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How Egocentric Distance Estimation Changes in Virtual Environments by Using a Desktop Display or the Gear VR*

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Abstract

Due to the importance of depth perception in virtual spaces, the combined effects of display devices and human factors on egocentric distance estimation were investigated. We developed a virtual environment that can assess distance estimation skills of users at 10 various distances, starting from 25 cm and ending at 160 cm. Our results show that people are either accurate or overestimate distances on a desktop display, while underestimation occurs with the Gear VR in most cases. Combined with display devices, human factors also had effects on distance estimates. With the Gear VR, 35.73% – 57.14% faster estimation times were obtained, and these can also be influenced by human factors and distances.

Keywords: desktop display, distance estimation, Gear VR, human-computer interaction, immersion, virtual reality

1 Introduction

The definition of *egocentric distance* is the distance between the observer and the object. The perception of egocentric distances is crucial as it is required for reaching, grasping, and interception tasks [4, 25]. Since this is a cognitive skill, it can be

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trained over time [26]. As virtual spaces can stimulate cognitive functions [19, 22], this skill can be improved using virtual reality (VR) technologies [1]. Since VR also redefines human-computer interfaces, interaction with VR applications can differ between each of them [20]. When designing and creating virtual environments (VEs), developers should also focus on humans [9, 33]. They are equally important as other, non-human parts of a VR system [32, 21, 15], and they also play a crucial role in it [5]. Because humans are important in such a system, cognition is also of crucial importance [2, 17]. Therefore, VEs should be carefully designed, since they can affect spatial skills [29, 14, 11].

Due to the complexity of a VR system, several factors can affect egocentric distance estimation. These include human, technical, and compositional factors, along with distance itself [31, 34]. Consequently, distances are perceived differently in VEs [35, 18]. Depending on the display device used and distances, accuracy of estimates can change in a VR system. We also examined in another study that display devices can affect egocentric distance estimation [13]. For improved depth perception, users should be provided with binocular disparity [31, 8, 24]. Regarding human factors, gender could have an effect [10, 6], although there are conflicting observations in the literature [7, 16, 28]. Murgia and Sharkey assessed the height of participants, but no significant effects were observed in their research [27]. However, according to another study [23], if the virtual height is varied, an effect could appear. Age can also influence distance estimation [30]. As shown in the study by Bian and Andersen [3], the accuracy of distance estimates can increase with age. In our other study [12], we came to the conclusion that the possibilities of correct estimates can be affected by multiple human factors.

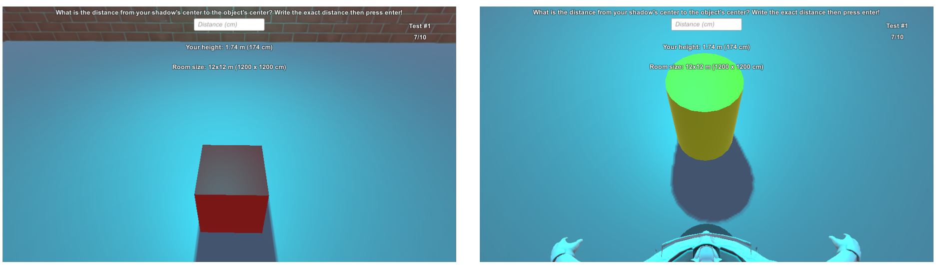
Naturally, there are other human factors beside gender, height, and age. Therefore, to understand the effect of several human factors, we evaluated multiple factors in addition to gender and height. In other words, we investigated the influence of handedness, video game playtime a week, what the participants study, and whether they wore glasses or had previous VR experience. Regarding technical factors, we examined immersion level with two display devices: a desktop display and the Gear VR. We also formed the following research question: *Does immersion level combined with these human factors influence egocentric distance estimation and its time?* To find an answer to this research question, we have developed a VE that can be used with the two display devices mentioned above. We used this VE to assess the egocentric distance estimation skills of several participants. While we have assessed the influence of human factors on the probabilities of correct distance estimates and the effect of display devices on estimates in other studies [13, 12], we have not compared the actual results grouped by human factors.

The structure of the article is as follows. In Section 2, we detail the materials and methods used in this research. Section 3 shows the results, while they are discussed in Section 4. Conclusions can be found in Section 5.

2 Materials and methods

The aforementioned VE can be used with a desktop display on PC, or with the Gear VR on Android. The used desktop display was an LG 20M37A (19.5”) device, while the Gear VR had a Samsung Galaxy S6 Edge+ inside it. Overall, the egocentric distance estimation skills of 239 participants were measured. 157 people ($min_{age} = 17, max_{age} = 38, M_{age} = 19.80, SD_{age} = 2.09$) used the desktop display, while 72 ($min_{age} = 18, max_{age} = 42, M_{age} = 22.51, SD_{age} = 6.63$) used the Gear VR. Those participants who used the desktop display were either civil engineering, mechanical engineering, or vehicle engineering students. Contrarily, those who used the Gear VR were IT students. Participants joined the study of their own volition and no names were gathered. Before the measurements commenced, they had to input some parameters such as the age, gender, height, etc. in the VE’s menu.

Participants could not move in the VE. Only the virtual camera could be rotated either with a mouse on PC or with their head on Android. This camera was placed at their actual height. Everyone had to estimate the egocentric distances to cubes, spheres, or cylinders between 25 cm and 160 cm at 15 cm intervals. Each of these had to be estimated twice in randomized order. Therefore, they had to estimate distances 20 times, one per round. For the last 10 rounds, a scale appeared on the ground. This scale consisted of 17 cubes and the dimension of each was 10 cm × 10 cm × 10 cm. In the PC version, the estimates had to be entered into an input box, while the participants had to verbally estimate in the Android version and a researcher typed the estimates into the dataset at the same time. Then, the participants had to look up at the ceiling and press enter or the touchpad on the Gear VR to advance to the next round. Figure 1 shows a test on the PC version.



(a) A test with a cube.

(b) A test with a cylinder.

Figure 1: Two tests with different objects.

If a round was finished, the collected data would be saved into a CSV file. Therefore, all human, technical, and display factors were written in a line inside the previously mentioned file. Even compositional factors were saved, but they were not focused on in this research. Each participant had 20 lines of data as there were 20 round on the test. It should be noted that before the whole procedure started, participants were informed about the process. We told them how to look around the VE and how to estimate in the respective version of the virtual space. The room's dimensions and scale's dimensions were also told to them. However, they were not informed about the investigated distances as well as the 15 cm intervals. We only mentioned that the distance was never zero. Still, zero was entered 10 times on PC, and one time in the VR version. For participating in the research, the students were motivated with extra points on certain subjects at the university. However, few students estimated distances very quickly, indicating that they only participated in the study because of the extra points. This could explain the outlier values.

Data distributions were assessed with the Shapiro-Wilk test in both versions. Neither the distribution of estimates in the PC version was Gaussian ($W = .88,\ p < .001$), nor in the Android version ($W = .79,\ p < .001$). The distributions of estimation times were also non-Gaussian in the PC ($W = .71,\ p < .001$), and in the Android version ($W = .68,\ p < .001$). Thus, the Wilcoxon rank sum test was used when either the estimates or their times were compared between platforms, while the test's signed rank variant was used for comparing the estimates to the actual distances. An $\alpha = .05$ was chosen for the analyses. This value represents the probability of committing a Type I error, which occurs when the null hypothesis is incorrectly rejected. This α value also establishes a threshold against which p-values are compared to determine statistical significance. In other words, if $p \leq .05$, we can consider the results statistically significant and we can reject the null hypothesis. If $p > .05$, we cannot consider the results statistically significant, meaning there is insufficient evidence to reject the null hypothesis.

3 Results

This section is divided into multiple subsections. Each of them involve results regarding a human factor. Before presenting them, however, the general results are shown in this section. The results regarding estimates are observable in Figure 2, while those that involve estimation times are presented in Figure 3. Box plots were used to illustrate the results. They allow to see the minimum, maximum values, the median, the quartiles and the outliers in a graphical form. Outlier values are shown with dots, while the median is represented by a black line in the boxes.

The same distances on both platforms were compared. The two smallest differences were at 145 cm ($W = 25514,\ p = .026$), and at 160 cm ($W = 25814,\ p = .014$). The differences were strongly significant for the remaining distances as $p < .001$.

When we compared the estimates with the actual distances in the PC version, not all of them were significant; however, most of them was overestimated. Between 40 cm and 160 cm, these were below 10%. Significant overestimates were found at 130 cm ($V = 20885,\ p = .017$), and at 160 cm ($V = 21559,\ p = .014$).

