PeriFocus: Examining the Effects of Peripheral Color and Shape Detection in Virtual Reality

Alexandru-Orestis Giuran
agiura17@student.aau.dk

Mathias Alen Mikkel Meineche Halilovic
mhalil16@student.aau.dk

Mads Aagaard Thomsen
math15@student.aau.dk

ABSTRACT

This paper examines the effects of training on peripheral color and shape detection in virtual reality. It will provide insight on designing a VR eye-tracking application where the focus is on not-gazing. Six participants were trained over 12 days by playing PeriFocus, where the goal is to use the peripheral vision for object identification using the features color, size and shape. On the first, fifth and last day, the participants' peripheral color and shape detection was tested using a visual acuity test. The experiment showed a statistically significant difference for training peripheral color detection but not for training peripheral shape detection, which also showed a high variability. A discussion goes into detail regarding the suboptimal experiment procedure and ideas for improvement.

KEYWORDS

Virtual Reality, Eye-tracking, Gaze-tracking, Video Games, Game Design, Multi-Modal Interaction, Eye Training, Peripheral Vision.

1 INTRODUCTION

One of the leading eye-tracking technologies is the Tobii Eye Tracker, with 167 game titles supported as of 2022 [25], and used by many researchers for their work [28]. Eye-tracking is often used for tracking one's gaze. Gaze-tracking is then often used for gaze interactions, like highlighting and selecting chess pieces [21]. A form of gaze interaction called gaze aversion has been explored, where the user must use their peripheral vision to inspect elements in a game called SuperVision [18, 19]. Playing SuperVision has shown to increase the angle at which participants would detect shapes and colors in their peripheral [19]. Peripheral vision plays a big role in sports that require the monitoring and detection of peripheral events in complex and time-demanding situations [13]. Handball players have also been found to have a faster reaction time to stimuli in their peripheral when compared to non-athletes [31]. It would be interesting to explore peripheral vision in VR, a technology that more accurately simulates human perception than a monitor does, due to stereoscopic vision [4]. Gaze-tracking in VR has been used for computational relief methods like foveated rendering [16, 17] and as a metric to determine e.g. user experience, emotion recognition and recognizing autistic children in the medical field [2, 7, 20]. Gaze-tracking in VR will likely be more available to the average consumer, with a new wave of VR head-mounted displays (HMD) on the way, with a focus on eye tracking technology [22].

This paper will investigate whether peripheral vision can be trained using a VR application. It will also present a unique opportunity to use a gaze aversion paradigm in an interactive VR environment.

2 BACKGROUND

To inform our design, it would be beneficial to look into how gaze-tracking has been used in human-computer interaction (HCI) and in VR applications. Different eye behaviours are also considered, as well as how the peripheral vision functions.

2.1 Gaze-tracking

When working with gaze-tracking, it is important to consider the different behaviors of the eyes in order to get a better understanding of how human eyes work [1]:

- **Smooth pursuits** referring to the eye's ability to follow moving objects.
- **Fixations** referring to the movement which helps the retina stabilize on a fixed object.
- **Saccades** referring to the eye's behaviour when moving to a new location in space, which is defined as the rapid eye movements, which have an integral part in stabilizing the fovea.

Gaze-tracking has been typically used for in HCI for gaze interactions.

Velloso & Carter[28] reviewed the various ways in which gaze-tracking has been used in computer games and looked at over 100 papers which used gaze-tracking as a gameplay mechanic. They considered the ways in which humans use their eyes and categorized them into different input types, further dividing them into different game mechanics. Špakov [21] used gaze-tracking as a modality for playing chess, making players able to fixate on a chess piece to highlight it, while blinking confirms the selection. Vidal et al.[30] used gaze as a gameplay mechanic in a social-gaze based game. They stated that gaze-tracking can enhance the level of immersion a player is feeling. These papers have shown that gaze-tracking as a game mechanic is viable and can be utilized in different ways, both as a selection mechanic but also more complex actions such as social gaze. In this paper, gaze-tracking is not used for social gaze or selecting elements. Rather, it is used to make sure users fixate on a fixed point, to shift their focus to their peripheral vision instead of their gaze.

Thaler et al. [24] studied the effect of the fixation point's shape on eye-movement stability. Even when fixated on a point, eyes make involuntary movements. Their results show that these movements can be reduced by using a target consisting of a bull's eye and a cross hair, shown in figure 1. Due to the nature of this paper, it would be beneficial to use a fixation point that helps the user reduce their involuntary eye-movements, so the same target will be used.

A common issue that affects gaze-interaction is the "Midas Touch" problem [11]. This occurs due to the way human eyes have evolved towards gathering information from the environment. The problem

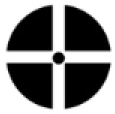


Figure 1: Figure showcasing the target that was found to be optimal as a fixation point that reduces involuntary eye-movements [24]

arises when the user is e.g., gazing at a chess piece to select it, without meaning to do so. This is why adding an additional input like blinking can limit the Midas Touch problem from occurring. In this paper, the Midas Touch problem may occur, since users will have to use their peripheral vision to inspect elements and resist the urge to gaze at them.

2.2 Gaze-tracking in VR

One of the features of VR is that it allows for stereoscopic vision. It refers to the ability of the brain to create a three-dimensional image derived from the two eyes [4]. When working with stereoscopic vision in VR, it is important to consider vergence and accommodation:

- **Vergence** referring to the eye's ability to focus at distance targets [1].
- **Accommodation** referring to the eye's ability to change focus from a distant object to a closer one, by changing the focal length of the eyes [10].

An issue that usually occurs when working with perception in VR is called the vergence-accommodation conflict. Usually vergence and accommodation works in tandem but in VR the eyes only accommodate to the HMD display screen, while the eyes still verge depending on depth. The vergence-accommodation conflict has been shown to cause eye strain and fatigue [10], thus the time spent inside VR needs to be considered.

While research in VR gaze-tracking is a novel field, multiple experiments have already been conducted. Patney et al. [17] have used gaze-tracking in order to create foveated rendering, thus increasing the performance of the VR application. Geraets et al. [7] tracked the participants' eyes, to observe where they would gaze at an avatar's face, when they had to determine the emotion expressed by the avatar. Alcañiz et al. [2] used gaze-tracking in order to distinguish between autistic and typically developing children attention behaviours, their results showing that their model had a 86% accuracy in recognizing autistic children. This shows that gaze-tracking can both enhance the performance of a VR experience and aid researchers in gathering more data. For gaze interactions in VR, the research field is still novel, making it interesting to expand upon.

2.3 Peripheral vision

Humans have a field of view of 210 degrees horizontally, with acuity degrading as it gets further away from the central vision point. This paper will consider peripheral vision as anything that is 8 degrees or more from the central vision point [9].

Peripheral vision is a field that is vastly explored and analyzed. The various aspects of it have been analyzed for hundreds of years [23]. Baldwin et al. [3] explored the perceived size and shape of objects in peripheral vision. Their results show that the original shape is perceived differently when located in the peripheral vision, changing both it's shape and size. For example, circles being perceived as oval. If the circle is aligned on the vertical axis, the object would have its height compressed. If however the circle would be aligned on the horizontal axis, it would become compressed in width, as shown in figure 2. This shows that the position of an object in the peripheral vision is important, when trying to compare sizes and shapes.

