said to have better spatial and wayfinding abilities than non-gamers. This study strives to find out if people who have good wayfinding abilities are also good at playing video games. 145 participants were found on various online gaming forums. They have filled in the *Wayfinding Questionnaire*, a self-report measure of wayfinding abilities. The outcome of the Wayfinding Questionnaire is compared to a measure of how "good" a player is at playing the game *Portal 2*, namely the time of completion of the first playthrough of the game. Self-assessed wayfinding abilities positively correlate with the outcome of the Wayfinding Questionnare and male participants score significantly higher on the Wayfinding Questionnaire than females. Self-assessed gamer skills positively correlate with the outcome of the Wayfinding Questionnaire. No significant correlation was found between the outcome of the Wayfinding Questionnaire and the first playthrough time. These results imply that wayfinding abilities and gamer skills are not related. It could also be possible that the first playthrough time does not properly represent gamer skills and that a better measure of gamer skills needs to be found.

1. Introduction

When coming up with a good topic for my graduation thesis, I stumbled upon a topic that encompassed more than one of my interests: namely video games and – my personal weakness – wayfinding abilities. I am very bad at wayfinding in real life, but I happen to be very good at wayfinding in video games. Even after picking up a game I have not played in years, I can still navigate through complex environments fairly easily. In contrast to that, I still have difficulties figuring out if I have to go left or right when I exit a store in a town I have visited many times before. Why is there a difference between my wayfinding abilities in reality and virtual reality and am I the only one experiencing this?

There are some studies that have directly compared wayfinding abilities in reality with wayfinding abilities in virtual reality. The subject of wayfinding abilities in reality has been studied often. Likewise, the subject of spatial and wayfinding abilities in video games has been studied as well. However the combination of the two, directly comparing real life wayfinding with virtual wayfinding, has not been done a lot before as the main research question.

The subject is not only of personal interest, but could also be very interesting for the use of virtual environments for training. If more people experience a difference in wayfinding abilities in reality and in virtual reality and if there is such a difference between the two that they cannot be compared as equals, does that undermine the use of virtual environments for training purposes? Goerger, S. R. *et al*. (1998) showed that using a virtual environment to learn the layout of a building, along with blueprints of a building, did not increase the performance of navigating the building. Another study emphasizes that it is wrong to assume that if someone can navigate a virtual space well, that they can navigate the real equivalent well. The study advices caution in using a video game environment

as a virtual environment in research, as video game players often have higher spatial abilities than non video game players. (Darken, R. P. *et al*., 2001)
Despite this warning, this research will be using a video game to study wayfinding abilities in virtual reality. This research will compare the wayfinding ability data gained from video gamers to a comparable and more global dataset in order to see if the gamer participants in this research have better wayfinding abilities than the average person.
Okagaki & Frensch (1994) suggest that adolescent gamers can increase their spatial abilities by spending time to play games. It is possible that experienced gamers have better spatial ability than novice gamers. Subrahmanyam & Greenfield (1994) also concluded that playing games that involve spatial abilities causes an increase in spatial ability in both boys and girls. (Okagaki, L., & Frensch, P. A., 1994; Subrahmanyam, K., & Greenfield, P. M., 1994)
These studies often compare spatial abilities before playing a video game with spatial abilities after playing a video game, but it does not compare spatial abilities in reality with virtual reality. More often than not these studies seem to assume spatial and wayfinding abilities in reality and in virtual reality are directly comparable. Spatial and wayfinding abilities and video game abilities do seem to be linked somehow. Experienced gamers tend to have higher wayfinding abilities and gaming tends to increase spatial abilities. This study strives to find out if people who have good wayfinding abilities in real life also have good wayfinding abilities in virtual reality. The real life wayfinding abilities of gamers will be compared to their gamer skills in a game in which wayfinding abilities are a necessity. Are people who have good wayfinding abilities also good at playing video games?

2. Related works

2.1 Wayfinding abilities

Studies have shown that there is a gender difference in wayfinding abilities. One such study is Lawton & Kallai (2002) which compared navigational abilities and wayfinding anxiety in men and women. The study concluded that men are better at orientation strategy and route strategy than women and that men have less wayfinding anxiety. (Lawton, C. A., & Kallai, J., 2002)
The gender difference in wayfinding abilities was also found by Subrahmanyam & Greenfield (1994) who tested spatial skills through video games in young boys and girls and by Okagaki & Frensch (1994) who tested spatial skills through video games in adolescences.
The gender difference in spatial abilities and wayfinding abilities may be attributed to evolution. Silverman & Eals (1992) suggested that males have better spatial abilities because that was necessary for hunting in hunter-gatherer times, as opposed to “gathering” females. Advantages in spatial skills, such as mental rotation, map learning and maze learning can also be attributed to increasing the ability to hunt in males. Females have advantages in spatial skills specifically tailored to gathering, such as memory for objects and locations (where do these plants grow?) and the spatial connection between certain objects (if you find one plant, you often find another plant nearby). (Silverman, I., & Eals, M., 1992)
A study by Coluccia & Louse (2004) gave an overview of studies comparing genders in wayfinding and spatial abilities from 1983 to 2003. In various studies, both in reality and virtual reality, females never perform better than males. Males and females either perform equally well or males perform better. The 2004 study mentions Silverman & Eals’ 1992 study as a biological explanation of gender differences in spatial and wayfinding abilities. The 2004 study also offers a environmental explanation, stating that males spend more time learning spatial abilities than females. Males are allowed and encouraged to explore more new territories than females and males have more toys catered to them in childhood to stimulate spatial abilities, such as LEGO. Another explanation that Coluccia & Louse (2004) offer is differences in strategy. Females and males have different strategies when it comes to wayfinding. Males rely on global reference points, whereas females rely on landmarks. Not only is the male strategy more efficient, they are also more capable of switching to

landmark-based navigation. Females have more difficulty switching strategies. Another explanation from the 2004 study is based on personality differences. Females have more spatial anxiety than males, which influences wayfinding and spatial abilities. (Coluccia, E., & Louse, G., 2004)

In order to be able to compare wayfinding abilities with gamer skills, it is important to study ways wayfinding abilities can be measured and it is important to pick an efficient and reliable measuring tool. Vilar & Rebelo (2010) defined three ways wayfinding abilities could be measured:

1. In the real world
2. Through photos and video
3. In virtual reality

All three methods have advantages and disadvantages. Measuring wayfinding abilities in the real world provides a real environment, with real lighting and sounds, but also makes it difficult to control unexpected variables – such as weather and safety – and tends to cost a lot of time and money. More often than not participants can only perform tests in real life one at the time and it is harder to find test subjects for difficult long tests than it is to find test subjects for simple short tests. (Vilar, E., & Rebelo, F., 2010)
Rey & Alcaiz (2010) also focuses on the lack of control in real life experiments. A wayfinding abilities experiment in a laboratory setting does have a very controlled environment, but may lack realism. In an experiment in real life, outside of a laboratory setting, there could too many stimuli outside of the control of the researcher. (Rey & Alcaiz, 2010)
Measuring wayfinding abilities through photos and video makes testing a lot easier. It can be tested in any place and can involve participants more easily than in real life. Multiple test persons can participate at the same time and it will take less times to perform the tests for both the participants and the researchers. However, measuring wayfinding abilities through photos and video does not provide a sense of presence and its reliability really depends on the quality of the video or images. Participants cannot manipulate the point of view of the photo or the video and are dependent on the point of view that the researchers have chosen for them. (Vilar, E., & Rebelo, F., 2010)
Measuring wayfinding abilities in virtual reality does provide a sense of presence and eliminates the unexpected variables of measuring in the real world. Disadvantages of using virtual reality to measure wayfinding abilities are motion sickness and limiting the field of vision of the participants. Vilar & Rebelo (2010) defines virtual reality as “an advanced interface between human and computer. With VR people are able to visualize, to manipulate and to interact with virtual environments”. This definition does not necessarily mean interacting with a world through a virtual reality headset and can also include playing video games, provided that the participant is able to visualize, manipulate and interact with the environment. The study calls this “desktop VR”. (Vilar, E., & Rebelo, F., 2010)
Another advantage of using virtual reality to measure wayfinding abilities is the ability to record what the test subjects perceive. This enables the researcher to better analyze the data from the tests. (Dombeck & Reiser, 2012).
An important part of wayfinding abilities is locomotion, the ability to move and look around. The environment changes due to locomotion and people update their location and orientation in motion. This is something that can be achieved in real life, but not in photos and video. Locomotion is a problem that researchers using virtual environments have to face as well, as being able to realistically move and look around on a computer screen is not the same as physically doing so. (Klatzky, R. L. *et al*., 1998; Van der Ham, I. J. M. *et al*., 2005)

