Usability testing with passthrough technology using MetaQuest 3 on everyday tasks

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Abstract

Passthrough technology has some problems due to the visual displacement between the passthrough cameras and the users' eyes, which causes users to face negative perceptual impacts. In this paper the usability of Meta Quest 3's passthrough capabilities was evaluated through performing experiments on 16 participants (10 male, 6 female) from Sabanci University to do everyday tasks in a controlled indoor campus setting with and without passthrough. These tasks include walking in a predefined route, solving jigsaw puzzles, playing office basketball, and drawing a circle. Our results show that passthrough technology decreased the users' experience in doing everyday tasks. They completed the tasks in longer periods of time and with higher error rates while using the headset.

Background of the Study

In this section, the process and the results of some of the previous studies that performed specific experiences and tests using passthrough functionality will be discussed. Presenting these results and works is important because, with the increasing adoption of mixed reality headsets and their video passthrough functionality, concerns over social and perceptual effects have arisen (Santoso & Bailenson, 2024).

Bailenson et al. (2024) conducted various usability tests on eleven participants (eight female, three male) using Meta Quest 3 headsets to find the struggles and challenges of the passthrough technology. Each of the participants spent roughly 140 minutes with the headsets, and they were supposed to do six tasks including estimating the distance, walking outdoors, playing games, having a conversation, eating, and cooking. Bailenson et al. (2024) mentioned that during their experiments they observed video distortion when there was a rotating and movement in their head and body while the distortion was rare when they were standing still.

For instance, they mentioned that sometimes they observed teleport effects, meaning objects and people passing in front of them disappear and are shown somewhere else. They have also experienced distortion in colors and reported that colors were shown to them with a lower contrast. Users struggled to do tasks such as catching a ball or solving jigsaw puzzles, eating, and hitting elevator buttons due to their inaccurate distance estimation. Moreover, the field notes of Bailenson et al. (2024) have shown that testers have experienced simulator sickness ranging from eye strain to nausea, headache, and dizziness during the tests. Although simulator sickness relies on several factors such as age and gender, it will be reduced by 35%-40% by using the headset on two separate days.

These days thanks to utilizing mixed reality headsets and passthrough technology, concerns over the perceptual and social effects of this technology have been raised. For instance, Santoso and Bailenson (2024) conducted usability tests using Meta Quest 3 to measure and quantify the qualitative data that they found regarding the impact of video passthrough on users. At first, they asked participants to perform Basic Body Awareness Therapy and Virtual Reality (VR) avatar body transfer to deduce a feeling of body awareness and a sense of embodiment. After this preparation, users were supposed to do the tests using a repeated design methodology, meaning each participant was randomly assigned to do the task at first with passthrough and then without it or at first without passthrough and then with passthrough. Their tasks include rotating their torso, waving at their mirror image, walking in a place, and standing still. Each of these steps lasted 15 to 30 seconds and was conducted in front of the mirror. Also, they asked users to do a blind walk to assess their ability to estimate the distances. In total, each user wore the headset for 4 minutes. After each task, participants were supposed to fill out the questionnaires regarding perceptual and social effects such as simulator sickness and body distortion. Santoso and Bailenson (2024) found that using passthrough even for less than an hour of use can cause simulator sickness symptoms such as nausea to appear in users. Also, they have observed inaccurate distance estimation and social absence, where users feel that they do not belong to the real world.

Pfeil et al. (2021) conducted the study *Distance Perception with a Video See-Through Head-Mounted Display* to examine how wearing a Video See-Through Head-Mounted Display (VST HMD) affects users' perception of distance in the real world within a controlled laboratory setting. The results showed that participants tended to underestimate distances when using the HTC Vive device with the ZED Mini attachment. The researchers included two independent variables: headgear and distance.

The headgear variable had three levels:

- Participants wore no headgear ("Nothing").
- Participants wore a VST HMD ("VST").
- Participants wore a plastic casing from a stripped-down HMD ("Shell").

The distance variable included four levels: 3m, 4m, 5m, and 6m. In total, the study involved 12 unique conditions. Each participant performed the blind-throwing task three times for each condition, resulting in 36 attempts.

The researchers first asked participants to review a consent document and familiarize themselves with the different headset arrangements and testing conditions. Participants then underwent an eye examination using a Snellen Chart, and the researchers recorded their vision accuracy. After collecting demographic data, the researchers explained that participants would throw bean bags at targets placed at different distances while using different levels of headgear. Participants started with a trial round, keeping their eyes open. Next, the researchers instructed participants to look at the target, close their eyes, and throw the bean bag toward the target. They recorded data based on the first contact of the bean bag with the ground.

In their 1995 study, *Quantification of Adaptation to Virtual-Eye Location in See-Thru Head-Mounted Displays*, Rolland and colleagues investigated the impact of a prototype see-through head-mounted display (HMD) on visuomotor adaptation. They examined how sensory rearrangement, caused by shifting the user's "virtual" eye position upward and forward toward the cameras' spatial location, influenced performance. Tests on hand-eye coordination and speed during a manual task revealed high perceived costs of eye displacement but also demonstrated evidence of adaptability.

Video see-through HMDs exemplify a virtual reality (VR) element that requires sensory rearrangement. This phenomenon refers to a shift in the typical relationship between bodily motions and the sensory input received by the central nervous system. Sensory rearrangement can also arise from intersensory conflict, where one sense's input pattern becomes uncoordinated with another.

The researchers implemented a 3 x 2 mixed experimental design, which included three within-subjects and two between-subjects levels. The primary within-subjects factor was the type of HMD, with three levels:

1. baseline task measures without an HMD,
2. see-through HMD tasks, and

3. identical tasks using a control HMD model.

The study involved 14 participants (2 females and 12 males), with varying levels of experience using HMDs. Two participants had extensive experience, four had moderate experience, one had very little experience, and seven had no prior experience.

The study focused on the adaptation effects of UNC's video see-through HMD, particularly the impact of eye displacement to a "virtual" location. The system consisted of two miniature fisheye lens video cameras, an opaque HMD with LEEP optics, and a flight helmet adapted from Virtual Research.

Participants completed two tasks: pointing and manual pegboard. In the pointing task, the researchers instructed participants to point at targets and measured accuracy across the x, y, and z dimensions to assess hand-eye coordination under visual displacement. The manual pegboard task required participants to place small pegs on a pegboard, allowing the researchers to evaluate how visual distortion affected precise hand movements.

Participants' pointing errors increased along the displaced spatial dimensions (y and z) when they first wore the video see-through HMD. Performance speed on the manual task dropped by 43% compared to baseline performance. However, as participants adapted to the sensory rearrangement, their pointing accuracy improved, though it never fully returned to baseline levels.

When participants removed the see-through HMD, the researchers observed evidence of altered hand-eye coordination. Negative aftereffects were evident, with pointing errors remaining higher than baseline levels, indicating that the sensory rearrangement influenced participants' performance even after the HMD was no longer worn.

To sum up, the study stresses the necessity for improved HMD arrangements to minimize sensory rearrangement and intersensory conflict. Additionally, additional investigation on user adaptation and the relief of negative aftereffects is vital for the successful implementation of HMDs in high-precision fields.

Human attention is a critical component in the process of learning and spatial awareness, particularly in virtual environments where natural visual stimuli can be controlled and manipulated. Karacan et al. (2010) conducted an eye-tracking study in a desktop virtual reality environment to explore how familiarity with a scene influences visual attention and the detection of changes. Participants explored a simulated virtual town with stationary objects like a park bench, a street lamp, a trashcan, and a mailbox, walking along a predefined path while avoiding virtual pedestrians. Throughout the trials, the researchers altered the scene by adding, removing, displacing, or replacing objects. The results demonstrated that participants with prior exposure to the environment were significantly better at detecting these changes compared to those with limited exposure, as their gaze fixations on altered objects were longer and more focused. This indicates that familiarity enhances attention allocation, leading to more effective visual scanning and scene comprehension.

The study also explored the concept of "change blindness," a phenomenon where significant changes in a visual scene often go unnoticed due to attentional limitations or distractions. To investigate this, Karacan et al. (2010) introduced object modifications, such as the sudden appearance or disappearance of objects, to determine how familiarity influences change detection. Participants who had explored the virtual environment multiple times before the change occurred exhibited improved change detection, with average fixation durations on altered objects increasing from 709 ms for inexperienced participants to 1922 ms for experienced ones. The findings suggest that memory representations formed through repeated exposure to the scene enabled participants to compare new observations against stored visual information, ultimately reducing change blindness effects and improving overall attention to detail.

The experiment further examined how different types of object modifications influenced visual attention. Karacan et al. (2010) tested four change conditions: object appearance, object disappearance, object displacement, and object replacement. Using eye-tracking data, they measured fixation durations and latencies to determine how quickly participants noticed the altered elements in the scene. Results revealed that experienced participants were more likely to detect and focus on these changes regardless of the type, spending more time fixating on changed objects than stable ones. For instance, participants fixated on newly appeared objects more frequently than displaced or removed ones. These findings suggest that long-term memory representations of the environment significantly enhance the detection of both subtle and obvious changes within a virtual space, emphasizing the role of memory in guiding visual attention.

Another key aspect of the study was the comparison between different groups based on familiarity levels. Karacan et al. (2010) divided participants into experienced and inexperienced groups, with the experienced group receiving six trials to familiarize themselves with the environment before changes were introduced. The eye-tracking data showed that the experienced group not only noticed changes faster but also fixated on altered areas for longer durations, with some participants verbally reporting changes after the experiment. Interestingly, while all types of changes attracted attention, the results indicated that familiarity had a greater influence on gaze behavior than the specific nature of the change itself. These results highlight the importance of repeated exposure and scene learning in improving change detection performance and visual attention management in virtual environments.

Eye-tracking technology has become increasingly integral to virtual reality (VR) systems, enhancing user interaction and providing insights into user behavior. Adhanom et al. (2023) conducted a comprehensive review of eye-tracking applications within VR, categorizing them into seven broad areas: foveated rendering, interaction, user monitoring, performance assessment, medical applications, psychological research, and usability studies. Their analysis highlighted how eye-tracking facilitates more immersive and efficient VR experiences by enabling systems to respond to users' gaze patterns in real-time.

In the realm of foveated rendering, eye-tracking allows VR systems to reduce computational load by rendering high-resolution images only in the user's direct line of sight, with peripheral areas displayed at lower resolutions. This technique leverages the human eye's sensitivity to detail in the foveal region, thereby optimizing system performance without compromising perceived image quality. Adhanom et al. (2023) noted that such applications of eye-tracking could lead to more cost-effective and accessible VR solutions by lowering hardware requirements.

The review also examined the use of eye-tracking for user interaction within VR environments. By monitoring gaze direction, systems can enable gaze-based selection and manipulation of virtual objects, offering a more intuitive and natural user experience compared to traditional input methods like handheld controllers. Adhanom et al. (2023) discussed various studies demonstrating that gaze-based interaction can enhance task performance and reduce user fatigue, particularly in complex virtual settings.

Furthermore, eye-tracking in VR has significant implications for psychological research and medical applications. It allows researchers to study visual attention, cognitive load, and emotional responses in controlled virtual settings, providing valuable data for understanding human behavior. In medical contexts, eye-tracking can assist in diagnosing and treating conditions such as strabismus or amblyopia by creating interactive therapeutic exercises tailored to the patient's gaze patterns. Adhanom et al. (2023) emphasized that the integration of eye-tracking in VR holds promise for developing innovative diagnostic tools and personalized treatment plans.

Methodology

In this paper, we have conducted four types of tests on 16 participants to find answers for our three research questions that include “How do users perceive the ease of completing everyday tasks using passthrough technologies?”, “What are the common challenges users face when performing physical tasks using passthrough technology?”, and “Does the use of passthrough technology enhance or hinder task performance compared to non-passthrough methods?”. These tests include doing everyday tasks once with the use of passthrough and the other time without passthrough. To counterbalance order effects, the order of using passthrough and not passthrough was assigned randomly to the users (Santoso & Bailenson, 2024).

Four chosen tasks consist of walking in a predefined path through a target , solving jigsaw puzzles, playing office basketball, and drawing a simple circle on a whiteboard. To perform these tasks, users used Meta Quest 3 headset. A screenshot of the users’ view using video passthrough and their normal sight is shown in Figure 1. This headset has the dual LCD panels with the 2064*2208 resolution per eye, 90Hz of refresh rate that can be increased up to 120Hz. This device has a 110° horizontal and 96° field of view providing an immersive experience. This device is utilizing a 4 MP RGB camera to enable passthrough feature and has 512 GB of storage. The weight of the device is 515 grams which makes it lighter and more comfortable for extended use.

(a) (b)

Figure 1. (a) Passthrough view for the users who wear Meta Quest 3 headsets

(b) View for the users who do not wear Meta Quest 3 headsets.

The pilot test was conducted on a single participant before the main usability testing phase. The objective of this pilot test was to identify potential issues in the design and execution of the planned experiments, allowing us to refine the process if necessary before testing the full participant group.

During the pilot test, the participant performed the same set of tasks planned for the main study, including:

- Walking in a predefined path with and without Meta Quest 3 headset.
- Solving a jigsaw puzzle under both passthrough and non-passthrough conditions.
- Performing the office basketball task with and without headset.
- Drawing a circle using the headset and without the headset.

The participant's feedback and observed performance were carefully analyzed, revealing several minor issues that were subsequently addressed. Firstly, the instructions for each test were not entirely clear, with some details about how the tests should be performed being difficult for participants to understand. To resolve this, the task descriptions were revised for improved clarity. Secondly, in the walking test, it is decided to randomize the box distance within a specified range for each trial, and the error measurement method was refined to calculate the percentage rate of error for more precise data analysis. Thirdly, while performing the puzzle task, two puzzles of equal difficulty but different designs were used. Therefore, instead of giving one puzzle set to participants with headset and other one to without headset, it is decided to disturbed puzzle randomly. Finally, in the office basketball task, concerns about muscle memory influencing performance led to the decision to alter the angles between trials with and without the headset while keeping the distance constant.

These adjustments ensured consistent target placement and clearer task instructions across all trials, improving the overall reliability of the experimental design and ensuring a smoother experience for the participants during the main usability study.

Users conducted the first task in the hallway of the FASS department, at Sabanci University. At first, we asked users to stand and wear the headset and observe the target which was placed at random and specific distance in front of them for exactly ten seconds. After that, we asked them to take out the headset, close their eyes and walk through the object based on their distance estimation ability. Meanwhile, two chaperones were taking care of the tester because his/her eyes were closed. This task was repeated another time with the headset off. In this time, again users had ten seconds to observe the target and walk through it with their eyes closed. We repeated the no headset condition one more time. In each step, the position of the target was changed, and one of the examiners was removing the target for safety of the user after showing it to the testers. For this task, time of the task completion and the accuracy of the estimations were recorded for each user.

For the second task, we asked participants to solve the twenty-piece puzzle in the size of 27 * 18.5 cm, one time with passthrough and the other time without passthrough. For each headset condition we provided users with different puzzles to prevent them from memorizing the previous puzzle. In this task, the time of the task completion was recorded. After testers solved the puzzles with both headset and no headset conditions we asked them some questions about their experiences. These questions were their understanding about color differences, distortion, and their overall feelings.

In the third task, participants were asked to perform the "office basket" activity, which involved throwing a paper ball into a box. Each participant completed the task twice: once with the headset on and once without the headset. To counterbalance the order effect, the order of conditions was randomized. Some participants began the task without the headset, followed by using the headset, while others started with the headset and then proceeded without it. For each condition, participants were allowed three attempts to throw the paper ball. A throw was considered successful only if the ball landed directly in the box. For example, if the ball entered the box after bouncing or touching another surface, it was not counted as a successful throw.

At last, we asked users to draw a simple single circle with the use of passthrough and also without passthrough. In our experiment, we asked users to draw a black circle while using the headset and draw a red circle while they were using no headsets. Through conducting this experiment, we aimed to understand whether users are able to draw a circle from a close distance while using the headsets. Through doing this experiment, we aimed to understand the intersensory conflict between the visual system and the kinesthetic system (Heller et al., 1999). In the following section, we present sample images captured during participant testing. Additional session images can be found in Appendix C.

(a) (b)

Figure 2. (a) Walking in a predefined path through a target with a headset.

(b) Walking in a predefined path through a target without a headset.

(a) (b)

Figure 3. (a) Solving a jigsaw puzzle with a headset.

(b) Solving a jigsaw puzzle without a headset.

(a) (b)

Figure 4. (a) Playing office basketball with a headset.

(b) Playing office basketball without a headset.

(a) (b)

Figure 5. (a) Drawing a circle with a headset.

(b) Drawing a circle without a headset.

We invited 16 students from Sabanci University to participate in our experiments. One of the participants was from Sabanci business school (SBS), while the others were from the faculty of engineering and natural sciences (FENS). Their ages ranged from 21 to 29. The average of the ages of testers was 24 with standard deviation of 1.825. Other characteristics of the participants are shown at Table 1. The prepared persona is available in the Appendix A.