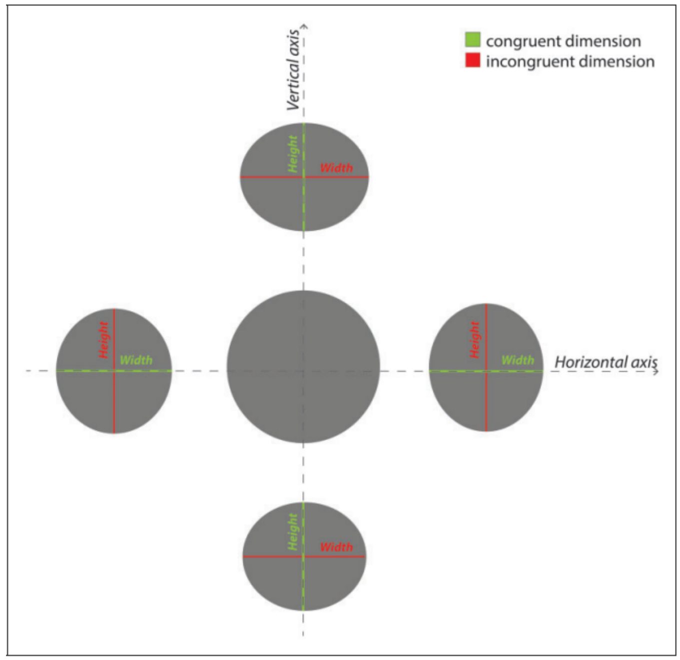


Figure 2: Figure showcasing how a circle is perceived differently depending on its placement in the peripheral vision. Notice the circles' height difference horizontally, as well as the width difference vertically when compared to the circle placed in the center [3].

Grindley and Townsend [8] researched the effect of attention with a variable number of stimuli. They conducted an experiment where a participant would have to state in which of the 4 screens the T shaped object was placed, as well as its orientation. An example of the experiment can be seen in Figure 3.
Their results hav e shown that when having multiple objects in their peripheral vision, it was easier for a participant to determine where the T shaped object was positioned and oriented. This is compared to only having the T shaped object shown on one of the screens without any other stimuli [8]. In this paper both alignment and number of shapes will be considered. Taking both papers presented above into account, multiple objects must be placed in the peripheral, aiding the participant in making the right choice. This also maintains a balance between the vertical and horizontal alignment of the given objects, trying to minimize changes happening in their perceived size and shape.

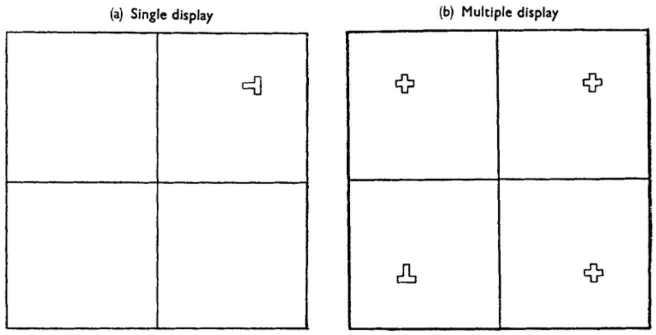


Figure 3: Figure showcasing the two different conditions found in Grindley and Townsend's [8] experiment. It was found that when participants' had to state the position and orientation of the "T", it was more challenging to do so with no other stimuli present in the peripheral (Left). When more stimuli are present, it is easier to state both the position and orientation of the "T" (Right).

2.4 Eye Tracking & Peripheral Vision

Velloso et al. [29] experimented with gaze aversion and peripheral vision. Gaze aversion entails that the player must not gaze at objects of interest. In their game, Virus Hunt, the player needs to destroy viruses in the blood stream by clicking on them. If a player gazes at a virus it will make it duplicate, thus punishing the players for gazing [29]. Therefore, peripheral vision must instead be used to inspect the viruses. Peripheral vision will be used in a similar way in this paper, making it a challenge to not gaze at objects of interest. Gomez & Gellersen [19] created three tasks centered around peripheral vision and gaze aversion. They created three games which explore different ways of feature identification:

- **Cyclops in a Balloons Adventure** for which the purpose was detecting colors in peripheral vision.
- **Medusa and the Mushrooms Attack** for which the purpose was exploring size differences in peripheral vision.
- **Narcissus and the cursed frames** for which the purpose was to explore what happens to perception in the central vision point, when the attention is on the periphery. They expected the "focus blindness" effect to take place, meaning that the player would not notice an object present in the center of their vision.

Their results show that after playing the game for one session, players improved their peripheral color and shape detection. A two week study was conducted for which peripheral shape detection was not tested for. This paper will take inspiration from the tasks, but we will test for peripheral shape detection. We will also consider how stereoscopic vision may affect peripheral color and shape detection in terms of different vergence distances.

3 PERIFOCUS

PeriFocus is made to examine whether it is possible to train peripheral color and shape detection in VR. Mainly inspired by Gomez and Gellersen's SuperVision [19], PeriFocus is designed to extend upon their research in a VR setting. PeriFocus is a VR application divided into three tasks, each designed to train different aspects of feature identification. In order to train the participants' peripheral vision during each task, they must fixate on a singular point, called the fixation point. This way, they must instead use their peripheral vision to complete the tasks.

3.1 Gameplay

A single playthrough of PeriFocus will have the participants play three, two minute long tasks. The time was decided in a pilot study, in order to reduce the severity of eye-strain caused by the vergence-accommodation conflict [10]. In between the tasks, there is a brief respite to let the participants relax their eyes. During either of the tasks, the participants are shown the fixation point and four different targets. The fixation point is based on the pattern that Thaler et al. [24] found to be optimal at reducing involuntary eye movements. This is beneficial, since involuntary eye movements might otherwise disrupt the participant's session.
With the fixation point being in the central vision, four targets are each positioned at 45° angles, as seen in figure 4. This arrangement is made so that the participants have to utilize the entirety of their peripheral vision, while reducing size and shape distortion as explored by Baldwin et al. [3].

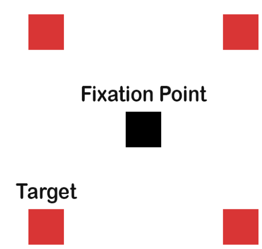


Figure 4: Figure showcasing the fixation point in the center, with four targets aligned at 45° angles. This is done to reduce the perceived distortion of targets in the peripheral [3].

While accommodation in VR is fixed to the HMD display screen, vergence still occurs when gazing at objects at different depths in a 3D application [10].
It would be interesting to explore the effects of vergence on peripheral vision in VR. Therefore, for any given task, the depth of the fixation point and targets will change over the course of the two minutes. Both will move independently between three levels of depth: 0.3, 0.6 and 0.9 meters away from the participant's position, see figure 5. This process will continue until all combinations are achieved, adding up to a total of nine times. Furthermore, the depth levels were decided based on a pilot study that showed that most significant changes in visual acuity happen at distances smaller than one meter.
Also, as the targets change depth levels, they will also appear smaller and closer to the fixation point. By adjusting the size and position accordingly, all targets were perceived as having the same size and distance from the fixation point. To ensure that the fixation point would be at the eye level of the participants, their height in VR was automatically adjusted.

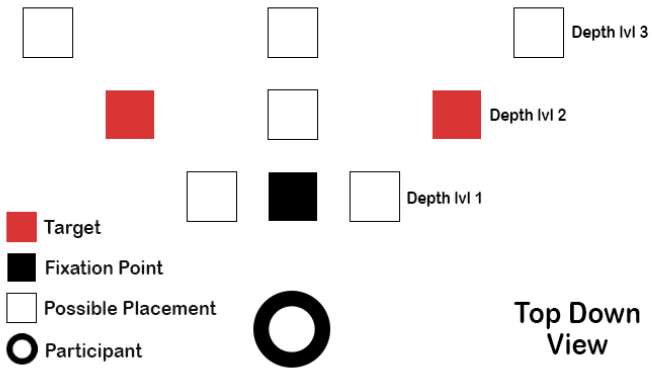


Figure 5: Figure showcasing the top down view of the possible placements of the fixation point and targets at different depth levels. In this figure, the fixation point is at depth level 1 and the targets are at depth level 2

The goal of each task is for the participants to do as many correct selections before the two minute timer ends. During the session, the participants are given audio cues telling them what targets to identify.