Multiple ways to measure wayfinding abilities have been used. Thorndyke & Hayes-Roth (1982) elaborates on a few of these methods, such as distance estimation through pointing at landmarks, learning routes through studying and drawing a map and learning routes by physically walking around in the area. Test subjects were asked to study a map until they could draw it from memory. Another group had been allowed to experience the area for themselves by exploring it. After both groups had studied the area, they were asked to draw a route map within the parameters of the area they had studied. The study concluded that the group that had physically been at the location performed better than the group that studied the map. (Thorndyke, P. W., & Hayes-Roth, B 1982)
Kozlowski & Bryant (1977) confirm some of these methods, such as pointing to unseen landmarks to assess general awareness of orientation, navigating through environments and estimating distances. These physical tasks are called "behavioral tasks". (Kozlowski, L. T., & Bryant, K. J., 1977) Other ways to measure wayfinding abilities are route reversal, recalling landmarks and street names and self-report questionnaires. (Coluccia, E., & Louse, G., 2004)

Self-report questionnaires are useful for certain demographics who are not able to perform behavioral tasks, such as walking around in an area, due to health reasons or due to low response rates of suitable test subjects. Self-report questionnaires are also useful to circumvent the time constraints and unexpected variables of wayfinding experiments in real life.
The Wayfinding Questionnaire (WQ) is a self-report questionnaire to assess navigation ability in the real world that was first used in a study by Van der Ham *et al*. (2013) By using the WQ, researchers could quantify real world wayfinding abilities without the disadvantages of physically testing participants in real world environments. The WQ was used on 62 stroke patients. The WQ-score of these participants was compared to a control group of 384 healthy participants and concluded that 29% of stroke patients had navigational ability impairment. (Van der Ham, I. J. M. *et al*., 2013)
The Wayfinding Questionnaire was further elaborated upon by Claessen *et al.* (2016). The WQ questions consisted of six spatial ability categories: mental transformation, mental imagery, angle/distance estimation, orientation ability, navigational strategies, and spatial anxiety. These categories were established through literature review and existing questionnaires. The WQ was validated internally in two studies. In Study 1 the WQ consisted of 26 questions. It was tested on 356 healthy participants. Study 1 brought the WQ back from 26 questions to 22 questions and divided the questions in three subscales: Navigation and Orientation, Spatial Anxiety and Distance Estimation. These three subscales had very good internal consistency and were weakly to moderately correlated to other subscales and strongly related to the total WQ-score. In Study 2 158 stroke patients tested the WQ. The 22-question version of the WQ was used. The three subscales established in Study 1 were supported in stroke patients in Study 2. All subscales had very good internal consistency and were weakly to strongly correlated to the other subscales and strongly related to the total WQ-score. (Claessen, M. H. G. *et al*., 2016a).
In a study by Rooij *et al*. (2017) the Wayfinding Questionnaire was tested 158 stroke patients and a control group of 131 healthy participants. 78 of the stroke patients filled in the WQ and participated in a Virtual Tübingen test (Claessen, M. H. G. *et al*., 2016b) to assess their navigational abilities. The performance in the Virtual Tübingen test of patients with a low WQ score was significantly poorer than patients with a normal WQ score. (Rooij, N. K. *et al.,* 2017)

A different wayfinding assessment tool is the Santa Barbara Sense of Direction Scale (SBSOD). This questionnaire is a self-report scale of environmental spatial skills. In this questionnaire people are asked to rate their own navigational abilities and more often than not their self-reported data is a reliable measure of their actual navigational abilities. The SBSOD was tested in four validity tests and was proven to be internally consistent. (Hegarty, M., 2002)
Another questionnaire is a combination of the Wayfinding Strategy Scale (Lawton, C. A., 1994) and the Indoor Wayfinding Strategy Scale (Lawton, C. A., 1996). This combined questionnaire was used to assess age and gender, route strategies, orientation strategies, wayfinding anxiety, and trait anxiety.

Wayfinding anxiety is significantly correlated to age and route strategies and orientation strategies. The other scales were not significantly correlated. (Lawton, C. A., & Kallai, J., 2002)
Another questionnaires is the Object-Spatial Imagery Questionnaire (OSIQ). This questionnaire is used to assess individual differences in visual imagery preferences and experiences. The study specifies object imagery and spatial imagery. Object imagery is about characteristics of objects, such as size and shape, whereas spatial imagery is about the relations between objects and the movement and location of objects. This questionnaire focuses more on spatial thinking than on wayfinding abilities. (Blajenkova, O. *et al*., 2006)
The Familiarity and Spatial Cognitive Style Scale is another self-report questionnaire, which determines navigational abilities. As the name suggests, this scale includes familiarity to a location as an important factor in one's navigational abilities. The study argues that when people are familiar with their environment they will be able to identify landmarks more easily, which will positively influence their navigational abilities. (Piccardi, L. *et al*., 2011)

2.2 Wayfinding abilities and virtual environments

As mentioned in Vilar & Rebelo (2010) there are multiple ways to measure wayfinding abilities. For this study wayfinding in virtual environments is the most interesting, as video games are considered virtual environments. Before going into wayfinding abilities and video games specifically, the subject of wayfinding abilities and virtual environments in general will be studied.
Moffat *et al*. (1998) researched if gender differences in spatial abilities and wayfinding abilities was also found when using a virtual environment. The study had a test group of 40 males and 34 females. All test subjects performed a maze-learning task, where they had to navigate through a maze in a series of four practice trials and five trials. The way to quantify navigational abilities in this study was time. The test subjects had a maximum amount of minutes to finish the maze. If they exceeded this time, the maximum time of the trial would be recorded. The test subjects performed these tests on a computer screen using the arrow keys of a keyboard. Navigational errors were also taking into account, like repeatedly walking into dead ends. Similar to earlier research about gender differences in spatial abilities, the study concluded that there was a male advantage for spatial route learning. (Moffat, S. D. *et al*., 1998)
A study set in a more realistic environment than a virtual maze was a study by Goerger, *et al*. (1998). The study took place in an office building. It was researched if the use of a virtual environment in combination with the floor plans of the building could enhance spatial knowledge of said building. One test group was given just the floor plans, the other group was presented with a realistic virtual environment of the building and the floor plans. The test group that was only given the floor plans performed better than the virtual group. The study concluded that short exposure to a complex virtual environment was not helpful for enhancing spatial knowledge. (Goerger, S. R. *et al*., 1998)
Another study that used a virtual environment of an office building to enhance special knowledge is Ruddle *et al*. (1997). Test subjects were shown a virtual environment of a building to learn to layout of that building and were shown a floor plan of the same building. The test subjects could walk in a straight line and look around with the arrow keys. Participants with average navigational abilities improved significantly when trained with the virtual environment. Their abilities were comparable to participants who had worked in the real building for one or two months. The difference in results from the Goerger study could be explained by the complexity of the virtual environment and the amount of time the participants were allowed to take. (Ruddle, R. A. *et al*., 1997)
Koh (1997) suggests that the best virtual training environment does not have to be the most realistic. The most important thing is reaching the highest performance on spatial tasks in the shortest amount of time. This also implies that a real world training environment is not automatically better than a virtual training environment, if ways to increase performance and decrease time to learn can be found that are impossible in the real world. (Koh, G., 1997)
Darken & Banker (1998) also come to the conclusion that the most important aspect of performing well on navigation tests is not the question between virtual reality and reality, but the navigational

abilities of the test subjects themselves. The study was divided in three groups: a test group that used a map, a group that used a map and was taken to the real environment and a test group that used a map and a virtual environment. The study concluded that above all else, the ability level of all test groups was a bigger influence than the virtual or real environment. The study also concluded that for intermediate users, using the virtual environment was more beneficial than using the real environment as it saved them time. For advanced "orienteers" there was no benefit in using a virtual environment. (Darken, R. P., & Banker, W. P., 1998)