Table 1. Demographic Characteristics of Participants (N=16)

Characteristic	Category	Count (N)
Gender	Women	6
	Men	10
Race/Ethnicity	Middle Eastern	16
Prior Virtual Reality Experience	Never	8
	Rarely	6
	Sometimes	2
Prior Passthrough Experience	Never	10
	Rarely	5
	Sometimes	1

After testers finished the experiments we invited them to fill out the five-page questionnaire which was designed based on the “Simulator Sickness Questionnaire”(SSQ; Kennedy et al, 1993) to assess the effect of passthrough on each individual's health, specifically nausea, oculomotor discomfort, and disorientation, adapted “Embodiment Questionnaire” written by Santoso and Bailenson (2024) to evaluate the embodiment of testers, “Body Distortion Questionnaire” designed by Santoso and Bailenson (2024) to measure the users' body distortion, and Virtual Embodiment Questionnaire (VEQ) mentioned by Roth and Latoschik (2020) to evaluate the change in perceived body schema. The main "Embodiment Questionnaire" is written by Peck and Gonzalez-Franco (2021); however, it is possible to select different questions and modify them based on the passthrough tasks and experiences (Santoso & Bailenson, 2024). The designed questionnaire is available on Appendix B. Moreover, during the tests, we asked some questions from the participants to better understand their feelings regarding using the passthrough, and how they feel about passthrough and non-passthrough conditions. Our observations based on their answers will be discussed in the results section.

Results / Analysis of Data

Simulator Sickness Questionnaire (SSQ)

To evaluate simulator sickness among participants, the Simulator Sickness Questionnaire (SSQ) developed by Kennedy et al. (1993) was administered. The SSQ included 16 items where participants rated common symptoms experienced after VR headset use on a scale from 0 (None) to 3 (Severe). Each symptom was categorized under Nausea (N), Oculomotor (O), and Disorientation (D).

Calculation Steps:

1. The sum of the scores was calculated separately for each category (N, O, and D).
2. The sum for each category was multiplied by a specific weight: Nausea (9.54), Oculomotor (7.58), and Disorientation (13.92).
3. The total SSQ score was computed by summing the weighted scores and multiplying the result by 3.74.

Descriptive Statistics and Interpretation:

- Standard Deviation (SD): 556.22 which is close to the average and indicates a high spread of sickness symptoms. Might be outliers in the data.
- Average (AVG): 735.81, showing moderate sickness levels across participants.
- Mode (MOD): 1595.93, the most frequently reported sickness level.
- Minimum (MIN): 0, indicating some participants experienced no sickness symptoms.
- Maximum (MAX): 1595.93, reflecting extreme symptoms for some participants.

Tools Used: Calculations were performed using Microsoft Excel.

Embodiment and Body Distortion

The Embodiment and Body Distortion assessments, based on Santoso and Bailenson (2024), measured participants' body distortion and sense of embodiment during VR usage.

Body Distortion:

- Rated on a 5-point Likert scale (Not at all to Extremely).

Embodiment:

- Rated on a 7-point Likert scale (Never to Always).

Descriptive Statistics and Interpretation:

- Body Distortion (AVG): 3.64, indicating moderate body distortion.
- Body Distortion (SD): 1.31, showing variability in responses.
- Body Distortion (MIN): 1.2, with some reporting low distortion.
- Body Distortion (MAX): 5.6, indicating severe distortion for some.
- Embodiment (AVG): 4.46, indicating a moderate sense of embodiment.
- Embodiment (SD): 0.84, showing lower variability.
- Embodiment (MIN): 2.8, with some participants reporting lower embodiment.
- Embodiment (MAX): 5.4, with others experiencing high embodiment.

Tools Used: Calculations were performed using Microsoft Excel, with averages and standard deviations calculated using standard formulas.

Virtual Embodiment Questionnaire (VEQ)

The Virtual Embodiment Questionnaire (VEQ) developed by Roth and Latoschik (2020) measured the participants' sense of embodiment across three categories: Ownership, Agency, and Change. Each question was rated on a 7-point Likert scale ranging from 1 to 7.

Descriptive Statistics and Interpretation:

- Ownership (AVG): 4.34, indicating moderate-to-high ownership perception.
- Ownership (SD): 1.80, suggesting considerable variation among participants.
- Ownership (MIN): 1, showing minimal ownership perception in some cases.
- Ownership (MAX): 7, indicating maximum ownership perception in others.
- Agency (AVG): 5.19, suggesting a relatively high sense of control.
- Agency (SD): 1.32, with moderate variability in responses.
- Agency (MIN): 3, indicating lower agency perception in some cases.
- Agency (MAX): 6.75, reflecting strong control perception in others.
- Change (AVG): 3.38, indicating moderate perception of body change.
- Change (SD): 1.91, suggesting high variability among participants.
- Change (MIN): 1, with minimal perception of body change in some participants.
- Change (MAX): 6.25, showing strong body change perception in some cases.

Tools Used: Calculations were performed using Microsoft Excel for averaging and standard deviation calculations.

For all metrics (SSQ, Embodiment, Body Distortion, and VEQ):

- Means and standard deviations were calculated using Excel's `AVERAGE` and `STDEV` functions.
- Graphs were generated using Excel's bar chart tool to visualize score distributions.

This standardized approach ensured consistency across the data analysis process, aligning with the referenced methodologies (Kennedy et al., 1993; Santoso & Bailenson, 2024; Roth & Latoschik, 2020).

Walking in a predefined path through a target

The walking task data included measurements with and without a VR headset. For both conditions, the target distance (in tiles) was recorded along with the error rate and time taken to complete the task.

- **Error Rate Calculation:** The error rate was calculated as the difference between the target and the actual distance.
- **Error Rate Percentage:** The error rate was converted into a percentage using the formula: (Error Rate / Target Distance) * 100

Descriptive Statistics:

- Average Error Percentage (ON): 23.69
- Average Error Rate (OFF): 16.76
- Standard Deviation: Moderate variability observed with 26.33 for ON and 25.26 for OFF conditions.
- MIN: 0, indicating perfect accuracy for some participants.
- MAX: 105, reflecting high error rates for some participants.

Jigsaw Puzzle Task Data Treatment

The jigsaw puzzle task data involved measurements of time taken to complete a puzzle with and without a VR headset. The data processing included:

- Time Calculation: The time taken (in seconds) to complete the puzzle was recorded for both conditions.
- Difference Calculation: The difference between the time taken with and without the headset was calculated for each participant. Then they are summed up to see if the total difference is positive (with the headset it takes more time) or negative. And all of the calculations below are done using the difference.

Descriptive Statistics:

- Sum of all differences: 1398 sec which is on the extreme positive side indicating in total with the headset it took more time for participants to complete the test.
- Average Time Difference: 87.37 sec
- Standard Deviation: 74.89 (high variability in completion times)
- MIN: -20 sec (some performed better with the headset)
- MAX: 214 sec (indicating a significant delay with the headset for some).

Office Basketball Task Data Treatment

The office basketball task data involved measurements of participants' success scores (out of 3) and completion times with and without a VR headset. The data processing included:

- **Success Rate Calculation:** The success rate was recorded for both conditions based on a score from 0 to 3.

- **Difference Calculation:** The difference between success rates with and without the headset was calculated for each participant. Then again like the jigsaw puzzle test, they are summed up to see if the final value is positive or negative, meaning participants are more successful with the headset.

Descriptive Statistics:

- Sum of successful baskets for all participants: On: 7, OFF: 10 indicating that in total there are more successes without the headset.
- Success Rate out of 3 (ON): AVG: 0.44, SD: 0.51
- Success Rate out of 3 (OFF): AVG: 0.62, SD: 0.71
- MIN: 0 with the headset and 1 without the headset.
- MAX: 1 with the headset and 2 without the headset.

Circle Drawing Task Data Treatment

The circle drawing task data involved a binary scoring system to assess whether participants drew a proper circle with and without a VR headset. Each participant's drawing was visually inspected, and a score of 1 was given if the circle was drawn correctly, while a score of 0 was given if it was not.

- Success Rate Calculation: The sum of successful circles drawn was calculated for both conditions.
- Descriptive Statistics: Sum values were compared between the headset on and off conditions to measure performance differences. With the headset the sum of correct circles is 11 meanwhile without the headset it is 10.

Below, the charts of our data collected by each participant by using google form.

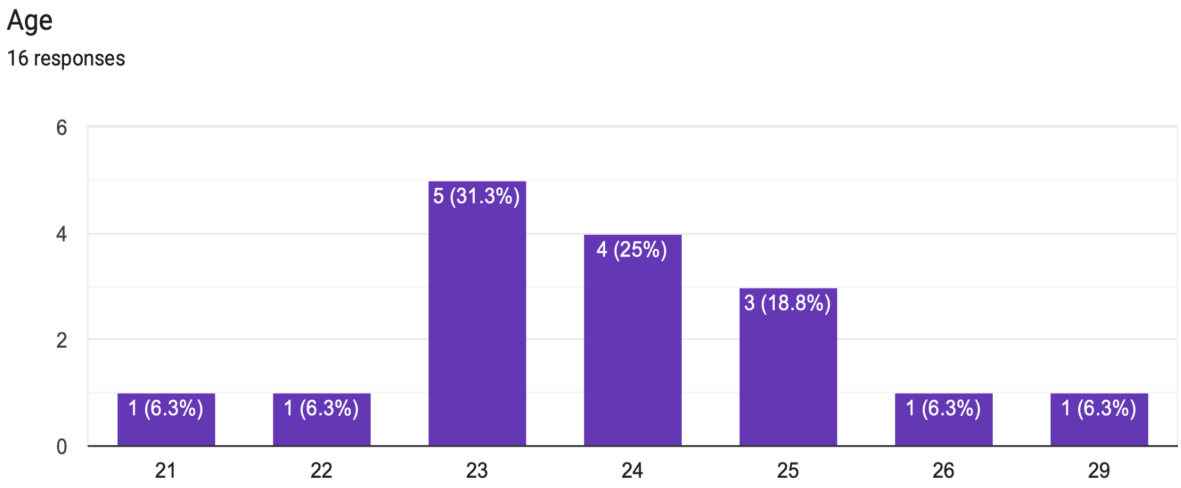

Figure 6. Barchart showing age distribution of our participants

- Most of the participants are around 23 and 24.

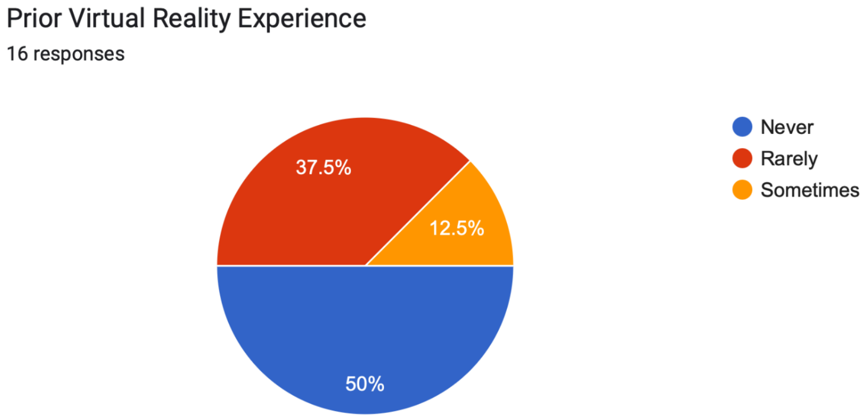

Figure 7. Pie chart showing prior virtual reality experience of participants

- Half of the participants have no prior experience with VR.

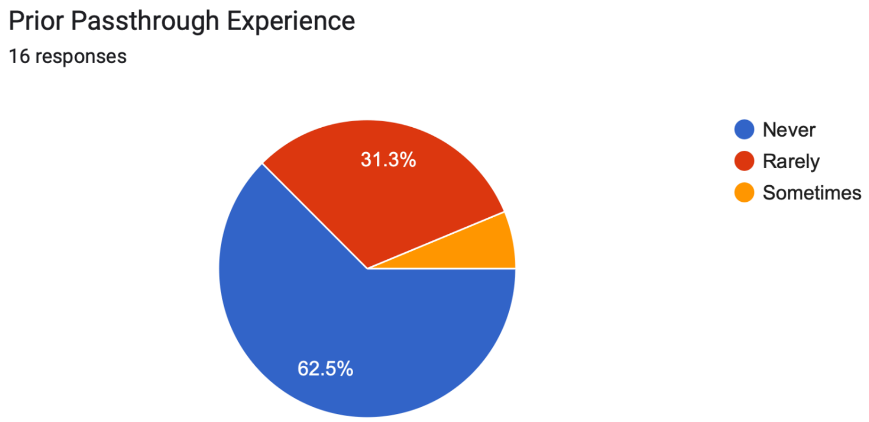

Figure 8. Pie chart showing prior passthrough experience of participants

- Most of the participants have no prior experience with Passthrough.

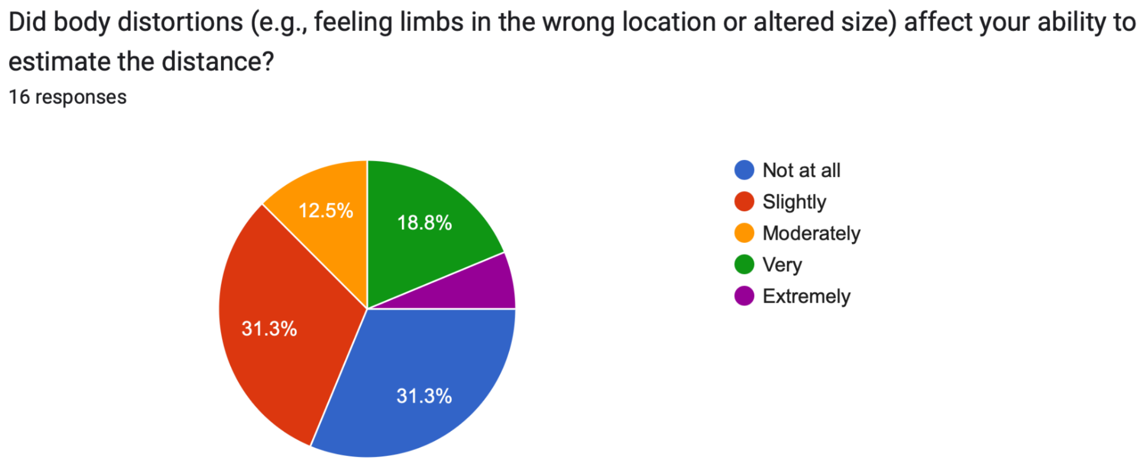

Figure 9. Pie chart showing how body distortion affects participants ability for distance estimation

- For distance estimation, most of the time body distortion did not have a high effect on participants.

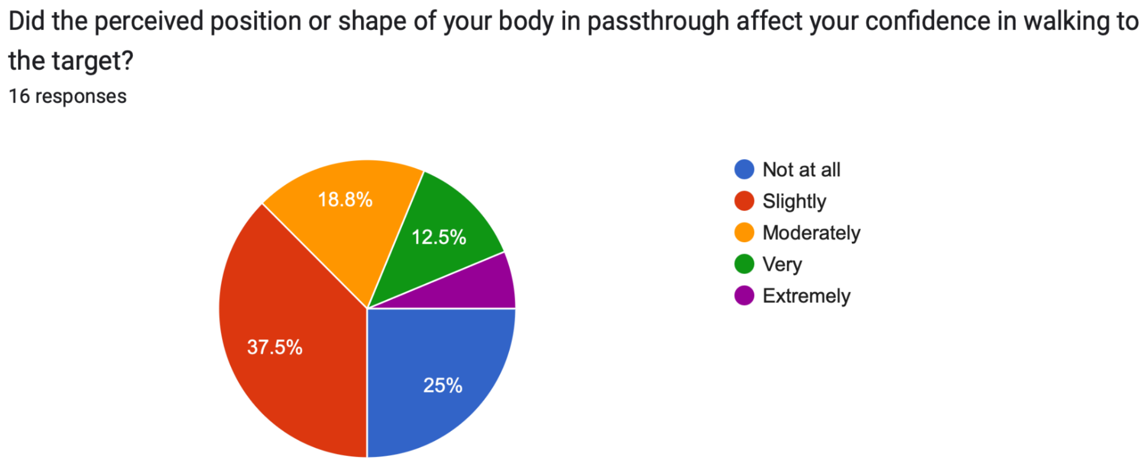

Figure 10. Pie chart showing how body distortion affects participants ability for distance estimation

- For distance estimation, most of the time body distortion did not have a serious effect on participants' confidence.

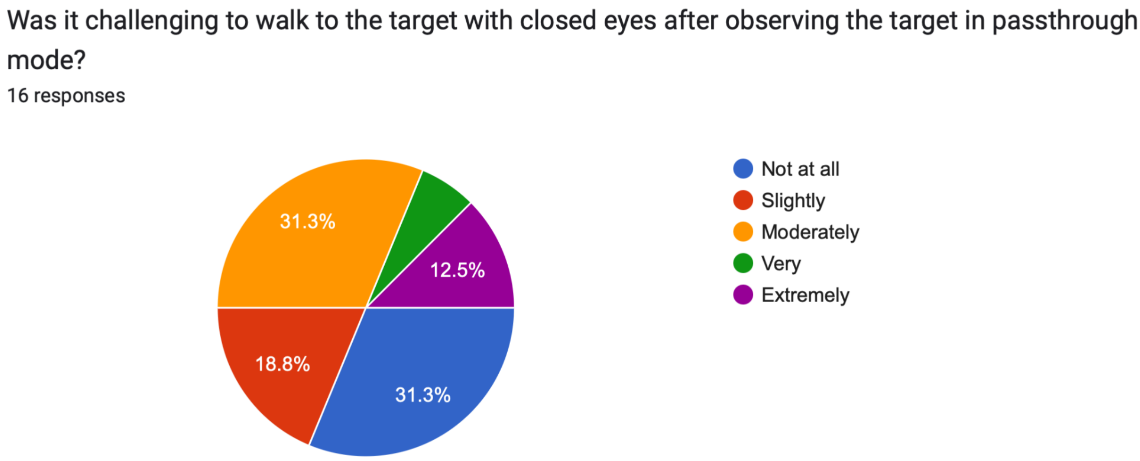

Figure 11. Pie chart showing how much was difficult for the participants to walk through the object in passthrough mode

- Participants found it moderately difficult to walk to target with closed eyes after they estimated the distance with passthrough.