Contrarily, when comparing the estimates with actual distances in the Android version, most underestimates occurred at all distances except at 25 cm. Therefore, the distances were overestimated for the latter. The results of the comparisons were the following: 25 cm ($V = 2610,\ p = .001$), 40 cm ($V = 1426,\ p < .001$), 55 cm

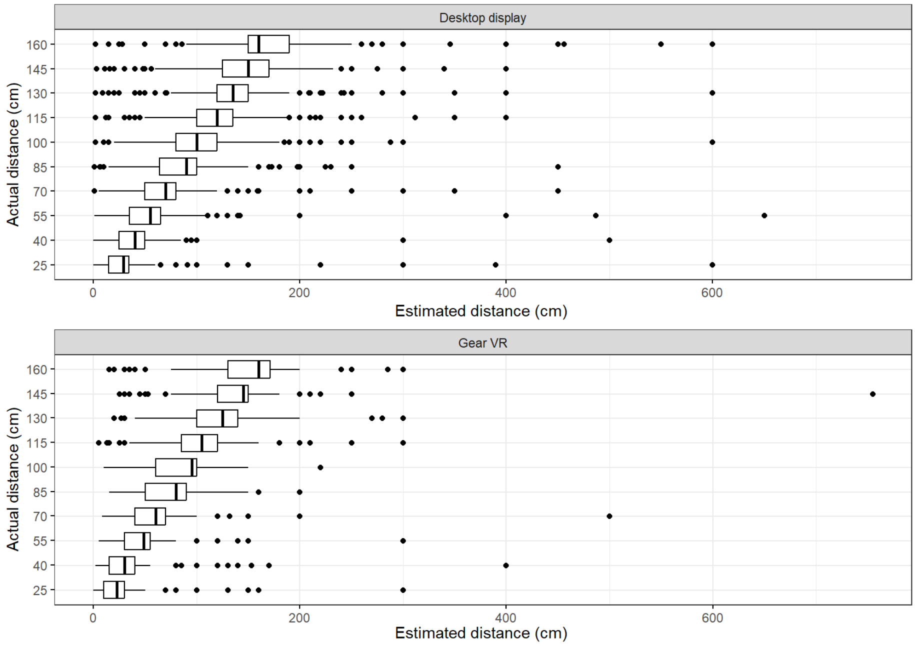


Figure 2: Estimates on both versions at every investigated distance.

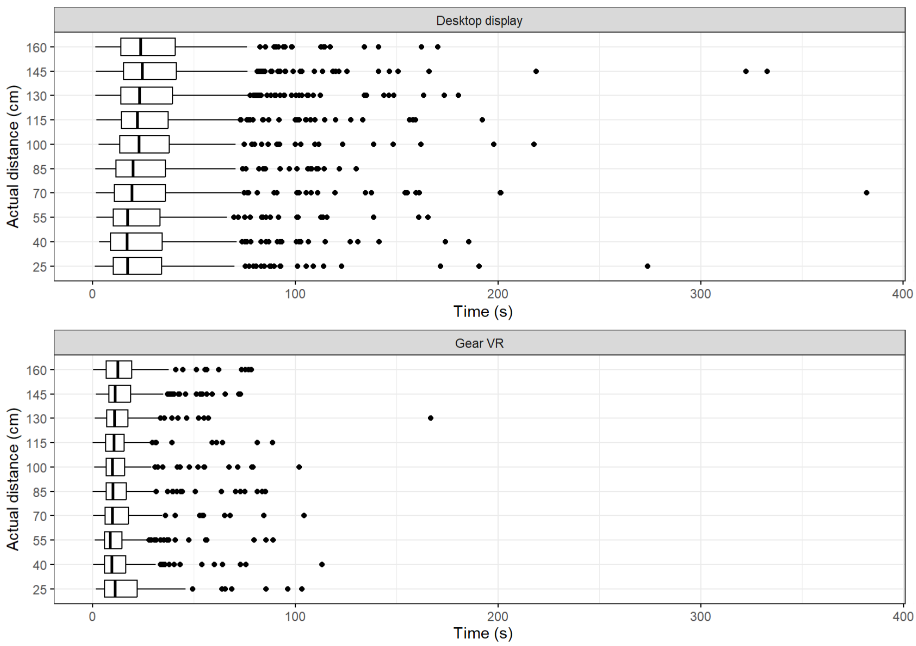


Figure 3: Estimation times on both versions at every investigated distance.

($V = 1718,\ p < .001$), 70 cm ($V = 1301,\ p < .001$), 85 cm ($V = 2224,\ p < .001$), 100 cm ($V = 976,\ p < .001$), 115 cm ($V = 2893,\ p < .001$), and 130 cm ($V = 2334,\ p < .001$). The underestimates at 145 cm and 160 cm were not significant.

As can be seen in Figure 3, estimation times were also compared between platforms. The results show that those who used the Gear VR, were significantly faster in estimating distances ($29260 \leq W \leq 35550,\ p < .001$). Depending on the distances, the distance estimation process of the students became faster by 35.73% – 57.14%.

3.1 Analyses by gender

128 males and 29 females used the PC version, while 49 males and 23 females used the Android version. Their estimates and estimation times can be observed in Figures 4 and 5. When comparing estimates to actual distances in the PC version, the following two significant differences were found in case of males: at 40 cm ($V = 9762,\ p < .032$) and at 70 cm ($V = 9124.5,\ p = .015$). In case of females, only one significant difference was found at 160 cm ($V = 943,\ p = .043$). However, in the Android version, the number of significant differences increased. For males, they were found between 25 cm and 130 cm ($393.5 \leq V \leq 1304,\ p < .015$). Contrarily, in case of females they were observable up to 115 cm ($111.5 \leq V \leq 317.5,\ p < .038$). Overall, males were 31.44% and 34.38% accurate in the PC and Android versions, respectively. The accuracy of females was 34.65% and 40.43%, respectively.

Regarding estimation times, they were significantly different between display devices at all distances in case of males ($17191 \leq W \leq 20103,\ p < .001$). However, in terms of females, these types of differences were only found between 40 cm and 160 cm ($1826 \leq W \leq 2113,\ p < .001$). Thus, the time it took for females to estimate distances at 25 cm was similar between the investigated display devices.

3.2 Analyses by handedness

122 right-handed and 35 left-handed students used the PC version. The Android version was used by 67 right-handed and 5 left-handed students. Their estimates and estimation times can be seen in Figures 6 and 7. Regarding right-handed students in the case of the PC version, significant differences between estimated and actual distances were found at 40 cm ($V = 8597,\ p = .011$), 70 cm ($V = 8292,\ p = .007$), and 160 cm ($V = 13025,\ p = .037$). Four significant differences were found in case of left-handed students in this version. These were at 25 cm ($V = 1559,\ p = .008$), 100 cm ($V = 888,\ p = .006$), 130 cm ($V = 1497,\ p < .001$), and 145 cm ($V = 1501,\ p = .044$). When the results of right-handed students were analyzed in the Android version, significant differences occurred up to 145 cm ($923 \leq V \leq 3289.5,\ p < .044$). Regarding left-handed students, significant differences could be found up to 115 cm ($0 \leq V \leq 7.5,\ p < .044$). Overall, the accuracy of both groups on both platforms was quite similar. 32.21% and 36.34% of the estimates of the right-handed students were accurate on PC and Android, respectively.

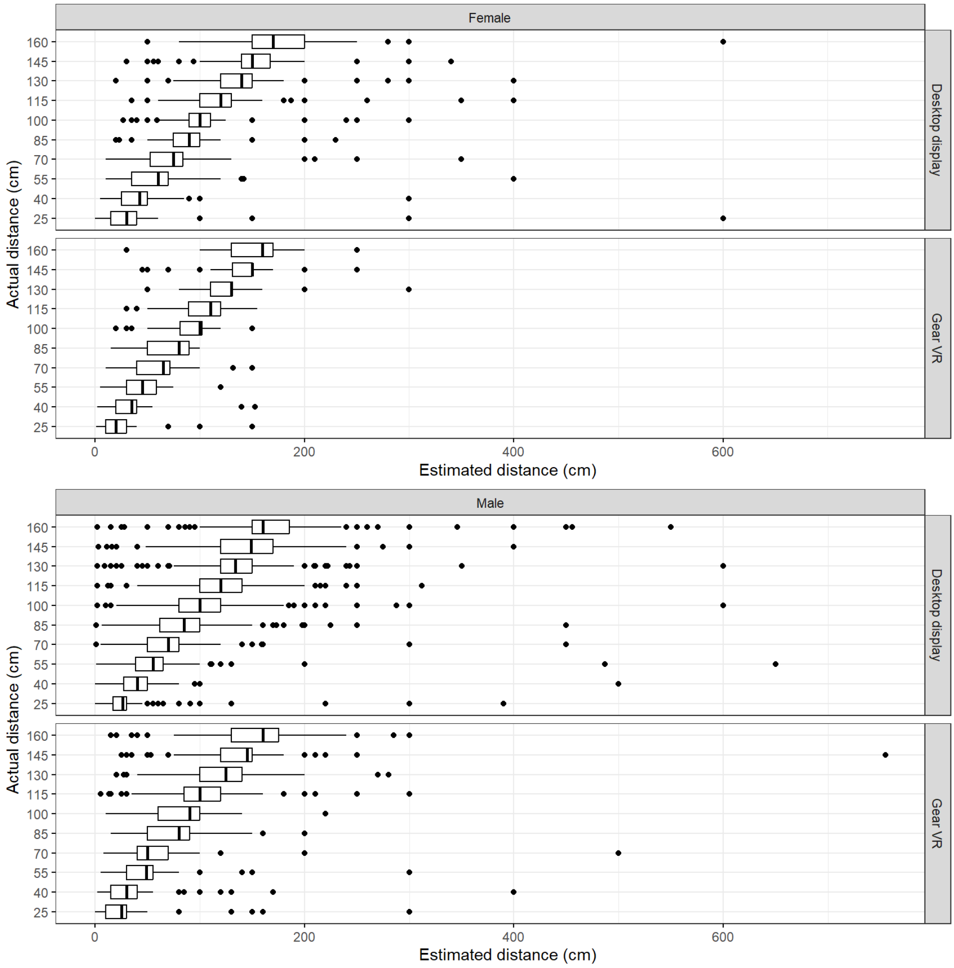


Figure 4: Estimates on both versions at every investigated distance grouped by gender.

31.42% and 36% of the estimates were accurate in the case of left-handed students on the respective two platforms.

When the estimation times were investigated, the following could be observed. The estimation times of right-handed students were significantly different between the two display devices ($21233 \leq W \leq 25401$, $p < .001$). Similarly to females, the estimation times of left-handed students were only significantly different between the display devices from 40 cm to 160 cm ($487 \leq W \leq 634$, $p < .047$).