Darken & Peterson (2001) emphasize that it is wrong to assume that if someone can navigate a virtual space well, that they can navigate the real equivalent well. The study advices caution in using a video game environment as a virtual environment in research, as video game players often have higher spatial abilities than non video game players. (Darken, R. P., & Peterson, B., 2001)

2.3 Wayfinding abilities and gaming

As mentioned in the previous section, people who play video games often have higher spatial abilities than non video game players. This finding is confirmed in a study by Schmidt-Daly (2016). Test subjects were asked to perform three spatial ability tests, through the use of a physical paper map, Google Maps and ARES, a 2-dimensional topographical map projected 3-dimensional sand. The test subjects with prior experience in video gaming performed significantly better on the spatial ability tests than people without gaming experience. (Schmidt-Daly, T. N. *et al*., 2016)

In the 1998 study about gender differences in a virtual environment by Moffat *et al*., the test subjects were asked about their previous gaming experiences, as that has been proven to be influential on spatial abilities. (Moffat, S. D. *et al*., 1998)

Subrahmanyam & Greenfield (1994) tested the effect of video game practice on spatial abilities in boys and girls between 10 and 12 years old. The test subjects did a pretest to determine spatial ability. After playing a game called Marble Madness, which incorporated spatial skills to play, the spatial ability of test subjects of both genders increased. In the control group a video game called Conjecture was used, which is a word game. There was no increase detected in spatial abilities in the control group. (Subrahmanyam, K., & Greenfield, P. M., 1994)

Another study that looked the effect of video game practice on spatial abilities was conducted by Okagaki & Frensch (1994). The test subjects, this time adolescences, did a pretest to determine spatial ability and spent 6 hours playing Tetris afterwards. Playing Tetris increased mental rotation time and spatial visualization time. The results replicate the findings in Subrahmanyam & Greenfield's 1994 study. The study implies that adolescent gamers can increase their spatial abilities by spending time to play games. (Okagaki, L., & Frensch, P. A., 1994)

In a study by Adams & Mayer (2013) the effect of playing Portal on spatial thinking and learning physics was tested. They studied the effect of playing video games with realistic physics would facilitate learning a physics lesson, as opposed to playing Tetris, a game which uses spatial ability, but does not incorporate realistic physics. The study concluded that playing Portal did not influence learning physics, but it did improve spatial cognition skills. (Adams, D. M., & Mayer, R. E., 2013)

A study by Dorval & Pépin (1986) also concludes that playing video games increases spatial abilities. In this study 70 test subjects without any gaming experience were given a pretest and a posttest after playing a video game. The spatial abilities of both test both female and of male test subjects increased. (Dorval, M., & Pépin, M., 1986)

Feng, *et al*. (2007) came to a few interesting conclusions about the influence of video games on gender differences and on the types of video games that influence spatial skills. The study was conducted on 6 males and 14 females who reported to have no video game experience. The test subjects were randomly assigned to play an action (e.g. a first person shooter game) or a non-action game. The study concluded that the spatial skills of both male and female players increased after playing an action game, decreasing and sometimes eliminating the gender differences in spatial abilities. No effect was found in the test group that played a non-action game. (Feng, J. *et al*., 2007)

2.4 Key findings

- Using virtual reality in measuring wayfinding abilities has advantages over using real environments and using photos or videos
- The Wayfinding Questionnaire is a good representation of real life wayfinding abilities, using "navigation and orientation", "distance estimation" and "spatial anxiety".
- Gender differences in spatial skills and wayfinding abilities are found in reality and in virtual environments
- The best training environment for wayfinding abilities does not necessarily have to be reality, but can be virtual reality
- Gaming experience influences spatial abilities. Gamers often have higher spatial abilities than non-gamers
- Playing action games or games that involve spatial thinking increases spatial abilities, even in non-gamers

3. Problem statement

This study compares gamer skills in a game in which wayfinding abilities are a necessity to wayfinding abilities of gamers in real life. A virtual environment (a game) will be used in this research and the test subjects will be gamers, which is a test group that research shows has high spatial and wayfinding abilities. (Darken, R. P., & Peterson, B., 2001; Schmidt-Daly, T. N. *et al*., 2016)
This study compares the wayfinding abilities of gamer participants to the wayfinding abilities of participants of earlier research (Van der Ham, I. J. M. *et al*., 2013; Claessen, M. H. G. *et al*., 2016a; Claessen, M. H. G. *et al*., 2016b) in order to see if gamer participants have better wayfinding abilities than a more general group of participants.
A difference, positive correlation or negative correlation between wayfinding in reality and wayfinding in virtual reality could have implications for the use of virtual reality for wayfinding training purposes.

4. Method development

The goal of this research is to find out if people who have good wayfinding abilities are also good at playing video games. There are three questions that need to be answered:

1. *How will wayfinding abilities be quantified within this research?*
2. *How will gamer skills be quantified within this research?*
3. *Which game will be used as a tool to conduct this research?*

It is important to find a way to quantify wayfinding abilities without giving test participants a physical test. Research has shown that self-report questionnaires about wayfinding abilities are a good indication of real life wayfinding abilities. (Coluccia, E., & Louse, G., 2004) Some of these self-report questionnaires will be compared in section 4.1 and the definitive wayfinding ability assessment tool to be used in this research will be chosen. In order to directly compare wayfinding abilities with gamer skills, a quantifiable way of determining how "good" someone is at gaming needs to be found. This can be anything ranging from a high score to the amount of steps a player character has taken. Section 4.2 will further elaborate on this question and on its answer. When the gamer skills are somehow quantified, it is time to pick a suitable game. It is possible that the gamer skills quantifier does not work with the game that is the most suitable tool to be used within this research. In this case, either a better game needs to be found or the gamer skills quantifier needs to be changed. In section 4.3 several games will be compared and the most suitable game for this research will be chosen.

4.1 Wayfinding abilities

Five wayfinding ability self- report questionnaires were considered to determine wayfinding abilities in reality. These self-report questionnaires can be found in table 1.

Self-report questionnaires	References
The Santa Barbara Sense of Direction Scale (SBSOD)	Hegarty, M., 2002
The Familiarity and Spatial Cognitive Style Scale	Piccardi, L. *et al*., 2011
The Wayfinding Strategy Scale and the Indoor Wayfinding Strategy Scale	Lawton, C. A., 1994; Lawton, C. A., 1996; Lawton, C. A., & Kallai, J., 2002
The Object-Spatial Imagery Questionnaire (OSIQ)	Blajenkova, O. *et al*., 2006
The Wayfinding Questionnaire (WQ)	Van der Ham, I. J. M. *et al*., 2013 Claessen, M. H. G. *et al*., 2016a

Table 1: Self-report questionnaires considered for this research

The SBSOD scale and the Familiarity and Spatial Cognitive Style Scale do not include spatial anxiety, which is shown to be of negative influence on navigational abilities (Walkowiak, S. *et al*., 2015). Although both scales have been researched and validated, spatial anxiety is an important factor that has to be taken into account in order to get a more accurate outcome on the questionnaires. An advantage of the Familiarity and Spatial Cognitive Style Scale is the inclusion of "familiarity".

The Wayfinding Strategy Scale and the Indoor Wayfinding Strategy Scale are about orientation and strategies used in wayfinding, but not on the ability to navigate. The subscales of the Wayfinding Strategy Scale and the Indoor Wayfinding Strategy Scale were also not very significantly correlated. The OSIQ assessed individual preferences and does not assess the ability to navigate. It is focused on the perspectives of its participants, both in object imagery and spatial imagery. It is an interesting questionnaire for spatial abilities, but not for wayfinding abilities.