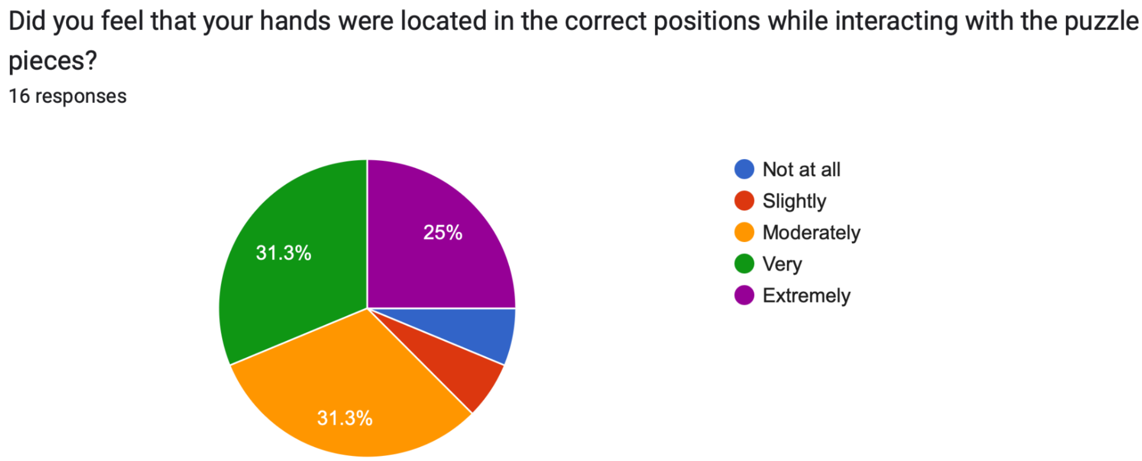

Figure 12. Pie chart showing how participants felt about their hands while solving the puzzles.

- Participants often feel as if their hands are located in the right position while doing the puzzle with the headset.

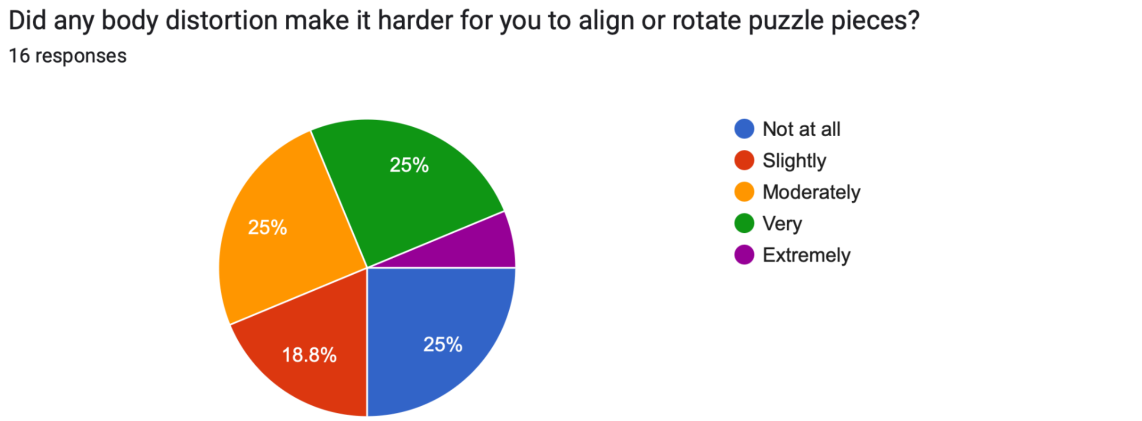

Figure 13. Pie chart showing how hard was rotating the puzzle pieces for the participants.

- While doing the puzzle with the headset, body distortion was problematic for participants.

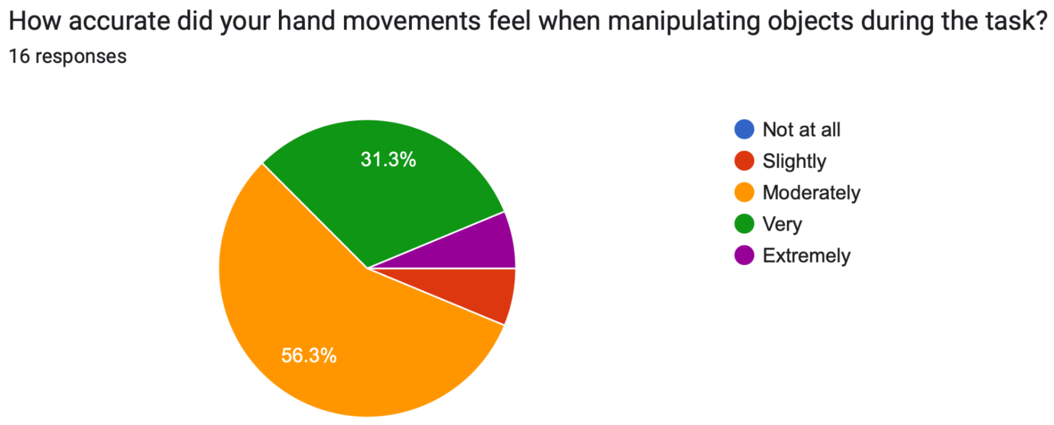

Figure 14. Pie chart showing the accuracy of hand movements in puzzle solving task

- For most of the time, hand movements felt accurate for participants while doing the puzzle with headset.

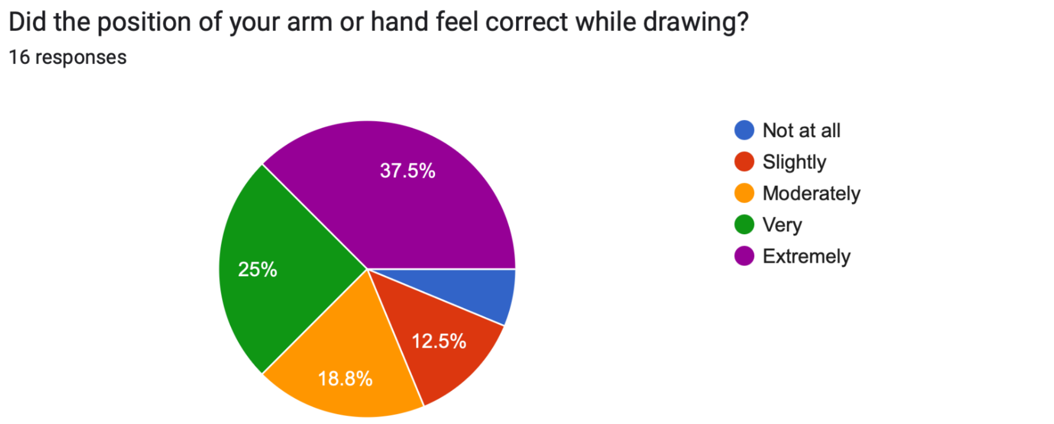

Figure 15. Pie Chart showing the accuracy of the hand position while drawing the circle

- For drawing a simple circle with the headset, arm and hand movements felt accurate except for a small proportion of the participants.

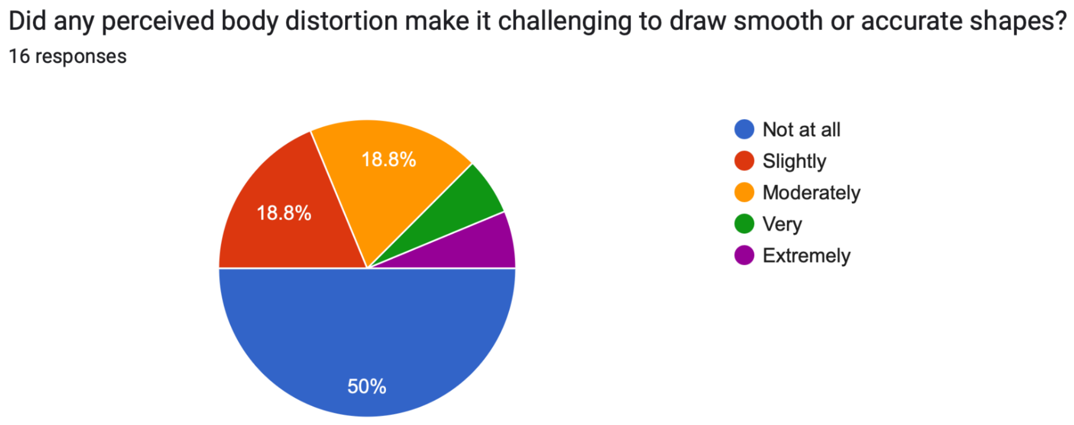

Figure 16. Pie chart showing the effect of body distortion on drawing the shapes.

- Body distortion was not a critical issue for drawing a simple circle with passthrough on.

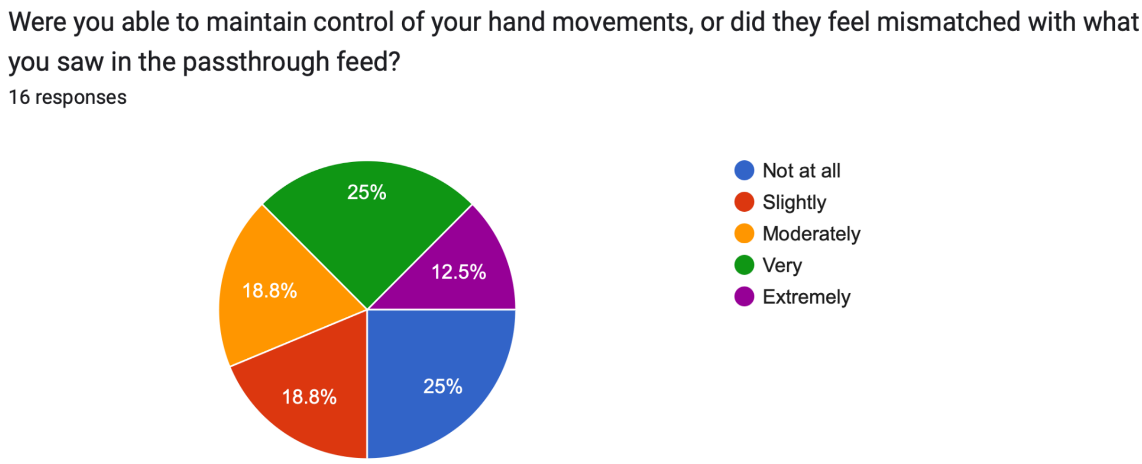

Figure 17. Pie chart showing the amount of hand controlling in hand movements.

- Controlling hand movements while throwing a ball with passthrough while having high variance for participants. Some of them found it challenging while others did not feel much difference.

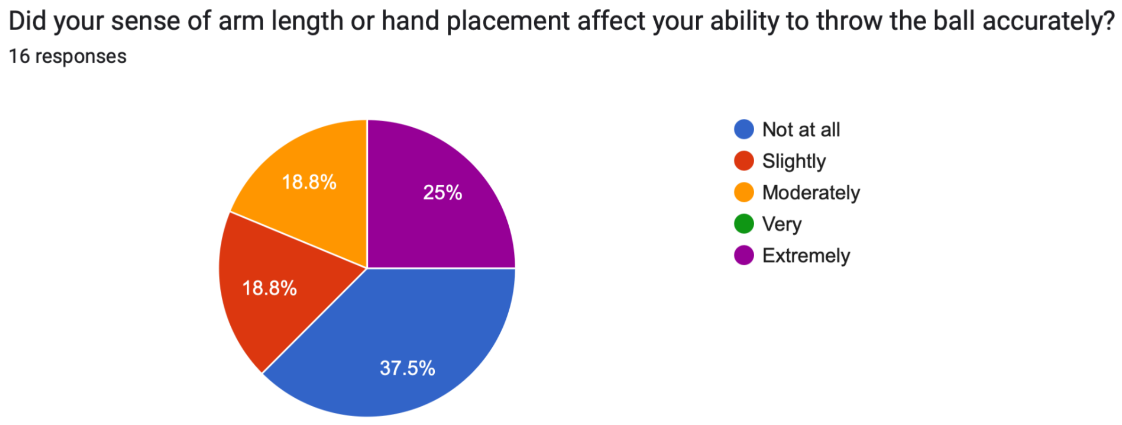

Figure 18. pie chart showing the effect of hand placement in office basketball task

- Arm length or hand placement extremely affected a quarter of the users' accuracy. However for the rest of them it was not a big issue.

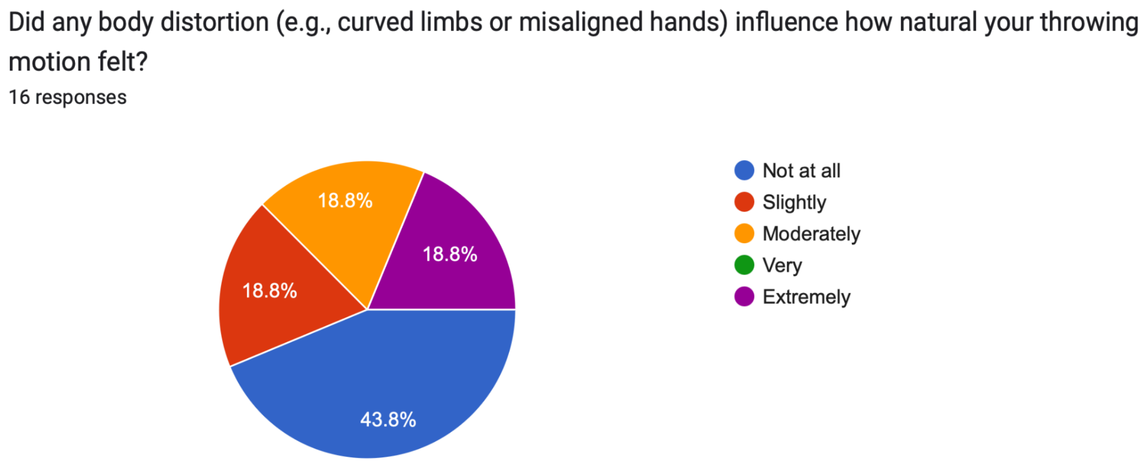

Figure 19. Effect of body distortion on office basketball task

- For approximately half of the users, body distortion did not influence natural throwing motion when the headset is on.

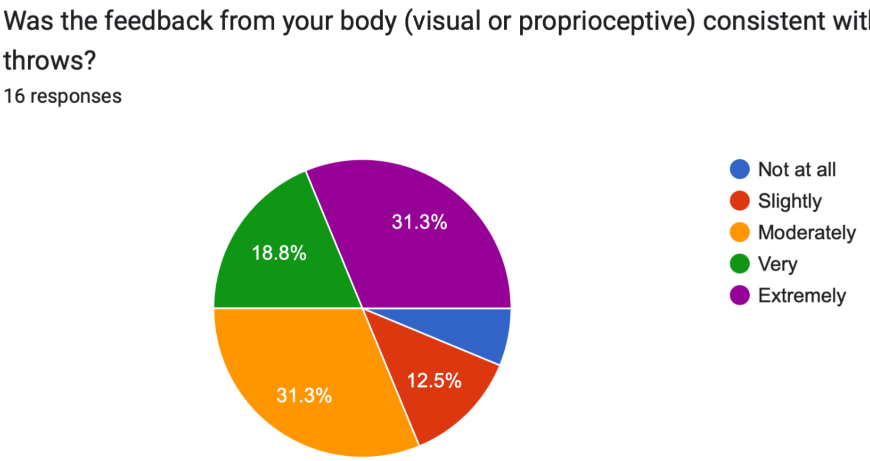

Figure 20. Pie chart showing the amount of consistency between body and throwing ball in office basketball task

- Usually feedback of the body and outcome of the throw was linked for the participants.

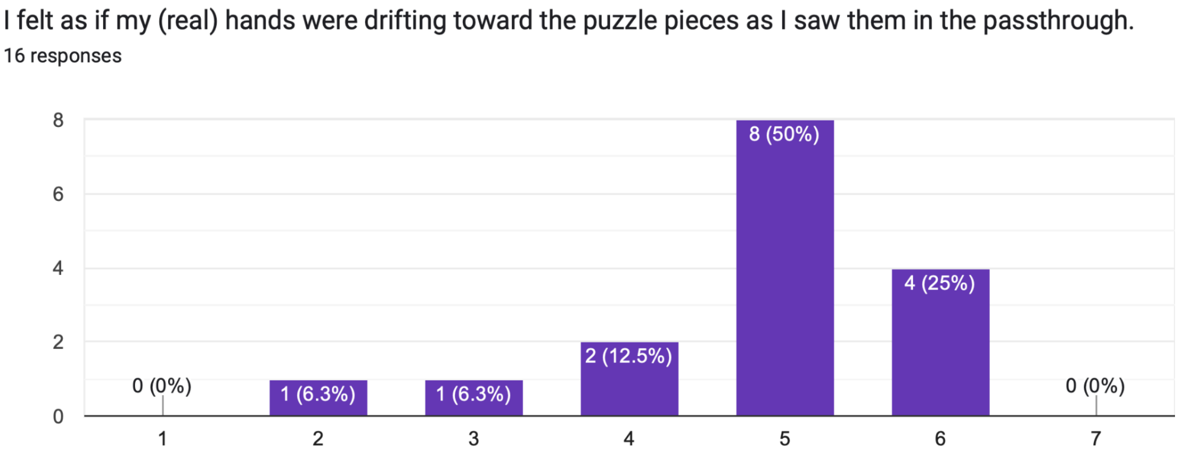

Figure 21. Bar chart showing the amount of hand drifting in puzzle solving task

- Participants felt as if their hands were drifting while solving puzzles.