As one of the challenges of PeriFocus, the participants must fixate on the fixation point, so it is important to reduce visual distractions as much as possible. Therefore, most of the feedback and communication is audio-based. The participants must use their peripheral vision to find the correct target among the four visible to them. In order to select the target, the participants must use a gun with a laser pointer, see figure 6.

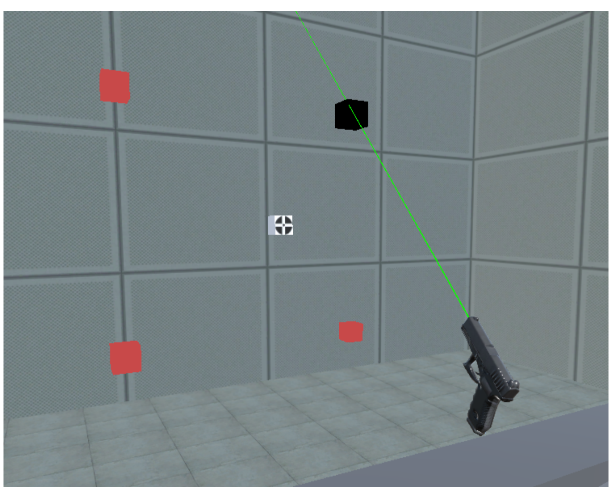


Figure 6: Figure showcasing a participant using their gun in PeriFocus to aim and shoot a target. Immediately after shooting the target, it turns black, indicating the wrong target was selected.

In case the selection is correct, the targets will reshuffle positions and a new audio cue will be given. If the selection is wrong, the target will switch its color to black for half a second and audio feedback indicating that a wrong target has been hit will be heard. Every time the depth level shifts for either the fixation point or targets, the targets will also reshuffle and a new audio cue will be given. By reshuffling at every depth level, it is ensured the time spent investigating the targets is not carried over to the next level. Additionally, to reduce the chance of e.g. fatigue influencing participants' performance for a specific task, the order of these is randomized. At the end of the three tasks, a score is shown to the participants, based on how many correct selections they had throughout the game. Furthermore, their score is ranked by the highest score of all previous participants to encourage competition. As a further incentive to encourage the participants to attend the full period of testing, a prize is given to the participant with the highest score at the end of testing. The prize consists of a medal and a stuffed animal.

As mentioned, PeriFocus is separated into three tasks, each training detection of a specific feature. These are:

- **Color Task:** Targets are shaped like cubes and colored differently: red, blue, green, yellow. The audio cue will announce one of these four colors. Furthermore, each color is fully saturated as to create a stronger contrast between the targets.
- **Size Task:** Targets are shaped like cubes and colored red. The sizes vary, having the size of 80%, 100%, 120% and 140% of the default target size. The audio cue will announce either "biggest" or "smallest" to signify the participants to select either the 140% or the 80% sized target, respectively. The sizes were determined in a pilot study and were chosen in order to challenge the participants without frustrating them.
- **Shape Task:** Targets are shaped after four distinct shapes, specifically, cube, sphere, heart and diamond, and colored red. The audio cue will announce one of the four shapes.

To avoid shadows influencing the detection of features, as participants may otherwise detect contrasts rather than the intended feature, shadows were removed from the targets.

In Velloso et al. [29] gaze aversion is used to encourage the participants to use their peripheral vision. Similarly, PeriFocus encourages participants to use their peripheral vision for inspection, by punishing them for switching their gaze from the fixation point for more than 100 milliseconds. In case of this occurring, the participants would not be able to select any targets, the 2 minute duration of the task would be paused and all targets would turn black as visual feedback. To continue the experiment, the participant would need to fixate on the fixation point again, where targets would then reshuffle and a new audio cue would be given. The 100 milliseconds duration was determined in a pilot study, and proved to be enough to stop participants from switching their gaze from the fixation point, while also allowing involuntary blinking.

3.2 Hardware & Software

PeriFocus is implemented for the HTC Vive HMD using the game engine Unity [26]. As the HTC Vive HMD does not come with eye-tracking functionality, external hardware is needed. For this purpose a binocular add-on from Pupil Labs [15] is used. The add-on consists of two 200hz low latency eye-tracking cameras with

IR illuminators [15], as well as clip-on rings to attach it to the HMD. The eye-tracking cameras and a Valve Index controller [27] is used for participants' input. Two standalone programs are used in combination with PeriFocus: Steam VR [6], which allows for easy VR-integration, and Pupil Labs Capture [14] which enables tracking of the participants' eyes. The program creates gaze-data, which can be sent to Unity and interpreted by custom code in order to make gaze interactive.

4 EVALUATION

A longitudinal study over the course of 12 days was conducted to determine if peripheral vision can be trained, specifically peripheral color and shape detection. A visual acuity test (VAT) was performed to measure this.

$H1_0$: The experiment will have no effect on peripheral color detection. **Hypotheses 1** states that there will be a statistically significant difference in participants' peripheral color detection between the first and last VAT.

$H2_0$: The experiment will have no effect on peripheral shape detection. **Hypotheses 2** states that there will be a statistically significant difference in participants' peripheral shape detection between the first and last VAT.

4.1 Apparatus

The apparatus used in the VAT was comprised of a protractor made out of 3mm cardboard, with a radius of 30 cm. A nose hole was included, making for a better fit. A small piece of wood, colored black, with a white dot in the middle was placed at the 90 ° angle of the protractor, creating a fixation point for the participants [5]. A picture of the protractor used can be found in figure 7.

Figure 7: Figure showcasing the protractor used for the VAT. It is made out of cardboard with a radius of 30 cm including a fixation point (left). Participant undergoing a VAT. Notice the red slip being moved along the protractor. (right).

A total of 27 slips of paper were created in a raster graphics editor and then printed, combining the three colors (red, green and blue) with three shapes (circle, triangle and square), three letters (A, B and C) and three numbers (1, 2 and 3). This follows the same procedure as the one used in Gomez & Gellersen [19]. The colors were derived from their RGB values, with red having the values (255,0,0); green having the values (0,255,0) and blue having the values (0,0,255). The shapes were placed at the top of the slips. Each slip had a height of ~10 cm and a width of two cm. A picture of the slips can be seen in figure 8. Furthermore, a HTC Vive HMD was used, which included eye-tracking cameras.

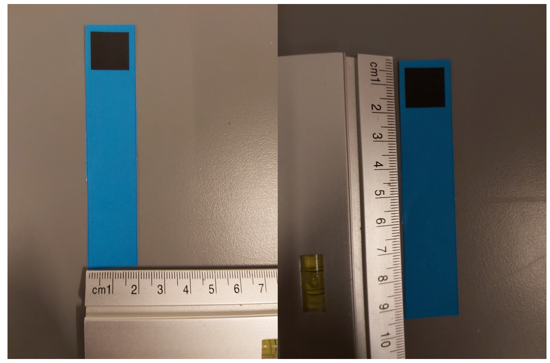


Figure 8: Figure showcasing a blue paper slip used in the VAT.

4.2 Participants

A total of eight participants were recruited for the experiment. Two participants had to be removed due to scheduling issues, leaving six participants for our experiment.
All participants were male. The mean age of the participants was 25 (SD = 1.63), with an age range of 23-28. These results were gathered as part of a demographics questionnaire, taken at the start of the experiment. Two more questions were included in the questionnaire, which evaluated the participants experience with computer games, as well as their previous experience with VR. These results can be found in appendix (A).