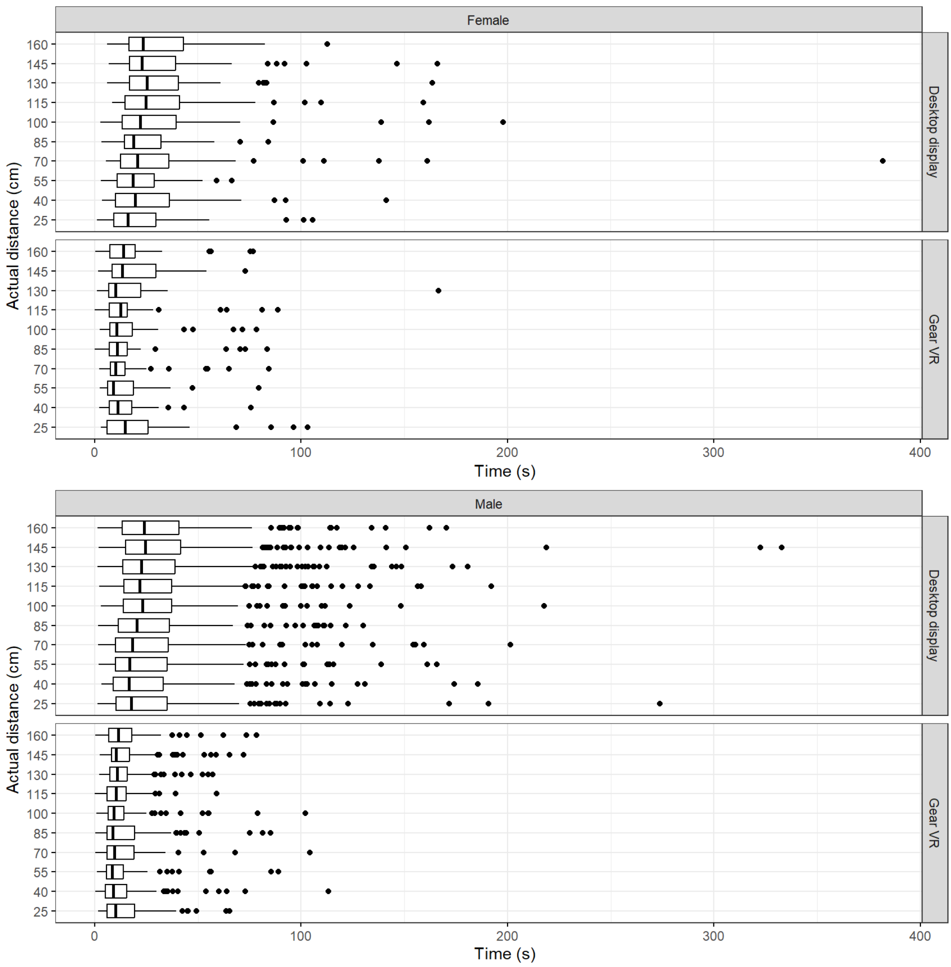
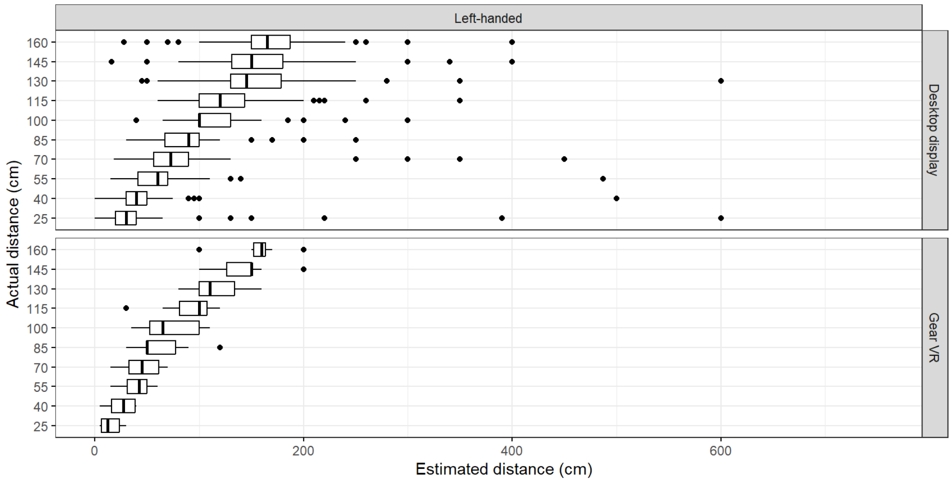


Figure 5: Estimation times on both versions at every investigated distance grouped by gender.



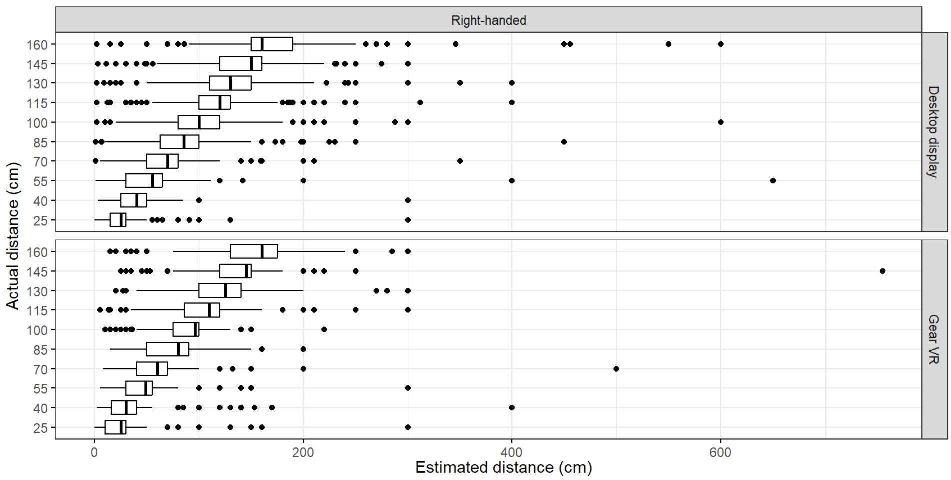


Figure 6: Estimates on both versions at every investigated distance grouped by dominant hand.

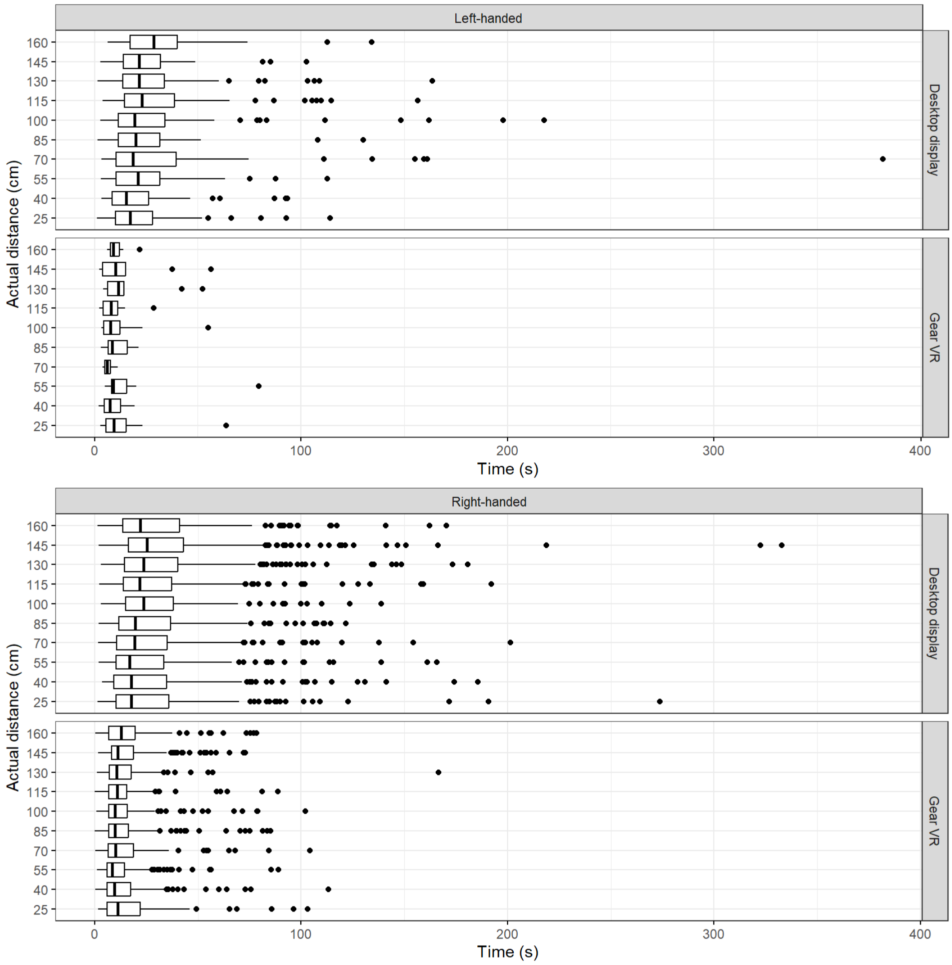


Figure 7: Estimation times on both versions at every investigated distance grouped by dominant hand.

3.3 Analyses by height

The students who took the tests in the PC, had an average height of 178.72 cm, while 175.86 cm in the Android versions. The standard deviations were 9.51 cm and 10.26 cm, respectively. The number of students grouped by display device and height can be seen in Table 1. Their estimates and estimation times can be found in Figures 8 and 9.

Table 1: The number of students in the dataset, grouped by display device and height (cm).