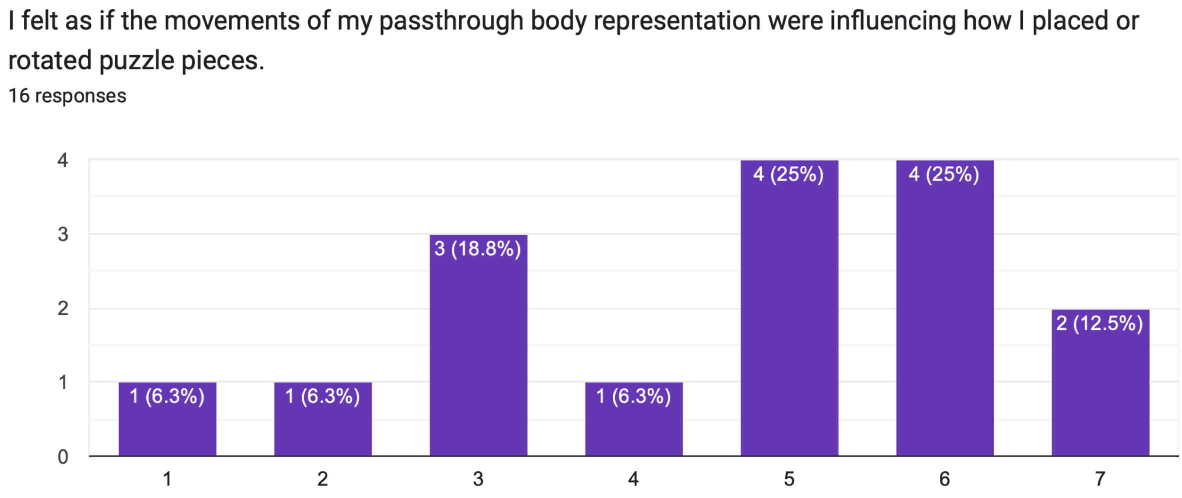

Figure 22. Bar chart showing the effect of passthrough on rotation of puzzle pieces.

- Participants think body representation moderately influences the puzzle placement they do.

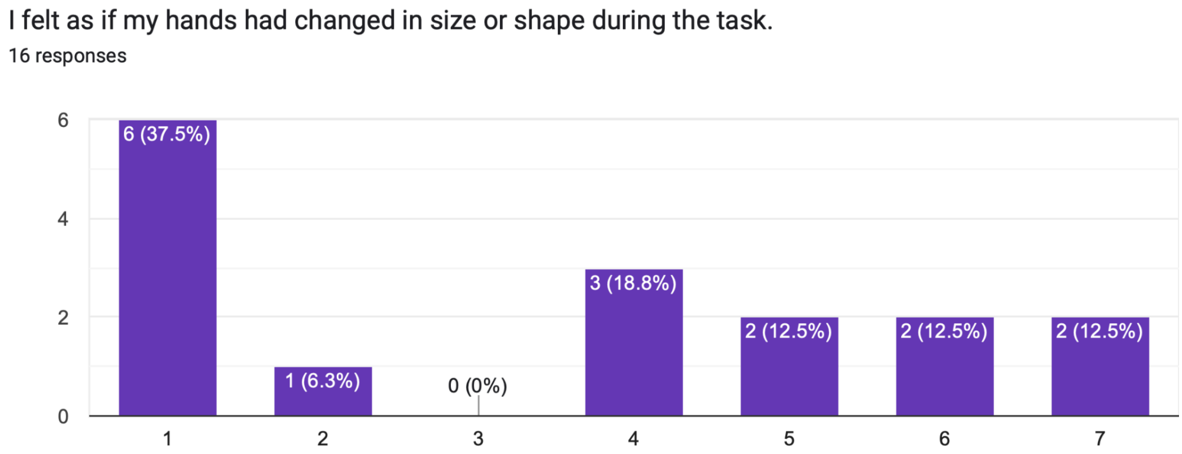

Figure 23. Bar chart showing how participants felt about their hands' size during the tasks

- Half of the participants did not observe any change about their hand sizes but the rest of them did.

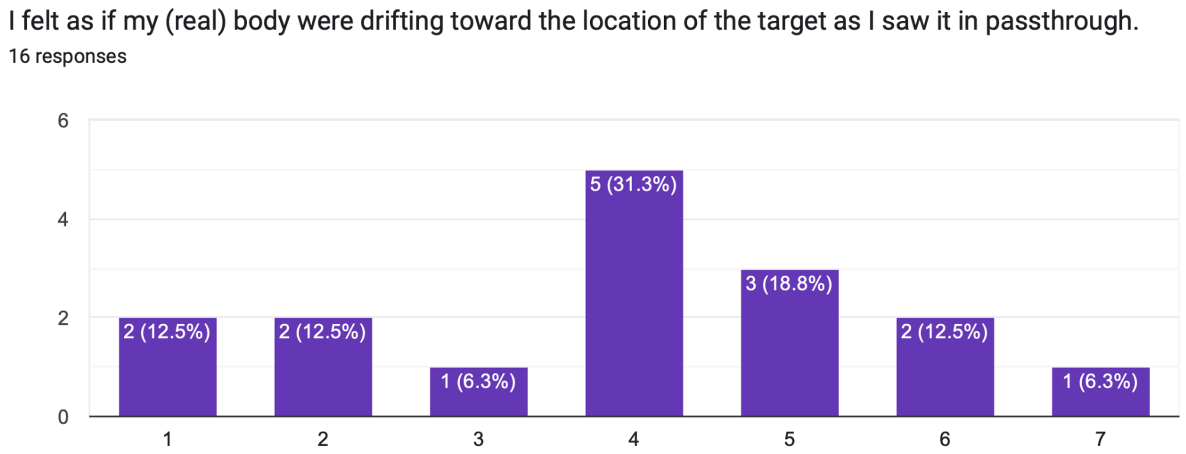

Figure 24. Bar chart showing the effect of drifting while using passthrough

- Participants moderately thought their bodies were drifting toward the target location.

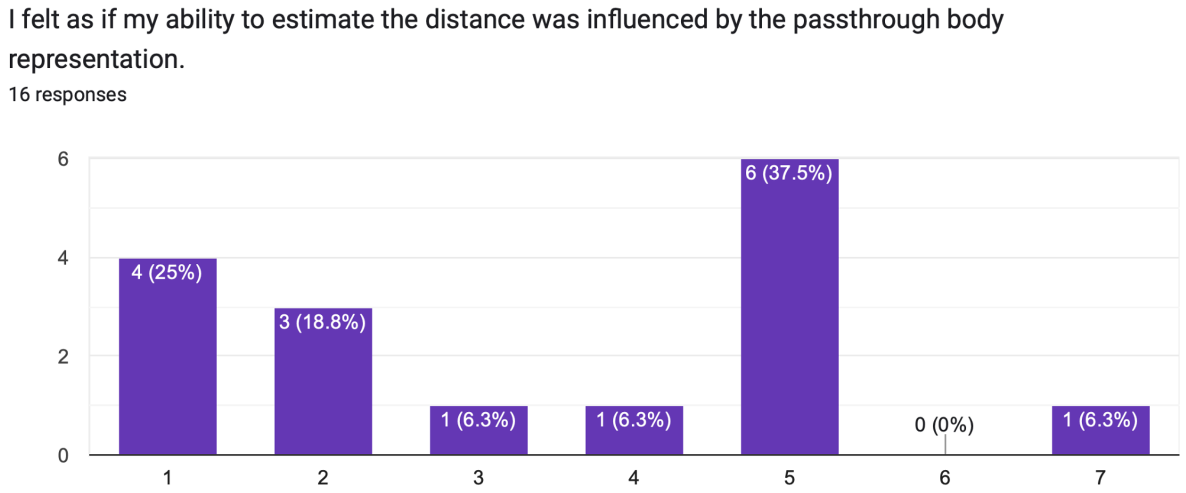

Figure 25. Bar chart showing the effect of passthrough on distance estimation tasks.

- Passthrough moderately affected distance estimation according to the participants.

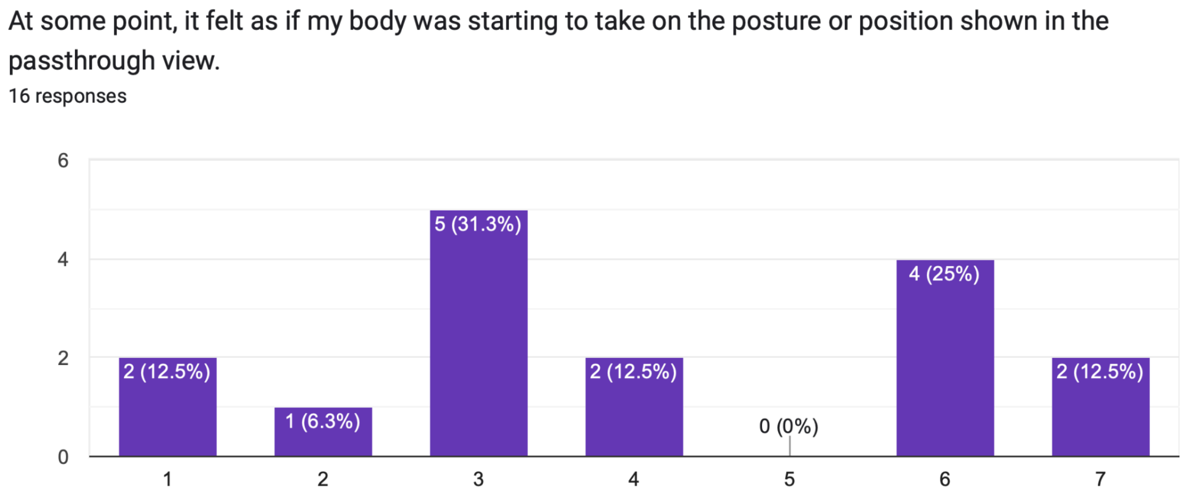

Figure 26. Bar showing how participants felt about the body position while using passthrough

- On average, participants did not change their posture according to the passthrough view.

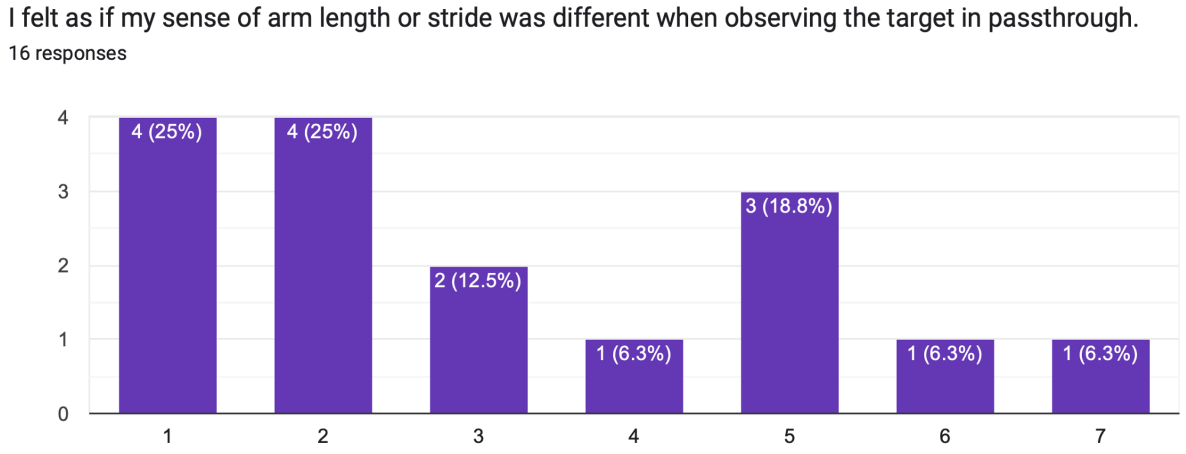

Figure 27. Bar chart showing the sense of participants about their arms while using passthrough

- For the most of the time, participants did not feel their arm's size changing.

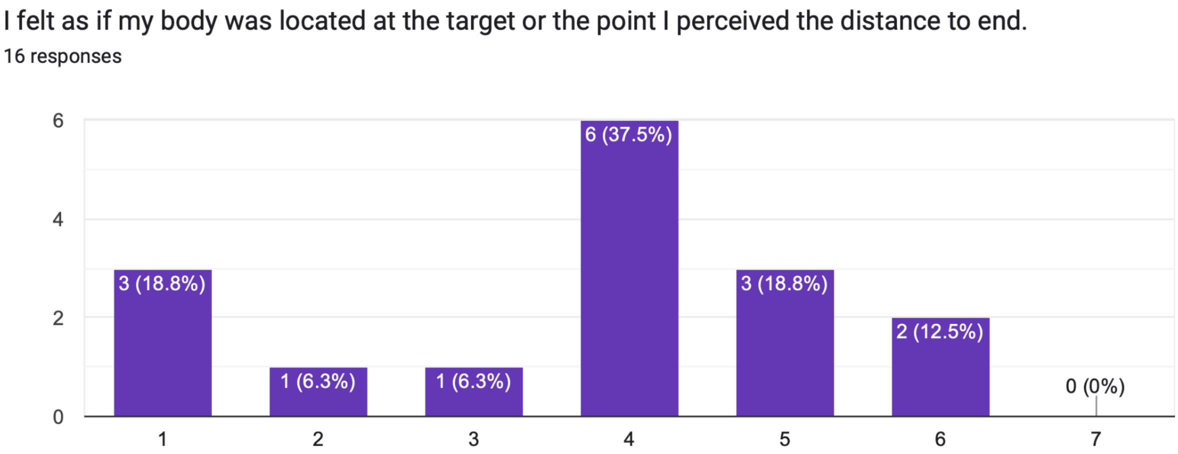

Figure 28. Bar chart showing how participants felt about their body position while using passthrough in distance estimation task.

- On average, participants thought they were located at the target.

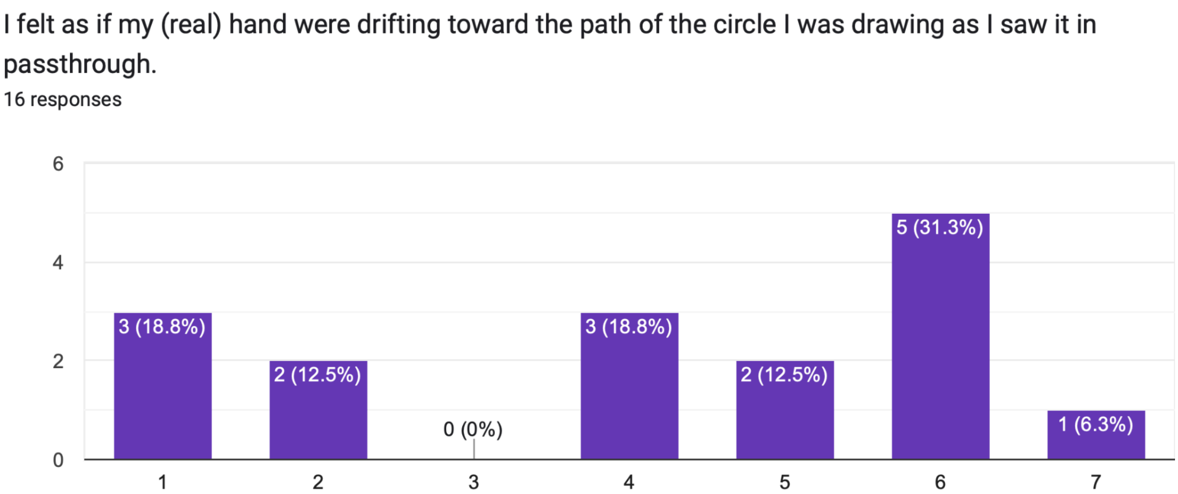

Figure 29. Bar chart showing how participants sensed about their hand drifting.

- Most of the time participants had no problem with passthrough in terms of hand drifting.