4.3 Procedure

When doing the VAT, the participant would position the protractor horizontally in front of their face, fitting their nose in the nose hole and were asked to fixate on the focus point, for which can be seen in figure 7. A researcher would start slowly moving a paper slip towards the center of the protractor. They were asked to note when they started to notice the slip, at which point the researcher would stop moving it. The participant was then asked to identify either the color or the shape that was drawn on the slip. If either was not identified, the researcher would continue to move the slip until both color and shape were correctly identified and their angles recorded.
The experiment took place over 12 days, and was not conducted on the weekends and Tuesdays due to participants' schedules. The participants would do a play-through of the experiment each day, which would take around seven minutes, two minutes for each challenge, as well as around one minute for eye-tracking calibration.
On the first day of testing, PeriFocus included a narrated tutorial, which explained the controls and a short description of the tasks.
Participants had to do additional steps on the following days:

- **Day 1**: Participants were asked to complete a demographics questionnaire, as well as a VAT and the tutorial.
- **Day 5**: Upon completing PeriFocus, participants had to take another VAT.

- **Day 12**: Upon completing PeriFocus, participants had to take a final VAT.

4.4 Logging Measurements

To examine the differences between the three tasks, three features were logged in PeriFocus. Score, which is a number that increments each time the correct target is shot. Error rate, which is the percentage of incorrect targets shot during a session. Task time, which is calculated as: (A), the time from when targets are presented, to (B), when a target is shot in seconds.
Features are logged to gauge participants' performance over time.

5 RESULTS

Hypothesis 1 and **Hypothesis 2** were tested comparing the VAT score for day 1 against day 12. It was found that the experiment had a statistically significant effect on participants' peripheral color detection ($p < .012$). **H1$_0$** can thus be rejected and **Hypothesis 1** accepted. **H2$_0$** can not be rejected as the experiment did not have a statistically significant effect on participants' peripheral shape detection ($p < .310$). This is still true if outliers are removed.

Condition	W S-R Test	Mean	SD
Color	p < .031	Day 1 = 58.17	Day 1 = 13.88
	v = 0	Day 12 = 73.83	Day 12 = 6.49
Shape	p < .156	Day 1 = 31.33	Day 1 = 15.93
	v = 3	Day 12 = 44.83	Day 12 = 19.24

Table 1: Table showcasing the Wilcoxon Signed-Rank Test results for the VAT day 1 and day 12, as well as the mean and SD.

Similarly, comparing the VAT scores for day 1 and day 5 shows a significant increase in the participant color detection score ($V = 0$, $p < .036$) while the participant shape detection score does not significantly increase ($V = 5$, $p < .590$). Comparing day 5 with day 12 shows no significant increase in both VAT color score ($V = 10$, $p = 1$) and shape score ($V = 5$, $p < .313$). See figure 9 for a VAT score comparison between day 1, day 5 and day 12.

5.1 Measurements

Comparing participants' measurement logs between day 1 and day 12, it can be seen that they scored significantly higher in all tasks on day 12, see table 2 and figure 10. It can be seen that participants reduced their task time significantly in all challenges, see table 3 and figure 11. Participants' error rates for the size and color task were similar, with the shape tasks having a higher variability, see figure 12. In all error rate instances, no statistically significant difference could be found ($p > .05$). It was the intention to also analyse the features on a micro level, where we would examine each depth level discussed in design, to see if the vergence discrepancy between the fixation point and targets would play a role in peripheral color and shape detection. Upon analyzing the data, it was realized that the logging script responsible for saving the depth level data was corrupted.

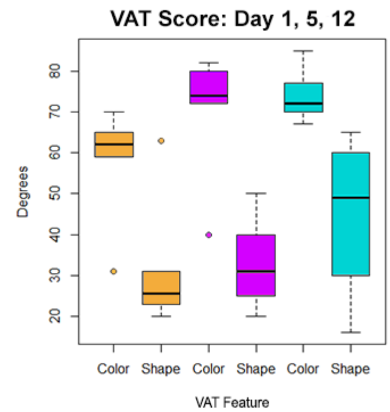


Figure 9: Boxplots showcasing the VAT scores for both shape and color, including outliers. From left to right: day 1 (orange), day 5 (purple) and day 12 (blue)

Task	W S-R Test	Mean	SD
Size	p < .031	Day 1 = 48.83	Day 1 = 10.94
	v = 0	Day 12 = 103.17	Day 12 = 8.98
Shape	p < .036	Day 1 = 41.83	Day 1 = 6.62
	v = 0	Day 12 = 85.83	Day 12 = 14.16
Color	p < .031	Day 1 = 66.17	Day 1 = 13.53
	v = 0	Day 12 = 106	Day 12 = 11.08

Table 2: Table showcasing score results for the three tasks for day 1 and day 12; Wilcoxon Signed-Rank Test results as well as the mean and SD.

Task	W S-R Test	Mean	SD
Size	p < .031	Day 1 = 2.37	Day 1 = 0.51
	v = 21	Day 12 = 1.16	Day 12 = 0.12
Shape	p < .031	Day 1 = 3.11	Day 1 = 1.09
	v = 21	Day 12 = 1.38	Day 12 = 0.22
Color	p < .031	Day 1 = 2.44	Day 1 = 1.36
	v = 21	Day 12 = 1.12	Day 12 = 0.13

Table 3: Table showcasing task time results for the three tasks for day 1 and day 12; Wilcoxon Signed-Rank Test results as well as the mean and SD.

Heatmaps were created to inspect the participants' gaze pattern. See figure 13 for participant 5's changes at three different stages. Heatmaps for all participants can be found in Appendix (B).

6 DISCUSSION & LIMITATIONS

H1$_0$ can be rejected, while **H2$_0$** can not. This means that we did find a statistically significant effect on peripheral color detection but not on peripheral shape detection. Both game score, which increased, and task time, which decreased, showed statistically significant differences in the three tasks, see table 2 and table 3. This suggests that

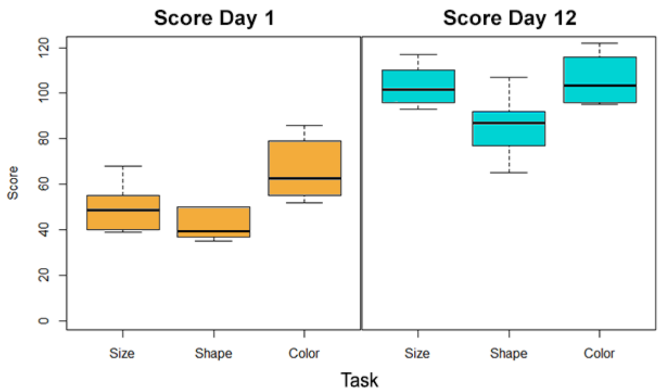


Figure 10: **Boxplots showcasing a comparison between scores from day 1 to scores from day 12**

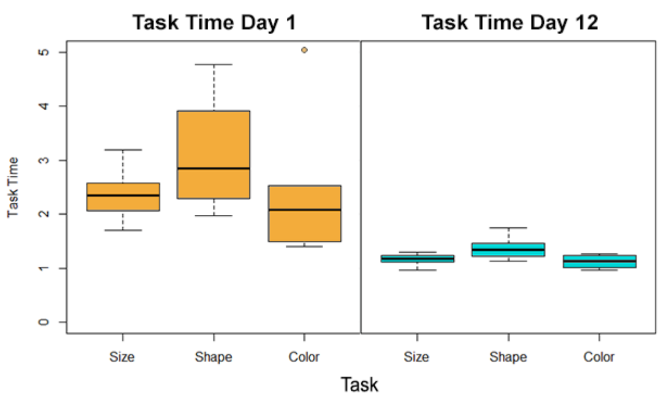


Figure 11: **Boxplots showcasing a comparison between task times from day 1 to task times from day 12**