Height (cm)	Desktop display	Gear VR
150–154	2	1
155–159	3	2
160–164	6	7
165–169	16	13
170–174	15	8
175–179	34	13
180–184	30	12
185–189	33	10
190–194	11	3
195–199	5	3
200–204	2	0

The most common height range among students using a desktop display was 175–179 cm (34 students). This was followed closely by students in the 180–184 cm and 185–189 cm ranges. The smallest number of students was in the height range of 200–204 cm. In contrast, students using Gear VR were most frequently found in the 165–169 cm range (13 students). It can also be seen that fewer students were taller than 190 cm, and the number of Gear VR users decreases in the highest height range (200–204 cm, with zero users).

When comparing estimates to actual distances in the PC version, six significant differences were found. The first two were observed in the case of students whose height was between 160 cm and 164 cm. These differences were observed at 85 cm ($V = 67,\ p = .029$), and 160 cm ($V = 52,\ p = .013$). The next three were found when the height of the students was between 175 cm and 179 cm. These were observed at 40 cm ($V = 565,\ p = .024$), 55 cm ($V = 759,\ p = .04$), and 70 cm ($V = 595,\ p = .028$). The last one was observed at 160 cm ($V = 1075.5,\ p = .023$), when the students' height was between 185 cm and 189 cm. 24 significant differences were found in the Android version. One was observed between the heights of 160 cm and 164 cm at 40 cm ($V = 13,\ p = .013$). Six were between the heights of 165 cm and 169 cm among the distances of 25 cm and 100 cm ($8 \leq V \leq 75.5,\ p < .039$). Two were observed between the heights of 170 cm and 174 cm, at the distances of 70 cm ($V = 10.5,\ p = .003$) and 100 cm ($V = 12,\ p = .037$). Seven were between the heights at 175 cm and 179 cm. These were observable between 25 cm and 130 cm ($0 \leq V \leq 73.5,\ p < .016$). Four were observable between the heights of 180 cm and

184 cm, at the distances of 40 cm ($V = 38,\ p = .012$), 55 cm ($V = 46.5,\ p = .016$), 70 cm ($V = 27.5,\ p = .006$), and 100 cm ($V = 8,\ p < .001$). Two were between the heights of 190 cm and 194 cm. These were observable at 115 cm ($V = 0,\ p = .035$), and 145 cm ($V = 0,\ p = .035$). The final one was between the heights of 194 cm and 199 cm at the distance of 130 cm ($V = 0,\ p = .031$).

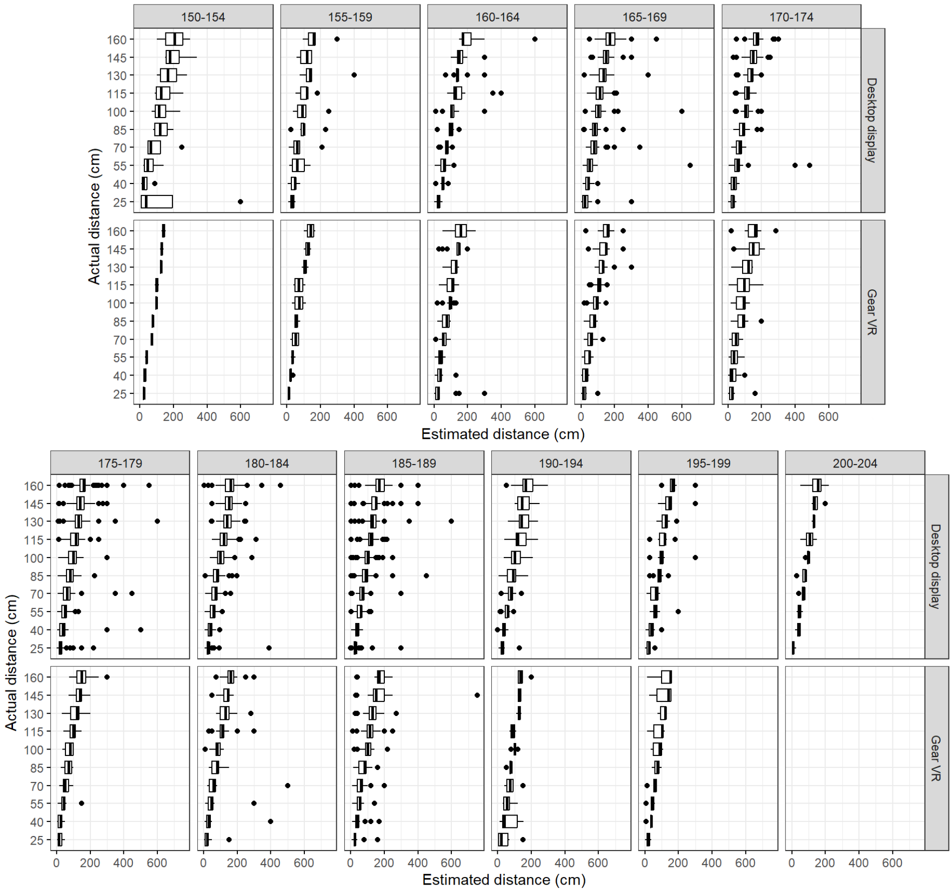


Figure 8: Estimates on both versions at every investigated distance grouped by height.

When the estimation times were examined between the display devices, the following could be observed. There were no significant differences in the height groups of 150–154 cm, 155–159 cm. This was also true for the group of 200–204 cm, although no student was that tall who used the Android version. Starting from the height of 160 cm, significant differences in time appeared from 55 cm. From the height of 170 cm, significant differences started at 25 cm. However, at the height 190 cm or above, the numbers of these differences decreased.

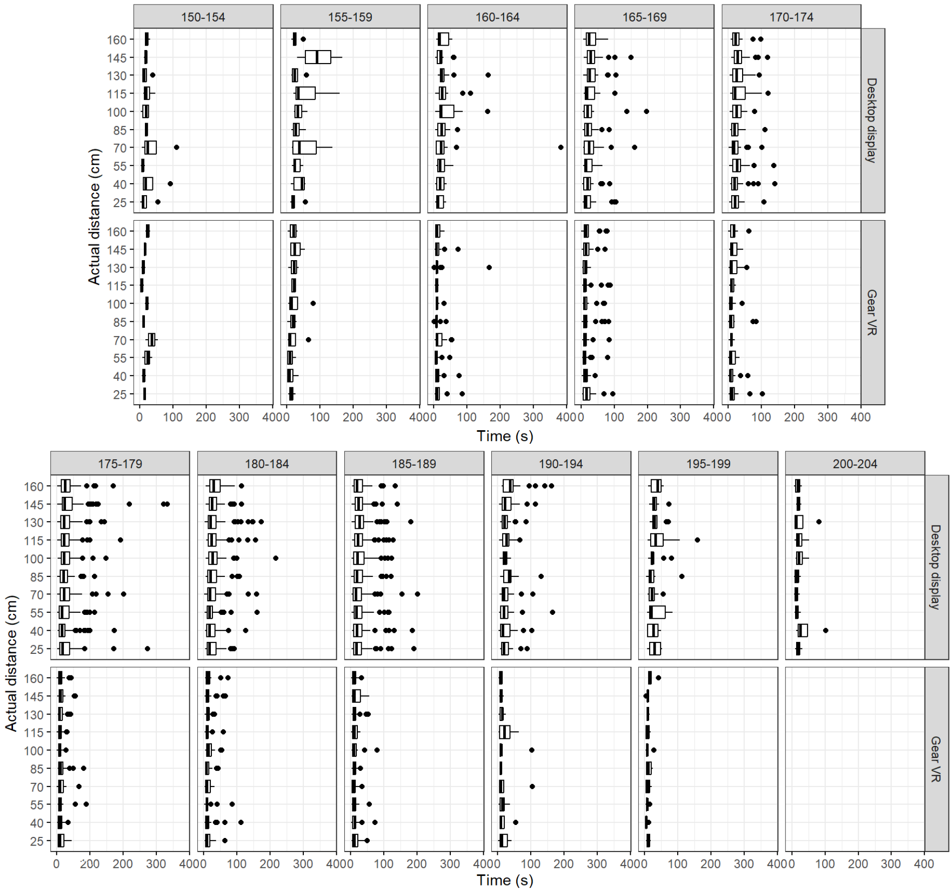


Figure 9: Estimation times on both versions at every investigated distance grouped by height.

3.4 Analyses by whether students wore glasses

In the case of the PC version, 66 students had glasses and 91 did not wear them. These numbers were 32 and 40, respectively, in the Android version. Their estimates and estimation times can be observed in Figures 10 and 11. Regarding students with glasses, three significant differences were found in the PC version when estimates were compared with actual distances. These were found at 130 cm ($V = 3850$, $p = .045$), 145 cm ($V = 4713$, $p = .219$), and 160 cm ($V = 4353$, $p = .022$). One significant difference was observed at 70 cm ($V = 4687$, $p = .037$) in case of students with no glasses. Regarding the Android version, significant differences were found between 40 cm and 115 cm ($194.5 \leq V \leq 620$, $p < .022$) when the results of students with glasses were looked at. In this version, significant differences were found between 25 cm and 130 cm ($295.5 \leq V \leq 849.5$, $p < .001$) in case of students who wore no glasses. Still, those who had glasses were more accurate as their accuracy was 33.63% in the PC, and 40.46% in the Android version, respectively. These numbers were 30.87% and 33% in case of those without glasses, respectively.