The Wayfinding Questionnaire does assess navigational ability and includes spatial anxiety. The Wayfinding Questionnaire occasionally specifies that the participants should think of places they are not familiar with. In this way, the Wayfinding Questionnaire does include "familiarity", by specifying which mindset the participant has when answering the question ("Do I know this location?"). In this way familiarity is not a variable that can unexpectedly bias the answers of the participant. The Wayfinding Questionnaire consists of three subscales: Navigation and Orientation, Distance Estimation and Spatial Anxiety. These three scales have their separate scores that can be compared to the gamer skills quantifier. The Wayfinding Questionnaire will be used in this research.

4.2 Gamer skills

In order to explore ways how to quantify how "good" a player is at a game, the game *Portal 2* (Valve Corporation, 2011) was chosen. *Portal 2* was the first game considered as a contender for the tool to be used in this research, but was not the only game that was considered. *Portal 2* was chosen as the most suitable tool to explore ways to quantify gamer skills because of its popularity and its integration with one of the most popular online gaming stores, *Steam*[1].

When looking at all the statistics available about *Portal 2*, a number of ways to quantify how "good" a player is were considered. On Steam it is possible to see how much time a player spent on the game. However, this is a measure of the total time spent on the game. There is no way to know if the total time spent is on one playthrough (in which case less time can be viewed as "better play") or if

[1] https://store.steampowered.com/

the player has replayed the game multiple times. A longer or shorter total time on Steam spent on *Portal 2* would not be an indication of being "good" at a game.
Another variable that is visible on Steam are achievements. An achievement in a game is a reward for reaching certain (and sometimes hard to accomplish) goals. For example: a player gets an achievement if he or she finishes a puzzle in less than a minute. A website that has a good overview of all earned achievements on Steam for the game *Portal 2* is the website trueachievements.com[2]. On this website a list of players who earned the most achievements in *Portal 2* is available. This is not the type of "good" we are looking for however. Considering this player base would only result in very similar data of the top fraction of players, instead of a varied player group. For example: the top 500 players of this website have earned all achievements. The top players on this website are players that have hunted for all the little secrets in the game. They did not gain their achievements because of their gamer skills, but through perseverance and repetition of the game. It is also possible that they have followed walkthroughs (which are manuals or videos explaining how to play the game and how to reach the achievements) in order to earn all the hard-to-find achievements.
Another set of statistics that would likely result in very similar data is found on the website speedrun.com[3]. On this website a long list of players and the times it took them to finish *Portal 2* is available. Although the website shows a list of the fastest times it took players to beat *Portal 2*, this is also not the type of "good" that we are looking for. Speedrunners have played the game many times in order to beat it as fast as possible. They did not gain their high score because of their gamer skills, but through repetition of the game.
Despite two unsuccessful attempts to use the total time spent on the game, namely through Steam and through speedrunner.com, the most interesting way to quantify gamer skills was found on the website howlongtobeat.com[4]. On this website a list of players and the time it took them to beat *Portal 2* is also available, but here the players can indicate whether or not it was their first playthrough. Using the times of the first playthroughs could be a good indication of gamer skills as it is concrete information about one single playthrough and it is the first time they played the game, eliminating prior knowledge. The playtime that the first playthrough of a game took was chosen as the way to quantify gamer skills within this research.

To the best of our knowledge, this quantifier has not been used in other research and it is not validated. Time was a measurement of wayfinding abilities in the study of Moffat *et al*. (1998), but this time was measured by the researchers and not self-assessed by the participants. This research is exploration science and we believe this quantifier expresses gamer skills in relation to navigational abilities.

[2] https://www.trueachievements.com/game/Portal-2/gamers
[3] https://www.speedrun.com/Portal_2/full_game
[4] https://howlongtobeat.com/game.php?id=7231&s=completions

4.3 The game

With the way to quantify wayfinding abilities and the way to quantify gamer skills decided upon, all that remains is choosing a suitable game to be used as a tool to conduct this research. Howlongtobeat.com proved to be a useful website to use, as it did not only include self-reported times of completion of almost any game available, it also gave an indication of how popular a game was and how many potential test subjects could be approached. A number of games were considered. The game had to satisfy three requirements:

1. *Wayfinding abilities are necessary to play the game.*
2. *There must be a way to quantify how "good" the player is in the game.*
3. *The game needs a big group of players that can be approached.*

The first game that was considered was the game *Portal 2* (figure 1). *Portal 2* is a game that takes place in an underground testing lab in the distant future. The player solves puzzles with the use of a "Portal gun". A Portal gun allows the player to shoot portals on certain surfaces in the game, allowing the player to move around from one portal to another. This often results in the player viewing the same area from a completely different point of view in an instant. The test chambers can get very large, which would be a navigational challenge even without the portals. The first *Portal* game has very similar gameplay to *Portal 2*, but is a much smaller game in terms of navigation.

Figure 1: *Portal 2* screenshot[5]

Next to *Portal 2*, games such as *Skyrim* (Bethesda Softworks, 2011) and *Grand Theft Auto IV* (Rockstar Games, 2011) were considered, because of their big open worlds. It would be very easy to get lost in these two games, which might be a good test of wayfinding abilities. However, these games encourage their players to explore the world and make it harder to quantify how "good" a player is at the game.

[5] https://thesenecatimes.wordpress.com/2012/12/13/a-portal-to-learning-physics-with-video-games/portal-2-screenshots-04/

The time of completion on howlongtobeat.com of these two games would not be a good indication of their gamer skills or of their wayfinding abilities, because the player could have taken a dozen detours and add hours to his/her time of completion before finishing the game. This insight led to another demand being added to the three existing demands:

4. *The game has to be relatively linear. The game had to be a straightforward game, which leads the player from the beginning to the end without too much ability to roam freely.*

Some other games were considered. *Hello Neighbor* (tinyBuild, 2017) is a game that encourages the player to move around the gigantic and illogical house of his neighbor. The player solves puzzles in order to reach the mysterious basement of the house, all the while being chased by the neighbor. The game demands wayfinding ability, as there are multiple floors to explore and multiple ways to go from one place to another. There are also less conventional ways of moving around the house, like floating around with an umbrella and building a stack of boxes to climb to any room in the house from the outside. The neighbor character chases the player and the player must avoid him at all costs. After fleeing from the neighbor in panic, the player would need to remember the path he/she took while running away. Without some good wayfinding skills, the game would be difficult to complete.

Hello Neighbor is a relatively new game. Although it is very popular, its number of players comes nowhere close to that of *Portal 2*. If we look at the data on howlongtobeat.com, *Portal 2* has more than 1500 playthroughs registered, whereas *Hello Neighbor* has three. Another downside is that the game has been available as an alpha and beta version for very long. The official version of the game has the most players to reach out to. However, the players who played the alpha or beta versions of the game already know the layout of the house and the measurement of how "good" they are at the game will not be as reliable.

Bendy and the Ink Machine (TheMeatly Games, 2017) is a game where you are trapped in an animation studio. The game is a maze of hallways and floors. It is a puzzle game and you are often repeating routes you have taken before through the hallways to retrieve objects needed to proceed. In this game, just as in *Hello Neighbor*, you are chased by someone. This could cause the players to lose their bearings after they had to flee. One could get easily lost in the many hallways of the animation studio. Just like *Hello Neighbor*, *Bendy and the Ink Machine* is a relatively new game with not as many players as *Portal 2*. On howlongtobeat.com eleven players have reported their playthroughs.

Slender: The Eight Pages (Parsec Productions, 2012) and *Slender: The Arrival* (Blue Isle Studios, Parsec Productions, 2013) are games where players must collect certain objects in a forest, while being chased by a monster. The games are set at night and the forest environment looks very similar all around the player. There are some landmarks, but they are few and far between. Players could lose their bearings after fleeing from the monster, just like in some of the previously mentioned games. Without good wayfinding abilities, these games would be very difficult. *Slender: The Eight Pages* was a very popular open source game. Despite its popularity, only eight people reported their playthrough on howlongtobeat.com. *Slender: The Arrival* was a more fine-tuned final version of the game, with the same general concept. Contrary to *Hello Neighbor*, the final version of this game had a completely different layout than the open source version of the game, which would not give its players prior knowledge about the layout of the final game. A total of 42 players have reported their playthrough on howlongtobeat.com. Based on the amount of players *Portal 2* is still considered the best game to use.