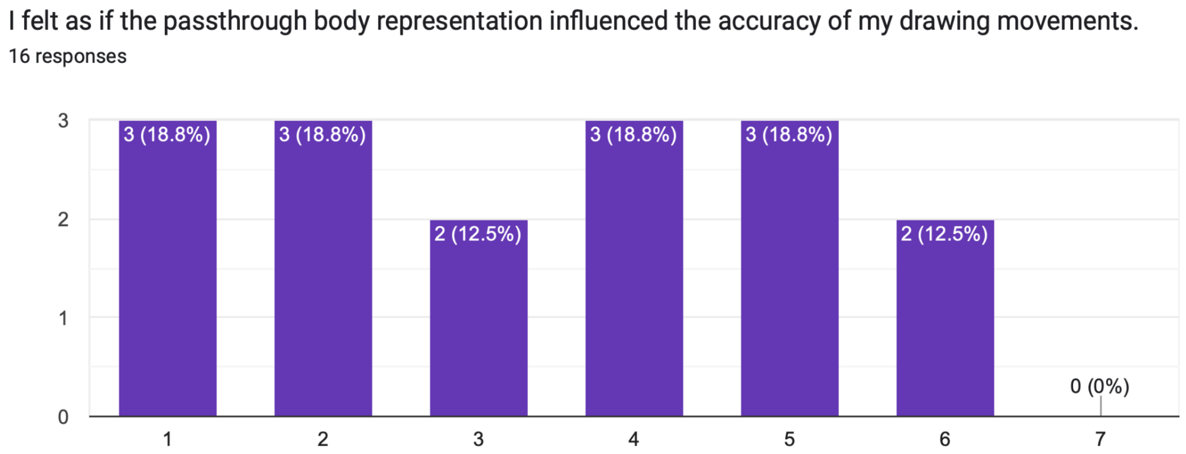

Figure 30. Bar chart showing how body representation in passthrough affected their drawings.

- On average, participants did not get affected by the representation of their body from passthrough.

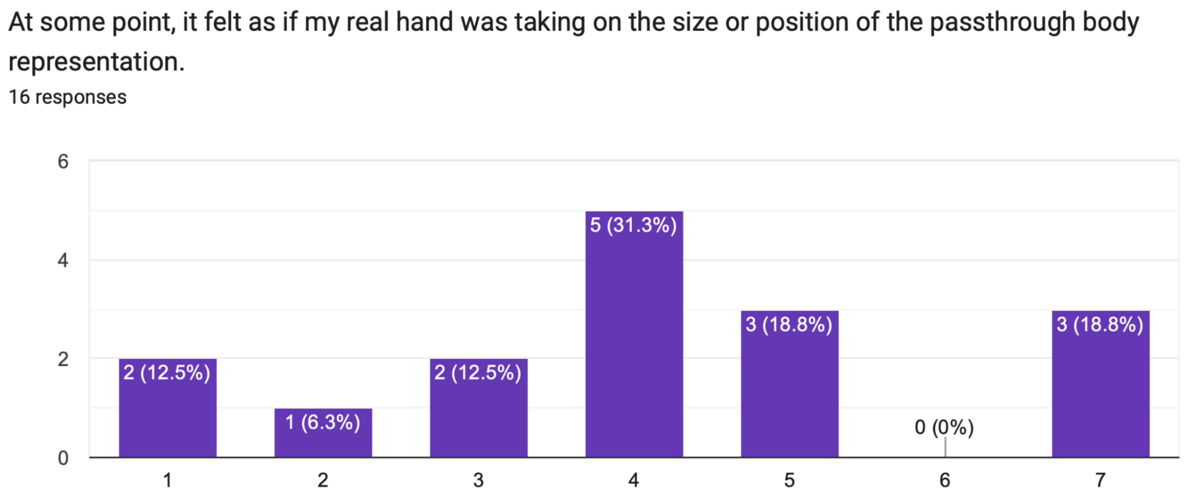

Figure 31. Bar chart showing how participants felt about their real hand size while using passthrough

- On average, participants think their hands took the position of the passthrough body presentation.

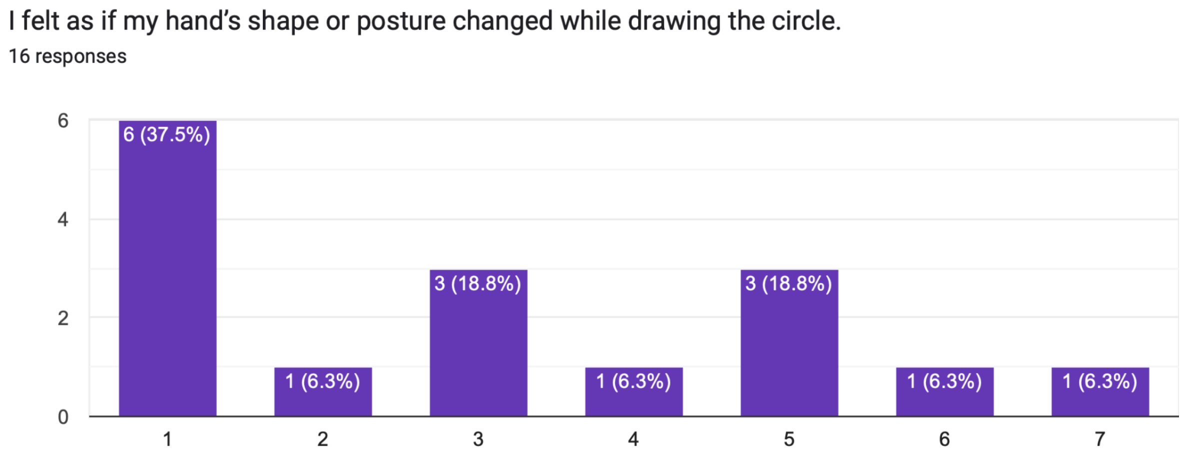

Figure 32. Bar chart showing if participants felt hand shape changing through using passthrough

- For most of the participants, the shape of their hand or posture have not changed.

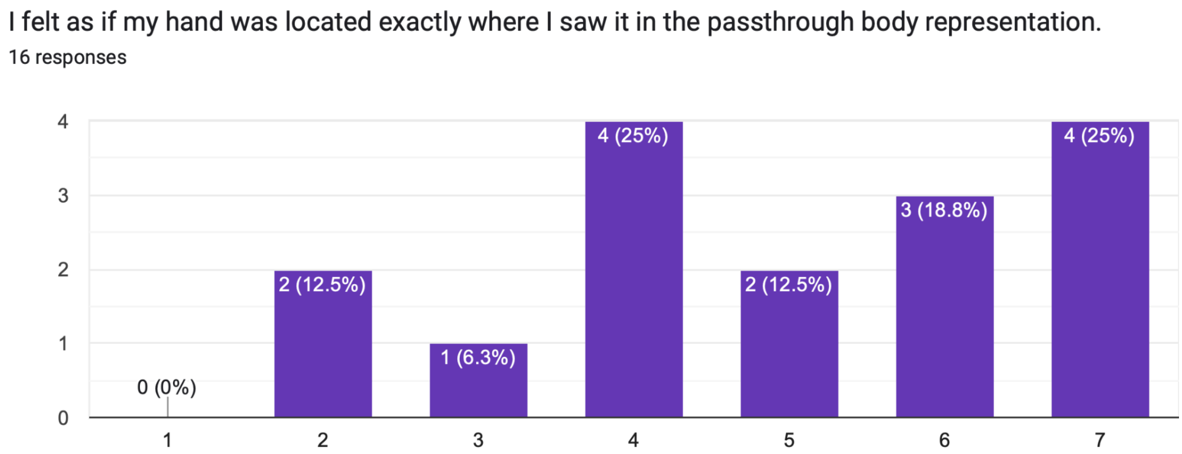

Figure 33. Bar chart showing the participants feelings about their real hands position while using passthrough

- Participants think their hand is located correctly with the passthrough.

I felt as if my (real) arm were drifting toward the ball or hoop as I saw them in passthrough.

16 responses

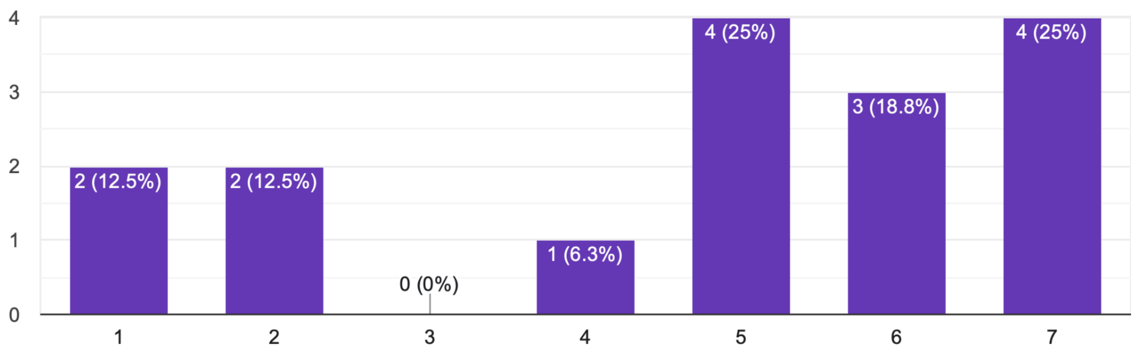

Figure 34. Bar chart showing the feelings of participants about arm drifting in the office basketball task.

- Oftentimes participants think their arms were drifting while doing an office basketball test.

I felt as if the movements of my passthrough arm influenced how I threw the ball.

16 responses

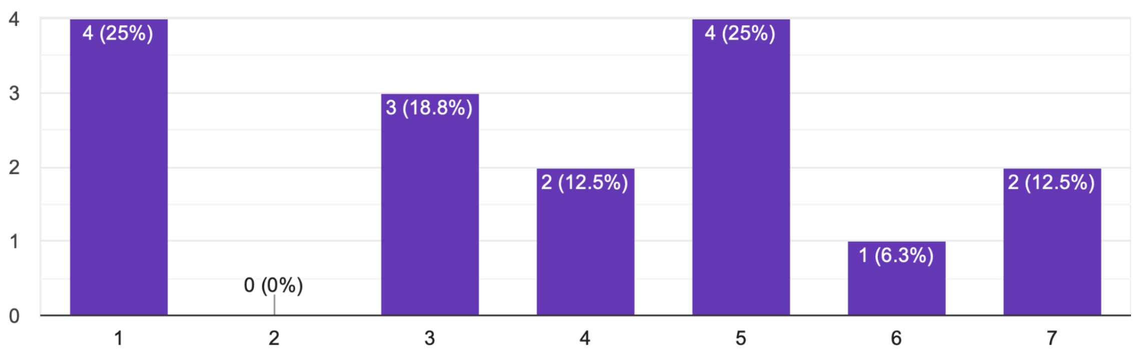

Figure 35. Bar chart showing the effect of passthrough while throwing the ball

- Users felt their passthrough arm movement influenced moderately how they threw the ball.

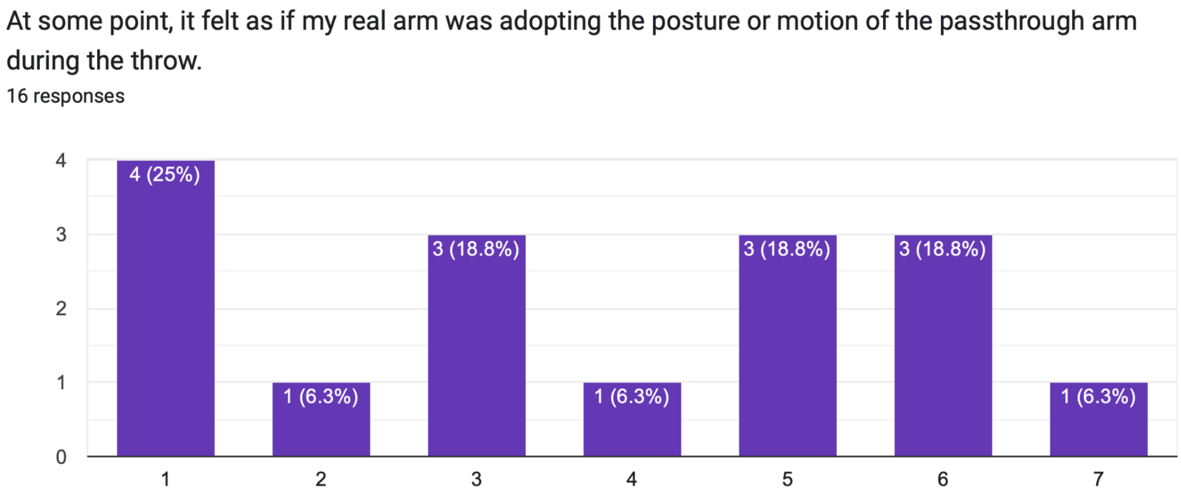

Figure 36. Bar chart showing the amount of posture adoption while using passthrough during office basket task.

- On average, users felt like their arm has adapted the motion of the passthrough vision of their arms.

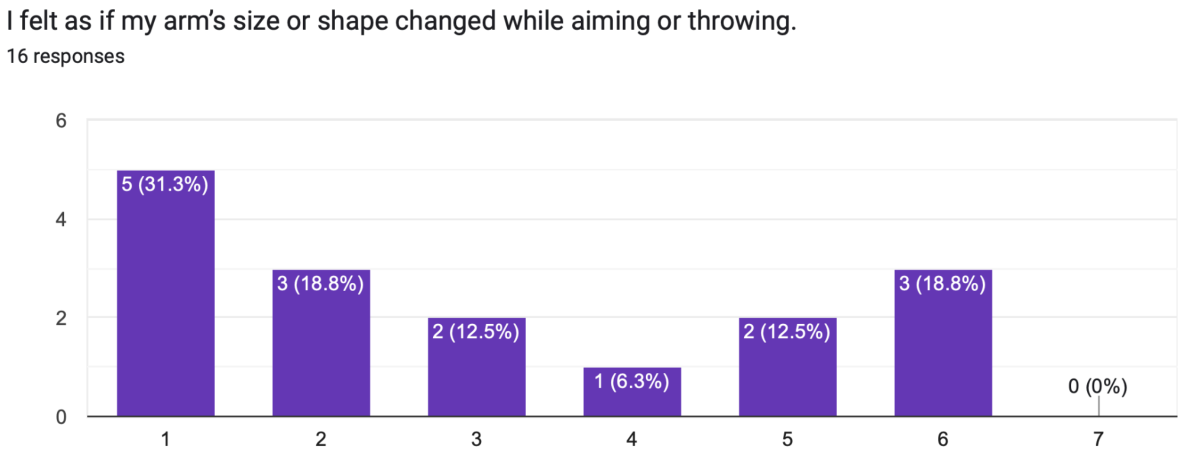

Figure 37. Histogram showing how much the arm's size or shape changed while aiming or throwing

- Participants do not think their arms' size changed dramatically.

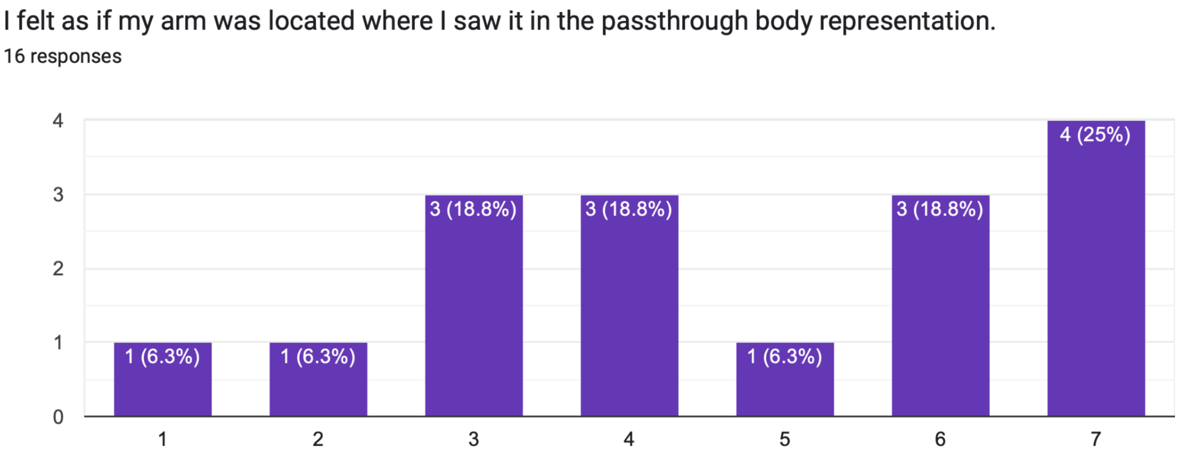

Figure 38. Histogram showing how much the arms was located where the user saw it in the passthrough body representation

- Participants most of the time agree that their arms are located accurately when compared with the passthrough view.

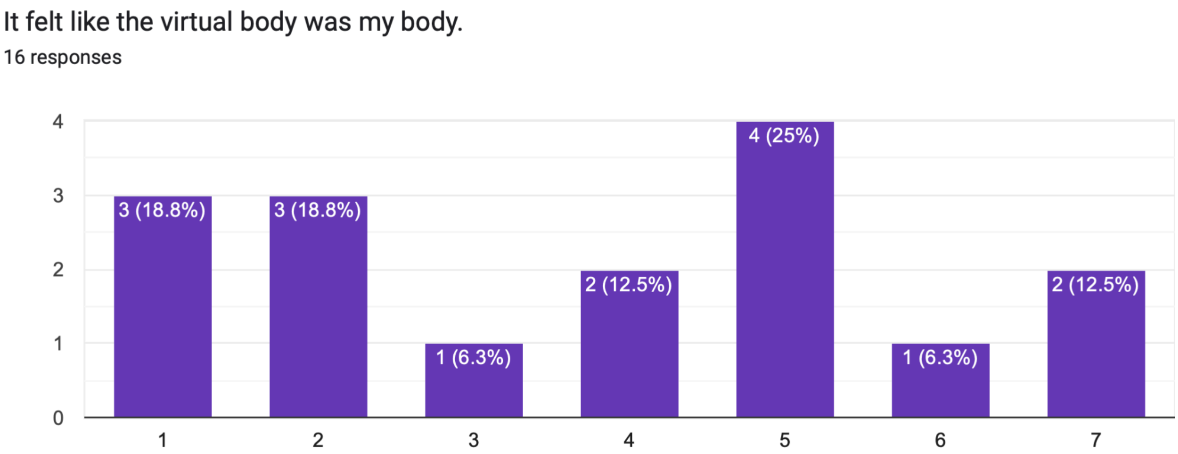

Figure 39. Histogram showing how much virtual body felt like the users' body

- On average, participants felt the virtual body was like their body.