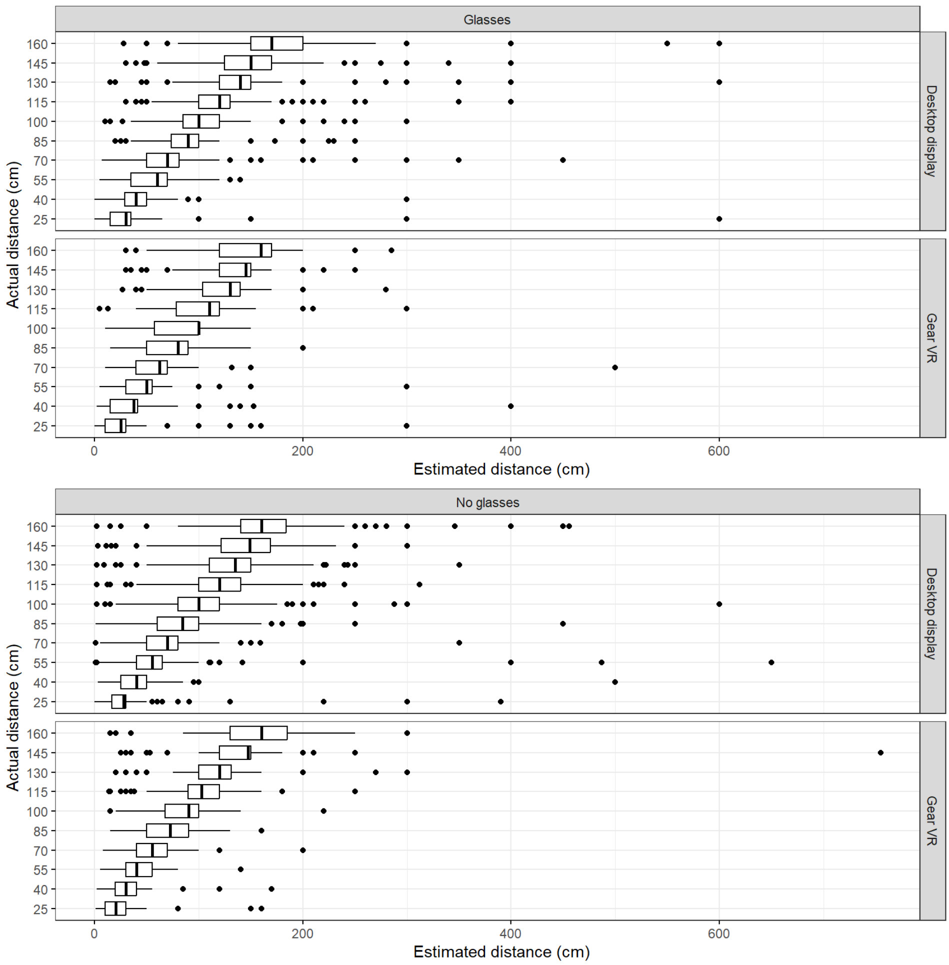


Figure 10: Estimates on both versions at every investigated distance grouped by whether glasses were worn.

Regarding estimation times grouped by whether one wore glasses, the following can be concluded: significant differences in estimation times could be found between the two display devices. These differences were less likely to have occurred by chance in the case of those who had glasses ($5305 \leq W \leq 6506,\ p < .003$), than those who did not wear them ($9582 \leq W \leq 11739,\ p < .001$). Since all were significant, it did not matter whether glasses were worn.

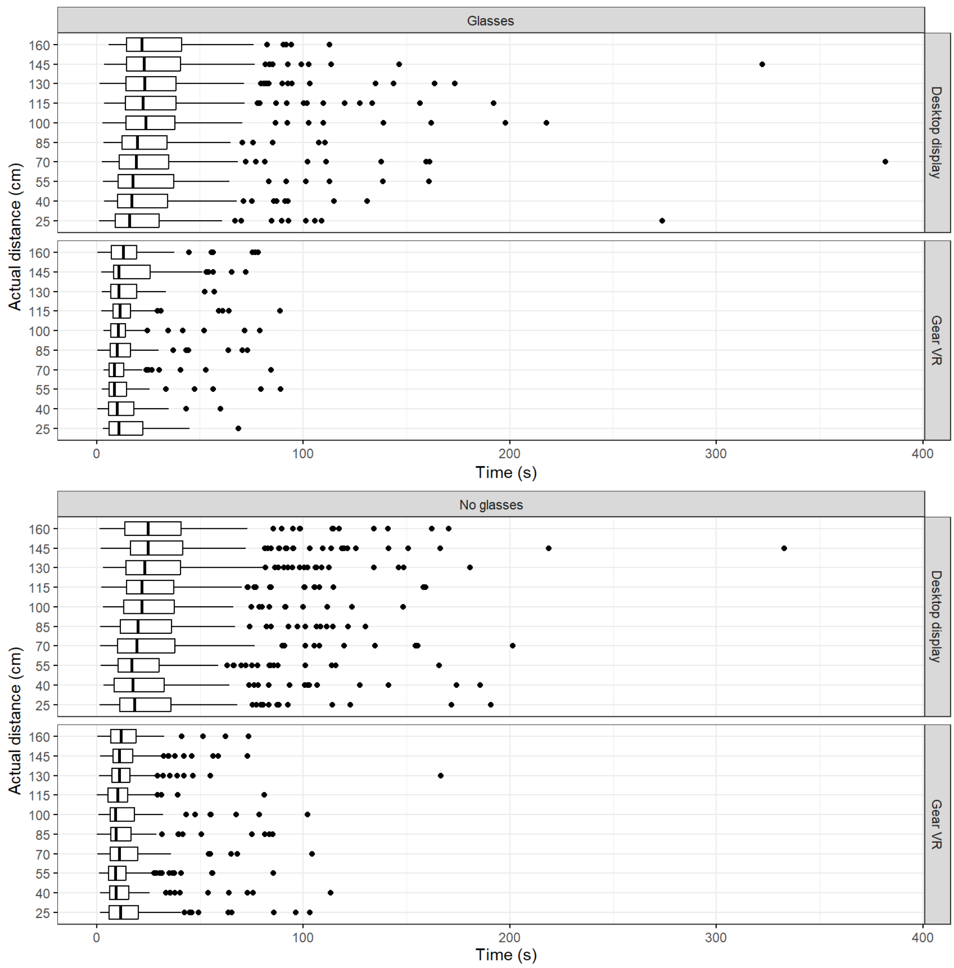


Figure 11: Estimation times on both versions at every investigated distance grouped by whether glasses were worn.

3.5 Analyses by video game playtime a week

According to the students, most of them did not play video games at all. However, many students played video games between 5–10 hours or 11–19 hours a week. The number of students grouped by display device and gaming hours a week can be observed in Table 2. Their estimates and estimation times can be seen in Figures 12 and 13.

Table 2: The number of students grouped by display device and gaming hours a week.

Gaming hours per week	Desktop display	Gear VR
0	42	21
1–2	31	8
3–4	18	8
5–10	32	18
11–19	20	10
20 or more	14	7

As can be seen in Table 2, the majority of students using a desktop display reported either 0 gaming hours (42 students), 1–2 hours (31 students) or 5–10 hours (32 students) per week. Similarly, most Gear VR users also fell into the zero gaming hours category (21 students). In the case of both devices, fewer students engaged in more than 20 hours of gaming per week: only 14 desktop display users and 7 Gear VR users were in this category.

When comparing estimates with actual distances, three significant differences were found between them in the PC version. One was at 25 cm in case of those who do not play video games ($V = 1962.5,\ p = .034$). Another at 70 cm in the case of those who play 1–2 hours a week ($V = 491.5,\ p = .047$), and the last one at 160 cm in the case of those who play 5–10 hours a week ($V = 968,\ p = .011$). Similarly to previous factors, the number of significant differences arose in the Android version. They were found between 40 cm and 85 cm in case of those who play zero hours a week ($71 \leq V \leq 185,\ p < .028$). Significant differences started at 55 cm and ended at 160 cm in case of those who play 1–2 hours a week ($1 \leq V \leq 19.5,\ p < .023$). Three such differences were observed in the case of those who play 3–4 hours a week: at 40 cm ($V = 10,\ p = .043$), 70 cm ($V = 7.5,\ p = .014$), and 100 cm ($V = 12.5,\ p = .04$). Those who play 5–10 hours a week had significant differences between 55 cm and 100 cm ($78.5 \leq V \leq 157.5,\ p < .035$). Two significant differences were observed in case of those tho play 11–19 hours a week: at 55 cm ($V = 26,\ p = .017$), and at 100 cm ($V = 4.5,\ p = .001$). In those who played 20 or more hours, four significant differences were found: at 40 cm ($V = 3,\ p = 051$), 55 cm ($V = 6,\ p = .006$), 70 cm ($V = 9,\ p = .019$), and 100 cm ($V = 2,\ p = .029$). In the PC version, those who did not play video games at all were the most accurate (33.80%). They were followed by students who play 5–10 hours a week (33.12%), 3–4 hours a week (33.05%), 1–2 hours a week (30.64%), 11–19 hours a week (30%), and lastly, 20 or more hours a week (28.92%). In the

Android version, the order of accuracy was the following: those who play 3–4 hours a week (41.25%), zero hours a week (41.11%), 11-19 hours a week (36.5%), 20 or more hours a week (36.42%), 5–10 hours a week (33.33%), and finally, 1–2 hours a week (25%).