4.4 Method

To sum up our process of method development, the three main questions that have been answered in the previous sections will be briefly repeated. The following choices were made:

1. *How will wayfinding abilities be quantified within this research?*
   Wayfinding abilities will be quantified through the Wayfinding Questionnaire. Test subjects will be asked to fill in the Wayfinding Questionnaire, which will result in a numerical value on three scales: Navigation and Orientation, Distance Estimation and Spatial Anxiety.

2. *How will gamer skills be quantified within this research?*
   Gamer skills will be quantified by using the time of completion of the first playthrough. This measure was chosen as one could argue that the faster the player finished the game, the faster the player navigated through the levels. By using the time spent on the first playthrough, prior knowledge of the layout is reduced. Test subjects will report their own first playthrough time in a questionnaire and the format will be hours:minutes:seconds.

3. *Which game will be used as a tool to conduct the research?*
   The game *Portal 2* was chosen to be used within this research, because wayfinding abilities are necessary to play the game. The game has a big group of players that are relatively easy to approach and the game is a relatively linear game, which leads the player from the beginning to the end without too much ability to roam freely.

The first playthrough time will be compared to the scales of the Wayfinding Questionnaire. If participants finish the game *Portal 2* very quickly, this research hypothesizes that they will have higher scores at the three scales of the Wayfinding Questionnaire, meaning that they are better at wayfinding than people with lower scores or a longer playtime. Furthermore, the data of gamer participants will be compared to the data of general participants of earlier research. (Van der Ham, I. J. M. *et al*., 2013; Claessen, M. H. G. *et al*., 2016a; Claessen, M. H. G. *et al*., 2016b) This research hypothesizes that the gamer participants have better wayfinding abilities than the general participants.

5. Results

5.1 Participants characteristics

A total of 145 participants answered the Wayfinding Questionnaire. The complete questionnaire can be found in the appendix. This research also had access to a dataset of Wayfinding Questionnaire answers of previous research of 2891 participants (Van der Ham, I. J. M. *et al*., 2013; Claessen, M. H. G. *et al*., 2016a; Claessen, M. H. G. *et al*., 2016b). The 145 participants of this research will be called the “gamer participants” and the participants of earlier research will be called the “general participants”. The self-reported gender and age of the gamer and general participants can be found in table 2.

Gamer participants				**General participants**			
Gender		**Age**		**Gender**		**Age**	
Male	123	Average age	21	Male	1000	Average age	46
Female	16	Maximum age	56	Female	1844	Maximum age	100
Other/Undefined	6	Minimum age	9	Other/Undefined	47	Minimum age	8

Table 2: Gender and Age (years) of the gamer participants and the general participants

The participants were asked how important they thought wayfinding abilities were in *Portal 2*. On a scale of 1 (not very important) to 5 (very important) the participants indicated an average of 4, leaning more towards important than not important. The average first time of completion of *Portal 2* for our sample is approximately 11 hours. This is slightly more than the overall average time of completion at howlongtobeat.com of 9 hours. When asked about the accuracy of their time estimation on a scale of 1 (not very accurate) to 5 (very accurate) the participants indicated an average of 3.

The participants were found in five different places: howlongtobeat.com, *Portal* subreddit[6], Game Theory Discord[7], *Portal 2* Steam forum[8] and acquaintances. Howlongtobeat.com is a website where people can report their playthrough times. The *Portal* subreddit is a community on reddit.com dedicated to the game *Portal* and *Portal 2*. The Game Theory Discord is a chat group for fans of the YouTube show Game Theory, which is a show about science in games. The *Portal 2* Steam forum is a forum on the gaming store Steam where people discuss *Portal 2*. Acquaintances are gamer friends of the main investigator on Facebook and/or in real life. Table 3 reports size of samples split per source of participants.
The participants were asked how accurate their time estimate of the first playthrough of Portal 2 was on a scale of 1 (not very accurate) to 5 (very accurate). An ANOVA test was performed on self-assessed accuracy and the source of data. There is a significant difference between self-assessed accuracy and source, with a significance of p=0.008. Outcomes can be considered significant if p<0.05. Participants from Steam were the most certain about their estimation and participants from reddit.com were the least certain. The self-assessed accuracy and the mean playthrough time per source is shown in table 3.

Participants		**Playthrough time**		**Accuracy**	
Source	*n*	Mean	SD	Mean	SD
Howlongtobeat.com	17	9.327	2.388	3.59	1.064
Portal subreddit	102	11.467	6.305	2.84	1.041
Game Theory discord	3	9.444	2.859	3.67	0.577
Portal 2 Steam forum	2	7.667	6.128	4.50	0.707
acquaintances	21	11.052	5.673	3.29	1.102
Total	**145**	**11.062**	**5.835**	**3.03**	**1.083**

Table 3: Source of participants, number of participants per source, mean the playthrough time and mean self-assessed accuracy of first playthrough time

The participants filled in the Wayfinding Questionnaire (WQ). The WQ consists of three scales: Navigation and Orientation (NO), Distance Estimation (DE) and Spatial Anxiety (SA), which respectively consist of 11, 3 and 8 questions. The participants answer questions on a Likert scale of 1 to 7. The SA scale was reversed to face the same way as the other two scales. Originally a high score on the SA scale meant that the participant has a lot of spatial anxiety. Reversing this scale means that low number on either of the three scales means that the participant is less good at that scale. Now a low score on the SA scale means that the participant has high spatial anxiety (and by extension is worse at wayfinding) just like a low score on the DE scale means that the participant is bad at estimating distances (and by extension is worse at wayfinding). From now on the reserved SA scale (RSA scale) will be used. The outcomes of the three scales of the gamer participants and the general participants can be found in table 4.

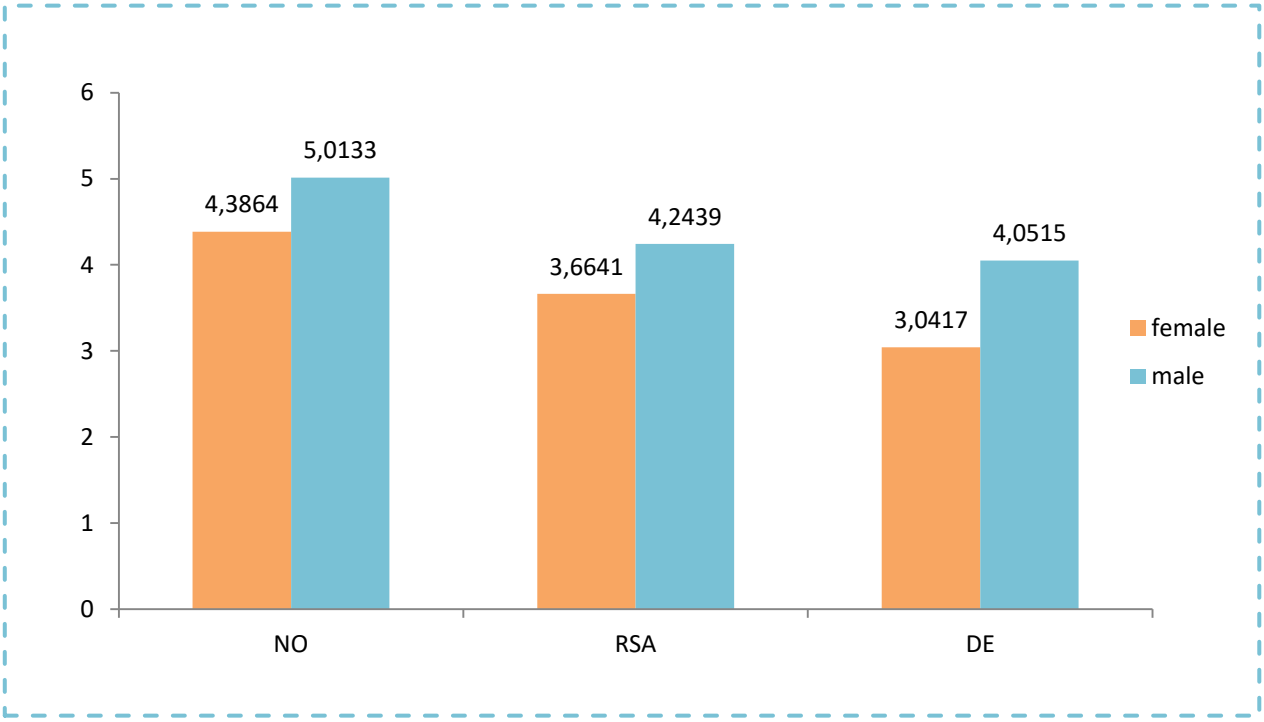
[6] https://www.reddit.com/r/Portal/
[7] https://discordapp.com/invite/23JnSJD
[8] https://steamcommunity.com/app/620/discussions/