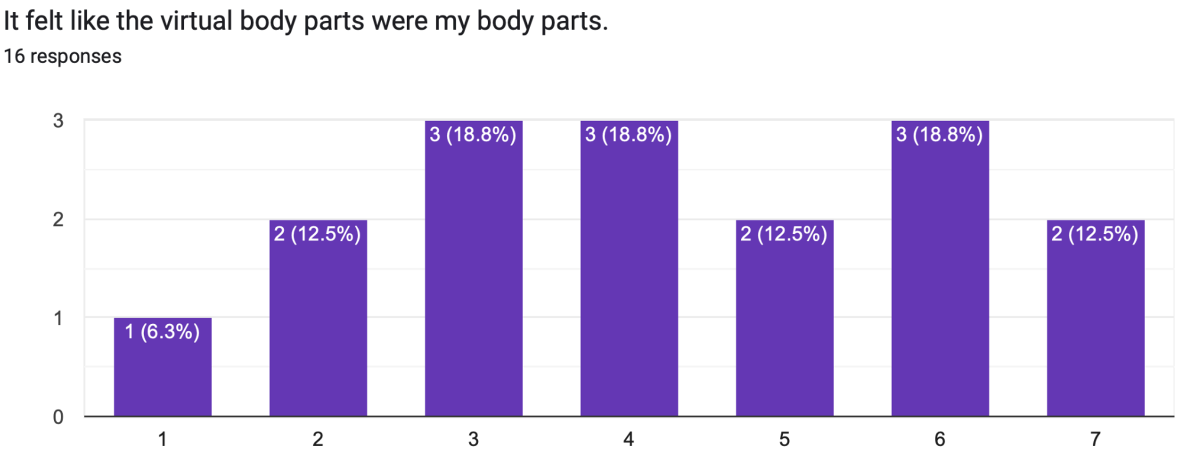

Figure 40. Histogram that shows how much the virtual body parts felt like the users'

- On average, participants felt the virtual body parts were like their body parts.

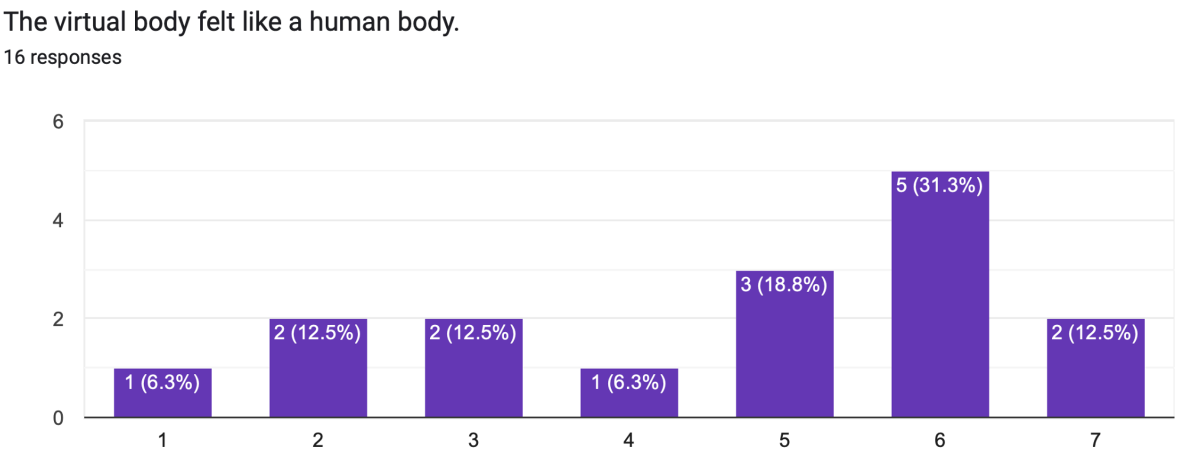

Figure 41. Histogram that shows how much participants think the virtual body felt like human body.

- On average, participants did not think the virtual body felt like the real human body.

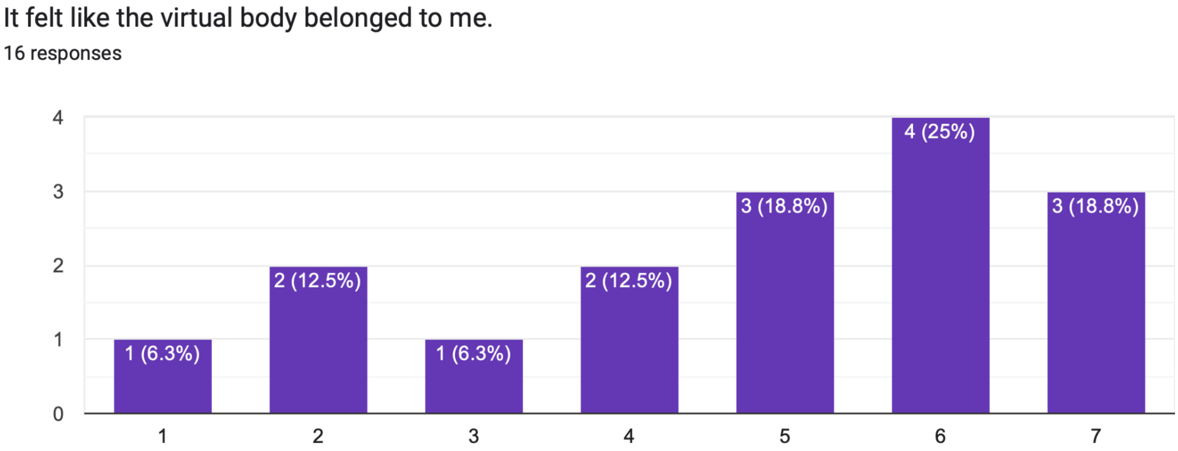

Figure 42. Histogram that shows how much participants felt like the virtual body belonged to them.

- On average, participants did not think the virtual body felt as if its their body.

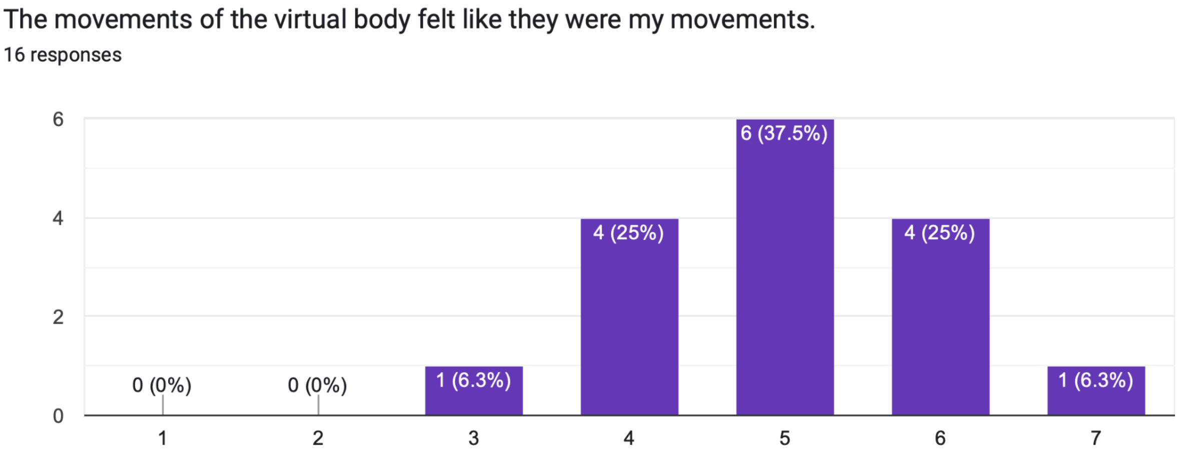

Figure 43. Histogram that shows how much participants felt like the movement of virtual body is actually their movements.

- Participants most of the time agree that their arms are located accurately when compared with the passthrough view.

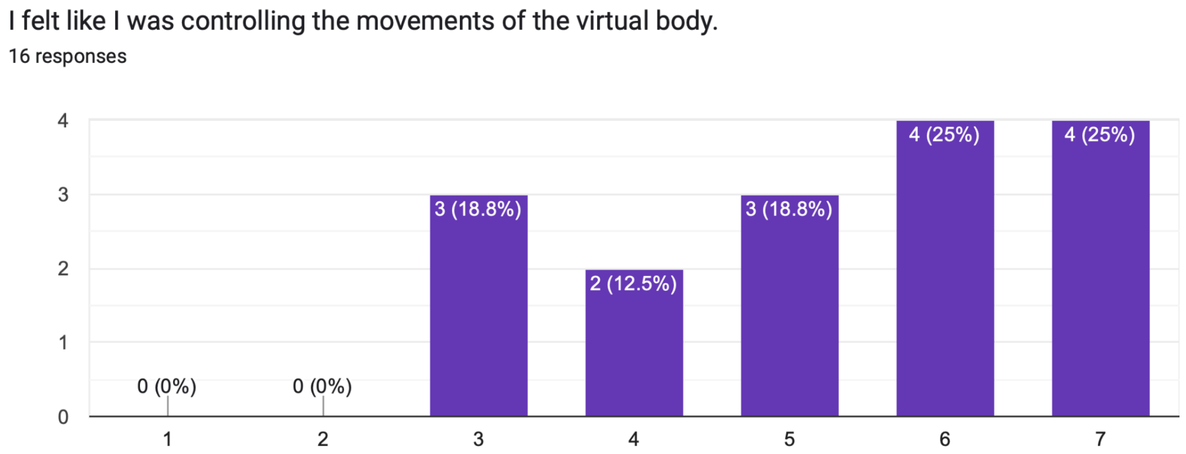

Figure 44. Histogram that shows how much participants felt like they are controlling their body movement.

- Participants most of the time felt like they were controlling the movement of the virtual body.

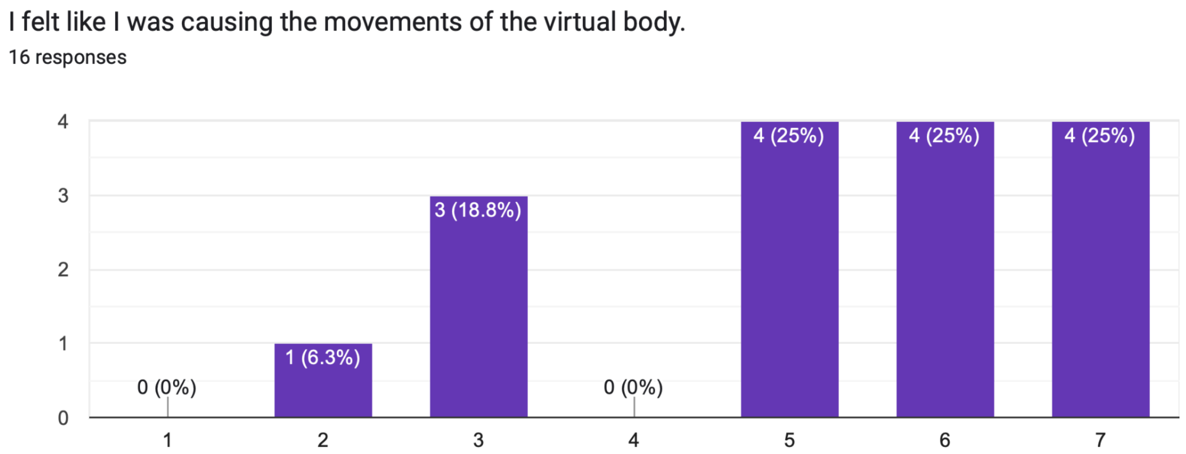

Figure 45. Histogram that shows how much participants felt like they are the cause of their body movement.

- Participants most of the time felt like they were responsible for the movement of the virtual body.

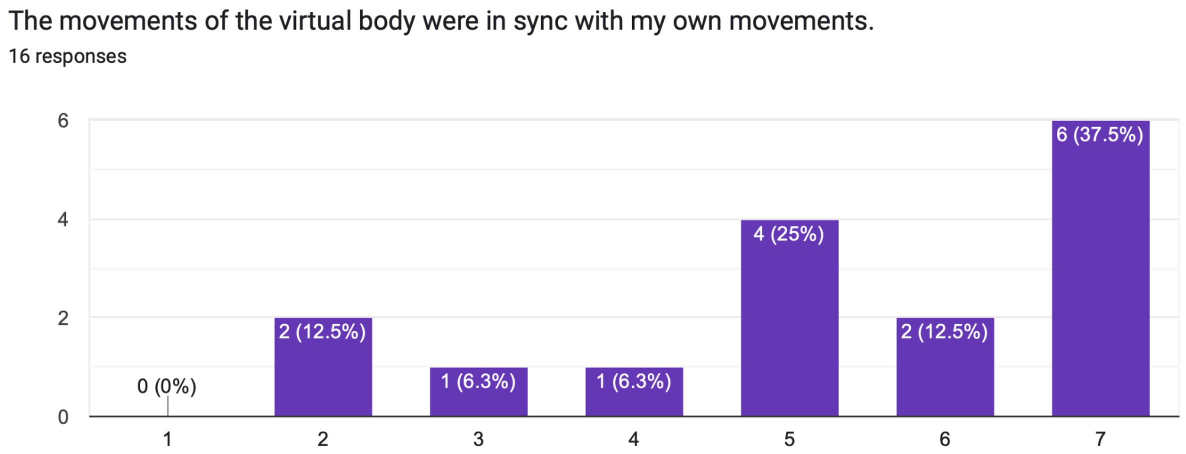

Figure 46. Histogram that shows how much participants' body were synchronised.

- Participants most of the time felt they are synchronized with the movement of the virtual body in

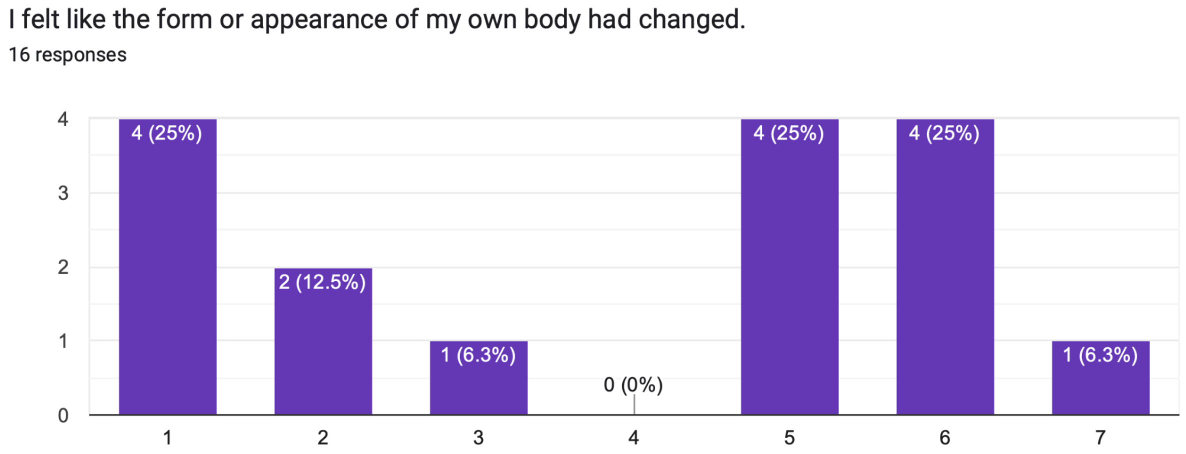

Figure 47. Histogram that shows how much participants felt like their body appearance is changed.

- Some of the participants thought their own body did not change meanwhile others felt otherwise so variance is high.

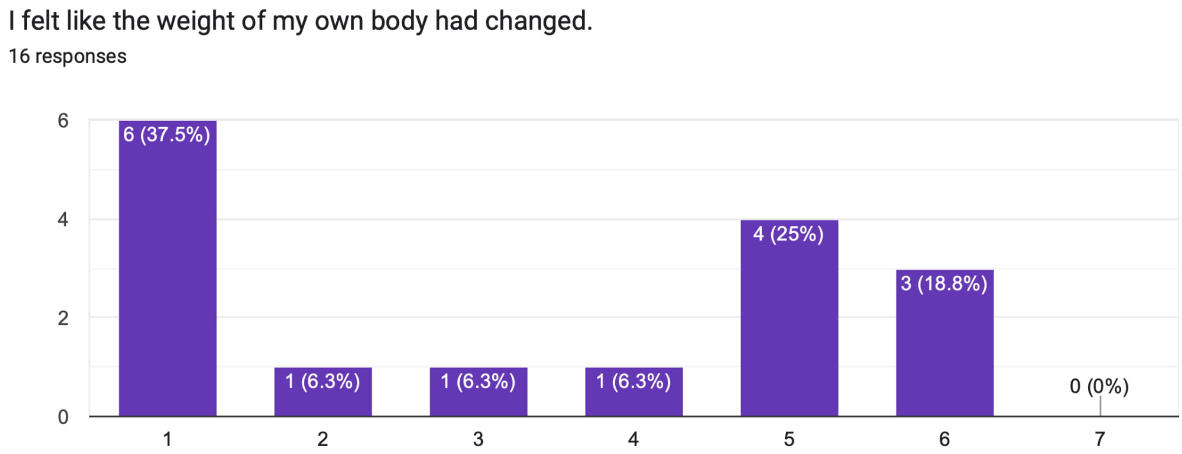

Figure 48. Histogram that shows how much participants felt like their body weight is changed.

