Understanding the Effect of Diminished Reality Screen Filters

by

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Abstract

Diminished reality refers to changing human perception by concealing, replacing, or removing objects, with the primary objective of decreasing the amount of unnecessary information. Most research in the DR domain focuses on the technical challenges, still, we need to investigate DR's conceptual aspects. Screens are prevalent in many spaces, providing potentially distracting visual stimuli. No previous work has looked at how DR can be applied to screens. I simulated DR screen filters in VR and investigated them in two studies where users experienced them while doing puzzle and conversation tasks. Participants were highly receptive to DR screen filters and preferred static ones, imagining using them to improve their work or study habits. DR screen filters also reduced participants' distractions while in a conversation task. Although participants claimed that filters helped them during other tasks explored in my two user studies, I did not observe significant differences in interaction performance.

Keywords: Diminished Reality; Virtual Reality; Mixed Reality; Cognitive Load; Visual Clutter; Human-Computer Interaction

Dedication

I would like to dedicate this work to my family, who always supported me in my decisions, even if they led me through unconventional paths. And to my friends, who provided much-needed breaks, conversations, and time to relax.

I also want to dedicate this work to all the good professors I met along the way, and a special thanks to Ticianne Darin and Glaudiney Mendonça, who made me fall in love with design and supported me during my undergrad.

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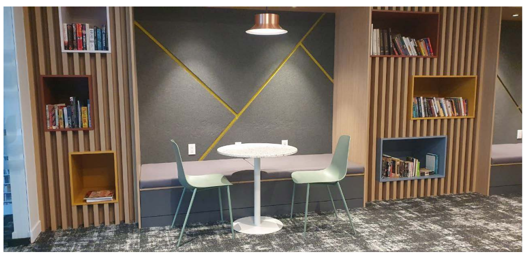
List of Acronyms

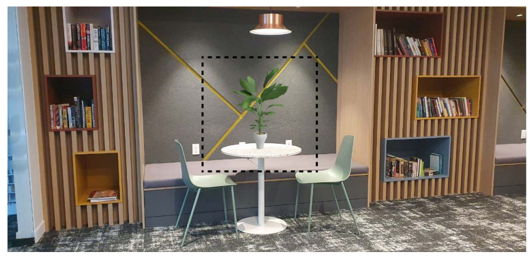
AR	Augmented Reality.
DR	Diminished Reality.
HCI	Human Computer Interaction.
HMD	Heads-Mounted Display.
HUD	Heads-Up Display.
MR	Mixed Reality.
PAR	Pervasive Augmented Reality.
ROI	Region of Interest.
TLX	Task Load Index.
VR	Virtual Reality.
XR	Extended Reality.

Chapter 1

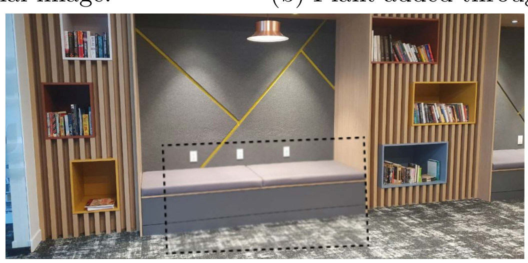
Introduction



(a) Original image.



(b) Plant added through Augmented Reality.



(c) Table and chair removed through a Diminished Reality (DR) method.

Figure 1.1: Illustrations exemplifying mediated reality interventions.

Mixed and augmented reality (MR/AR) are popular research subjects on the extended reality (XR) spectrum, with applications in many fields for both commercial and leisure activities. One less explored aspect of this spectrum is diminished reality (DR). First introduced by Steve Mann [36], the term refers to changing the human perception of reality by concealing, replacing, or removing real-world objects (figure 1.1). AR and MR enhance perception by adding virtual elements to the world. Meanwhile, DR primarily aims to reduce visual overload and density by decreasing unnecessary information.

Studies have explored DR applications in different domains, such as interior design [50], live video correction [22], uncluttering environments [6], XR games [27, 49], fashion [52], equipment manipulation [47], x-ray vision [18, 26], and driving [32, 48]. The technique even showed promising results for augmenting attention for individuals with autism [60]. Most research in the DR domain focuses on the technical challenges of implementing DR with existing technologies [41]. However, to understand the potential range of applications of DR intervention and how users will experience this form of mediated reality, we need to research both the user-facing aspects of DR and the technical challenges.

Previous research has explored the user's perspective of a DR prototype to unclutter an environment [7]. However, as far as I know, no work focuses on DR to mediate screens. Screens are a prevalent distraction in many shared spaces, such as offices, pubs, and coffee shops. Additionally, they provide constantly changing visual stimuli, which can be particularly distracting. A potential solution to reduce the impact of such distractions is DR screen filters, which alter the appearance or completely block real-world content through an AR headset. DR systems can then track and change the content shown on the screens, leading to various DR opportunities, including screen blockers, content distortion, live image filters, swapping video content, or providing contextual subtitles.

There is no previous recommendation of DR's desirable effects for screens. To understand and evaluate the use of such DR screen filters, I simulate them within a VR system and investigate how users perceive these DR techniques while they perform puzzle and conversation tasks under different conditions. Furthermore, I also evaluate if DR can improve user task performance when subjected to video distractions by assessing their interaction performance and cognitive load. The outcome of my research can provide valuable information on developing more comfortable and effective DR experiences for altering the perception of screens.

1.1 Context

My research investigates human-computer interaction (HCI), DR, and cognitive load. Building on insights from HCI, I aim to investigate the potential uses of this emerging technology and evaluate the user's experience by assessing how this technology can improve participants' cognitive load and minimize distractions. To situate the current constraints, I discuss related work to address the technical limitations of DR. Moreover, I review efforts focused on creating pervasive AR (PAR) applications. Afterward, I discuss studies that investigate how XR impacts user attention. Finally, I survey projects that aim to improve the user experience in various domains through DR.

1.2 Motivation

Considering the current state of DR systems, most studies focus on addressing the current technological constraints. However, insufficient focus has been given to investigating how users perceive and interact with DR technology. Therefore, this work aims to contribute to understanding how such technology might be used once it becomes readily available. A recent study with a similar aim focused on uncluttering desks [7]. Yet, to the extent of my knowledge, no previous work investigated the effect of DR for filtering screen content, despite this being a realistic target for the technology and a prominent source of distraction in our daily lives. Therefore, I hope that the insights from my research contribute to an initial understanding of how to better develop DR techniques for blocking screen content and how users perceive this form of technology.

1.3 Hypothesis and research questions

My goal is to understand how users perceive DR screen filters to block screen content and if such filters can improve their overall experience when presented with screen-based distractions. Therefore, I propose the following research questions:

1. How do participants perceive different DR screen filter options for blocking screens? What kind of filters do they prefer?
2. What potential applications can users foresee for DR filters in their daily lives?
3. Do DR screen filters aid participants in performing tasks faster than when distracted by screens?
4. Do DR screen filters reduce participants' perceived distraction when engaging in a conversation task while distracted by screens?
5. Do DR screen filters reduce participants' cognitive load when distracted by screens?

Based on the mentioned research questions, this study's central hypothesis is that participants will generally have a positive attitude towards the use of DR screen filters and will recognize the applicability of such technology in their daily lives by recalling situations where they were distracted by screens, especially screens that they had no control over. I also expect that the DR screen filters will help participants stay focused and that this will improve their task performance. However, previous studies [8, 12, 27, 42, 46] have shown that XR applications usually exhibit more impactful results in subjective ratings and cognitive load than in primary performance. This indicates that even though such technology might not improve performance, it will still enhance usability since it minimizes user task load and increases user satisfaction.

1.4 Thesis structure

In Chapter 2, I review the current literature for related work. I discuss studies in the following areas: DR technologies, pervasive augmented reality, XR and attention, and the DR user experience.

In Chapter 3, I explain the methods and methodology of my experiment. I describe the apparatus and prototype DR screen filters I used to evaluate the DR filter experience. I detail the technology behind the prototype and the filter prototypes I created.

In Chapter 4, I describe the first study I conducted, detailing the study design, the measures, and the results I observed.

In Chapter 5, I chronicle my second study, including the design, measures, and results.

In Chapter 6, I discuss the results of both studies and the insights I gathered during the experiment, highlighting the research findings.

In Chapter 7, I summarize the research contributions and discuss limitations and possible directions for future work.

Chapter 2

Related Work

Here, I first review the concept of DR and early work in this field, followed by an overview of the current technical constraints of this technology. After that, I discuss work that evaluated the effects of XR and attention. Finally, I discuss other research that evaluates different experiences using DR as a technology for mediated reality.

Steve Mann [36] introduced the concept of DR in 1999. Steve Mann claims that the goal of AR includes adding objects to the real world. Still, that idea can be extended to also taking away or altering visual perception with the ultimate goal of mediating reality. To illustrate the concept of DR, Mann gives the example that you could use mediated reality to obfuscate real-world colors and leave only highlighted elements with a specific color. He also mentions a refined sample, where one could work with an AR computer screen while making the real world behind it grayscale so that the user could be aware of what is happening in the real world without being distracted.

In a subsequent study, Mann and Fung [37] explored the concept of an "eye-tap" device for mediating reality, delving further into the idea of deliberately diminishing reality or adding information without overloading the user's perception. This study presented the idea that DR could be used as a blocking mechanism to filter offensive, sensitive, or annoying media like advertisements i.e.. It could be used as a real-world parallel to web browser extensions that hide or block specific content. This extension of XR was used to replace unwanted information, which defines the concept of diminished reality.

If we consider Mann's definition and Milgram and Kishino's Reality-Virtuality Continuum [39], DR is within the "realm" of AR technologies. Consequently, I review some studies presenting AR interventions here since their interactions align with the aforementioned goals of removing, replacing, or altering real-world elements.

2.1 DR technical overview

"Full" DR is currently only partially feasible, as there are presently many technological constraints for implementing such visual interventions consistently. Most studies on DR focus on enhancing the technology to overcome the associated barriers. Since it is not the focus of my work, I cover only the basic concepts and limitations of DR technology in this review. Saito et al. [41] provide a comprehensive classification of technical DR work for the current state of DR implementations.

All DR systems follow similar steps to mediate the user view. The first step is background tracking, where the camera captures the current real-world view. The second step is detecting the region of interest (ROI), where the system needs to identify the portions of the view it should apply the DR technique to, which typically involves selecting one or more target objects. The third step is generating the hidden view, which diminishes reality by modifying the user's visual perception. This work mainly discusses the user's experience with the generated DR intervention.

Current work on implementing DR has presented two distinct mechanisms for removing a target object or area. There is no consensus on which method is better since both have technical issues and unavoidable limitations and are better suited for particular scenarios or tasks. Two "non-destructive" implementations of DR focus on replacing or altering objects instead of removing them, and I describe them in the following subsections.

2.1.1 Inpainting approach

The DR inpainting approach works similarly to regular image or video inpainting, which, in essence, estimates the current background of an object that is to be removed based on the surrounding area. With a perfect real-time inpainting method, we could remove objects from a view by generating the background obstructed by that object. This method is ideal when one only needs to remove objects in front of a mostly static and planar surface, such as hiding a piece of furniture in a room [50].