The data of this research was compared to the available data of the Wayfinding Questionnaire from previous research. The general participants were used in research of stroke patients. The dataset of 2891 general participants consists of control groups of healthy participants.
A small effect size or Cohen's *d*=0.09 was found on the NO scale. An effect size of between *d*=0.00 and *d*=0.20 is considered small, an effect size of *d*=0.20 to *d*=0.50 is considered medium and an effect size above *d*=0.50 is considered large. Cohen's *d*=0.09 indicates that the gamer participants are slightly better at navigation and orientation than the data from previous research. A large negative effect of *d*=-0.69 was found on RSA and a medium negative effect of *d*=-0.29 was found on DE, indicating that the gamer participants score lower on the DE and RSA scales than the general participants. (table 4)

Scale	Mean WQ scales gamer participants		Mean WQ scales general participants		Cohen's *d*
	Mean WQ scales	SD	Mean WQ scales	SD	
NO	4.9023	1.0056	4.8380	1.15123	0.06
DE	3.8802	1.2531	4.2858	1.31758	-0.29
RSA	4.1523	1.2360	5.0560	1.39944	-0.69

Table 4: Mean of Wayfinding Questionnaire scales of *n*=145 gamer participants, mean of Wayfinding Questionnaire of all WQ data for *n*=2891 general participants and Cohen's *d* per scale.

Despite the difference between the number of male (*n*=123) and female participants (*n*=16), there is a significant difference between gender and two of the three scales of the Wayfinding Questionnaire. An ANOVA test was performed on gender and the three subscales. Males score higher on the NO scale than females with a significance of *p*=0.016. On the DE scale males score higher than females with a significance of *p*=0.001. On the RSA scale males score higher than females, but this positive correlation is not significant (*p*=0.076). The mean of the Wayfinding Questionnaire scales per gender can be found in graph 2.



Graph 2: Mean of Wayfinding Questionnaire scales per gender

5.2 Internal consistency of the Wayfinding Questionnaire

The answers of the Wayfinding Questionnaire of 145 gamer participants were analyzed. The three scales of the Wayfinding Questionnaire, Navigation and Orientation (NO), Distance Estimation (DE) and reversed Spatial Anxiety (RSA) are significantly correlated.

There is a positive correlation of r=0.620 between NO and DE, meaning that if a participant has a higher score on NO, he will also have a higher score on DE. There is also a positive correlation between DE and RSA and a positive correlation between NO and RSA. All of the correlations between the three scales are significant and can be found in table 5.

Scale	**Correlations**			**Cronbach's Alpha (α)**
		NO	DE	
NO	Pearson Correlation (*r)* Sig. (*p)* *n*			0.859
DE	Pearson Correlation (*r)* Sig. (*p)* *n*	0.620 <0.001 145		0.752
RSA	Pearson Correlation (*r)* Sig. (*p)* *n*	0.405 <0.001 145	0.285 0.001 145	0.844

Table 5: Correlations of the Wayfinding Questionnaire scales: Navigation and Orientation (NO), Distance Estimation (DE) and reversed Spatial Anxiety (RSA) and the Cronbach's Alpha scores per scale

All three subscales of the Wayfinding Questionnaire are reliable. The NO scale has a Cronbach's Alpha score of α=0.859, the DE scale has a score of α=0.752 and the RSA scale has a score of α=0.844. A Cronbach's Alpha score between α=0.700 and α=0.800 is considered acceptable and a Cronbach's Alpha score above α=0.800 is considered good. The only scale that has a score below α=0.800 is the DE scale, but this could be attributed to the fact that this scale only consists of 3 questions. An acceptable or good Cronbach's Alpha means that comparable answers are given to questions within a scale. For example: participants who give a low answer on one NO scale question will also give low answers on other NO scale questions. The Cronbach's Alpha scores can be found in table 5.

5.3 Self-assessed gamer and wayfinding skills

The gamer participants were asked to assess their own gamer and wayfinding skills. When estimating their wayfinding abilities on a scale of 1 (I am very bad at wayfinding) to 5 (I am very good at wayfinding) the participants averaged on 4, suggesting that on average the participants consider themselves good at wayfinding. The participants were also asked to estimate their gamer skills on a scale of 1 (not very experienced) to 5 (very experienced). The participants indicated an average of 4. On average, the gamer participants are leaning towards being experienced gamers.

When comparing their own assessments of their wayfinding abilities with the scores of the Wayfinding Questionnaire, the results are significantly positively correlated. The score the gamer participants gave their own wayfinding abilities is positively correlated with all three scales. This means that a higher assessment of their own wayfinding abilities is also shown through a higher score on the NO, DE and RSA scales. (table 6)

When comparing the self-assessment of gamer skills of the gamer participants with the outcomes of the Wayfinding Questionnaire, a significant correlation that was found between self-assessed gamer skills and the DE scale and the NO scale. It is a positive correlation, meaning that if participants assess that their gamer skills are high, they also tend to be better at distance estimation and navigation and orientation. (table 6)

Self-assessed gamer skills were also compared to self-assessed wayfinding abilities. A positive correlation of r=0.355 was found between the two, with a significance of p<0.001. This indicated that if a participant is confident about their wayfinding abilities, they are also confident about their gaming abilities.

Question	**Correlations**			
		NO	DE	RSA
How would you estimate your own wayfinding abilities?	Pearson Correlation (*r*) Sig. (*p*) *n*	0.576 <0.001 145	0.332 <0.001 145	0.384 <0.001 145
How would you estimate your own gamer skills?	Pearson Correlation (*r*) Sig. (*p*) *n*	0.207 0.013 145	0.249 0.002 145	0.067 0.421 145

Table 6: The correlation between self-assessed wayfinding abilities and the Wayfinding Questionnaire scales and correlation between self-assessed gamer skills and the Wayfinding Questionnaire scales

5.4 Wayfinding abilities and gamer skills

The way to quantify "good" gamer skills within this research is the first time of completion of the first playthrough of *Portal 2*. This measure is compared to the scores of the three subscales of the Wayfinding Questionnaire. No significant positive or negative correlations were found between the self-reported first playthrough time and the scales of the Wayfinding Questionnaire. (table 7)

Scale	**Correlations**	
		First playthrough time
NO	Pearson Correlation (*r*) Sig. (*p*) *n*	0.059 0.479 145
DE	Pearson Correlation (*r*) Sig. (*p*) *n*	0.028 0.738 145
RSA	Pearson Correlation (*r*) Sig. (*p*) *n*	0.050 0.548 145

Table 7: The correlation between the first playthrough time and the Wayfinding Questionnaire scales

When only using the first playthrough times of gamer participants (n=55) who indicated that their time was accurate or very accurate (self-assessed accuracy score 4 or 5) on a scale of 1 (not very accurate) to 5 (very accurate), no significant correlation was found between the first playthrough time and the scales of the Wayfinding Questionnaire.

The averages of self-assessed accuracy were also measured per source. When only using the first playthrough time of participants (n=14) of the three most accurate sources, no significant correlation was found.