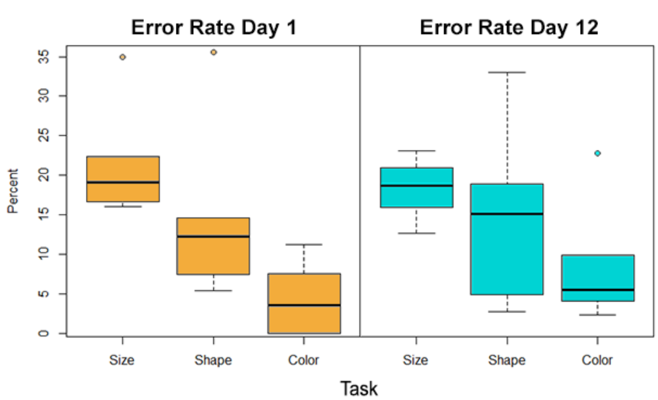


Figure 12: **Boxplots showcasing a comparison between wrong targets from day 1 to wrong targets from day 12**

when participants' performed better at PeriFocus, they also scored higher in the VAT. While the task time and SD was reduced by a significant amount for the size and color task, the error rate stayed largely consistent. However, the error rate variability for the shape task increased over time. This may be due to participants putting more emphasis on scoring higher in the time given and relying more on guesswork to choose the correct shape. It may be advantageous to penalize wrong targets more, e.g. by deducting points, which would shift the focus towards accuracy. Another option would be to remove time as a factor from PeriFocus and instead give participants a set amount of targets per session. Either way, participants may be more inclined to spend more time to identify the shapes in their peripheral and potentially reduce their error rate. Furthermore, we did not log which targets were shot by the participants. This may have been insightful data that would have allowed us to inspect the differences between the sizes, colors and shapes. For example, we may have found that certain shapes are easier to distinguish in the peripheral than others. Heatmaps were used as a visual inspection tool and we found that the spread was generally reduced, indicating that participants could resist the urge to investigate the targets in their peripheral. This shows an improvement in the control of their eye movements. As our logging script for logging features on the depth levels was corrupted, it would be interesting to evaluate whether vergence in VR plays a role in peripheral color and shape detection. This would inform future research working with peripheral vision in VR. The vergence-accommodation conflict and its negative effect on eyes was considered when conducting a pilot study, but it was not measured. It would have been advantageous to use the Simulator Sickness Questionnaire [12] before and after a session of PeriFocus, to gauge the eye strain experienced by the participants. While Gomez & Gellersen's [19] VAT results showed a statistically significant difference in their 1 day study, their VAT shape detection score had a SD around 3 times higher than their VAT color detection SD. They also did not measure VAT shape detection in their follow-up 2 week study, which was measured in this paper. We also encountered high variability of the VAT shape detection results, with an SD three times higher than that of VAT color detection. This might have been affected by the procedure used for the VAT. The results recorded for identifying primitive shapes (Circle, Square, Triangle) were generally higher than the ones recorded which had either a number (1, 2, 3) or a letter (A, B, C) as the chosen shape. This may be due to similarities between letters and numbers to primitive shapes. For example, we noticed a couple of participants mistaken the letter "C" for a circle, or the letter "A" for a triangle. Both this paper and Gomez & Gellersen's [19] follow this procedure, however the source material for which the VAT procedure was derived from does not draw the shapes on the slips [5]. Rather, the slips are cut with scissors to form the shapes, e.g. cutting the corners of the slip to form a triangle. In this way, perceiving contrast between the shape and the slip color would not be a factor, which may affect the VAT shape detection results. It could be interesting to only use primitive shapes, which may lead to less variability and a statistically significant difference. Furthermore, looking at Gomez & Gellersen's [19] VAT color detection mean score for the first day (mean = 81.20, SD = 4.08) and last day (mean = 87.90, SD = 2.73), we comparatively had a much lower mean score for day 1 (mean = 58.16, SD = 13.88) and day 12 (mean = 73.83, SD = 6.49). We are unsure as to why there is such a large difference; it may be due to both experiments having a small sample size. It can be difficult to compare our experiment with theirs due

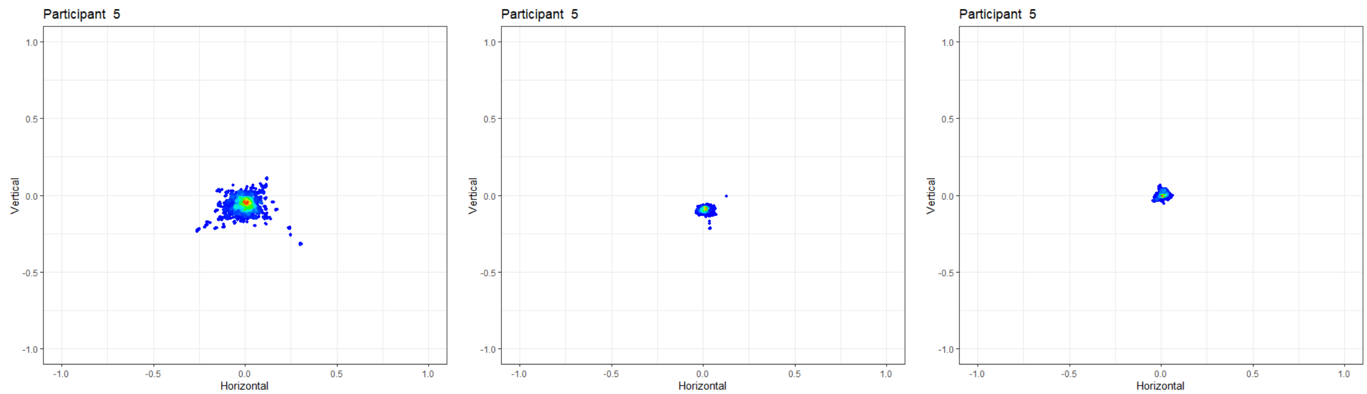


Figure 13: Heatmaps showcasing participant 5 on day 1 (left), on day 5 (middle) and on day 12 (right). Note the reduction of spread over time.

to Gomez & Gellersen [19] not stating how they created the slips, including their size, color and how the shapes were drawn on them. They also did not take participant to screen distance into account.

In terms of recreating our experiment, we created the paper slips in RGB color space, but printers use the CMYK color space, which creates a misrepresentation of the actual color wanted when printed. Also, a variable not considered for the VAT is the lighting conditions of the experiment room, which may influence color detection in the peripheral. Only six participants were able to take part of the study, meaning that even though our results showed a statistically significant difference, it might not mean that this would be true for a larger sample size. Furthermore, none of our participants were female, which further limits the ability to generalize our results to the population. The research lab used for the experiment, which contained the Vive HMD with eye-tracking cameras, had a limited booking availability, making it difficult to fit a higher amount of people for the experiment. While we purchased a medal and a stuffed animal for the highest scoring participant, we could not promise money compensation, which made recruiting participants difficult. Including a VAT after the weekend would show the effect of not training one's peripheral for two days. A more complex peripheral task than color and shape detection can be explored, such as using gaze-tracking in a social gaze related environment [30], perhaps by noticing social gestures in the peripheral.

7 CONCLUSION

Inspired by Gomez and Gellersen [19], this paper's purpose was to determine whether peripheral color and shape detection is able to be trained in VR within a 12 day study. The training was found to have a statistically significant effect on peripheral color detection. However, the training did not show a statistically significant effect on peripheral shape detection, with a high variability, which increased by the end of the study. It was discussed how the experiment procedure may not have been optimal in assessing PeriFocus' effect on peripheral shape detection. Further studies with a modified procedure might show results with a lower variability and a potentially statistically significant effect.