One of the challenges of this method is that it is computationally intensive [22] and, therefore, hard to implement in real-time. Furthermore, the inpainting technique works better with simple, planar backgrounds. Current technologies struggle to replicate more complex environments or scenes with several layers of depth in the background. Worse, inpainting is limited to static backgrounds, as there is currently no inpainting method for a dynamic scene, such as a location where people constantly move in the background of the environment.

Furthermore, the inpainting method for DR assumes no other object is behind the removed object. By definition, this approach cannot show any view behind the region of interest from the current viewpoint. For example, if we used inpainting DR to remove a door or a window, we would only see a wall but never the room/environment behind it.

2.1.2 Observation approach

The observation approach captures information about the environment with and without the objects to be diminished. This method works by either pre-observing the background before the ROI was inserted in the view or using multiple cameras to observe different viewpoints of the same area. This method is effective in providing see-through experiences. Using several cameras, the system can even provide X-ray vision [18], allowing the user to observe otherwise occluded areas.

The strength of this approach is that it can generate a more realistic result for the mediated reality and deal with dynamic backgrounds through the multi-camera method. The challenges of this method are the need to position multiple cameras to record the ROI and simultaneously track the ROI, all while accommodating all 6 degrees of freedom for the viewer. However, the main limitation of this method is that it requires multiple cameras and viewpoints to be captured simultaneously, which is challenging or even impossible in a real problem or daily life situation without a lot of camera infrastructure.

2.1.3 Alteration approach

The altering method works by modifying the user's regular view to enhance or diminish elements that are either real or virtual. This approach is similar to Mann's idea [36] of showing the physical world in grayscale so that the user could monitor the environment but focus on the virtual screens while working. This method is also helpful for supporting visual search or guiding the user by diminishing contrast and saturation of specific content [37]. This approach can also be used to blur specific content from the user view [10].

The strength of this method is that it is easier to implement. Still, it has limited applications since most scenarios will not directly benefit from simply altering the visual perception of the whole natural world. Also, tracking and selecting specific objects that should not be diminished can still be challenging.

2.1.4 Replacement approach

The replacement method overlays a virtual object on top of existing real objects to block or alter them. This method is proper when modifying a planar element, for instance, changing or removing a billboard [37], or superimposing a virtual object over an existing real one [20].

Compared to the altering method, replacement is easier to achieve, as no real-world objects must be removed. However, this method must still simulate the real-world lighting on the overlaid objects to deliver a result that resembles reality. Further, to superimpose a virtual object over a real one, the system needs a virtual object of the same size or larger or to apply this method in conjunction with one of the earlier mentioned approaches to remove the existing area first. My research simulates such a DR method since the constraints of this technique are not relevant to my work, and its applicability makes it more likely to be implemented relative to a (more technically challenging) method that completely removes a screen from the environment. This should also be sufficient since blocking a screen should diminish the constantly changing visual stimuli.

2.2 Pervasive AR

As just discussed, current methods of implementing DR still have significant drawbacks and limitations. Aside from the challenges of generating a mediated reality, there are still technical challenges related to estimating the ROI of the object(s) that need to be concealed. One common approach in DR prototypes is to use QR codes or other visual tracking tags [38] to enable the system to identify which objects should be removed, similar to what is done in video editing. While this approach is helpful for prototyping, it is not applicable in a real-world scenario. In this context, some studies evaluated the applicability of eye gaze [14] or gesture-based [24] selection for AR applications.

Gebhardt et al. [14] presented a study where AR labels were used to show the price of objects on a shelf, and the ROI was detected based on the user's gaze to show the labels only when they were relevant for the user, to avoid overloading them with information. Hong et al. [24] proposed a method of defining the ROI by combining a user gesture and current view based on the distance and angle of the content relative to the viewing device. Datta Siddharta [10] prototyped a method of selecting target objects based on image recognition; however, this method currently requires a database of pre-recorded images to train the algorithm.

For AR and DR applications to be fully integrated into our daily lives, they must be implemented as being pervasive without disturbing the user and instead enhancing their experience. Furthermore, current head-mounted displays (HMDs) are still bulky and impractical for continuous use, and using one in everyday settings could socially isolate the user [36]. Some studies are approaching how to create PAR experiences [16] with the argument that many AR applications are only helpful for a single purpose and that PAR could be the improvement needed for greater adoption of the technology.

PAR applications consider several factors like the environment (e.g., indoors or outdoors), the interactions (e.g., gestures, controllers), and external and internal states. Lindlbauer [33] proposed an automated optimization for XR applications based on user activity and cognitive load, and this approach used a rule-based decision algorithm to automatically show applications with a different level of density (e.g., compressed or expanded) and positions. Cheng et al. [8] prototyped a system that automatically adapts XR screen layouts based on the user's current environment and associates them with real-world objects.

Filters to block screen content could easily be implemented within the PAR framework. This intervention would then automatically select the screens using geometric associations (such as detecting rectangles with the correct aspect ratio) and only show the content of these screens when it is context-relevant to the user so that they would not be distracted. This could even consider the user's gaze relative to the screens. Furthermore, such technology would also consider the user's activity, cognitive load, and environment so the screens are only blocked when it is advantageous for the user, i.e., the DR devices would need to be smart enough to provide information only when necessary.

2.3 XR and attention

Cognitive load theory is a vital issue in HCI, as attention is a limited resource directly related to a user's cognitive load [23]. Assessing the user's cognitive load is a standard metric to evaluate prototypes, as evidenced by the frequent use of the NASA TLX. The upcoming works have studied how XR can influence user perception, attention, and distraction.

Yantaç et al. [60] explored the idea of using DR to augment the attention of individuals with autism spectrum disorder, where they ran a series of workshops with designers and domain experts. They realized the idea of a mirror wall interface to filter visual information and remove irrelevant visual data. Vortmann and Putze [56] prototyped an attention-aware user interface on AR. Their approach mapped the user's attention state with electroencephalography and eye tracking. Then, it provided this data to the interface, which showed or hid virtual content depending on the user's external attention. They compared the attention-aware system with a baseline condition, showing that their enhancements improved its usability scores.

Wyckoff, Ball, and Moreu [59] explored using AR to reduce gaze distractions. Their work showed that using AR can reduce the distance the gaze traveled for monitoring activities since AR can show virtual information overlaid on physical structures, eliminating the user's need to shift attention between monitors and the infrastructure constantly. Kim and Gabbard [28] evaluated how AR head-up displays impact the attention of drivers. They assessed the claim that AR HUDs can enhance drivers' attention since they provide users with additional information while looking at the road. They evaluated two AR pedestrian collision warning design alternatives inside a driving simulator. Their results show that only one of the alternatives enhanced the driver's attention and concluded that AR overlays can be distracting and informative, depending on their design.

Plabst et al. [46] explored the visualization and disruption of different notification options for AR. The users had to perform a memory puzzle while being asked to press a red button whenever prompted by a notification. Their findings suggest that different notification placements should be used depending on the task and AR intervention context. Generally, a head-stabilized "subtitle" placement was preferred. Doerr et al. [12] evaluated the performance of VR visual attention guidance methods under different levels of visual distractions. They showed that using colored circles or animated swarms performed better and had higher scores for user experience.

Sobhani and Farooq [51] used a VR application to evaluate the distraction caused by smartphone usage while crossing a street. Their results indicated that smartphone users are distracted and that using smart LED pedestrian crossings helps improve safety but is not enough to overcome the distraction of smartphone use. Parmar and Silpasuwanchai [45] investigated the effect of attention tunneling when simultaneously walking and interacting with AR games. They compared the impact of attention tunneling when walking and stationary with three AR tasks. Their results showed that the walking condition had a significantly higher tunneling effect on cognitive tasks regardless of the task.

2.4 The effect of DR on the user's experience

Even though most of the efforts in DR research focus on the technical aspects of its implementation, some studies explored different ways this technology can be used for both technical and hedonic uses.

Rameau et al. [48] explored using DR to see through cars. They implemented such a system based on two wirelessly connected cars that share information from their cameras. The rear vehicle then uses that information to hide the car in front and enable its driver to see further ahead without being blocked by the automobile in front. Lindemann and Rigoll [32] also explored the use of DR for the driving domain. Their study used a simulated virtual environment where participants could drive semi-transparent cars, which they believed could help drivers detect occluded objects and better estimate low-height obstacles. They did a prototype study with different levels of transparency and occluded-area sizes. Their results show that participants preferred large see-through areas but had no conclusive preference for the ideal amount of transparency.

In the industrial operation domain, Plopsky, Taylor, and Carter [47] introduced Invisirobot, a system that uses DR to make robots semi-transparent, facilitating user operation of those devices without the physical constraints of those robots occluding essential areas. Their preliminary research indicated that users would prefer to have the control to toggle the visualization of the robotic hands.

Many projects explored the use of DR for mobile applications. Kim et al. [27] used DR to remove content-irrelevant objects and people while the user played an AR game. Their results showed that making the passerby pedestrians transparent and semi-transparent enhanced the game experience and made the players less distracted and more engaged with the in-game pet avatar. Song, Gong, and Wong [52] developed the VTON shoes, where the system removes the user's shoes and replaces them with a 3D model. Similar experiences were explored for glasses, makeup, clothes, and furniture.

Chan, Ryskeldiev, and Nanayakkara [6] used DR to remove storage clutter to motivate the user to list items on an online marketplace. They conducted interviews where users indicated that such a technology could make them more likely to detach from their belongings. Hasselman et al. [20] proposed using DR to experience rephotography, which involves juxtaposing historical building 3D models over existing structures. Their experiment showed that the 3D model had better ratings for visual quality, realism, and coherency when compared with existing 2D alternatives.

Other studies explored DR uses for more hedonic pastime activities and meditation. Sakai et al. [49] explored the use of DR in virtualized sports. They created D-Ball, a dodgeball-inspired game where participants have diminished vision, seeing only the ball and part of the opposing players' limbs. Hendriks et al. [21] introduced Azalea, which uses a smartphone application connected to a cushion to diminish distractions and enrich the remote dialogue. While this application differs from what is usually considered DR, the authors argue that it takes the design principle of DR to propose a concept of how this could be applied to service and product design to motivate people to diminish environmental distractions.

Approaching a more general understanding of mediated reality, Bonnail et al. [5] discussed how XR technologies could be used for memory manipulation by conducting workshops with XR researchers and cognitive psychology experts. While the main focus of this work was brainstorming ideas on how XR could be used for memory manipulation and creating a classification for those mediated realities, some of the solutions were tied to DR applications. They believed DR applications could enhance memory retention in a classroom where DR can blur distractions so the user can focus on the lecture. Also, DR can steer visual attention, which could be especially useful for people with attention disorders. They also claim that XR can improve the mental state in a scenario where the user can manually hide objects or environments that trigger negative emotions.

Datta Siddharta [10] prototyped a cellphone-based system that blurs target objects from the user view. His system first logs a users' view history. The user would then later define which objects they would like to blur from their view. The system then uses image recognition to detect similar objects and creates bounding boxes with Gaussian blur filters to hide those elements in the user's view. In his prototype, he created four scenarios with specific objects to block (graves, price labels, bikes, and dogs) and collected images to train the detection for each object.

Cheng et al. [7] conducted a study to compare how users perceive DR techniques under different scenarios. In their first study, participants experienced seven distinct DR effects in four examples: clutter management, search, privacy protection, and remote guidance. The results showed that participants generally preferred the transparency method for DR and wanted to maintain contextual information about the diminished objects. In a secondary study, they investigated the extent to which DR would be used for clutter management by recording the data of the elements selected to diminish and the amount of opacity used. Their study resulted in a series of recommendations for DR applications.