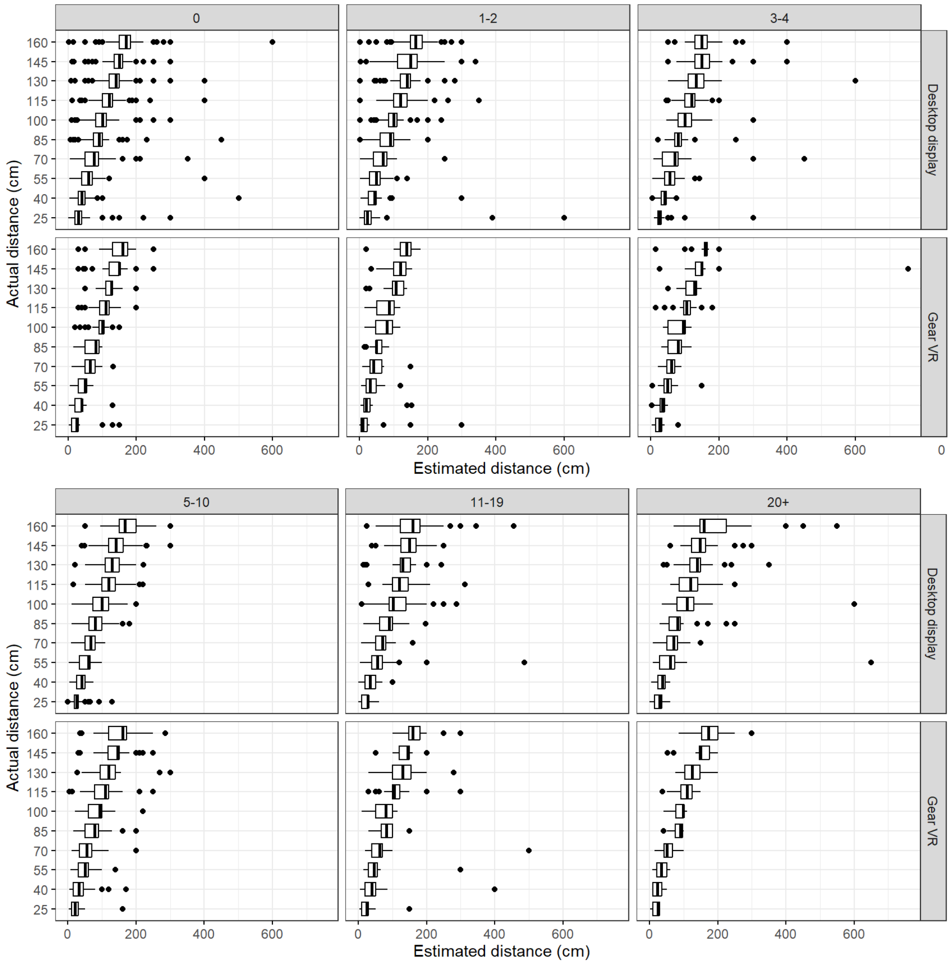


Figure 12: Estimates on both versions at every investigated distance grouped by video game playtime.

Regarding estimation times between the two display devices, the number of non-significant differences increased as the playtime a week increased. The number of such differences was as follows. Zero in the case of those did not play at all, one in the case of those who play 1–2 hours a week (at 25 cm), zero in the case of those who play 3–4 hours a week, one in the case of those who play 5–10 hours a week (at 40 cm), three in the case of those who play 11–19 hours a week (at 25 cm, 40 cm, and 145 cm), and five in the case of those who play 20 hours or more a week (at 25 cm, 40 cm, 55 cm, 70 cm, 85 cm, and 160 cm).

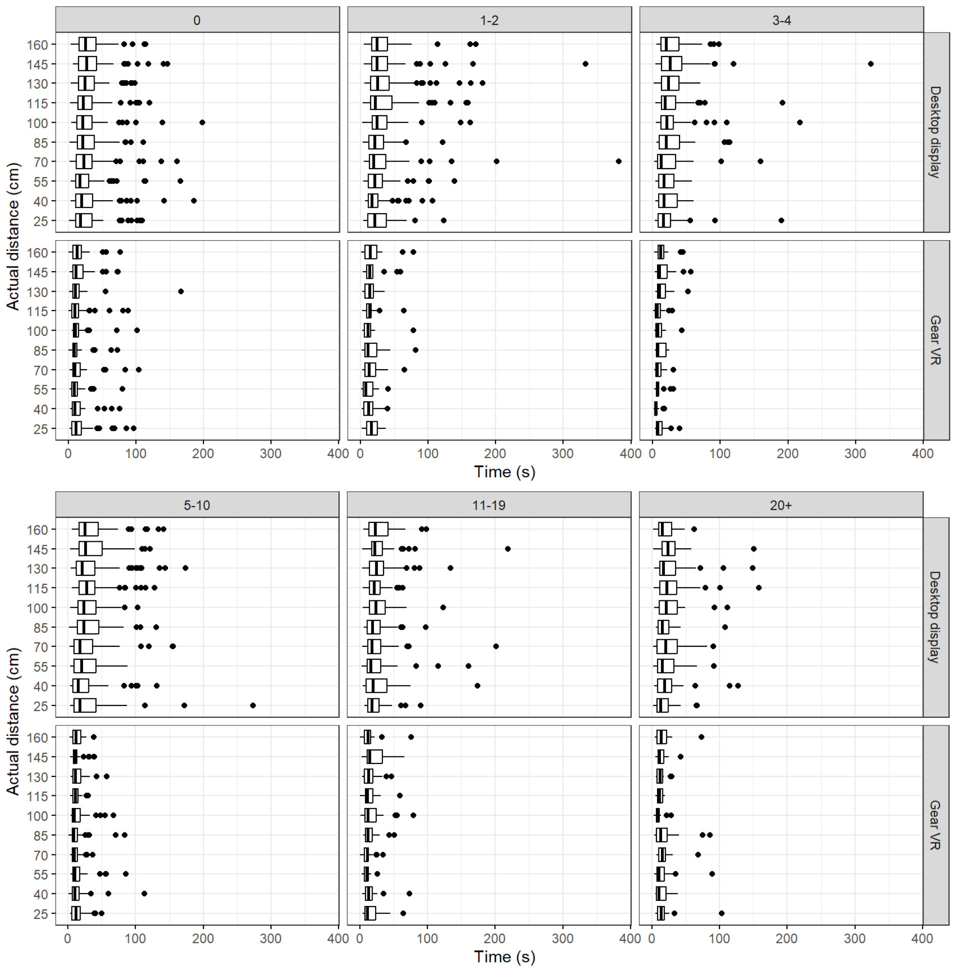


Figure 13: Estimation times on both versions at every investigated distance grouped by video game playtime.

3.6 Analyses by whether the participants had previous VR experience

In the PC version, 57 students indicated that they had previous VR experience, while 100 indicated that they did not. These numbers were 29, and 43 in the Android version, respectively. As before, the estimates were first compared to actual distances. Their estimates and estimation times can be found in Figures 14 and 15. For those who had previous VR experience, only one was found at 145 cm ($V = 3986.5,\ p = .009$) in the PC version. No significant differences were found for those who had no previous VR experience. In the Android version, significant differences could be found from 40 cm to 145 cm in case of people who had previous VR experience ($150.5 \leq V \leq 461.5,\ p < .038$). If those who did not have this kind of experience were investigated, significant differences were observable up to 130 cm ($367 \leq V \leq 1159,\ p < .007$). Regarding the estimates of those people who had previous VR experience, 33.68% of them were accurate in the PC version. This number was quite similar in the Android version: 33.27%. On the contrary, those who did not have this kind of experience were less accurate on PC (31.1%). However, these participants were more accurate in the Android version (38.37%).

When the estimation times were analyzed by whether the participants had previous VR experience, the following could be concluded: Significant differences could be found between the two display devices in both groups at all distances. The significance of the estimation times for those who had previous VR experience was less likely to have occurred by chance ($4444 \leq W \leq 5121,\ p < .001$) than in the case of those who did not have such experience ($10822 \leq W \leq 13602,\ p < .001$). Still, it did not matter whether one had previous VR experience.

3.7 Analyses by what the participants study

From those who used the PC version, 81 were civil engineering, 27 were mechanical engineering, and 49 were vehicle engineering students. All those who used the Android version were IT students (72). As this fact reduced the number of possible comparisons, only the estimates of engineering students were compared to each other. Their estimates can be observed in Figure 16. According to the results, four significant differences were found. One regarding civil engineering students at 40 cm ($V = 3789,\ p = .031$). Two in the case of mechanical engineering students, one at 130 cm ($V = 831.5,\ p = .004$), and another one at 160 cm ($V = 721,\ p = .048$). The last one occurred when the estimates of vehicle engineering students were assessed. It was found at 160 cm ($V = 2236.5,\ p = .043$). Still, possibly due to the Gear VR, IT students were the most accurate with 36.31%. They were followed by vehicle engineering students (34.48%), then civil engineering students (32.40%), and lastly, mechanical engineering students (26.48%).