REFERENCES

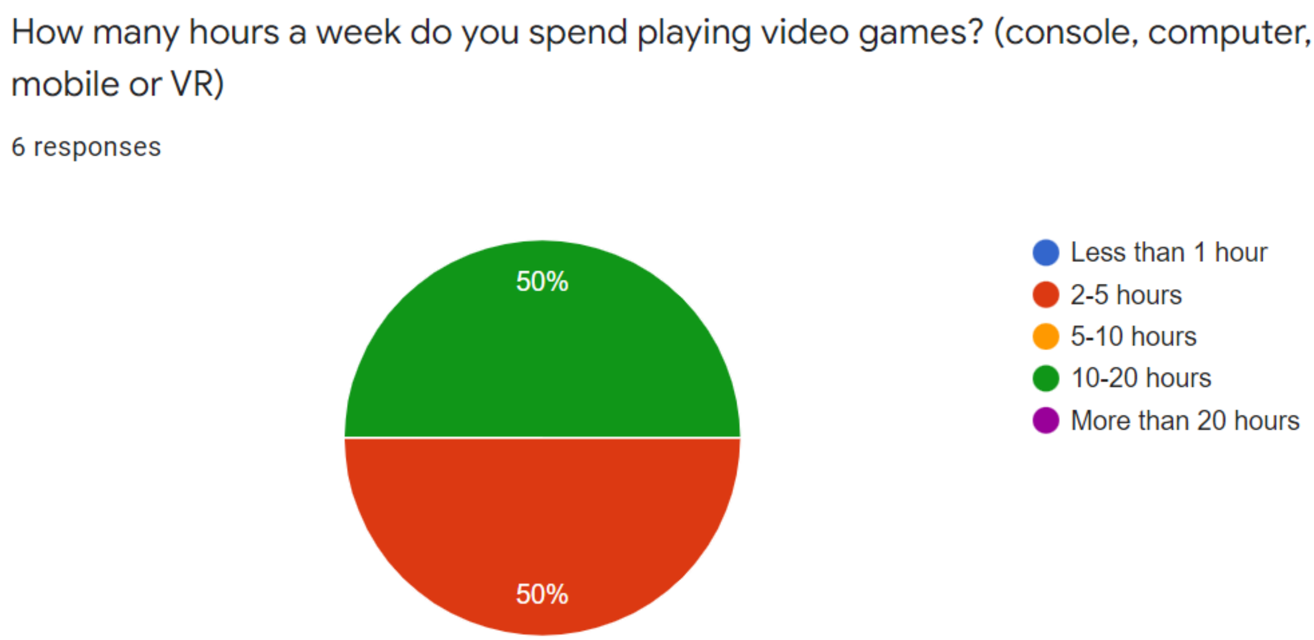
[1] [n.d.]. .
[2] Mariano Alcañiz, Irene Alice Chicchi-Giglioli, Lucía A Carrasco-Ribelles, Javier Marín-Morales, Maria Eleonora Minissi, Gonzalo Teruel-García, Marian Sirera, and Luis Abad. 2022. Eye gaze as a biomarker in the recognition of autism spectrum disorder using virtual reality and machine learning: A proof of concept for diagnosis. *Autism Research* 15, 1 (2022), 131–145.
[3] Joseph Baldwin, Alistair Burleigh, Robert Pepperell, and Nicole Ruta. 2016. The perceived size and shape of objects in peripheral vision. *i-Perception* 7, 4 (2016), 2041669516661900.
[4] Floyd E Bloom, Nicholas C Spitzer, Fred Gage, and Tom Albright. 2009. *Encyclopedia of Neuroscience, Volume 1.* Vol. 1. Academic Press.
[5] Science Buddies. 2016. Put your peripheral vision to the test. https://www.scientificamerican.com/article/put-your-peripheral-vision-to-the-test/
[6] Valve Corporation. 2021. *Unity SteamVR Plugin.* https://assetstore.unity.com/packages/tools/integration/steamvr-plugin-32647
[7] CNW Geraets, S Klein Tuente, BP Lestestuiver, M van Beilen, SA Nijman, JBC Marsman, and W Veling. 2021. Virtual reality facial emotion recognition in social environments: An eye-tracking study. *Internet interventions* 25 (2021), 100432.
[8] GC Grindley and Valerie Townsend. 1968. Voluntary attention in peripheral vision and its effects on acuity and differential thresholds. *The Quarterly journal of experimental psychology* 20, 1 (1968), 11–19.
[9] Carl Gutwin, Andy Cockburn, and Ashley Coveney. 2017. Peripheral popout: The influence of visual angle and stimulus intensity on popout effects. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems.* 208–219.
[10] David M Hoffman, Ahna R Girshick, Kurt Akeley, and Martin S Banks. 2008. Vergence–accommodation conflicts hinder visual performance and cause visual fatigue. *Journal of vision* 8, 3 (2008), 33–33.
[11] Robert JK Jacob. 1995. Eye tracking in advanced interface design. *Virtual environments and advanced interface design* 258 (1995), 288.
[12] Robert S Kennedy, Norman E Lane, Kevin S Berbaum, and Michael G Lilienthal. 1993. Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness. *The international journal of aviation psychology* 3, 3 (1993), 203–220.
[13] André Klostermann, Christian Vater, Ralf Kredel, and Ernst-Joachim Hossner. 2020. Perception and action in sports. On the functionality of foveal and peripheral vision. *Frontiers in sports and active living* (2020), 66.
[14] Pupil Labs. 2021. *Pupil Lab HMD-Eyes Repository.* https://github.com/pupil-labs/hmd-eyes
[15] Pupil Labs. 2021. *Pupil Labs Products / VR AR.* https://pupil-labs.com/products/vr-ar/
[16] Sebastian Marwecki, Andrew D Wilson, Eyal Ofek, Mar Gonzalez Franco, and Christian Holz. 2019. Mise-unseen: Using eye tracking to hide virtual reality scene changes in plain sight. In *Proceedings of the 32nd Annual ACM Symposium on User Interface Software and Technology.* 777–789.

[17] Anjul Patney, Marco Salvi, Joohwan Kim, Anton Kaplanyan, Chris Wyman, Nir Benty, David Luebke, and Aaron Lefohn. 2016. Towards foveated rendering for gaze-tracked virtual reality. *ACM Transactions on Graphics (TOG)* 35, 6 (2016), 1–12.
[18] Argenis Ramirez Gomez and Hans Gellersen. 2019. Exploring the Sensed and Unexpected: Not Looking in Gaze Interaction. In *Proceedings of the Halfway to the Future Symposium 2019*. 1–7.
[19] Argenis Ramirez Gomez and Hans Gellersen. 2019. SuperVision: Playing with gaze aversion and peripheral vision. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*. 1–12.
[20] Jose L Soler-Dominguez, Jorge D Camba, Manuel Contero, and Mariano Alcañiz. 2017. A proposal for the selection of eye-tracking metrics for the implementation of adaptive gameplay in virtual reality based games. In *International Conference on Virtual, Augmented and Mixed Reality*. Springer, 369–380.
[21] Oleg Špakov. 2005. EyeChess: the tutoring game with visual attentive interface. *Alternative Access: Feelings & Games* 5 (2005).
[22] Scott Stein. 2022. *Watching Me, Watching You: How Eye Tracking Is Coming to VR and Beyond*. https://www.cnet.com/tech/computing/watching-me-watching-you-how-eye-tracking-is-coming-to-vr-and-beyond/
[23] Hans Strasburger, Ingo Rentschler, and Martin Jüttner. 2011. Peripheral vision and pattern recognition: A review. *Journal of vision* 11, 5 (2011), 13–13.
[24] Lore Thaler, Alexander C Schütz, Melvyn A Goodale, and Karl R Gegenfurtner. 2013. What is the best fixation target? The effect of target shape on stability of fixational eye movements. *Vision research* 76 (2013), 31–42.
[25] Tobii. 2022. *Enhance PC Games With Eye Tracking*. https://gaming.tobii.com/games/
[26] Unity. 2021. *Unity Development Platform*. https://unity.com/
[27] Valve. 2021. *Valve Index: Controllers*. https://www.valvesoftware.com/en/index/controllers
[28] Eduardo Velloso and Marcus Carter. 2016. The emergence of eyeplay: a survey of eye interaction in games. In *Proceedings of the 2016 annual symposium on computer-human interaction in play*. 171–185.
[29] Eduardo Velloso, Carl Oechsner, Katharina Sachmann, Markus Wirth, and Hans Gellersen. 2015. Arcade+ a platform for public deployment and evaluation of multi-modal games. In *Proceedings of the 2015 annual symposium on computer-human interaction in play*. 271–275.
[30] Melodie Vidal, Remi Bismuth, Andreas Bulling, and Hans Gellersen. 2015. The royal corgi: Exploring social gaze interaction for immersive gameplay. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*. 115–124.
[31] Teresa Zwierko. 2007. Differences in peripheral perception between athletes and nonathletes. *Journal of Human Kinetics* 19, 2008 (2007), 53–62.