My current work presents the next step in understanding how users perceive and interact with DR techniques, specifically for mediating screen content. The study mentioned above by Cheng et al. [7] was used as inspiration for my pursuits. Thus, I used a similar approach to their work: I first investigated which filter options users prefer and how these filter options impact their performance and distraction during different tasks.

Chapter 3

Methods

I performed two user studies to understand and evaluate the use of DR screen filters to block screen content. I simulated these filters in a VR system, a method of prototyping XR interactions that is frequently used to overcome current technical limitations [7, 8, 14, 17, 33, 51]. In the following sections, I further describe the methodology of the experiment, the apparatus, and the DR screen filters I created.

3.1 Methodology

For my study, I chose a mixed-method approach, which simultaneously collects quantitative and qualitative data while using a primary analysis method as guidance and a secondary one as support [25]. In my experiments, I use quantitative experimental analysis as the primary analysis method, with the analysis of the interviews and questionnaires serving as support data. For the experiments, I chose a repeated measures approach that I will describe in more detail in the design section for each study. For the qualitative analysis, I collected data from questionnaires and semi-structured interviews.

3.2 Apparatus

I created my prototypes in Unity 2021 [55] with an Oculus Quest 2 HMD as a VR head-mounted display. Throughout the experiments, I ran the Oculus Quest 2 with a wired connection to an Acer Nitro 5 Laptop to enhance the graphics, facilitate the switch between conditions, and simplify storing the log files.

The Unity scene used the ArchVizPro Interior Vol. 6 [1] assets, but I modified the environment by adding televisions from the Unity VR Course Library. To minimize file size and loading times, and since I did not require the user to move during the experiments, I also removed all objects that were not visible from the user's initial perspective. The VR controls were implemented inside Unity using the XR Interaction Toolkit [54].

As previous research has shown that supporting both virtual hands and raycasting simultaneously can enhance the user experience [57], I adopted this modern interaction

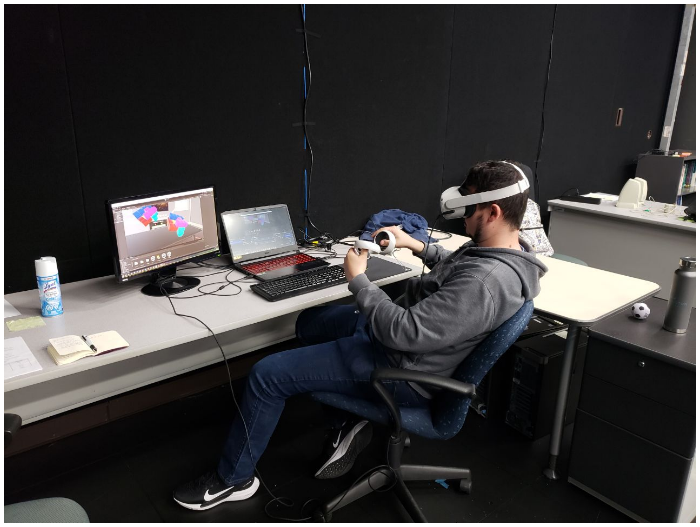


Figure 3.1: Participant performing the task.

paradigm. Thus, when the controller collides with an object of interest, it functions as a virtual hand; otherwise, it controls a ray. I used the hand model from the Oculus integration asset [44] and manually adjusted the hand animations to work within the XR interaction toolkit. Specifically, I disabled the hand models when holding an object so they would not interfere with its visibility.

I recorded the screen during the experiment using OBS Studio [2]. All actions critical for the experimental tasks and the experimental measures were logged inside Unity into a CSV file. Inside Unity, I also used a secondary camera not attached to the player to take screenshots of the scene at crucial time points.

The consent form, as well as the questionnaires, were shown through Survey Monkey [40]. The interview audio was also recorded with OBS Studio [2]. Figure 3.1 shows a participant in the experiment.

3.3 DR screen filters

As the main aim of my research is to understand the user perception of AR filters to block screen distractions, I implemented five distinct filter options to evaluate how users perceive such effects. All filters were implemented in the virtual environment as parallelepiped blocks that float in front of the screen elements, with different textures to change their appearance. I chose this method to implement the filters (and investigate this in VR) because the replacement approach is much more robust and feasible with current technologies. I acknowledge that the same method could be achieved by some screen finding/tracking algorithm that overlays content on top of the detected screens through an AR headset. Further, and considering the current level of DR technologies, making a screen completely transparent, e.g., through background inpainting or using the observational approach, is still very

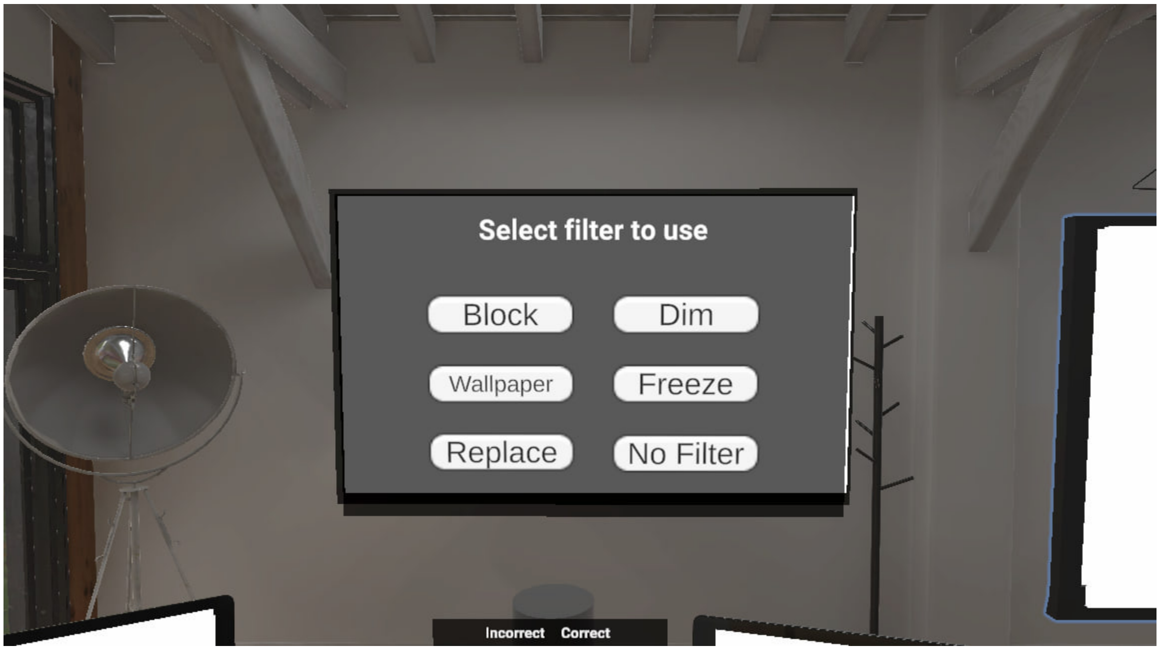


Figure 3.2: Filter selection UI.

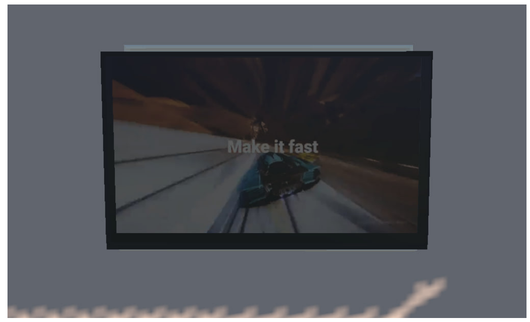
challenging in an unconstrained public setting. Consequently, I did not explore functionality that makes screens disappear completely.

The filters for all screens in the scene were, by default, inactive. In the experimental condition where the participant could change the filters, they selected them by pointing the controller at the television and pressing the grip button after being prompted by a tooltip, which opens a menu (figure 3.2) where they can then select one of the filter options to use via the trigger button. I implemented the following filters (Figure 3.3):

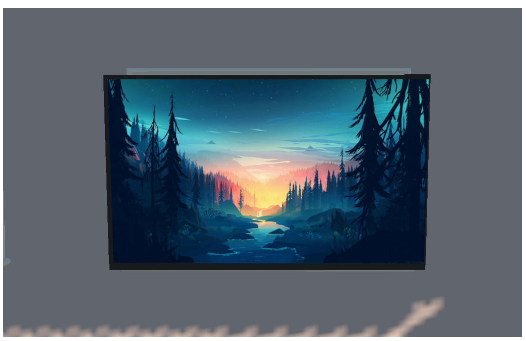
- **Block(a):** The block filter renders an opaque dark gray box in front of the screen to block the visuals and make it appear as if the screen is turned off.
- **Dim(b):** The dim filter is similar to the block filter but makes the gray box semi-transparent so that the user can still keep track of the screen content but with reduced brightness and contrast.
- **Wallpaper(c):** The wallpaper filter renders a static image on the blocking box. This method lets the user occlude the visually distracting screen with a static, aesthetically pleasing image.
- **Replace(d):** The replacement filter renders another video on the box so that it appears instead of the current screen content. With this filter, the participant can block a potentially distracting video and replace it with something more soothing. In my prototype, I used a slow-moving video showing mountains and nature.

- **Freeze(e):** When activated, the freeze filter retrieves the current frame being played on the video and sets the box texture to the same frame. This makes it appear as if the video was paused. However, the original video continues to play forward behind the filter. The idea was to provide an interaction that would partially maintain the original content while removing the distraction provided by a video.

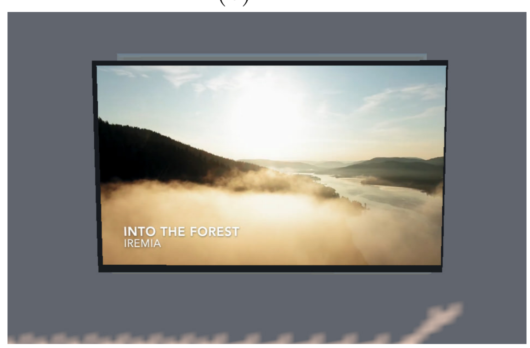
(a) Block.



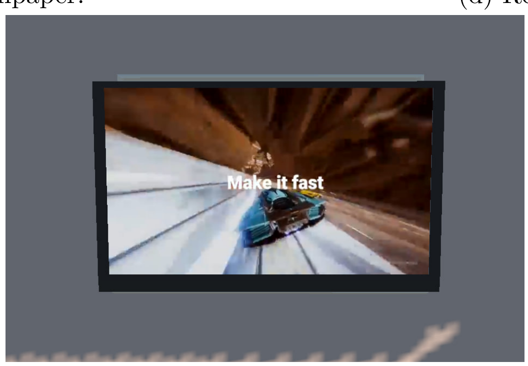
(b) Dim.



(c) Wallpaper.



(d) Replace.



(e) Freeze.

Figure 3.3: Screenshots illustrating the appearance of the different filter options.

Chapter 4

First Study

Here, I describe the first study I performed on my implementation of DR screen filters.