- On average, participants think passthrough did not affect their body weight.

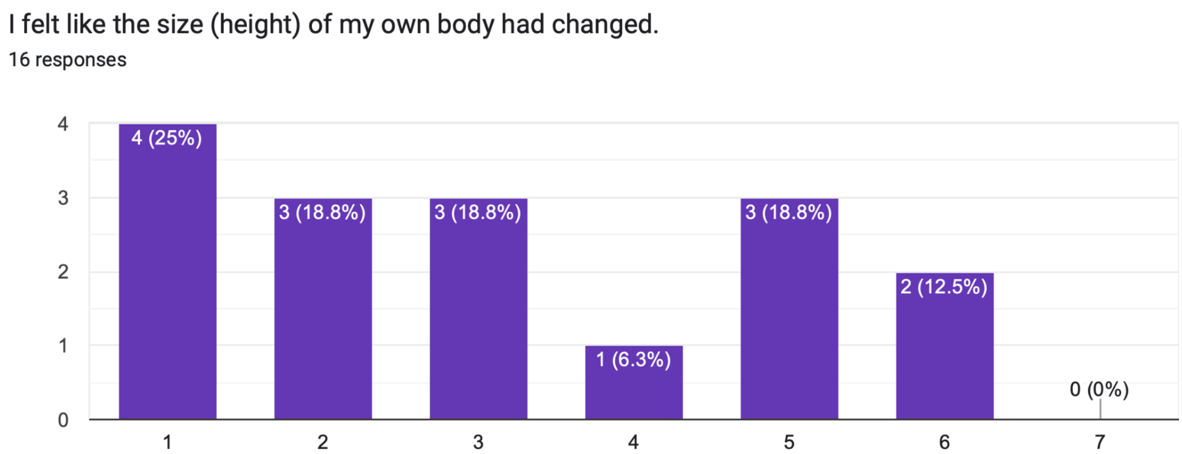

Figure 49. Histogram that shows how much participants felt like their height is hanged.

- On average, participants think passthrough slightly affects their body height.

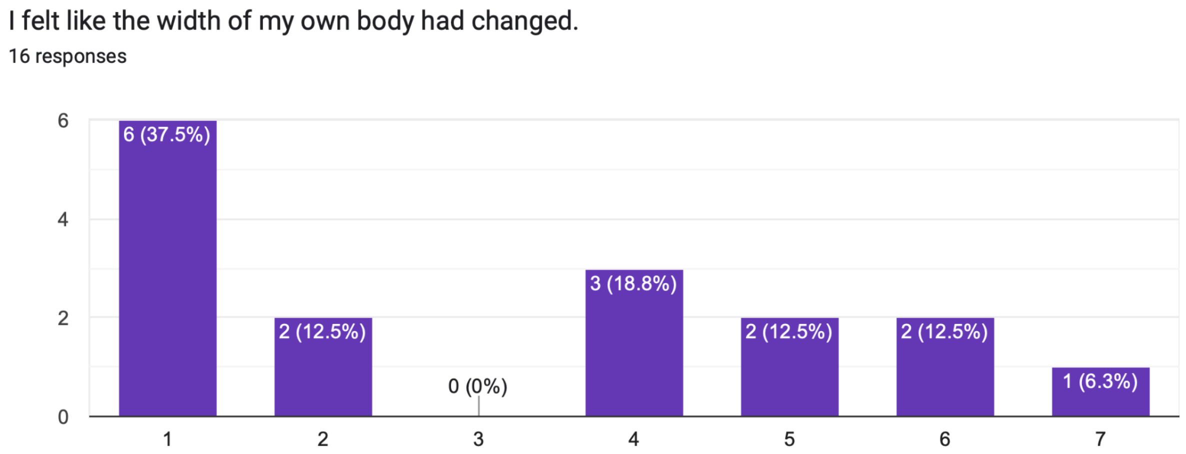

Figure 50. Histogram that shows how much participants felt like their body width is changed.

- On average, participants think passthrough slightly affects their body width.

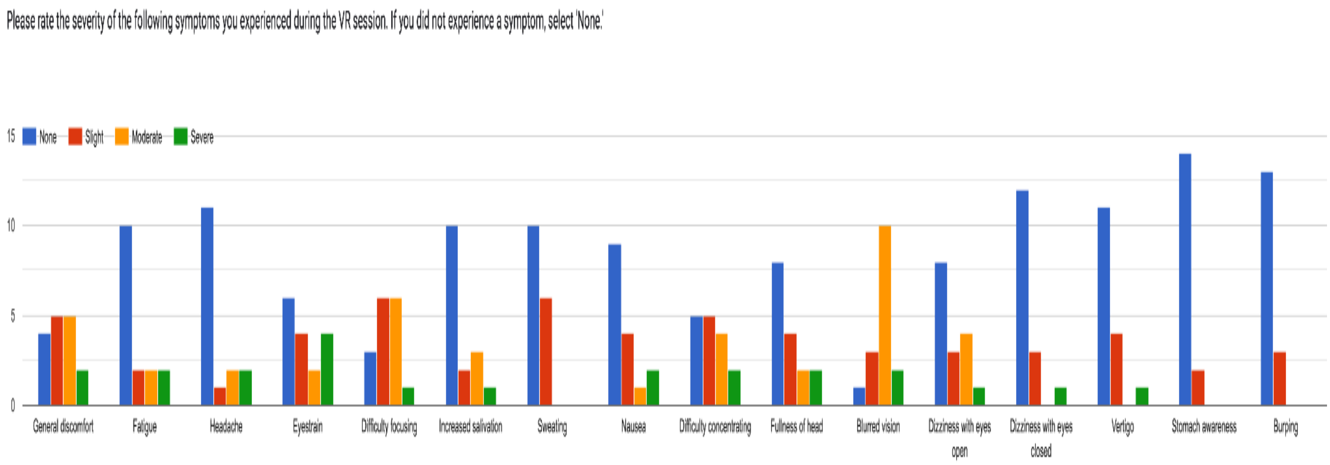

Figure 51. Histogram that shows severity of symptoms that participants experienced during VR sessions.

- It is evident that the majority of participants reported experiencing minimal discomfort, with the "None" category being the most frequently selected across symptoms like fatigue, headache, and stomach awareness. However, certain symptoms, such as blurred vision and difficulty focusing, show a higher frequency of "Moderate" and "Severe" ratings compared to others, indicating more pronounced discomfort in these areas. Symptoms such as dizziness, both with eyes open and closed, along with nausea and vertigo, display a mixed distribution, with a significant presence across all severity levels. The dominance of the "None" category suggests that most users experienced minimal negative effects, but the noticeable spikes in more severe categories for specific symptoms indicate areas where further investigation may be warranted to improve the VR experience.

To sum up,

- Participants experienced moderate levels of simulator sickness, with notable variability.
- Symptoms such as nausea, oculomotor strain, and disorientation were common, as reflected by the SSQ scores.
- Participants reported a moderate sense of embodiment and moderate body distortion during VR tasks.
- Variability in answers presented individual differences in adaptation to the virtual environment.
- In the walking task, error rates were higher with the headset, indicating that visual distortion impacted spatial judgment and accuracy.
- Participants took longer to complete puzzles with the headset, which implies that it is more difficult to control hand-eye coordination under visual distortion.
- Success rates were lower with the headset in the office basketball task, showing the difficulty of motor accuracy in the virtual environment.
- Drawing performance was comparable between conditions, with slightly more correct circles drawn with the headset.
- Visual distortion, lag, and motion sickness affected participants' performance and comfort.
- Tasks requiring detailed motor skills, such as puzzle-solving and basketball, were more difficult with the headset.

Below are the experiences shared by participants as they completed the puzzle task while using the headset. These insights were gathered through direct conversations and observation.

- Ashkan described his experience with the jigsaw puzzle as frustrating while using the headset. He struggled to put the puzzle pieces together because they frequently misaligned, making the process more challenging.

- Elman found the headset comfortable overall but noted that it was slightly inconvenient for individuals wearing glasses, making it harder for them to see clearly.
- İdil reported no significant issues during the task, likely due to her one year of experience with headsets.
- Ömer experienced some distortion and had difficulty distinguishing between near and far objects. He found the puzzle with more figures particularly challenging because the light reflections made it harder to identify the shapes. Additionally, he noticed a slight lag in the system.
- Bilgehan observed that certain puzzle features appeared ambiguous due to the camera, making it harder to differentiate details.
- Ekin found it easy to distinguish puzzle pieces but mentioned some visual distortion. She also felt uncomfortable while moving her hands, as the headset made her adopt more controlled motions compared to her freer movements without it.
- Sena appreciated the accurate perception of colors and shapes but found her vision blurry. She felt restricted in her hand movements, which slowed her down. Additionally, the screen caused eye fatigue and a sense of limited vision.
- Houshmand experienced blurry vision when he moved his head and believed the refresh rate of the headset was not good.
- Mohammad reported eye strain during the task and noted that some puzzle pieces were not easily detectable.
- Mert observed trembling in his vision, which affected his overall performance.
- Giray had difficulty aligning adjacent puzzle pieces and distinguishing colors. When distortion occurred, he relied on his intuition to complete the task.
- Müge felt confused when she saw virtual hands during the task. She believed the hands were intended to guide her but found them disorienting.
- Ecem also experienced initial confusion, as she saw a virtual hand holding a remote. Additionally, she reported blurry vision through the passthrough display.
- Kağan experienced nausea and motion sickness while using the headset. He also found it difficult to see his hands, and the color tones appeared slightly off to him. Despite these issues, he had no difficulty selecting patterns.
- Ayşegül noted that her vision was blurry on the sides, which she attributed to the cameras on the headset.

Overall, the user experience can be divided into 3 parts: positive aspects, challenges, and confusion.

Positive Aspects

- Several participants mentioned the accurate perception of colors and shapes, which helped them engage with the task.
- Users with prior experience using headsets, such as İdil, reported no considerable challenges, indicating familiarity can lessen usability issues.
- Some users, like Ekin, found distinguishing puzzle pieces manageable despite minor visual distortions.

Challenges

- Many participants, including Sena, Ayşegül, and Ecem, reported blurry vision, particularly through the passthrough display or at the edges of the screen.
- Participants like Ashkan and Giray struggled with aligning puzzle pieces, while others, such as Sena and Ekin, felt restricted in their hand movements, leading to slower task performance.
- Users like Kağan experienced nausea and motion sickness, while others, such as Mohammad and Mert, reported eye strain or trembling vision.
- Several participants observed technical issues, such as lag (Ömer), low refresh rates (Houshmand), and ambiguity in features caused by the camera (Bilgehan).

Confusion

- Virtual elements, such as virtual hands, caused confusion for Müge and Ecem, disrupting their focus during the task.
- Some users relied on intuition to overcome challenges, especially when visual cues were lacking, as Giray demonstrated during alignment tasks.

To conclude, the results can be distributed into four categories: performance, visual distortion, simulator sickness, and hand-eye coordination.

Performance

- Quantitative data indicated that tasks generally took longer and tended to cause more errors with the headset compared to those without it. For example, in the jigsaw puzzle

task, participants took an average of 87 seconds longer with the headset, and error rates in the walking task increased to 23.69% from 16.76% with the headset.
- Success rates in tasks needing motor precision, such as basketball, were also lower with the headset.

Visual Distortion
- Both qualitative and quantitative results emphasized visual distortion as an obstacle. Some participants experienced blurry vision, difficulty differentiating objects, and challenges with spatial judgment. These issues contributed to the increased error rates and slower task completion times observed in the quantitative data.
- Qualitative feedback like Ömer's difficulty distinguishing near and far objects and Mert's observation of trembling vision indicated these problems.

Simulator Sickness
- The Simulator Sickness Questionnaire (SSQ) indicated moderate sickness levels with high variability. Symptoms like nausea, eye strain, and motion sickness were common, as conveyed by participants; for instance, Kağan, Mohammad, and Sena.
- Eye strain and fatigue, along with restricted hand movements, were declared, affecting participants' comfort and efficiency.

Hand-eye coordination and Movement
- The Jigsaw puzzle test displayed high perceived costs in motor coordination when using the headset. Participants' qualitative feedback reinforced this, with Ashkan and Giray expressing difficulty aligning puzzle pieces or adjusting to restricted hand movements.

Discussion and Conclusion

In this section, the results are interpreted in terms of efficiency, effectiveness, and satisfaction according to the International Organization for Standardization ISO (Stewart, 1998).

Efficiency

Efficiency measures correlate a relationship between the cost of resources and the degree of effectiveness achieved . Appropriate resources may contain mental or physical effort, time, materials, or financial cost (Stewart, 1998).

- Quantitative results showed that tasks such as solving the jigsaw puzzle and walking through a predefined path took longer with the headset. For example, when wearing the headset, participants took an average of 87 seconds to finish the task. This shows that the efficiency decreased with the headset.
- The average error rate for the walking task was greater when wearing the headset (23.69%) than when not wearing it (16.76%). This indicates that there is a decrease in efficiency when obtaining accurate spatial navigation.
- Qualitative feedback, for example, Sena and Ekin's feedback on restricted hand movements, delivered that users had to put more effort into the task to complete, and it affected overall efficiency.
- The headset placed extra cognitive and physical demands which reduced users' ability to perform tasks quickly. Improving visual clarity and interaction design could reduce these inefficiencies.

Effectiveness

Effectiveness metrics communicate the user's goals or subgoals and the accuracy and comprehensiveness of achieving them (Stewart, 1998).

- Tasks requiring accuracy, such as office basketball, demonstrated lower success rates with the headset (0.44) compared to without (0.62). This means the headset reduced the effectiveness.
- Qualitative feedback featured difficulties in distinguishing shapes and distances, as reported by Ömer, Bilgehan, and Kağan which reduced task accuracy.
- The headset's visual distortion and lag lowered users' ability to perform tasks accurately. Improving the calibration, refresh rate, and interaction mechanics could make the system more effective.

Satisfaction

Satisfaction measures users' perspectives toward product use and how comfortable they are (Stewart, 1998).

- Participants experienced simulator sickness, including nausea (Kağan), eye strain (Mohammad), and motion sickness (Houshmand), which negatively affected satisfaction.

- Virtual hands caused confusion for participants like Müge and Ecem. This might have made the task less enjoyable.
- Most participants found the tests fun; however, discomfort and confusion reduced overall satisfaction.

In the context of our research questions, the results are interpreted as follows:

1. How do users perceive the ease of completing everyday tasks using passthrough technologies?

The users reported that the completion of the tasks was not hindered by the use of passthrough technology; however, it took them longer to complete them with the headset. Additionally, the visual distortion and motion sickness caused their experience to be lacking in terms of efficiency and satisfaction.

2. What are the common challenges users face when performing physical tasks using passthrough technology?

Most participants reported blurry vision and distortion throughout their use of the passthrough. Rarely, some participants experienced nausea and motion sickness. Additionally, some participants were confused by the virtual hand features, which appear when the users' hands are detected. These inhibited their performances with the headset.

3. Does using passthrough technology enhance or hinder task performance compared to non-passthrough methods?

Overall, participants' task performances were hindered by the passthrough technology. However, there were some cases in which some users performed better with passthrough, although they were outliers.

The results show that visual distortion, motion sickness, and the feeling of restriction in body movements affect users' performances negatively. Therefore, due to a combination of these effects, their overall performance is deficient.

According to Norman (1988), specific actions serve as a bridge between an individual's goals and the possible steps required to achieve them, resulting in the *Seven*

Stages of Action. The first stage involves forming the goal, where users define their objective—in this case, completing the given task. The second stage is planning the action, such as deciding to solve a puzzle. The third stage entails specifying an action sequence, for example, starting by assembling the puzzle's edges before working on the interior. The fourth stage involves performing the action sequence, where users actively engage in solving the puzzle. The fifth stage is perceiving the world, during which users encounter visual distortions while interacting with the system. In the sixth stage, users interpret their perception, attempting to understand the real state of the environment despite the distortions. Finally, in the seventh stage, users compare the outcome with the goal, evaluating the placement of the puzzle pieces to determine if they have successfully completed the task.

As stated in the Psychology of Human-Computer Interaction, the integration of a sensory system is provided by the visual system (Card et al., 2018). While using the passthrough technology, the visual distortion results in users' perceptions of the real world to be skewed. This results in motion sickness and user errors. Moreover, lags caused by the headset affect users' perceptions, delaying their actions.

The findings of this study indicate that motion sickness, visual distortion, and the sensation of physical movement restriction have a negative impact on users' performance. Their overall performance is poor because of a combination of these impacts. Therefore, addressing visual distortions and blurriness should have greater emphasis. Moreover, the virtual hands can be presented to the users in a less distracting way; for example, the transparency of the hands can be increased.

Our study had some limitations that may have influenced the results:

1. **Pilot Testing**

The pilot test was conducted with a team member who had prior experience with the passthrough headset and was familiar with the tasks. This familiarity may have introduced bias, as the pilot participant's performance may not reflect that of an average user.

2. **Participant Experience**

Two participants, İdil and Bilgehan, had prior experience with the headset. Their familiarity with the device could have impacted their performance, making it less representative of typical first-time users.