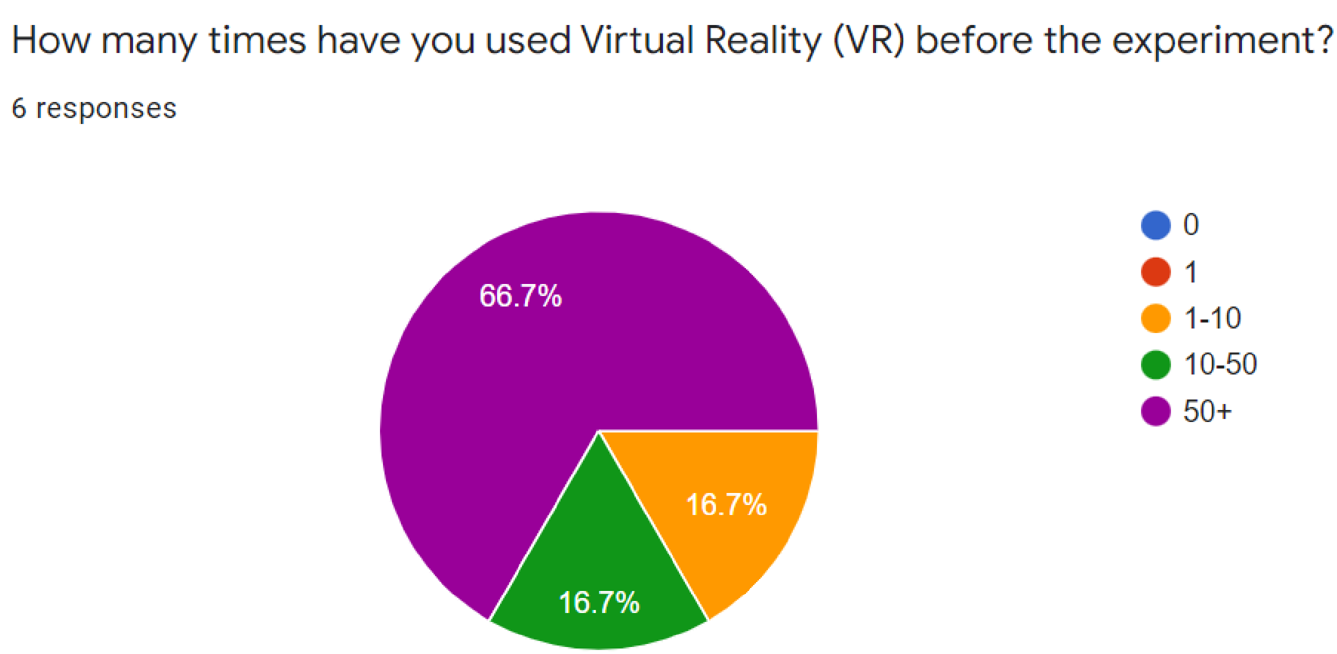
Appendices

A DEMOGRAPHIC QUESTIONNAIRE RESULTS

B ADDITIONAL HEATMAPS



Pie chart expressing the results given by the participants



Pie chart expressing the results given by the participants

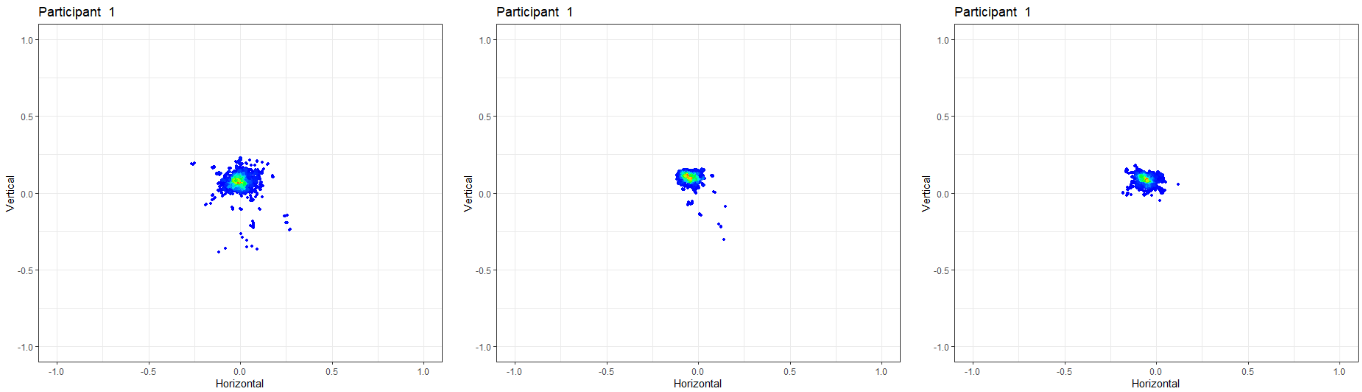


Figure 14: Participant 1 on Day 1 (left), Participant 1 on Day 5 (middle) and Participant 1 on Day 12 (right).

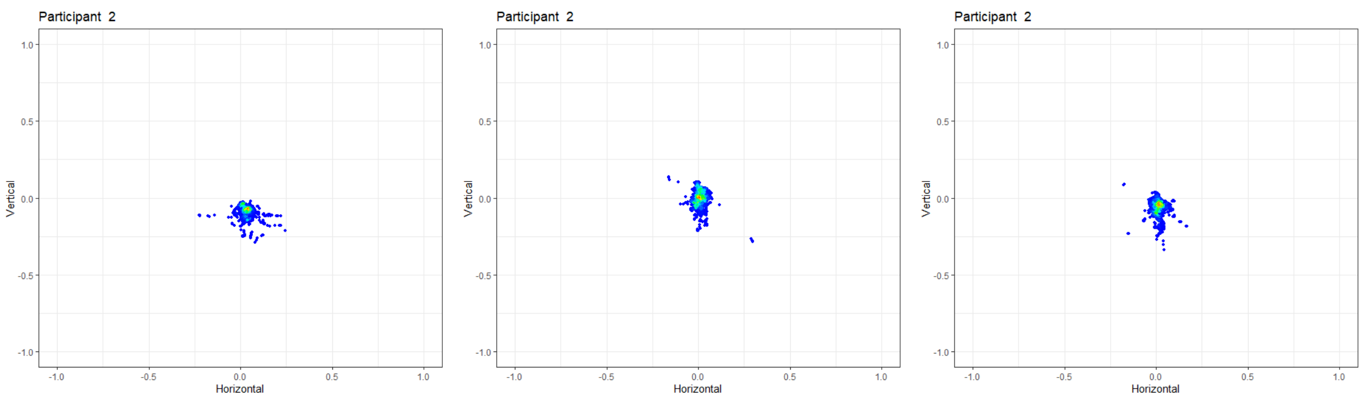


Figure 15: Participant 2 on Day 1 (left), Participant 2 on Day 5 (middle) and Participant 2 on Day 12 (right).