4.1 Study Design

This study's first experiment was separated into two phases to investigate the user's perception of the DR filter. The first step of this user study was designed to train users in the system and the main puzzle task and to investigate what they thought about the different DR filter techniques and which ones they liked the best, while the second step was used to evaluate if DR screen filters aid participants in performing the puzzle task faster than when distracted by active screens.

4.1.1 Puzzle blocks

To evaluate the effect of the filters for blocking distractions due to active screens, I created a 3D puzzle using different blocks to serve as the user's primary task. The task required the user to assemble five blocks in a target combination, where each block's shape (Figure 4.1) is inspired by the classic Tetris pieces [43]. The blocks were 3D objects that could be grabbed by the user and simply connected by releasing two colliding blocks. Once combined, the pieces would create a joint. To break such a joint, the user needed to grab both blocks and apply enough opposite forces on the parts to break the connection.

The puzzle tasks always used the same five blocks but in different configurations. There were 13 puzzle tasks, and one was always used as the training condition. The other 12 tasks were selected randomly (without replacement). For performing the experiment, the user was seated on an office chair. In VR, they saw a virtual desk in front of them (figure 4.2). Behind that table, the participants saw a target model, and they had to connect the five puzzle blocks that were accessible in the environment in a manner identical to the target. The target model could also be freely picked up and manipulated so the user could compare and plan how to position the pieces.

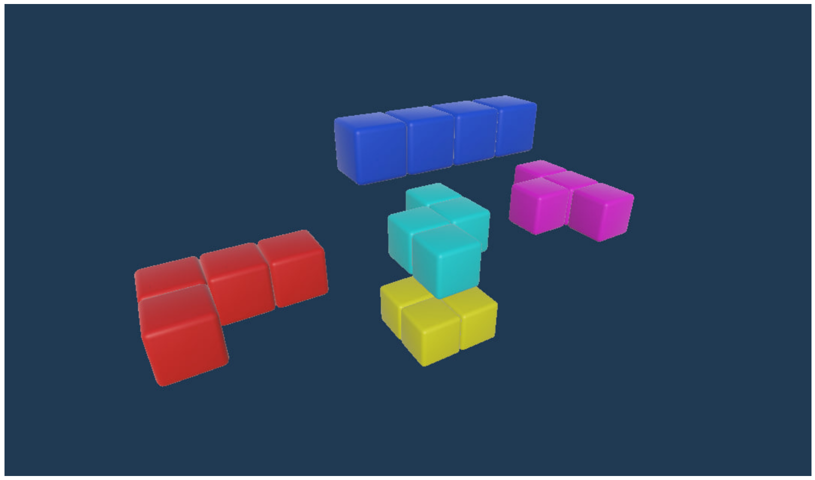


Figure 4.1: Image of the block pieces.

At any given point, the participant could check the number of correct connections by looking at a panel (Figure 4.3) placed inside the virtual environment. Once they were done with the puzzle task, i.e., the connections were correct, they could press a "proceed" button. After this, the system would re-spawn the puzzle pieces and move to the next randomly selected puzzle task. Once all the puzzles were done for each condition, a popup would appear to inform participants accordingly.

4.1.2 First task

The first task environment (Figure 4.4) was designed to familiarize the user with the controls and the different filter options. Participants were asked to perform a sample block puzzle task to learn how to manipulate the blocks. The participants were also instructed to interact with the screen and try different filter options. There was only one screen in this environment, and the sample tasks were always the same. Participants were asked to complete the sample task once with each filter option active. During this task, no measures were recorded so the participants could perform the activity without concerns about time pressure.

4.1.3 Second task

The second phase used a repeated measure within-subject design. The study included three conditions (Figure 4.5). In one of the conditions, the environment had no screens; in another, the scenario had five (immutable) screens playing different videos; and the last condition also had screens, but the participant could block any of them with any of the filter techniques explored in the first task.

In the with screens condition, five videos were playing on different screens around the participant, see 4.2. I selected popular videos from different categories on YouTube that could generally be perceived as being distracting. I selected videos from the following cat-

Figure 4.2: View of the scenario for the puzzle block experiment. The puzzle target is visible just below the center screen, while the five pieces the user has to assemble are currently placed somewhere close to the bottom left screen.

egories: Animals, Advertisements, Soccer Highlights, Trick Shots, Fails, and awesome moments. The selected videos were roughly 15 minutes long but were all compilations of shorts, with each short being around 5 seconds. The associated abrupt transitions would likely result in additional distractive moments, as previous research has shown that shifts in motion are particularly effective in drawing user attention [3]. All videos and their positions were consistent across participants, and as the length of the videos was longer than the time needed to finish one condition, they did not loop. Still, I did not control the participant's field of view, and therefore, they could shift their view of the main task and the videos as desired.

The order of the conditions was counterbalanced across participants using balanced Latin squares. For the dependent variables, I considered the time to complete each task and the number of interactions. For each condition, the participants had to perform four block assembling puzzles selected randomly. Therefore, the four tasks did not repeat across conditions, and each trial's orders differed for each user.

4.1.4 Procedure

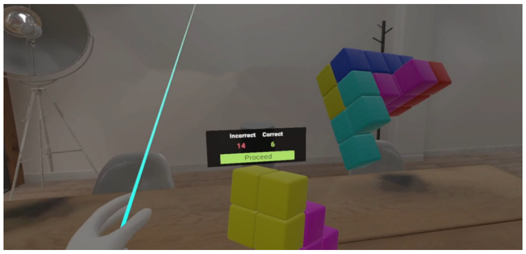
The experiment started by briefing the participants about the test and providing them with the consent form, followed by a pre-assessment questionnaire with demographic questions as well as questions about how often they play video games, use 3D software, experience VR content, and how comfortable they are with screens playing while they do other tasks. Afterward, I asked participants to complete a VZ2 paper folding test, which measures spatial reasoning [13] and which I used to assess spatial abilities. Participants had to submit their answers through an online survey.

Figure 4.3: Example of a target combination.

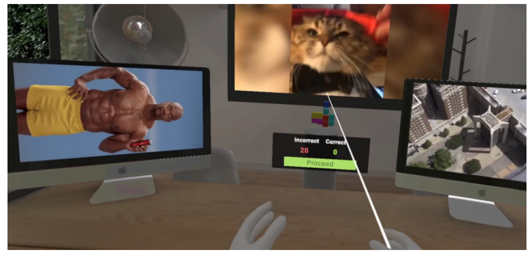
Figure 4.4: Training environment used for the first task.

Subsequently, the participants underwent the first training phase, which allowed them to learn to do the block puzzle in VR and experience the different DR techniques for screen filters. Then, they were asked to rank-order each filter from most preferred to least preferred and comment on their choice, also evaluating the filters based on perceived usefulness and comfort. Before the study's second phase, I conducted a short semi-structured interview asking participants what they thought about the task and the filter option and about potential uses for DR in their daily lives.

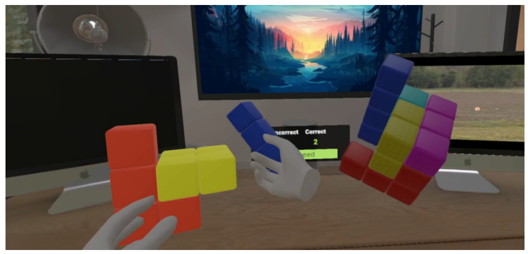
In the study's second phase, participants performed the VR puzzle task under three different distraction conditions (Task 2). After each condition, the participants completed a simplified version of the NASA Task Load Index questionnaire [19], which I will describe in more detail in the upcoming section. Upon finishing all the conditions, I performed another



(a) Without Screens.



(b) With Screens.



(c) With Filters.

Figure 4.5: Pictures of the three task conditions.

semi-structured interview, asking about their experience with the different conditions and screen distractions in their work and home environments.

4.2 Measures

4.2.1 Quantitative

Success

Task success was measured through the number of correct connections. Since an indicator showed participants this information, participants rarely completed a puzzle task incorrectly. Thus, This measure was mainly used to disregard the task time when the participant could not complete the puzzle correctly.

Task time

The primary quantitative measure was task time, which counted seconds from when the participant grabbed the first block piece until they pressed the proceed button. This allowed the participants to check the target model and apply filters between tasks without counting the time spent on such secondary activities. I also measured the total task time from when the puzzle was instantiated in the environment until it was solved. However, I did not consider it a valid performance indicator, as different participants might have spent different time preparing for the task.

Number of interactions

The number of interactions with the puzzle pieces was used as a secondary performance metric. This measure was collected to see if the conditions would influence the number of steps needed for the participant to complete the puzzle task.

Task load index

I used a modified version of the NASA task load index questionnaire [19], removing the temporal demand question and altering the questionnaire to use a 7-point Likert scale. I also changed the scale labels to make them more appropriate to each question, see Appendix A 7.4. The TLX questionnaire was selected to record the subjective cognitive load, contrasting the more objective measures.

4.2.2 Qualitative

Pre-assessment

The pre-assessment questionnaire aimed to record participants' demographic data and understand their previous experiences with video games, 3D modeling software, and VR. This was done to collect data on any potential external confounding variables that could influence the internal validity of the results. In the questionnaire, I also asked how comfortable the participants were with a TV playing while they did other tasks. This was asked to learn more about participants' preferences and to record the context for the post-experiment interview.

The Demographic questions asked the participants to select their age group in increments of 5 (e.g., 25-29, 30-34), followed by their gender. Finally, I asked for their highest level of education, ranging from high school to Ph.D. or higher. The questions about their background with video games, 3D, and VR all asked how often they experience them. The participant then had to rate them on a 7-point scale with the following steps: never experienced, less than once a month, once a month, a few times a month, about once a week, a few times a week, and every day. The question about how comfortable they are with the TVs in the background had a 5-point Likert scale with the following options: very comfortable, comfortable, neutral, uncomfortable, and very uncomfortable.

Post-training questionnaire

The post-training questionnaire was filled out after the first phase of the study. It consisted of 4 questions. The first question asked participants to rank-order the DR screen filters from most preferred to least preferred. The second question asked participants to explain the reason for their preferred choice (in text format). The third and fourth questions asked participants to rate each filter on how useful and comfortable they perceived them to be on a

5-point scale. This post-training questionnaire was used to get feedback on filter preferences and perceived utility.

Post-training interview

After the post-training questionnaire, I conducted a semi-structured interview, where I also asked follow-up questions to elaborate on the participant's previous answers. The goal was to understand how participants felt about the task, what they thought about the different filter options, and what potential uses they could see for the DR technology.

The first question asked what they thought about the tasks' controls, followed by what they thought about the puzzle block task in general. Afterward, I explored what participants thought about the different screen filter options and if there was any particular one they liked best or least. Finally, I explained the concept of DR to the participants. I gave a scenario where they could access such technology without a head-mounted display (e.g., "Imagine this technology was embedded in regular eyeglasses ..."). I asked if they could think about situations where such DR implementation could be helpful in their daily lives.

Post-experiment interview

The post-experiment interview was done after the participant finished the second task and had filled out the TLX questionnaire. This was also a semi-structured interview to uncover how the participants felt about the environment and the different conditions they experienced.

I started the interview by asking participants how they felt in the VR environment and then asked them to compare the conditions (e.g., "What did you think about the filter condition, also comparing it to the condition with screens or without screens?").