The age difference between when the participants played *Portal 2* and the age that they are now was also calculated. Participants with a small difference between their current age and the age they played the game have played *Portal 2* more recently than participants with a bigger age gap. Participants who have played the game recently could have a more accurate time estimate than people who have not. When only using the first playthrough times of participants (n=54) who have played *Portal 2* within two years prior to the time of this research with the subscales of the Wayfinding Questionnaire, no significant correlation was found.

6. Conclusion

The main research question this study has been trying to answer is: Are people who have good wayfinding abilities also good at playing video games? This question was answered by comparing the time of the first playthrough of *Portal* 2 to the outcome of the three scales of the Wayfinding Questionnaire for 145 gamer participants.

In order to answer the main research question a literature study was conducted. Some conflicting information was found about the use of virtual environments and wayfinding abilities. A study by Goerger (1998) suggests that virtual environments do not contribute to enhancing spatial knowledge, whereas a study by Ruddle (1997) suggests that it does contribute to spatial knowledge. The difference in results could be explained by the complexity of the virtual environment and the amount of time the participants were allowed to take. A study by Darken & Peterson (2001) emphasizes that it is wrong to assume that if someone can navigate a virtual space well, that they can navigate the real equivalent well. The study advices caution in using a video game environment as a virtual environment in research, as video game players often have higher spatial abilities than non video game players. As this research not only made use of a video game environment, but also specifically targeted gamers as test participants, there is a chance that the participants are above averagely good at wayfinding. The participant group might be too homogeneous and this could influence the results. A study by Adams & Mayer (2013) used the first *Portal* game to research spatial abilities. *Portal*'s gameplay is very comparable to *Portal 2.* Playing *Portal* caused an increase in the spatial abilities of the participants. This too can imply that the participants of this research are above average at wayfinding. (Adams, D. M., & Mayer, R. E., 2013)

An interesting aspect to mention about most of the gaming research referenced within this research is that most researchers are not experts when it comes to gaming. Gaming research itself is a young field of study and it is possible that some research simplifies the field. Dorval & Pépin (1986) make use of old games that are not really comparable to games like *Portal 2.* Feng & Pratt (2007) do make use of more modern games, but they used only 48 participants in their study and only two games (a game they define as an action game and a game they define as a puzzle game) and they use these games to make statements about the entire genres of games. Being inexperienced in an increasingly more complex field of study does not invalidate the results of some of these studies, but it is important to be critical about methods and results in (gaming) research.

In our study, there are 16 female participants and 123 male participants. Females make up approximately 10% of the total participants. Statistica.com[9] shows that there has been a gender difference in video gamers from 2006 until 2017 (the last year for which data was available) with a difference of about 40% female gamers and 60% male gamers. Those numbers differ greatly from the gender difference found within this research. Statistica.com does not take video game genre into account. It is possible that puzzle-action games, such as *Portal 2* are not popular among female players. Another possibility is that there are female players of *Portal 2*, but they did not know their first playthrough time. It is also possible that the population of the sources used within this research is more male than female. Statistica.com[10] shows statistics about reddit.com, the biggest source of participants within this research. The gender difference in 2016 2017 (the last year for which data was available) on reddit.com was approximately 30% female and 70% male. Despite female participants taking up about 10% of the total participants, a significant difference was found between wayfinding abilities and gender. Male participants scored higher on two of the three Wayfinding Questionnaire subscales (NO and DE) than females. The data of the RSA scale of this test group does lean towards a male advantage, but it is not significant. Perhaps this is because of the low number of female participants, which could influence the results.

[9] https://www.statista.com/statistics/232383/gender-split-of-us-computer-and-video-gamers/

[10] https://www.statista.com/statistics/517155/reddit-user-distribution-usa-gender/

The answers of the Wayfinding Questionnaire of 145 gamer participants were analyzed. The three scales of the Wayfinding Questionnaire, Navigation and Orientation (NO), Distance Estimation (DE) and reversed Spatial Anxiety (RSA), are significantly positively correlated, meaning that if a participant has a higher score on one scale, he or she tends to have a higher score on the other scales. The three scales also have an acceptable to good internal reliability in this participant group. This is in line with previous studies of the Wayfinding Questionnaire. (Van der Ham, I. J. M. *et al*., 2013; Claessen, M. H. G. *et al*., 2016a; Claessen, M. H. G. *et al*., 2016b)
The self-assessed wayfinding abilities of participants were also compared to the three scales of the Wayfinding Questionnaire and a positive correlation was found. Since both the question "How would you estimate your own wayfinding abilities?" and the Wayfinding Questionnaire are self-assessments, it makes sense that if participants are confident about their abilities on the single question, they will likely be confident on the questions of the Wayfinding Questionnaire.
When comparing the assessment of gamer skills of the participants with the outcomes of the Wayfinding Questionnaire, a significant correlation that was found was between self-assessed gamer skills and the DE scale and the NO scale. It is a positive correlation, meaning that if a participants assesses that their gamer skills are high, they are also better at distance estimation and navigation and orientation. Again this could be explained by the confidence of the participant on self-assessment questions, despite the question subject – wayfinding abilities and gaming – being different. It is likely that participants who assess their own gaming abilities high also assess their wayfinding abilities high.

The main research question remains to be answered. The first playthrough time of the main story of *Portal 2* was compared to the three scales of the Wayfinding Questionnaire and no significant correlations were found.
There are a couple of factors that could influence these results. The first factor has already been mentioned in this conclusion, namely that the participant group is too homogeneous. Studies by Schmidt-Daly (2016) and Darken & Peterson (2001) suggested that gamers have better spatial abilities than non-gamers. When comparing the data of the 145 gamer participants of this research to the available data of the WQ from previous research of 2891 general participants (Van der Ham, I. J. M. *et al*., 2013; Claessen, M. H. G. *et al*., 2016a; Claessen, M. H. G. *et al*., 2016b), the gamer participants only score slightly higher on Navigation and Orientation with a small Cohen's *d* effect size of d=0.09. The gamer participants score lower on Distance Estimation and Spatial Anxiety than a general participant group. The difference on Distance Estimation could possibly be explained by the small amount of questions in this scale as it exists of only three questions. It is interesting to see that the gamer participants have a lot more Spatial Anxiety than the other participant group. The average age of the other participant group is 46 years old compared to the 21 years old of the participants of this research, so perhaps age is a factor in Spatial Anxiety. The comparison suggests that the gamer participants are slightly better at Navigation and Orientation, but are worse at Distance Estimation and Spatial Anxiety. It is possible that there are gamers among the general participants, as these participants were not asked if they were gamers in previous research. This could influence the difference between the two groups.
Accuracy of the self-reported playthrough time might also be a factor that influenced the results of the main research question. It is possible that participants misremembered their playthrough time or were dishonest with their estimation. Dishonesty is a factor we cannot prove or disprove, but there are three ways that accuracy can be estimated within this research. First of all, the participants were directly asked how accurate their time estimation was. When using only the playthrough times of gamers that estimated that they were accurate or very accurate (n=55) in the comparison of the first playthrough time and the Wayfinding Questionnaire scores, no significant Pearson Correlation was found.
The second way to estimate accuracy among the participants is through accuracy by source. This research also looked at the different answers per source. Howlongtobeat.com was expected to have the most accurate playthrough time estimations, as it is a website specifically made to log the

playthrough times of various games. The results show that the Steam forum (*n*=2) had the most accurate time estimations, followed by the Game Theory discord (*n=3)* in second place and howlongtobeat.com (*n*=17) in third place. The difference between the sources was significant when using an ANOVA test, but the small amount of participants in certain sources (such as Steam forum and Game Theory discord) does need to be taken into account. Even though the source of participants did influence the accuracy of the playthrough time, no significant Pearson Correlation was found when comparing the first playthrough times of the gamer participants of the three most accurate sources (*n*=14) to the Wayfinding Questionnaire scores.