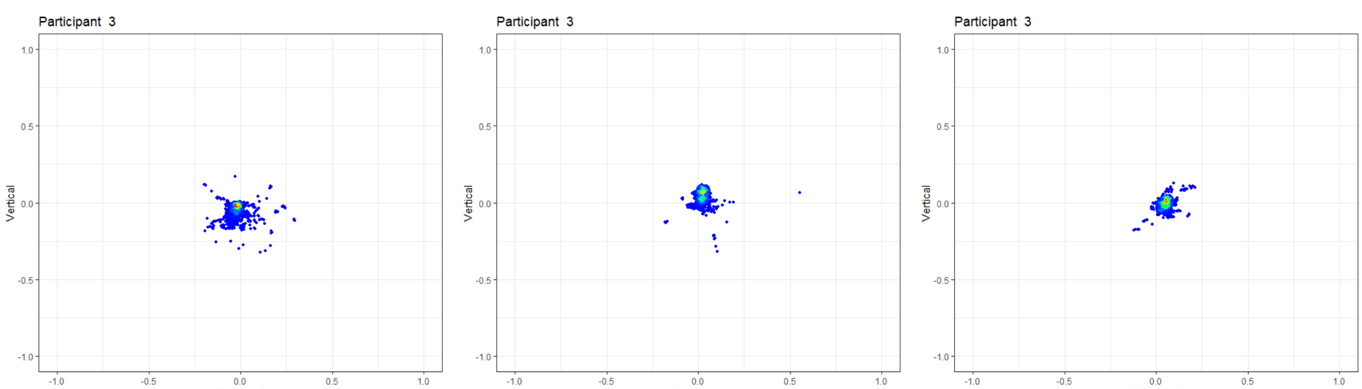


Figure 16: Participant 3 on Day 1 (left), Participant 3 on Day 5 (middle) and Participant 3 on Day 12 (right).

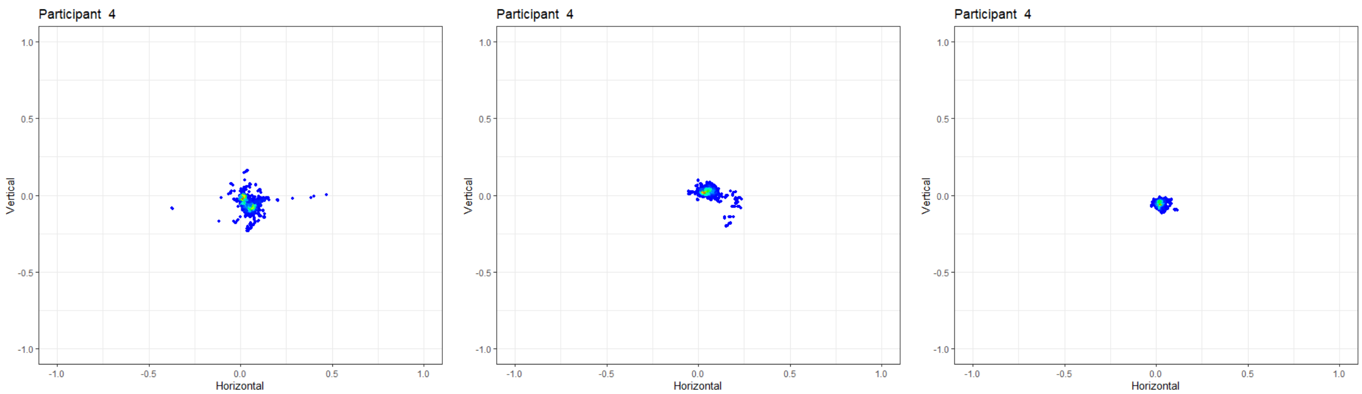


Figure 17: Participant 4 on Day 1 (left), Participant 4 on Day 5 (middle) and Participant 4 on Day 12 (right).

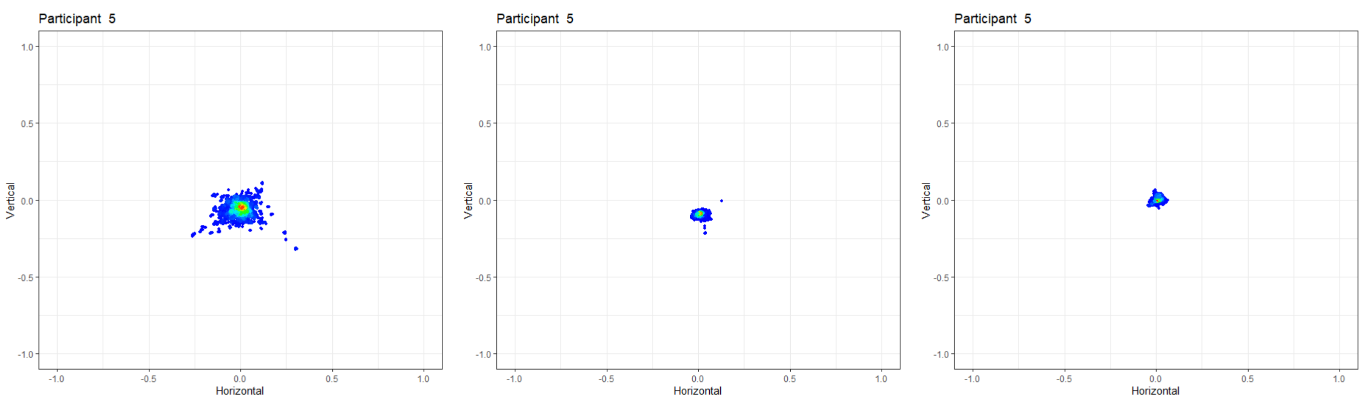


Figure 18: Participant 5 on Day 1 (left), Participant 5 on Day 5 (middle) and Participant 5 on Day 12 (right).

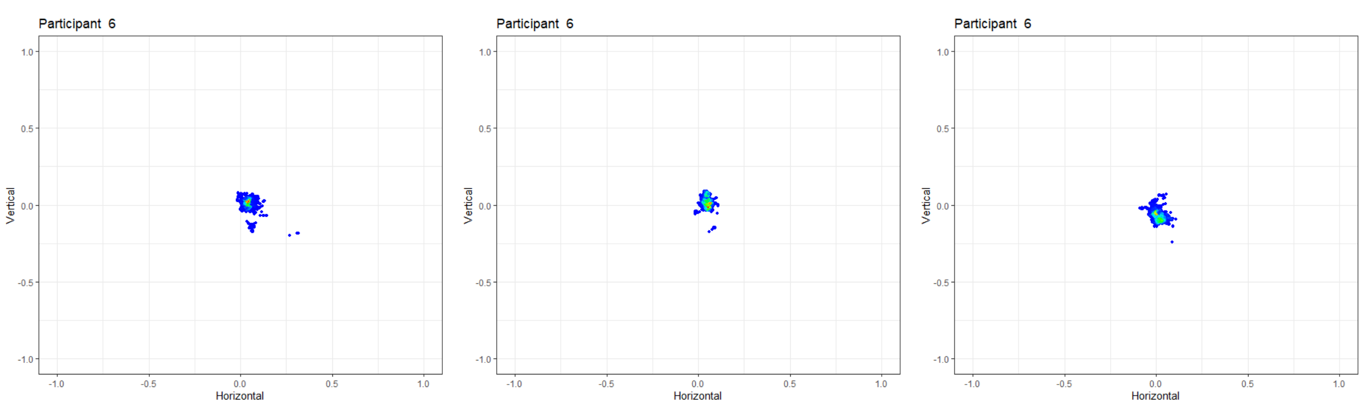


Figure 19: Participant 6 on Day 1 (left), Participant 6 on Day 5 (middle) and Participant 6 on Day 12 (right).