The final set of questions asked participants to describe their work environment and if there were other screens or potential distractions. This was followed up by asking if participants would leave screens on at home when doing chores like cooking or cleaning and asking for clarification on those activities. Although such activities are not comparable to a highly demanding cognitive task, I wanted to get some insight into participants' routine TV usage.

4.3 Results

4.3.1 Participants

I conducted the study with 18 participants (nine male and nine female). Most participants' age was between 25 to 29 (N = 8) or 30 to 34 (N = 5). The most common highest level of education was a bachelor's degree (N = 12). Three had completed a master's degree, three had a post-secondary diploma, and one participant's highest level of education was high school. The study took around one hour, and all participants were compensated with 15 Canadian dollars for participating.

4.3.2 Quantitative

Paper folding questionnaire

Participants exhibited a mean score of 12.6 out of a maximum of 20 in the paper folding test, with a standard deviation of 3.6. Generally speaking, participants with higher scores on the paper folding task also exhibited faster times to complete the 3Dpuzzle task (figure 4.6), indicating that there may exist a correlation between spatial reasoning and performance in the puzzle task, with R^2=0.30, which is to be expected based on previous research, e.g., [35].

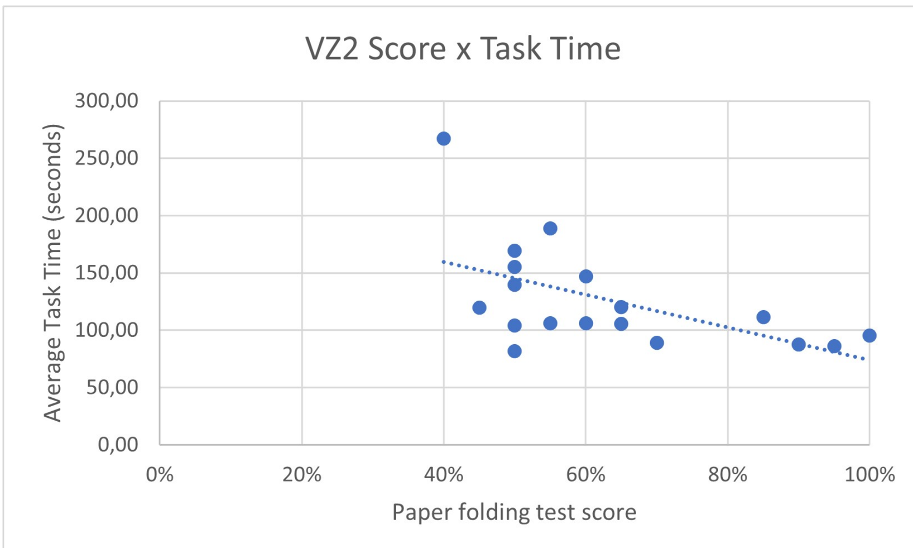


Figure 4.6: Correlation between paper folding task and task time.

Task success

In total, 216 tasks were conducted across all the participants and conditions. One participant missed four trials due to their time constraints. Five puzzle tasks failed simply because the participant accidentally pressed the proceed button before even starting the task. These nine instances were removed from the analysis.

Task time

Before analyzing the time data, I removed all outlying data points exceeding three times the interquartile range beyond the 10% and 90% quartiles. This removed 11 outliers and left me with 196 valid task recordings. Figure 4.7 shows a chart for the average task time by condition.

The mean time to complete the task was lower in the filter condition (M = 105.31, SD = 40.62), followed by the without screens (M = 111.59, SD = 50.55), and then the with screens (M = 116.78, SD = 64.26). The results from an Anderson-Darling test showed that the samples for all conditions most likely do not follow a normal distribution ($p < .05$). A Levene test was used to check the homogeneity of variance. The results show that the variance among these groups is not the same ($F_{2,34} = 6.72$, $p < .05$). To identify if there is a potentially statistically significant difference, a Friedman test was performed. The results indicate no statistically significant difference between the conditions at the .05 significance level ($\chi^2 = .778$, $p = .678$).

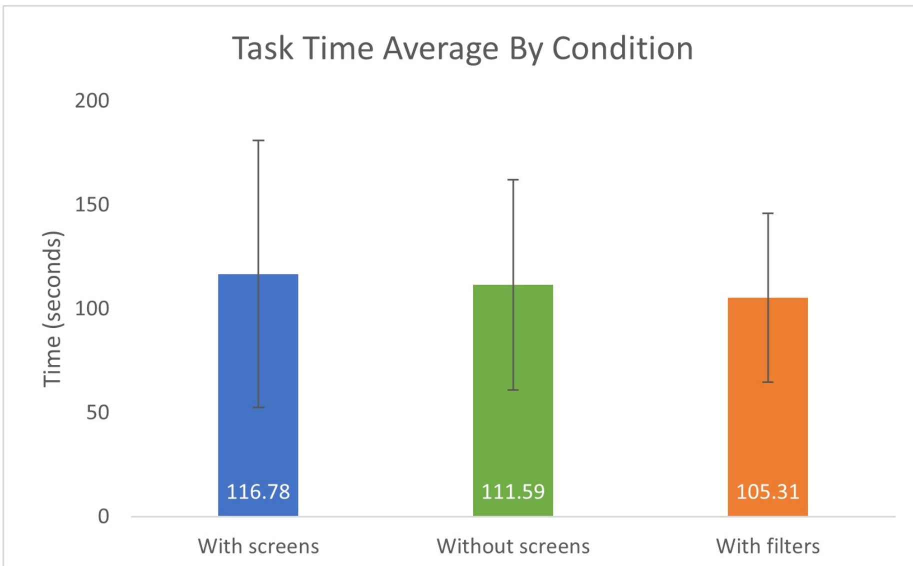


Figure 4.7: Mean times to complete the task by condition, the standard deviation is represented as error bars.

Number of interactions

The number of interactions follows a similar pattern as the task time, where the filter condition has the least number of interactions (M = 39.38, SD = 17.79), followed by the without screens condition (M = 40.04, SD = 18.81), and lastly the screen condition (M = 45.62, SD = 28.56). However, this difference was once again not significant. Also, similar to the time to complete the task, the sample did not follow a normal distribution ($p < .05$). Furthermore, there is a clear correlation between the time to complete the task and the number of interactions with $R^2 = 0.83$. (figure 4.8). Observations from the experiment recording indicate that this is a direct consequence of mistakes made during the puzzle block task since an error would require the participant to remove the pieces and then rebuild the puzzle, resulting in more interactions and, thus, more time to complete the task.

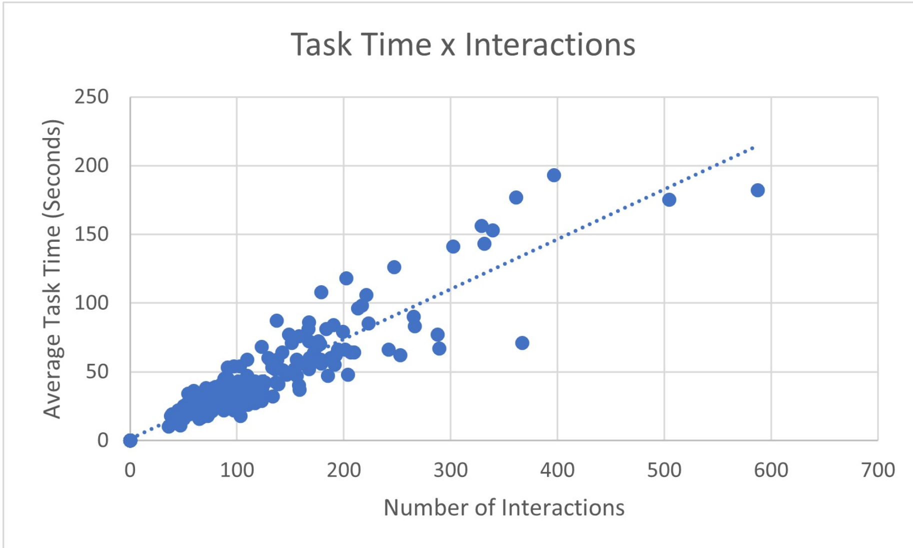


Figure 4.8: Correlation between number of interactions and task time.

Task load index

The NASA TLX results exhibited a considerable variation across participants, but there was no significant difference between the conditions. Generally, participants reported a moderate level of mental and physical demand (figure 4.9). The mental demand had the most significant difference in means between conditions, with the screen's condition having the highest one (M = 3.9), followed by filters (M = 3.5), and finally without screens (M = 3.3). The physical demand means for all conditions remained between 3.2 and 3.3. This indicates that participants perceived the activity to be only slightly demanding.

Participants reported, on average, a high level of success, with the means for all conditions around 6.0 and 5.8. When asked how hard they had to work to achieve the level of performance, the means were around 4.0 to 3.8. This highlights that participants likely did not consider the time to complete the task but based their answers on successfully completing the puzzle task. Furthermore, they reported a somewhat high level of effort was needed to accomplish the task, which is likely related to the difficulty they experienced in performing the puzzle task.

Finally, participants reported generally low levels when asked how insecure, discouraged, irritated, stressed, or annoyed they were. The highest mean was in the screen condition (M = 2.6), followed by filters (M = 2.4), and finally without screens (M = 2.3). This result implies that participants were not annoyed by the conditions, with only minor differences between them.

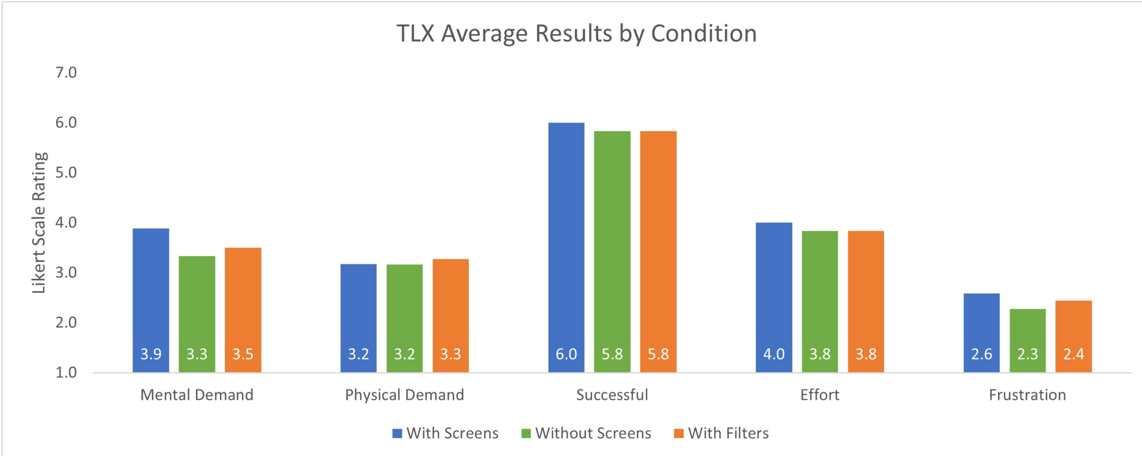


Figure 4.9: TLX Average of the user scores by condition.

4.3.3 Qualitative

This section describes the results from the two questionnaires and the two interviews. This analysis combined audio transcripts with notes taken by the researcher during the experiment. The transcripts were transcribed and then coded in NVivo [34], using a thematic analysis method. The observations were transcribed into digital format and grouped based on relevant themes.