The third way to estimate accuracy is through looking at when the participants played *Portal 2.* Participants who have played the game recently could have a more accurate time estimate than people who have not. When only using the first playthrough time of participants (*n=54*) who have played *Portal 2* within two years prior to the current time with the subscales of the Wayfinding Questionnaire, no significant Pearson Correlation was found. The accuracy of the time estimation did not influence the results of the main research question.

Another factor that can influence the results of the main research question is prior knowledge of the game, and therefore a biased playthrough time. Such prior knowledge was partially avoided by choosing the *first* playthrough time. The participants have not played the game before, thus prior knowledge is minimized. The only way participants could have prior knowledge is if they have watched someone else play the game before. This can be done by physically sitting next to someone playing the game or by watching a playthrough online (e.g. via YouTube). Within this research prior knowledge by watching someone else play the game is considered to be of little influence. *Portal 2* is a long game and watching someone else play it does not do justice to the large layout of the game and the influence the sudden change of perspective through the use of portals has.

It is also possible that the first playthrough time simply is not a good quantifier for gamer skills. Research using the first playthrough time as a quantifier for gamer skills has not been done before. This study argued that when participants play the game for the first time, they will have better gamer skills if they finish the game faster.

It could also be possible that there are other factors than just gamer skills or wayfinding abilities that influence the playthrough time. *Portal 2* is also a puzzle game and if participants get stuck on certain puzzles that will increase their playthrough time. *Portal 2* is a game that is divided in chapters. It is possible that a gamer takes a break from playing Portal 2 after a chapter is done. This could take the gamer out of the flow of the game and the gamer must potentially familiarize with the environment and the puzzles again. The first playthrough time could also be longer because the player is taking their time taking in the environment and enjoying themselves. This does not mean that the player is not good at gaming, it simply means that they are gaming at their own comfortable pace. The first playthrough time would be a better indication of gamer skills if the player was actively told to play the game as fast as possible. Perhaps a shorter and even more straightforward game had to be chosen as the tool for this research, even though that could have negatively influenced the amount of participants that could be reached. Alternatively, players from the population under study here could be asked to play a shortened version or section of *Portal 2* as quickly as possible.

This research started out with the question of why I could find my way around in video games, but not in real life and it evolved into wayfinding abilities in reality and wayfinding abilities in virtual reality. This research does not offer a conclusive suggestion for the use of virtual environments for training purposes. For future work it would be interesting to build a virtual environment, specifically a video game, that is straightforward and where navigational abilities are necessary to complete it. Taking inspiration from some of the other games considered for this research, namely *Hello Neighbor* and the *Slender* games, the game for future research should be a maze game where the player is chased by a monster. In this way the player is encouraged to find their way as quickly as possible in order to avoid being caught by the monster. The time of completion of this video game would be compared to the outcome of the Wayfinding Questionnaire. In order to stay in line with the current research method of crowd-sourcing participants through several online gaming-themed forums, this

game should be publicly available online and should clearly measure when a player starts and finishes. Perhaps with a more controlled environment, less distractions of puzzles and storylines and time estimations that are measured and not self-assessed, the correlation between wayfinding in virtual reality and wayfinding in reality can be re-evaluated.

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Appendix

Questionnaire

Participant characteristics

What is your gender?

- Female
- Male
- Other:

How old are you now?

How old were you roughly when you finished your first playthrough of Portal 2? *

How long did it take you to beat the main story of Portal 2 on your first playthrough? *
Estimate how long it took from waking up in the Relaxation Chamber until reaching the surface. This does not include playing any bonus levels or playing co-op mode.
Hours:Min:Sec

How accurate is your time estimation? *
This question is about your time estimation on the previous question. Your time estimation is considered very accurate if you know for certain the time to the minute or second. Your time estimation is considered not very accurate if it is a broad estimation. Both 'Very accurate' and 'Not very accurate' answers are equally appreciated and will be used in this research.

Not very accurate	1	2	3	4	5	Very accurate

On what platform did you play Portal 2? *

- PC
- Playstation 3
- Xbox 360
- Other:

How would you estimate your own gamer skills? *

Not very experienced	1	2	3	4	5	Very experienced

How would you estimate your own wayfinding abilities? *

I am very bad at wayfinding	1	2	3	4	5	I am very good at wayfinding

How important are wayfinding abilities when playing Portal 2? *

Not very important	1	2	3	4	5	Very important

What is your <source> username?
Three participants will be randomly selected to receive a free drawing of their own choosing. Some conditions will apply. Please leave your <source> username here if you want to enter the raffle. It is not mandatory to answer this question. If you do not want to enter the raffle, you can skip this question.

The Wayfinding Questionnaire

1. When I am in a building for the first time, I can easily point to the main entrance of this building. *

Not at all applicable to me	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***Fully applicable to me***

2. If I see a landmark (building, monument, intersection) multiple times, I know exactly from which side I have seen that landmark before. *

Not at all applicable to me	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***Fully applicable to me***

3. In an unknown city I can easily see where I need to go when I read a map on an information board. *

Not at all applicable to me	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***Fully applicable to me***

4. Without a map, I can estimate the distance of a route I have walked well, when I walk it for the first time. *

Not at all applicable to me	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***Fully applicable to me***

5. I can estimate well how long it will take me to walk a route in an unknown city when I see the route on a map (with a legend and scale). *

Not at all applicable to me	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***Fully applicable to me***

6. I can always orient myself quickly and correctly when I am in an unknown environment. *

Not at all applicable to me	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***Fully applicable to me***

7. I always want to know exactly where I am (meaning, I am always trying to orient myself in an unknown environment). *

Not at all applicable to me	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***Fully applicable to me***

8. I am afraid of losing my way somewhere. *

Not at all applicable to me	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***Fully applicable to me***

9. I am afraid of getting lost in an unknown city. *

Not at all applicable to me	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***Fully applicable to me***

10. In an unknown city, I prefer to walk in a group rather than by myself. *

Not at all applicable to me	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***Fully applicable to me***

11. When I get lost, I get nervous. *

Not at all applicable to me	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***Fully applicable to me***

How uncomfortable are you in the following situations (items 12, 13 and 14):

12. Deciding where to go when you are just exiting a train, bus, or subway station. *

Not uncomfortable at all	***1***	***2***	***3***	***4***	***5***	***6***	***7***	**Very uncomfortable**

13. Finding your way in an unknown building (for example a hospital). *

Not uncomfortable at all	***1***	***2***	***3***	***4***	***5***	***6***	***7***	**Very uncomfortable**

14. Finding your way to a meeting in an unknown city or part of a city. *

Not uncomfortable at all	***1***	***2***	***3***	***4***	***5***	***6***	***7***	**Very uncomfortable**

How applicable are the following situations (items 15 - 22):

15. I find it frightening to go to a destination I have not been before. *

Not at all applicable to me	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***Fully applicable to me***

16. I can usually recall a new route after I have walked it once. *

Not at all applicable to me	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***Fully applicable to me***

17. I am good at estimating distances (for example, from myself to a building I can see). *

Not at all applicable to me	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***Fully applicable to me***

18. I am good at understanding and following route descriptions. *

Not at all applicable to me	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***Fully applicable to me***

19. I am good at giving route descriptions (meaning, explaining a known route to someone). *

Not at all applicable to me	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***Fully applicable to me***

20. When I exit a store, I do not need to orient myself again to determine where I have to go. *

Not at all applicable to me	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***Fully applicable to me***

21. I enjoy taking new routes (for example shortcuts) to known destinations. *

Not at all applicable to me	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***Fully applicable to me***

22. I can easily find the shortest route to a known destination. *

Not at all applicable to me	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***Fully applicable to me***

Other questions

Would you like to read the final version of the graduation thesis?

You have to give your email address on the final question of this questionnaire in order to receive the graduation thesis.

- Yes
- No

Would you like to enter the raffle for a drawing of your choice?
Three participants will be randomly selected to receive a free drawing of their own choosing. Some conditions will apply. You have to give your <source> username or your email address on the final question in order to enter the raffle.

- Yes
- No

If you want to receive the graduation thesis or enter the raffle, please enter your contact information below.
If you do not want to receive the graduation thesis or enter the raffle, you can skip this question.