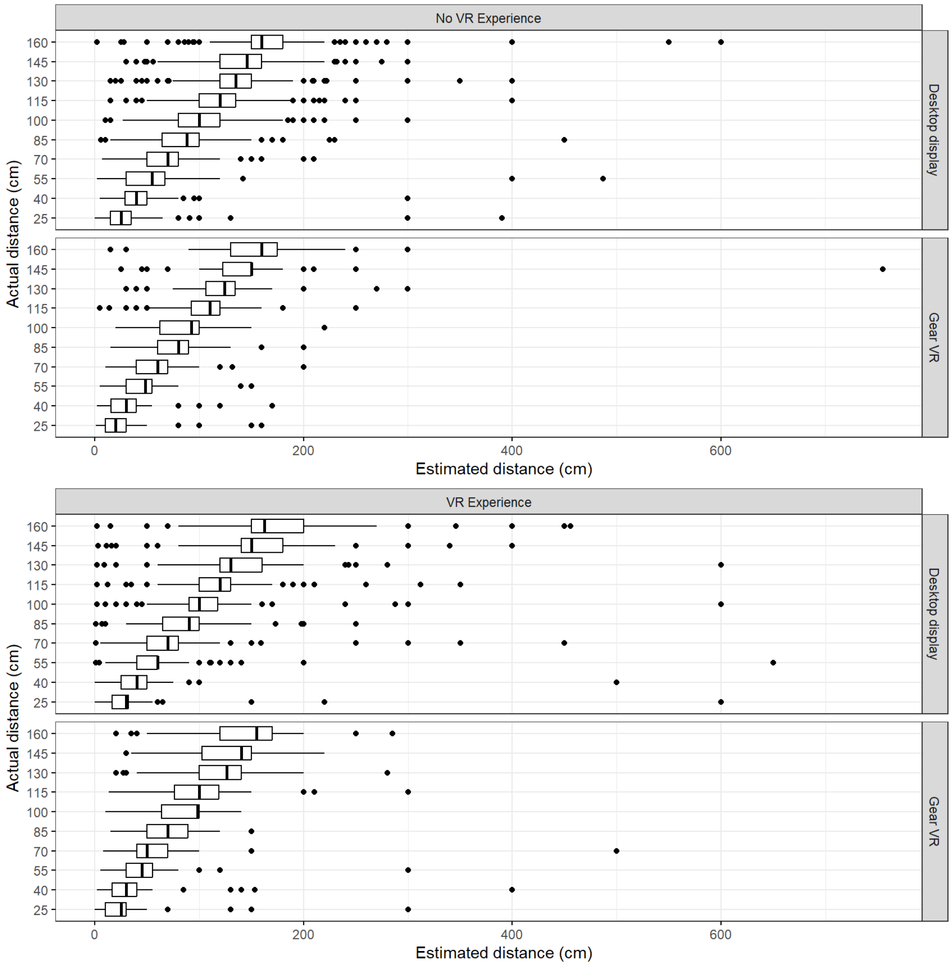


Figure 14: Estimates on both versions at every investigated distance grouped by whether one had previous VR experience.

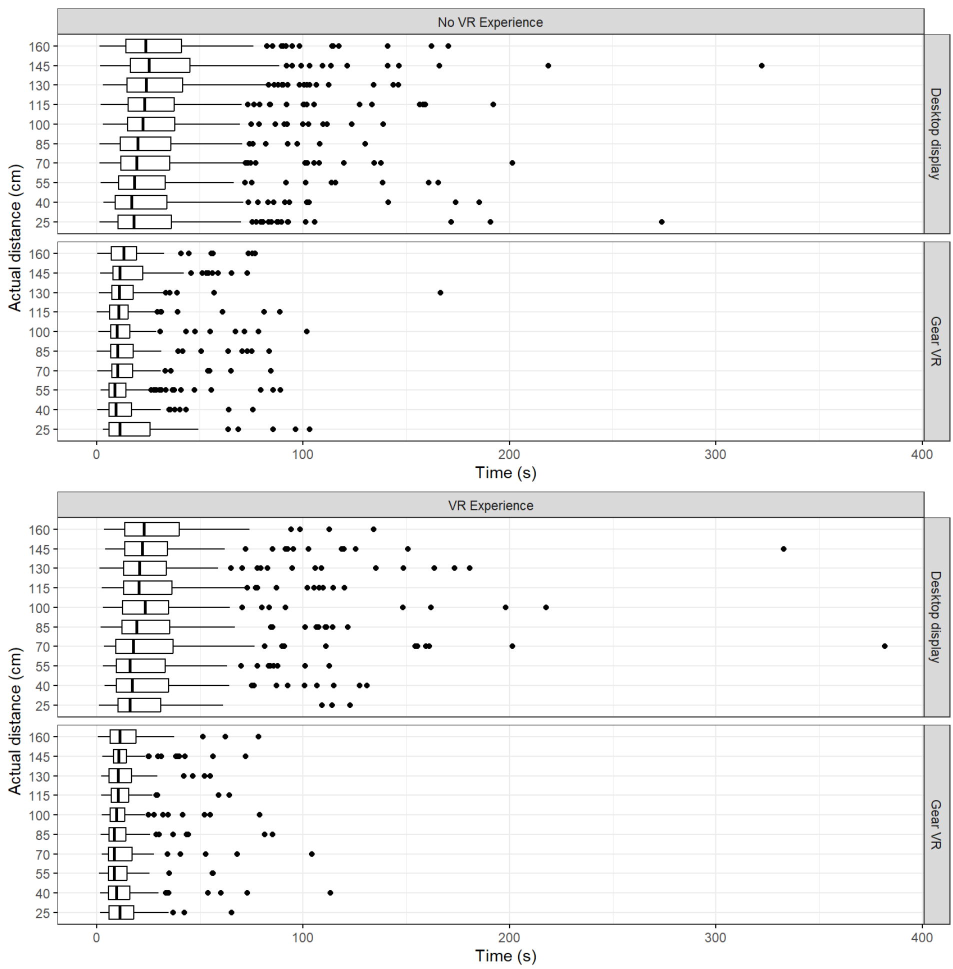


Figure 15: Estimation times on both versions at every investigated distance grouped by whether one had previous VR experience.

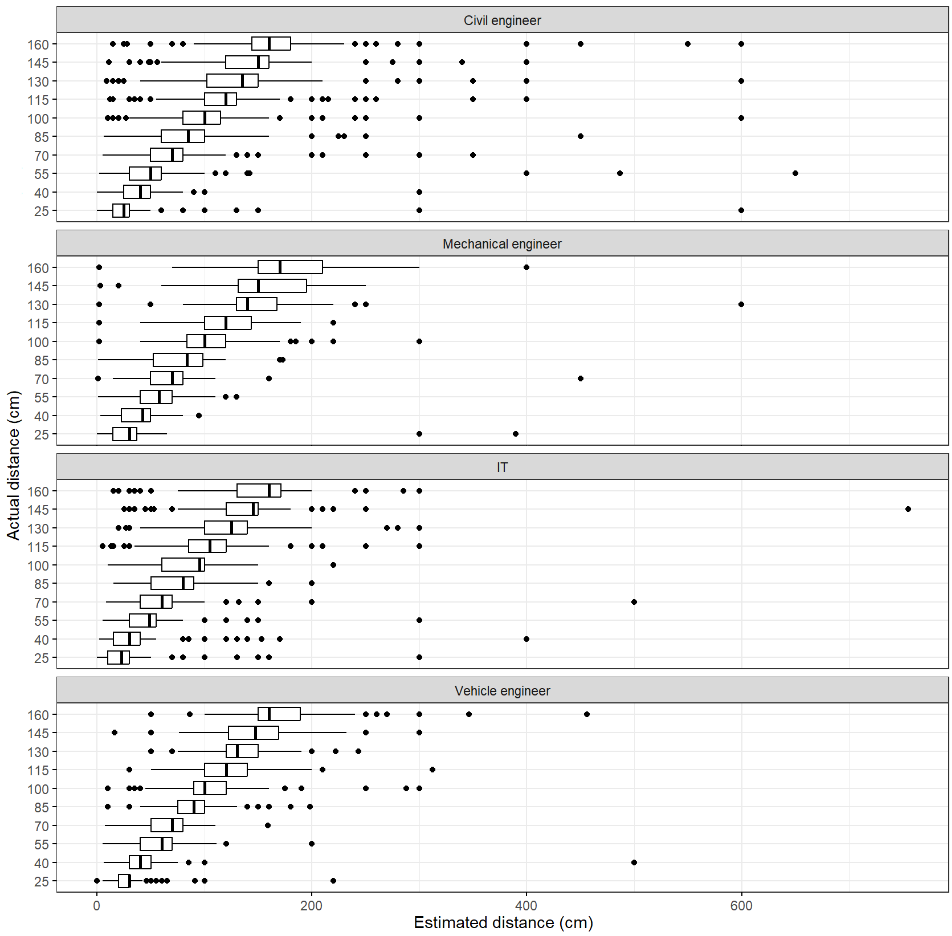


Figure 16: Estimates at every investigated distance grouped by what the participants study.

4 Discussion

The results show that our research question was answered. Naturally, display devices have an effect on distance estimation by themselves [29, 31, 8, 24]. By combining immersion levels with human factors, both the egocentric distance estimation process and estimation time can be influenced. In addition to this fact, each factor had a different effect on them.

Regarding the effects of gender, there is no consensus in the literature. Some say that it does not have a significant effect on distance estimation [7, 16, 28]. However, some studies have mentioned that it actually has an effect [10, 6]. Our results show that females had better accuracy than males in both versions. Gender can also influence estimation times. We also found that the time of females was similar between both versions at 25 cm.

The effect of handedness was smaller, as the difference between the accuracy of both groups was small in both versions. Still, the estimation times of left-handed students were similar between the two versions at 25 cm.

Also, according to multiple studies, distance estimation is not affected by height [6, 27]. However, we found that students in certain groups can estimate distances differently. The estimation times of the students in the height groups of 150–159 cm and 190–199 cm had zero or few significant differences between the display devices. All others were significantly different.

Students with glasses had more significant differences between estimates and actual distances than those who did not wear them in the PC version. The reverse of this statement could be observed in the Android version. Regarding estimation times, whether one wore glasses or not did not had an effect on them.

The number of hours of playing video games a week can also have effects on both estimates and estimation times. No pattern was found with respect to the estimates. However, the more the students played, the more non-significant differences occurred regarding estimation times.

Whether students had previous VR experience provided interesting results. Those who did not have such experience performed the best on the Gear VR. Whether having previous VR experience in the PC version did not influence the estimates. The case was similar with estimation times. This factor did not affect them.

Lastly, it was assessed whether the studies of the participants affected the estimates. When comparing the three types of engineering students, it could be observed that the studies had a small influence. Estimation times were not compared due to having different types of students on each display device.