Pre-assessment

Participants gave widely varying responses on how often they played video games. Most participants use 3D software less than once a month (N = 6) or have never used it before (N = 5). Similarly, most participants experienced VR content less than once a month (N = 11) or had never experienced it before (N = 5). When reporting how comfortable they were with screens playing while they do other tasks, five participants said they were very comfortable, five said they were comfortable, six reported they were neutral, and only two said they were uncomfortable with screens playing while they do other tasks. The results show no correlation between the previous use of 3D software and task performance. As most participants had no VR experience, I could not evaluate if there was any correlation between that and the performance on the test.

When looking at the levels for how often participants play video games and task time, participants with more video game experience generally performed better in the puzzle block test (figure 4.10) with $R^2 = 0.19$. This does not seem surprising as gaming experience is known to improve spatial skills [11]. A not anticipated result is that participants who were more comfortable with TV playing in the background while doing other tasks generally performed worse in the test (figure 4.11).

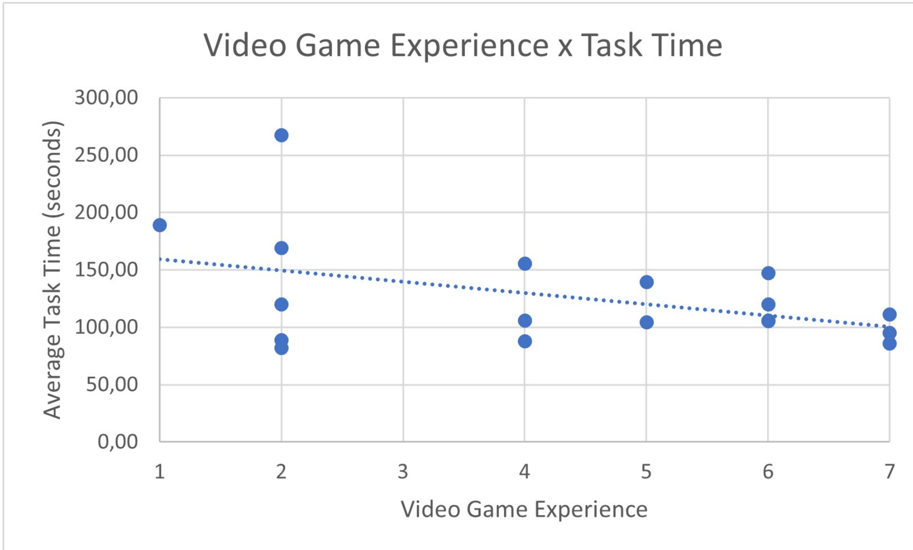


Figure 4.10: Correlation between video game experience and task time.

Post-training questionnaire

I evaluated the filter options' ranking as an average (of the rank) and how often each filter was preferred. The average shows that participants favored the wallpaper (M = 3.67), followed by block (M = 3.56), freeze (M = 3.17), dim (M = 3.00), and finally replacement (M = 1.61) (figure 4.12). When looking at the number of instances each filter was selected as the preferred choice, I see a similar result, with wallpaper with nine selections being followed by block with four instances, two instances of both dim and freeze, and only one instance for the video replacement filter (figure 4.13).

The answers for the reason why they preferred a filter fall into two distinct reasons. First, seven participants selected either wallpaper, block, or freeze because they like static images: "It's easier to pay attention to something when the images are frozen or not so bright" (P6). Secondly, five participants preferred wallpaper not only because it was static but also because of its calming visual: "I like the idea of a static image that is pleasant to look at" (P8). Finally, four participants gave only general answers to why they chose the preferred filter: "Least Distracting." Two participants did not report any difference.

The answers for how comfortable and useful they perceived each filter to be follow the same pattern as the other results, where wallpaper always has the highest rating, followed by block, freeze, dim, and replace. These matching results across different prompts identify that wallpaper was the preferred filter because it makes the screen static while providing a pleasant-to-look-at visual.

Aside from the results from the questionnaire, I also recorded how the filters were used. The recordings of experiments show how many participants used each of the filters. Note that the same participant could use multiple filters during their trials or choose not to use them at

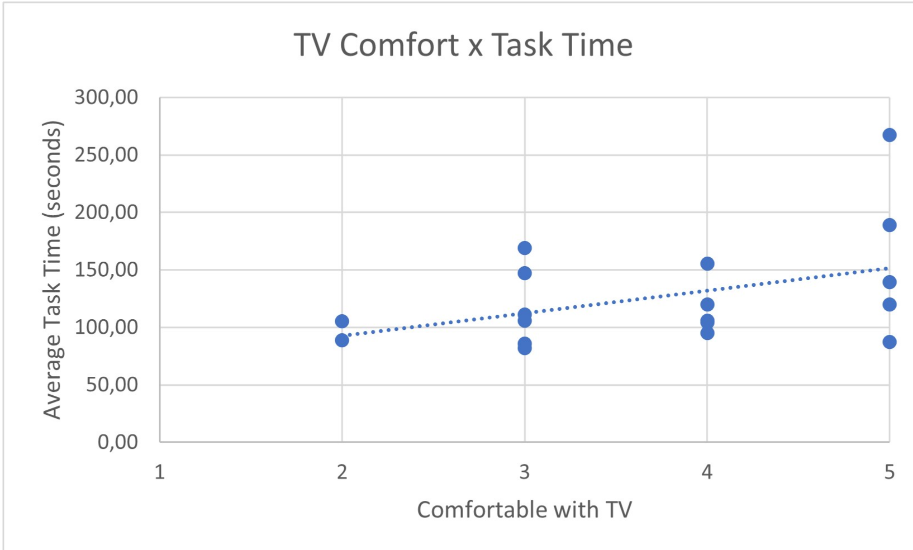


Figure 4.11: Correlation between comfortable TV levels and task time.

all. The actual filter use was somewhat different from their preferred choice; 13 participants used the block filter during the experiment, 7 participants used the wallpaper filter, 4 participants used the freeze filter, 3 participants used dim, and 3 used the replacement filter. Finally, 4 participants did not apply any filter during their experiment.

Considering these results, I can see that even though wallpaper was the preferred filter, block was used most frequently. If we disregard the participants who did not use any filter, all but one participant used the block filter during the experiment. I believe this happened because the participants selected which filter they preferred after experiencing them in a scenario where only one screen provided a visual distraction. I analyzed filter uses in the second task, where five screens were present. Therefore, the block filter might be better when the user wants to remove the content of many simultaneously active screens. In hindsight, it would have been better if I had asked participants to rate their preferred filter option both after the training scenario and once again after the filter condition, as this would have given them more time to experience the filter and could potentially have changed their preference after experiencing them for a longer time.

Post-training interview

Most users experienced issues with the controllers (N = 6), mentioning that their hands would collide: “the most difficult part was not to make physical contact between the controllers” (P7). Other issues with manipulating the blocks included that they felt that rotating the blocks was hard (N = 3) or stating that the blocks would not fit the way they expected (N = 10). “It’s a little bit hard because when I want to detach them, it’s hard, and also when I want to combine them, the gesture and try to fit them” (P14). On the

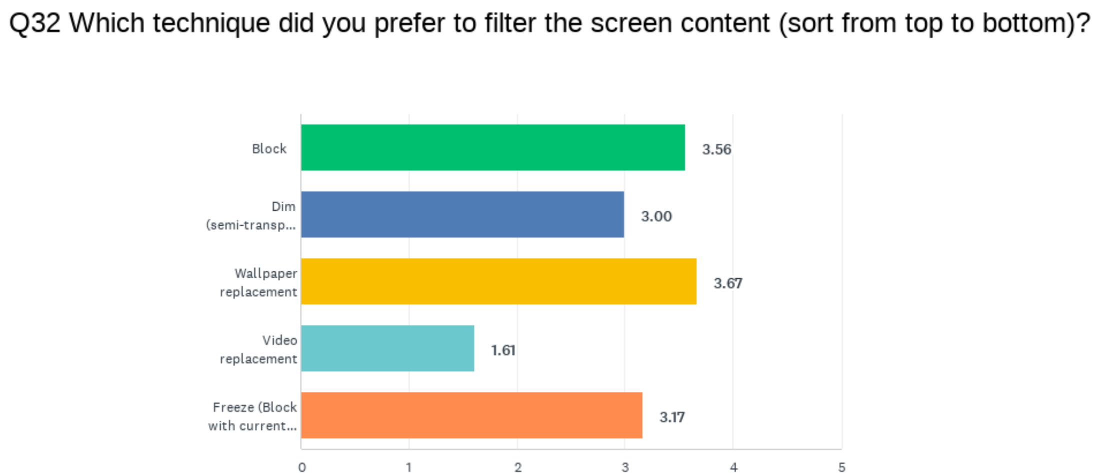


Figure 4.12: Average preferred filter rankings for each filter.

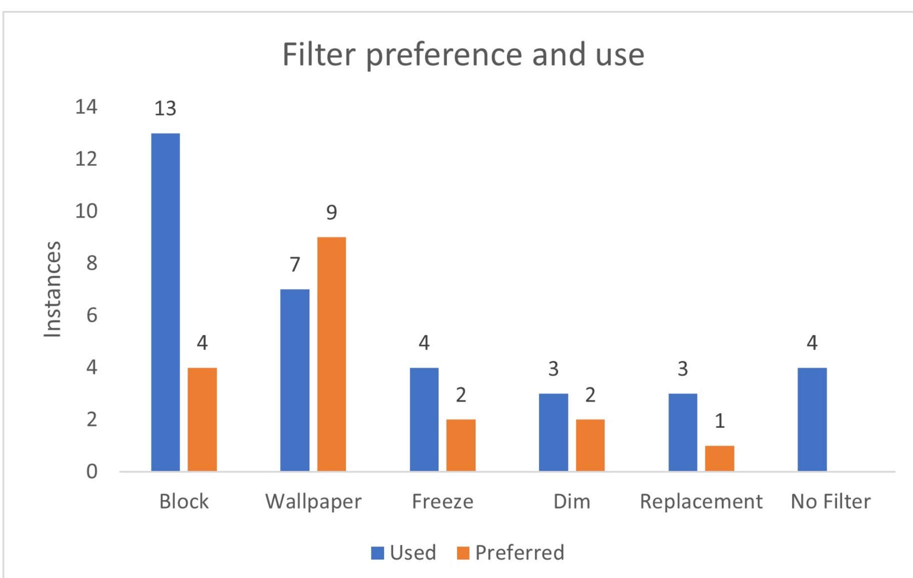


Figure 4.13: Instances of how often each filter was used and selected as preferred.

other hand, a few participants mentioned that manipulating the blocks was easy (N = 3), and others had different issues, like hand/tracking jitter or stating that the blocks lacked weight.

When asked about assembling the blocks, most participants mentioned it got easier after some time (N = 5), while others mentioned it was hard initially (N = 7). Yet, all agreed on there being initial confusion with the task: “Like I think after a while I do feel pretty hands-on, I start to be more immersed in this scenario. At first, it did feel like something funky that I was not used to. But I guess I was getting increasingly used to the whole thing” (P2). Another recurring feedback was that having the reference to check was useful (N = 3).