3. **Test Repetition**

Each task was performed only once with the headset on and once with the headset off. However, during our literature review, we identified studies where participants completed tasks twice under each condition (with and without the headset). This difference in methodology may limit the comparability of our results to those studies and reduce the reliability of our findings due to a smaller dataset.

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APPENDIX A - Persona

Demographics:

- Age: 25
- Gender: Male
- Education: Master’s student in Engineering
- Location: Istanbul, Tuzla

Goals:

- Develop their technical abilities through projects and assignments.

- Gain experience working on engineering problems.
- Build a network.

Challenges:

- Balancing coursework, research, and professional development.
- Applying theoretical knowledge to practical applications.
- Navigating Istanbul’s fast-paced environment while managing personal and academic responsibilities.

Interests and Hobbies:

- Engaging in hands-on projects.
- Exploring Istanbul during weekends.

Technology Use:

- Proficient in general engineering tools like AutoCAD, MATLAB, and Python.
- Familiar with data analysis and simulation software.
- Uses online learning platforms to explore new skills, such as 3D modeling and machine learning.

Motivations:

- Driven by curiosity and the desire to make tangible contributions to society.
- Get a high-paying job after graduation.
- Excited about the prospect of working on meaningful, real-world problems.
- Use engineering skills to create efficient and sustainable solutions.

APPENDIX B - Questionnaires

Passthrough effects questionnaire

* Indicates required question

1. Email *

2. Name and Surname *

3. Age *

4. Prior Virtual Reality Experience *

   Mark only one oval.

   - Never
   - Rarely
   - Sometimes

5. Prior Passthrough Experience *

   Mark only one oval.

   - Never
   - Rarely
   - Sometimes

Body Distortion Questionnaire

Thank you for participating in this study. This questionnaire is designed to understand how your perception of your body and movements is affected while performing tasks in a virtual environment using passthrough visuals. We aim to explore how body distortions, such as feeling limbs in the wrong location or altered in size, might influence your performance and experience.

Each section of this questionnaire focuses on a specific task that you completed during the study. You will be asked to reflect on your experience and rate your agreement.

Distance Estimation Task:

6. Did body distortions (e.g., feeling limbs in the wrong location or altered size) affect your ability to estimate the distance? *

Mark only one oval.

- Not at all
- Slightly
- Moderately
- Very
- Extremely

7. Did the perceived position or shape of your body in passthrough affect your confidence in walking to the target? *

Mark only one oval.

- Not at all
- Slightly
- Moderately
- Very
- Extremely

8. Was it challenging to walk to the target with closed eyes after observing the target in passthrough mode? *

Mark only one oval.

- Not at all
- Slightly
- Moderately
- Very
- Extremely

Puzzle-Solving Task:

9. Did you feel that your hands were located in the correct positions while interacting with the puzzle pieces? *

Mark only one oval.

- Not at all
- Slightly
- Moderately
- Very
- Extremely

10. Did any body distortion make it harder for you to align or rotate puzzle pieces? *

Mark only one oval.

- Not at all
- Slightly
- Moderately
- Very
- Extremely

11. How accurate did your hand movements feel when manipulating objects during the task? *

Mark only one oval.

- Not at all
- Slightly
- Moderately
- Very
- Extremely

Drawing a Circle Task:

12. Did the position of your arm or hand feel correct while drawing? *

Mark only one oval.

- Not at all
- Slightly
- Moderately
- Very
- Extremely

13. Did any perceived body distortion make it challenging to draw smooth or accurate shapes? *

Mark only one oval.

- Not at all
- Slightly
- Moderately
- Very
- Extremely

14. Were you able to maintain control of your hand movements, or did they feel mismatched with what you saw in the passthrough feed? *

Mark only one oval.

- Not at all
- Slightly
- Moderately
- Very
- Extremely

Office Basketball Task:

15. Did your sense of arm length or hand placement affect your ability to throw the ball accurately? *

Mark only one oval.

- Not at all
- Slightly
- Moderately
- Very
- Extremely

16. Did any body distortion (e.g., curved limbs or misaligned hands) influence how natural your throwing motion felt? *

Mark only one oval.

- Not at all
- Slightly
- Moderately
- Very
- Extremely

17. Was the feedback from your body (visual or proprioceptive) consistent with the outcome of your throws? *

Mark only one oval.

- Not at all
- Slightly
- Moderately
- Very
- Extremely

Embodiment Questionary

In this questionnaire, you will be asked to reflect on your experience and rate statements about your sense of embodiment on a **7-point scale**:

- **1 = Never**
- **2 = Almost Never**
- **3 = Rarely**
- **4 = Half of the time**
- **5 = Often**
- **6 = Most of the time**
- **7 = Always**

Solving a Puzzle :

18. I felt as if my (real) hands were drifting toward the puzzle pieces as I saw them in the passthrough. *

1	2	3	4	5	6	7
☆	☆	☆	☆	☆	☆	☆

19. I felt as if the movements of my passthrough body representation were influencing how I placed or rotated puzzle pieces. *

1	2	3	4	5	6	7
☆	☆	☆	☆	☆	☆	☆

20. At some point, it felt as if my real hands were turning into the passthrough body representation I saw while solving the puzzle. *

1	2	3	4	5	6	7
☆	☆	☆	☆	☆	☆	☆

21. I felt as if my hands had changed in size or shape during the task. *

1	2	3	4	5	6	7
☆	☆	☆	☆	☆	☆	☆

22. I felt as if my hands were located where I saw them in the passthrough body representation. *

1	2	3	4	5	6	7
☆	☆	☆	☆	☆	☆	☆

Distance Estimation :

23. I felt as if my (real) body were drifting toward the location of the target as I saw it in passthrough. *

1	2	3	4	5	6	7
☆	☆	☆	☆	☆	☆	☆

24. I felt as if my ability to estimate the distance was influenced by the passthrough body representation. *

1	2	3	4	5	6	7
☆	☆	☆	☆	☆	☆	☆

25. At some point, it felt as if my body was starting to take on the posture or position shown in the passthrough view. *

1	2	3	4	5	6	7
☆	☆	☆	☆	☆	☆	☆

26. I felt as if my sense of arm length or stride was different when observing the target in passthrough. *

1	2	3	4	5	6	7
☆	☆	☆	☆	☆	☆	☆

27. I felt as if my body was located at the target or the point I perceived the distance to end. *

1	2	3	4	5	6	7
☆	☆	☆	☆	☆	☆	☆

Drawing a Circle :

28. I felt as if my (real) hand were drifting toward the path of the circle I was drawing as I saw it in passthrough. *

1	2	3	4	5	6	7
☆	☆	☆	☆	☆	☆	☆

29. I felt as if the passthrough body representation influenced the accuracy of my drawing movements. *

1	2	3	4	5	6	7
☆	☆	☆	☆	☆	☆	☆

30. At some point, it felt as if my real hand was taking on the size or position of the passthrough body representation. *

1	2	3	4	5	6	7
☆	☆	☆	☆	☆	☆	☆

31. I felt as if my hand's shape or posture changed while drawing the circle. *

1	2	3	4	5	6	7
☆	☆	☆	☆	☆	☆	☆

32. I felt as if my hand was located exactly where I saw it in the passthrough body representation. *

1	2	3	4	5	6	7
☆	☆	☆	☆	☆	☆	☆

Office Basketball :

33. I felt as if my (real) arm were drifting toward the ball or hoop as I saw them in passthrough. *

1	2	3	4	5	6	7
☆	☆	☆	☆	☆	☆	☆

34. I felt as if the movements of my passthrough arm influenced how I threw the ball. *

1	2	3	4	5	6	7
☆	☆	☆	☆	☆	☆	☆

35. At some point, it felt as if my real arm was adopting the posture or motion of the passthrough arm during the throw. *

1	2	3	4	5	6	7
☆	☆	☆	☆	☆	☆	☆

36. I felt as if my arm’s size or shape changed while aiming or throwing. *

1	2	3	4	5	6	7
☆	☆	☆	☆	☆	☆	☆

37. I felt as if my arm was located where I saw it in the passthrough body representation. *

1	2	3	4	5	6	7
☆	☆	☆	☆	☆	☆	☆

Virtual Embodiment Questionnaire

Please read each statement and answer on a 1 to 7 scale indicating how much each statement applied to you during the experiment. There are no right or wrong answers. Please answer spontaneously and intuitively

VEQ Ownership :

38. It felt like the virtual body was my body. *

1	2	3	4	5	6	7
☆	☆	☆	☆	☆	☆	☆

39. It felt like the virtual body parts were my body parts. *

1	2	3	4	5	6	7
☆	☆	☆	☆	☆	☆	☆

40. The virtual body felt like a human body. *

1	2	3	4	5	6	7
☆	☆	☆	☆	☆	☆	☆

41. It felt like the virtual body belonged to me. *

1	2	3	4	5	6	7
☆	☆	☆	☆	☆	☆	☆

VEQ Agency :

42. The movements of the virtual body felt like they were my movements. *

1	2	3	4	5	6	7
☆	☆	☆	☆	☆	☆	☆

43. I felt like I was controlling the movements of the virtual body. *

1	2	3	4	5	6	7
☆	☆	☆	☆	☆	☆	☆

44. I felt like I was causing the movements of the virtual body. *

1	2	3	4	5	6	7
☆	☆	☆	☆	☆	☆	☆

45. The movements of the virtual body were in sync with my own movements. *

1	2	3	4	5	6	7
☆	☆	☆	☆	☆	☆	☆

VEQ Change :

46. I felt like the form or appearance of my own body had changed. *

1	2	3	4	5	6	7
☆	☆	☆	☆	☆	☆	☆

47. I felt like the weight of my own body had changed. *

1	2	3	4	5	6	7
☆	☆	☆	☆	☆	☆	☆

48. I felt like the size (height) of my own body had changed. *

1	2	3	4	5	6	7
☆	☆	☆	☆	☆	☆	☆

49. I felt like the width of my own body had changed. *

1	2	3	4	5	6	7
☆	☆	☆	☆	☆	☆	☆

Simulator Sickness Questionary

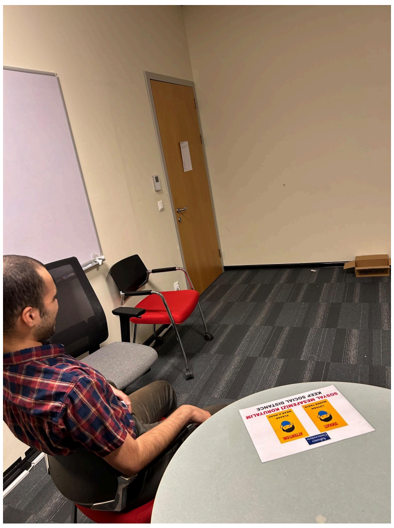
50. Please rate the severity of the following symptoms you experienced during the VR session. If you did not experience a symptom, select 'None.' *

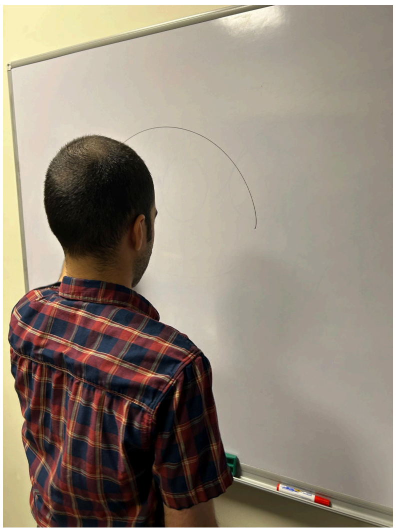
Mark only one oval per row.

	None	Slight	Moderate	Severe
General discomfort	◯	◯	◯	◯
Fatigue	◯	◯	◯	◯
Headache	◯	◯	◯	◯
Eyestrain	◯	◯	◯	◯
Difficulty focusing	◯	◯	◯	◯
Increased salivation	◯	◯	◯	◯
Sweating	◯	◯	◯	◯
Nausea	◯	◯	◯	◯
Difficulty concentrating	◯	◯	◯	◯
Fullness of head	◯	◯	◯	◯
Blurred vision	◯	◯	◯	◯
Dizziness with eyes open	◯	◯	◯	◯
Dizziness with eyes closed	◯	◯	◯	◯
Vertigo	◯	◯	◯	◯
Stomach awareness	◯	◯	◯	◯

Burping	○	○	○	○

APPENDIX C: Images from the test sessions



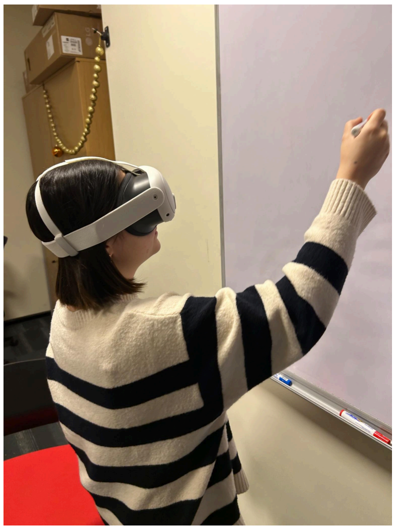




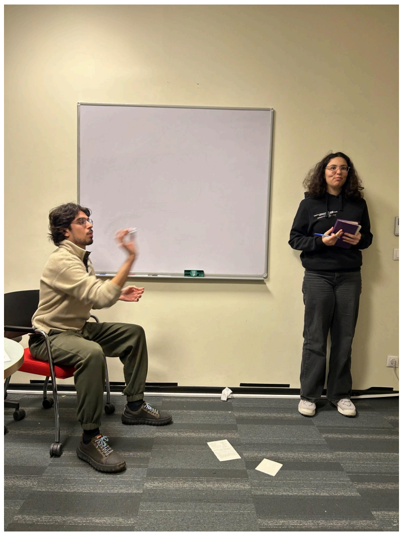


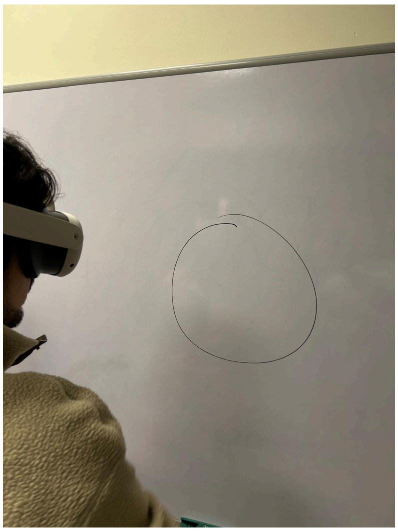
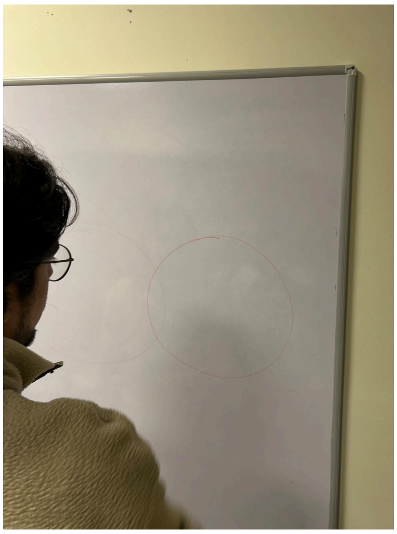




≈   

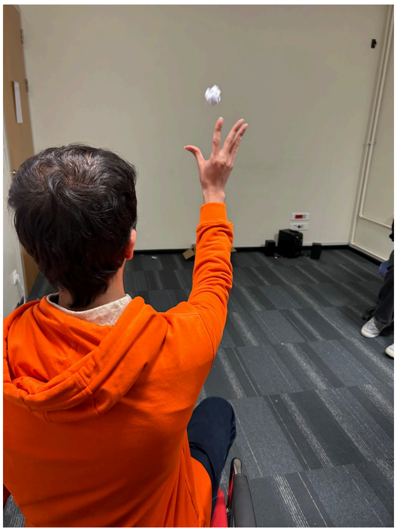
  



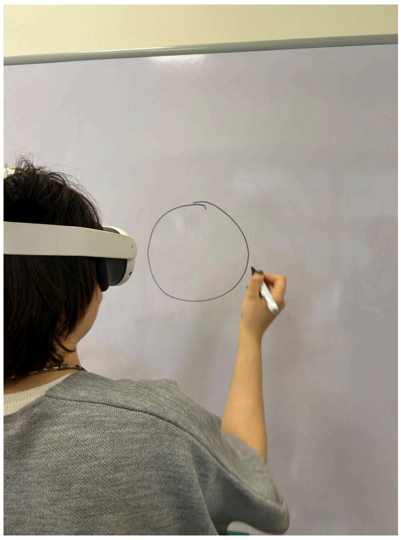
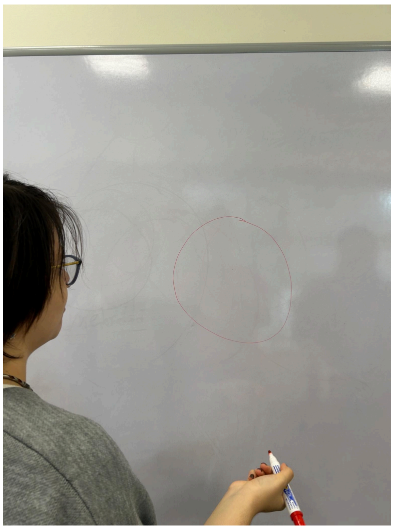











G006
KAPASİTE
CAPACITY

ATTENTION!
SOSYAL MESAFEMIZI KORUYALIM