5 Conclusions

A VE was developed to assess egocentric distance estimation skills of university students. In addition to the components of VEs, display devices and human factors are crucial for the estimation process. Depending on the level of immersion, either overestimation or underestimation can occur. In general, students were more likely to overestimate distances to objects at 130 cm and 160 cm with a desktop display. With the Gear VR, they underestimated distances to objects that were 40 cm–130 cm away, while overestimation occurred when objects were 25 cm away from them. However, each human factor had different effects on estimates and estimation times. By using the Gear VR, estimation times can also be decreased by 35.73%–57.14% depending on the human factors and distances. The designers of future VEs have to keep these in mind.

References

[1] Backlund, P., Engstrom, H., Hammar, C., Johannesson, M., and Lebram, M. Sidh – a game based firefighter training simulation. In *2007 11th International Conference Information Visualization (IV'07)*, pages 899–907. IEEE, 2007. DOI: 10.1109/IV.2007.100.

[2] Baranyi, P., Csapo, A., and Sallai, G. *Cognitive infocommunications (CogInfoCom)*. Springer, 2015. DOI: 10.1007/978-3-319-19608-4.

[3] Bian, Z. and Andersen, G. J. Aging and the perception of egocentric distance. *Psychology and aging*, 28(3):813, 2013. DOI: 10.1037/a0030991.

[4] Bingham, G. P. Calibration of distance and size does not calibrate shape information: Comparison of dynamic monocular and static and dynamic binocular vision. *Ecological Psychology*, 17(2):55–74, 2005. DOI: 10.1207/s15326969eco1702_1.

[5] Burdea, G. C. and Coiffet, P. *Virtual reality technology*. John Wiley & Sons, 2003.

[6] Coelho, H., Melo, M., Branco, F., Vasconcelos-Raposo, J., and Bessa, M. The impact of gender, avatar and height in distance perception in virtual environments. In *New Knowledge in Information Systems and Technologies: Volume 2*, pages 696–705. Springer, 2019. DOI: 10.1007/978-3-030-16184-2_66.

[7] Creem-Regehr, S. H., Willemsen, P., Gooch, A. A., and Thompson, W. B. The influence of restricted viewing conditions on egocentric distance perception: Implications for real and virtual indoor environments. *Perception*, 34(2):191–204, 2005. DOI: 10.1068/p5144.

[8] Cutting, J. E. and Vishton, P. M. Perceiving layout and knowing distances: The integration, relative potency, and contextual use of different information about depth. In *Perception of Space and Motion*, pages 69–117. Elsevier, 1995. DOI: 10.1016/B978-012240530-3/50005-5.

[9] Drettakis, G., Roussou, M., Reche, A., and Tsingos, N. Design and evaluation of a real-world virtual environment for architecture and urban planning. *Presence: Teleoperators and Virtual Environments*, 16(3):318–332, 2007. DOI: 10.1162/pres.16.3.318.

[10] Foreman, N., Sandamas, G., and Newson, D. Distance underestimation in virtual space is sensitive to gender but not activity-passivity or mode of interaction. *CyberPsychology & Behavior*, 7(4):451–457, 2004. DOI: 10.1089/cpb.2004.7.451.

[11] Guzsvinecz, T., Orbán-Mihálykó, É., Sik-Lányi, C., and Perge, E. The effects of display parameters and devices on spatial ability test times. *Applied Sciences*, 12(3):1312, 2022. DOI: 10.3390/app12031312.

[12] Guzsvinecz, T., Perge, E., and Szűcs, J. Analyzing Accurate Egocentric Distance Estimates of University Students in Virtual Environments with a Desktop Display and Gear VR Display. *Electronics*, 12(10):2253, 2023. DOI: 10.3390/electronics12102253.

[13] Guzsvinecz, T., Perge, E., and Szűcs, J. Examining the Results of Virtual Reality-Based Egocentric Distance Estimation Tests Based on Immersion Level. *Sensors*, 23(6):3138, 2023. DOI: 10.3390/s23063138.

[14] Guzsvinecz, T., Sik-Lanyi, C., Orban-Mihalyko, E., and Perge, E. The influence of display parameters and display devices over spatial ability test answers in virtual reality environments. *Applied Sciences*, 10(2):526, 2020. DOI: 10.3390/app10020526.

[15] Horvath, I. Innovative engineering education in the cooperative VR environment. In *2016 7th IEEE International Conference on Cognitive Infocommunications (CogInfoCom)*, pages 000359–000364. IEEE, 2016. DOI: 10.1109/coginfocom.2016.7804576.

[16] Interrante, V., Ries, B., and Anderson, L. Distance perception in immersive virtual environments, revisited. In *IEEE Virtual Reality Conference (VR 2006)*, pages 3–10. IEEE, 2006. DOI: 10.1109/VR.2006.52.

[17] Katona, J. A review of human–computer interaction and virtual reality research fields in Cognitive InfoCommunications. *Applied Sciences*, 11(6):2646, 2021. DOI: 10.3390/app11062646.

[18] Kenyon, R. V., Phenany, M., Sandin, D., and Defanti, T. Accommodation and size-constancy of virtual objects. *Annals of Biomedical Engineering*, 36:342–348, 2008. DOI: 10.1007/s10439-007-9414-7.

[19] Korečko, Š., Hudák, M., Sobota, B., Marko, M., Cimrová, B., Farkaš, I., and Rosipal, R. Assessment and training of visuospatial cognitive functions in virtual reality: proposal and perspective. In *2018 9th IEEE International Conference on Cognitive Infocommunications (CogInfoCom)*, pages 39–44. IEEE, 2018. DOI: 10.1109/CogInfoCom.2018.8639958.

[20] Kortum, P. *HCI Beyond the GUI: Design for Haptic, Speech, Olfactory, and Other Nontraditional Interfaces*. Elsevier, 2008.

[21] Kovari, A. CogInfoCom supported education: A review of CogInfoCom based conference papers. In *2018 9th IEEE International Conference on Cognitive Infocommunications (CogInfoCom)*, pages 000233–000236. IEEE, 2018. DOI: 10.1109/COGINFOCOM.2018.8639879.

[22] Kövecses-Gősi, V. Cooperative learning in VR environment. *Acta Polytechnica Hungarica*, 15(3):205–224, 2018. DOI: 10.12700/aph.15.3.2018.3.12.

[23] Leyrer, M., Linkenauger, S. A., Bülthoff, H. H., Kloos, U., and Mohler, B. The influence of eye height and avatars on egocentric distance estimates in immersive virtual environments. In *Proceedings of the ACM SIGGRAPH Symposium on Applied Perception in Graphics and Visualization*, pages 67–74, 2011. DOI: 10.1145/2077451.2077464.

[24] Luo, X., Kenyon, R. V., Kamper, D. G., DeFanti, T. A., et al. On the determinants of size-constancy in a virtual environment. *International Journal of Virtual Reality*, 8(1):43–51, 2009. DOI: 10.20870/ijvr.2009.8.1.2712.

[25] Mazyn, L. I., Lenoir, M., Montagne, G., Delaey, C., and Savelsbergh, G. J. Stereo vision enhances the learning of a catching skill. *Experimental Brain Research*, 179(4):723–726, 2007. DOI: 10.1007/s00221-007-0957-5.

[26] Miller, C. L. and Bertoline, G. R. Spatial visualization research and theories: Their importance in the development of an engineering and technical design graphics curriculum model. *Engineering Design Graphics Journal*, 55(3):5–14, 1991.

[27] Murgia, A. and Sharkey, P. M. Estimation of distances in virtual environments using size constancy. *International Journal of Virtual Reality*, 8(1):67–74, 2009. DOI: 10.20870/ijvr.2009.8.1.2714.

[28] Naceri, A. and Chellali, R. The effect of isolated disparity on depth perception in real and virtual environments. In *2012 IEEE Virtual Reality Workshops (VRW)*, pages 107–108. IEEE, 2012. DOI: 10.1109/VR.2012.6180905.

[29] Naceri, A., Chellali, R., and Hoinville, T. Depth perception within peripersonal space using head-mounted display. *Presence: Teleoperators and Virtual Environments*, 20(3):254–272, 2011. DOI: 10.1162/PRES_a_00048.

[30] Plumert, J. M., Kearney, J. K., Cremer, J. F., and Recker, K. Distance perception in real and virtual environments. *ACM Transactions on Applied Perception (TAP)*, 2(3):216–233, 2005. DOI: 10.1145/1077399.1077402.

[31] Renner, R. S., Velichkovsky, B. M., and Helmert, J. R. The perception of egocentric distances in virtual environments-a review. *ACM Computing Surveys (CSUR)*, 46(2):1–40, 2013. DOI: 10.1145/2543581.2543590.

[32] Schroeder, R., Heldal, I., and Tromp, J. The usability of collaborative virtual environments and methods for the analysis of interaction. *Presence: Teleoperators and Virtual Environments*, 15(6):655–667, 2006. DOI: 10.1162/pres.15.6.655.

[33] Sutcliffe, A. G., Poullis, C., Gregoriades, A., Katsouri, I., Tzanavari, A., and Herakleous, K. Reflecting on the design process for virtual reality applications. *International Journal of Human–Computer Interaction*, 35(2):168–179, 2019. DOI: 10.1080/10447318.2018.1443898.

[34] Viguier, A., Clement, G., and Trotter, Y. Distance perception within near visual space. *Perception*, 30(1):115–124, 2001. DOI: 10.1068/p3119.

[35] Willemsen, P. and Gooch, A. A. Perceived egocentric distances in real, image-based, and traditional virtual environments. In *Proceedings IEEE Virtual Reality 2002*, pages 275–276. IEEE, 2002. DOI: 10.1109/VR.2002.996536.