Reflecting on the filter options after the training scenario, participants generally mentioned they liked wallpaper because it was nice or complemented the room: “I particularly like the wallpaper because it can contribute to the room being nicer”(P15). Others favored freeze because they could use it to still have some context. Generally, the comments for dim and replacement were that they were not so helpful. Block was not mentioned as much, probably because participants had a neutral feeling about it and did not pay much attention to it. Some participants said that block was “not fun” or that block, wallpaper, and freeze felt the same. Many participants mentioned they did not pay much attention to the filter options (N = 6) or that they made no difference (N = 4). The likely reason is that there was only one screen during the training task, and it was not directly in the line of sight of the participants. They likely also experienced a higher cognitive load because they were learning the task: “I wouldn’t pay too much attention [to the screen] because I was too busy assembling the blocks” (P18).

When asked about potential uses of DR in their daily lives, participants mentioned different ways it could help them while working or studying (N = 9): “Studying and also working like when I had to focus on just on my screen, and they’re in office situations many people are walking around and moving around” (P11). The public scenarios that participants mentioned included a doctor’s waiting room, libraries, coffee shops, offices, classrooms, and inside their (shared) households. Three participants also said they would want to use this technology to hide a cluttered environment: “When my room is too messy, it can get annoying. It’s hard for me to focus on that kind of environment” (P18).

Another topic mentioned by some participants (N = 4) was that DR could help during transit by removing distractions such as animated billboards and bright lights: “The most important thing for me is like in transit. Sometimes when you are driving, especially at night, billboards with images, moving images, these kinds of things could be very distracting” (P6). Two participants mentioned it would be helpful to block ads while walking around; another two participants thought it could be useful but not for them, and finally, three participants could not think of using DR technology in their daily lives.

Some participants mentioned they would like some extra functionalities aside from those available in the experiment and wanted to use the freeze function with the option to rewind the freeze frame so they could look at something specific. Another mentioned they would like to select a different image for the wallpaper, and one participant wished for a blur function.

Post-experiment interview

After the second task, I asked participants how they felt in the VR environment. A substantial part of the participants mentioned they felt comfortable (N = 7) and that the environment was exciting or fun. However, an equal number of participants reported feeling uncomfortable (N = 7). Some of them mentioned that they got tired after using it for a while, and others said they had issues with the perception of depth or experienced eyestrain.

I asked participants to reflect on the three different conditions for the experiment. Most participants mentioned that the screens were annoying or distracting (N = 11): "With the TV on, I got a little bit distracted by the ones right in front of me" (P13). Four of them mentioned a specific screen content that annoyed them: "In the first condition, I did look at that cat video for a few seconds before the task" (P2). Three participants reported they did not care about the screens, and two said they liked them because they added an ambiance that made them feel more immersed.

When asked about the condition with filters, most participants said it was better than screens (N = 8), and participants mentioned that they liked to have the control to select which screens would show content. "Well, it's better when I can control. If I can turn off the screens, I guess it's less distractive" (P9). Two participants who did not like the filter condition said it cluttered the environment or made them more aware of the screens because they had to interact with them. "With filters, I feel there were many things happening, hmm. Feels like the room was full" (P3). Seven participants said that without the screens, they were more comfortable, while two participants noted that without the screens, they were annoyed because it made them feel hyper-focused on the puzzle task. Three participants said that they saw no difference among the conditions.

For distractions in their daily lives, participants mentioned that in their work environments, they usually get distracted by people walking by. Another behavior mentioned was that sometimes other family members would watch TV while the participant was working or studying; one participant worked as a journalist and commented there were multiple screens playing videos in their work environment. When asked about background interaction with a TV, some participants mentioned always having the TV on at home (N = 5). Most participants keep a screen on while doing chores (N = 9): "When I do like a chore at home or when I do something like fold my clothes, for example, I do have like a show running in the background" (P2). or listen to audio (N = 6) "I usually listen to music, so I prefer having the screen off" (P12). Participants also mentioned using the computer or cell phone to play video or audio while doing chores. Only three participants said they do not have TVs at home because they prefer a quieter environment.

Experimental observations

During the task, participants experienced various issues, such as having trouble with the controllers (N = 10) or breaking puzzle block connections by mistake (N = 7). “I guess the only problem which I faced while arranging the blocks was [that it] sometimes by mistake kind of exploded” (P8) or troubles selecting UI elements (N = 8). Also, many participants expressed frustration (N = 7) when they made a mistake or realized they had built the wrong combination and would have to adjust multiple pieces’ locations. Usually, this frustration came in the form of negative statements about themselves, such as “I’m not the best at spatial abilities,” “I don’t have enough dexterity,” “I’m not so good with VR,” or “My hands shake a lot.” This behavior might indicate that participants worried about their performance and verbally expressed a reason why it might not be so good.

One of the potential reasons behind the selection mistakes was the Heisenberg effect [58], since participants had to simultaneously aim the laser pointer and use the buttons. Others pressed the proceed button twice by mistake, which caused four failed tasks. Another typical interaction issue was that when participants made a mistake and had to break the connection of a piece, they would also break other (correct) connections, which vastly increased their task time in those scenarios. Since the block pieces did not snap into a perfect position, sometimes the participant’s puzzle task would be almost correct, but the blocks were far enough away that the system considered one block incorrect. However, to fix this, participants needed to remove and re-connect the piece, which could cause a bigger issue when multiple connections were broken by accident.

Regarding the use of filters during the test, four participants preferred not to use filters. When asked about the reason for not blocking, they answered the screens were not bothering them, and they felt that taking a moment to filter the screen would waste their time. “I didn’t block them because I didn’t think they bothered me. It does feel like there’s a timer in my head, so I feel like OK. Like if I spend time on clicking the TV and then choosing to block them, I’m spending more time on things that don’t even matter” (P2). Six participants changed the filters during the test, and when asked why they changed the filters between tasks, they mentioned that they were trying the options out or wanted to see how they would perceive the different filters: “I was changing because I wanted to. To see if it’s affected how fast I could complete the task” (P11). When using filters, most participants blocked the central screen, a few blocked only the screens on the sides, and some blocked all the screens.

Chapter 5

Second Study

5.1 Study Design

I performed a second study to follow up on the first study and investigate other tasks that might show more sensitivity to distractions due to screens. Here, I designed the first task to explore the impact of DR screen filters on participants in an attention-based task. With the second task, I wanted to see how filters could impact a participant's perception during a conversation.

5.1.1 Stroop task

Figure 5.1: The Stroop test panels and prompt.

For my second experiment, I implemented a Stroop-inspired task in VR (figure 5.1) [53]. The original Stroop task was a psychological experiment where the participants are presented with a list of words and must speak the font color aloud. This experiment demonstrates that a mismatch between the font color and the written word induces stress and cognitive load for the participant, raising their chances of making a mistake (figure 5.2). My Stroop test implementation is similar to the one used in Grandl et al.'s work [15]. Here, participants are presented with a word prompt and then have to select one of six target panels with distinct colors through raycasting: red, green, blue, purple, yellow, and orange. One important distinction with Grandl et al.'s work is that I did not use the room walls as the panel; instead, I presented the targets as six smaller floating panels so that there was still enough space in the environment to present the screens. My redesign also reduced the need for participants to rotate their bodies. During the task, the participant has to select the correct panel according to the instructions implied by the task, as in Grandl et al.'s study. As their research showed, this is a workable substitution for the original Stroop test

Figure 5.2: Example of a series of trials for the original Stroop task.

The task instructions were displayed as two words, one above the other. The top word defines the type of the task, being either "WORD" or "COLOR," whereas the bottom word describes the target panel, showing the word for the color of one of the panels but in a font color that corresponds to another panel. The participant then needs to consider the task specified by the top word, use the appropriate information from the bottom, and select the proper panel as a response. Consider the scenario where, at the bottom, the participant sees the word "red" colored in blue. Here, if the task type is "WORD," then the participant should select the red panel, but if the task type is "COLOR," the participant should instead select the blue panel (figure 5.3). This variation of the original Stroop test is very similar to the original one, where people had to say aloud the correct choice, but here, they only have to select the correct answer.

In my implementation, I made all the tasks incongruent, i.e., the text of the bottom word never matched its color. Further, I guaranteed that subsequent tasks always involved a different panel name and color relative to the previous selection. I made these decisions to avoid the issue that the same prompt might appear twice in sequence. Also, since my primary goal is to evaluate the effect of screen distractions, I prioritized presenting a consistent type of task, i.e., always incongruent Stroop trials.

The first task environment was similar to the one used in the second task from the first study; however, there were only two conditions, as the screens were either presented with or without filters. Also, participants only had access to the block filter instead of having the option to select the filter, simulating turning the screen off. Each participant first did 15 practice trials to get used to the system and the two different task types. Afterward, they

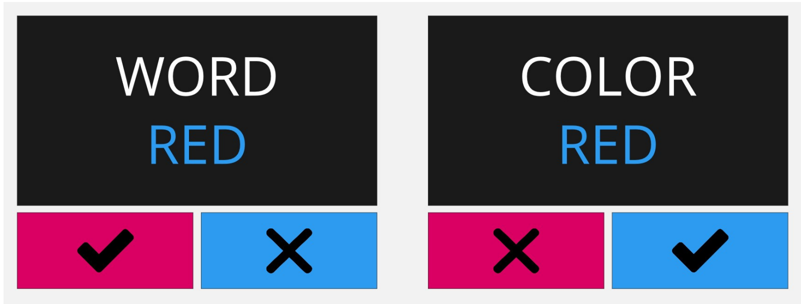


Figure 5.3: On the left, the task type is WORD, so the red panel is the correct choice, on the right, the task type is COLOR, so the blue panel is correct

performed 120 trials for each condition, similar to the Stroop room study [15]. For each of the 120 trials, my implementation made sure that there was an equal amount of task types (60 "WORD" tasks and 60 "COLOR" tasks), with a randomized order for each time I ran the experiment.

5.1.2 Conversation task

Previous research has shown that maintaining a conversation demands a fixed cost of attention [29]. One of the possible use cases for screen filters in such a scenario would be to block those visual distractions while the user is conversing with someone else. As inspiration, I used a scenario where the DR user is talking with someone in a living room, cafe, or sports bar and keeps getting distracted by the news or a game that is playing in the background instead of being able to focus entirely on the conversation.

I thus included a conversation task in the second experiment to see how DR screen filters impact such scenarios. The task consisted of conversing with the researcher for 5 minutes. The experimenter used a list of 45 questions to engage the participant in the conversation, where the experimenter would randomly select (without repetition) and pose one question at a time to the participant. This procedure is somewhat similar to the one used by Kunar et al. [29]. Once the participant answered the question, the experimenter would then move to another question. The conversation questions were generated using ChatGPT and refined to remove any questions touching sensitive subjects, see Appendix C.

Participants were instructed to answer the questions truthfully but were allowed to request another question if they did not feel comfortable answering a given one. If their answer was too short, the researcher asked participants to elaborate, or if the participants were taking too long to answer a specific question, the researcher would prompt them with another question. Consequently, participants would talk about 9 to 10 conversation topics on average during each condition. The second task was also performed in two DR screen conditions, one with filters and another without.

I acknowledge that this question-and-answer procedure is not a precise reproduction of a real conversation, since the dialogue was more unilateral and structured than usual. Still, I selected this method because previous research [4] shows that this process requires participants to plan their response on the spot, which induces cognitive load. Unlike natural conversations, the unpredictably varying nature of the questions used in this experiment made it harder for participants to prepare their responses ahead of time. As my experiment was more focused on evaluating the possible distraction of the screens themselves I avoided using quiz questions with definitive answers since I wanted participants to engage in a conversation naturally. Regardless, the two other approaches to the conversation task that I did not select are still interesting directions that could be further explored in subsequent studies.

5.1.3 Procedure

The experiment started with briefing the participants and using the same demographic and pre-assessment questionnaire as in the first study. Subsequently, the participants performed the Stroop task, starting with 15 practice trials, followed by 120 trials for each condition, with the order being counterbalanced. After each condition, they were asked to fill out the simplified version of NASA TLX and two extra questions about how focused they were and how they rated their performance. Before starting the second task, I performed a short interview about their thoughts on the two conditions and gathered general comments.

Then, the participants completed the 5-minute conversation task twice by answering the sample questions under the same conditions as in the first part, again using a counterbalanced order. After each condition, they answered a short questionnaire asking them to rate how natural the conversation was, if the questions were representative of a normal conversation, and how distracted they were during the conversation. Upon finishing all the tasks, I performed a semi-structured interview to gather their insights on the two conditions, solicit general comments, and ask them general questions similar to those used in the first study.

5.2 Measures

5.2.1 Quantitative

Success

Task success for the Stroop test was measured as the number of correct trials, i.e., where the participant selected the correct panel. Otherwise, the task was considered incorrectly completed. I then compare the number of correct Stroop tasks between the two conditions.

Task Time

The task time was counted in seconds. The timer counted the duration of each trial in the Stroop test, starting the moment each task was displayed until the participant made a choice. I also calculated the sum of the total task time across all the trials for each condition.

Task Load Index

I used a modified NASA TLX questionnaire, similar to the one used in the first study. However, I added two new questions: “How focused were you when performing the task?” and “How do you rate your performance on the task?” Both questions followed a similar question style with a 7-point Likert scale ranging from very distracted or very slow to very focused or very fast. I also added two open-ended questions asking if there were any particular moments where the participant had trouble concentrating and if external factors distracted them, see Appendix B 7.4. I mention the results of those two general questions with the observations.

Subjective Conversation Ratings

To evaluate the impact of the conditions on the conversation, I used a procedure similar to the one used by Boiteau et al. [4], where after each condition, the participant had to rate if the conversation was natural, if the questions were representative of a normal conversation, and how distracted they were. They answered these questions on a 7-point Likert scale, from strongly disagree to strongly agree. They used a similar scale for the distraction question, ranging from very focused to very distracted.

5.2.2 Qualitative

Pre-Assessment

I used the same pre-assessment questionnaire as the first study.

Post-task interview

After both conditions were done for either the Stroop or conversation task, I interviewed the participants. This semi-structured interview aimed to uncover the participants’ thoughts about how they felt when the screens were present compared to when the screens were blocked by filters, as well as gathering general comments or thoughts they might have about the task they had just performed.

Post-experiment interview

After a participant had finished all trials and all conditions, I also did a post-experiment interview. This interview used questions similar to the ones used in the first study, asking participants to describe the presence of screens and distractions in their work environments and if they leave screen(s) on while doing chores at home. Finally, I asked about their thoughts about using DR and the potential applications they could foresee for such a technology.

5.3 Results

5.3.1 Participants

As I wanted the participants to be unfamiliar with my prototype, I recruited a new set of participants for this second study. I conducted this study with 16 participants (twelve female, four male). All participants reported normal or corrected-to-normal vision and no color vision deficiencies. Most participants' ages were between 18 to 24 (N = 8) or 25 to 29 (N = 4). Five had a high school diploma, six participant's highest level of education was a bachelor's degree, three had post-secondary diplomas, and two held a master's degree. Participants were compensated with 15 Canadian dollars, and the study took around one hour to complete both tasks and the interviews.

5.3.2 Quantitative

Success

All but two participants had at least 100 correct Stroop tasks (out of the 120) for each condition, showing that participants generally succeeded in performing the task. Still, one participant had only 65 correct tasks, i.e., slightly more than half, and I thus removed this participant as I believed they did not fully understand the task. When looking at the mean number of correct tasks per condition with screens (M = 114.06, SD = 8.41), I saw that it was just slightly higher than the filter condition (M = 112.69, SD = 13.15), and the difference between the two conditions was not significant.

Task Time

Before analyzing the time data, I removed all data points from the participant who did only 65 tasks correctly. I also removed a few outliers above three times the interquartile range beyond the 10% and 90% quartiles. This removed 244 (6%) trials and left 3596 trials. Figure 5.4 shows a chart for the average task time by condition.

The mean time to complete a task was slightly lower in the filter condition (M = 2.80, SD = 1.44) than in the condition with screens (M = 2.80, SD = 1.62). The results from an Anderson-Darling test showed that the samples for all conditions most likely do not follow a normal distribution ($p < .05$). To identify if there is a potentially statistically significant difference, I performed a Wilcoxon signed-rank test. The results indicate no statistically significant difference at the .05 level between the conditions (Z = 1,079 p = .281).

I could not identify any significant differences in task time by trial result. Therefore I assume that getting the trial correct or not had no impact on the speed to finish the task. Furthermore, I analyzed the task time by trial number, and aside from the initial trial in each task (where the participants were naturally slower due to getting familiar with the system), there was no significant difference between the trial numbers, and participants exhibited consistent times throughout the experiment for both the filter and screen conditions. This means I did not find evidence for the presence of a speed-accuracy tradeoff in this study.

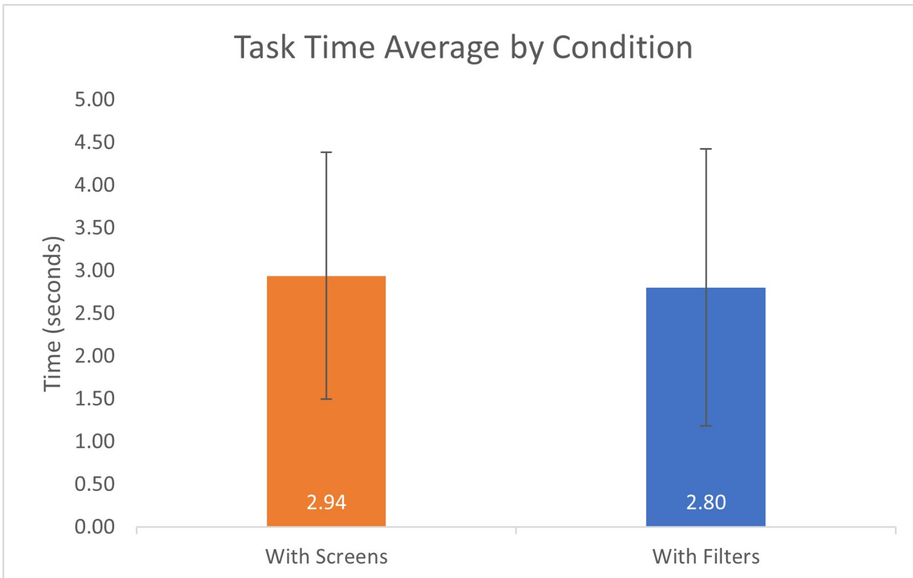


Figure 5.4: Mean times to complete the task by condition, error bars show the standard deviation.

Task Load Index

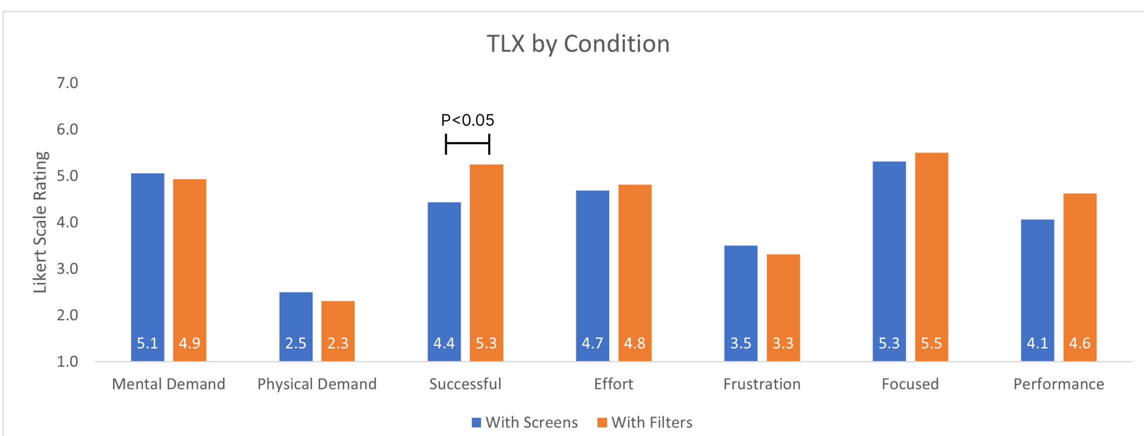


Figure 5.5: TLX results for the second study.

Figure 5.5 shows the results for the TLX ratings by condition. Participants exhibited better scores in almost all categories for the condition with filters. However, only the question "How successful were you in accomplishing what you were asked to do?" resulted in a marginally significant difference. Both conditions had medium to high results for mental demand, with screens having the highest mean (M = 5.06) followed by filters (M = 4.94). On the other hand, the levels of physical demand were relatively low, both with screens (M = 2.5) and filters (M = 2.31).

Participants rated their success higher in the filter condition (M = 5.25) and lower in the screen condition (M = 4.44). A dependent measures t-test shows that this difference was significant (t(15) = 2.228, $p < .05$) with a medium effect size, as identified by Cohen's d = 0.57. However, a one-way MANOVA across all questions indicated that this is only a marginally significant result ($F_{1,15} = 4.069$, p = 0.053, $\eta_p^2 = 0.119$), which indicates that this may be a spurious result. The answers for how hard they had to work were higher in the filter condition (M = 4.81) than in the screen condition (M = 4.69). When rating how insecure, discouraged, irritated, stressed, and annoyed they were, the participants had slightly higher results for the screen condition (M = 3.5) than for the filters condition (M = 3.31); the results were at medium to low levels in both conditions. But again, all of these differences were not significant, except for the question about task success.

The final two metrics were collected on the additions to the TLX questionnaire. When asked how focused they were, participants responded with high levels for both conditions, rating the filter condition slightly higher (M = 5.5) than the screen condition (M = 5.31). They also rated their performance somewhat higher in the filter condition (M = 4.63) than in the screen condition (M = 4.06), albeit with non-significant differences.

Subjective Conversation Ratings

Figure 5.6 shows the results for the conversation ratings by condition. The scores for how natural the conversation was and how representative of a normal conversation the questions were were quite similar across the two conditions. With filters (M = 6.44), they had a slightly higher score for how natural it was than with screens (M = 6.13), while screens exhibited a slightly higher result for how normal the questions were (M = 6.44) compared with the condition of the filter (M = 6.38). The results of how distracted they were during the conversation showed a more drastic difference, with a substantially higher level for the screen condition (M = 3.19) than the filter condition (M = 1.69). A dependent measures t-test identified that this difference was significant (t(15) = 3.223, $p < .005$), with a large effect size, as indicated by Cohen's d = 0.80.

5.3.3 Qualitative

This section describes the results from the pre-assessment questionnaire, the two post-task interviews, and the post-experiment interview. The interviews were transcribed and then

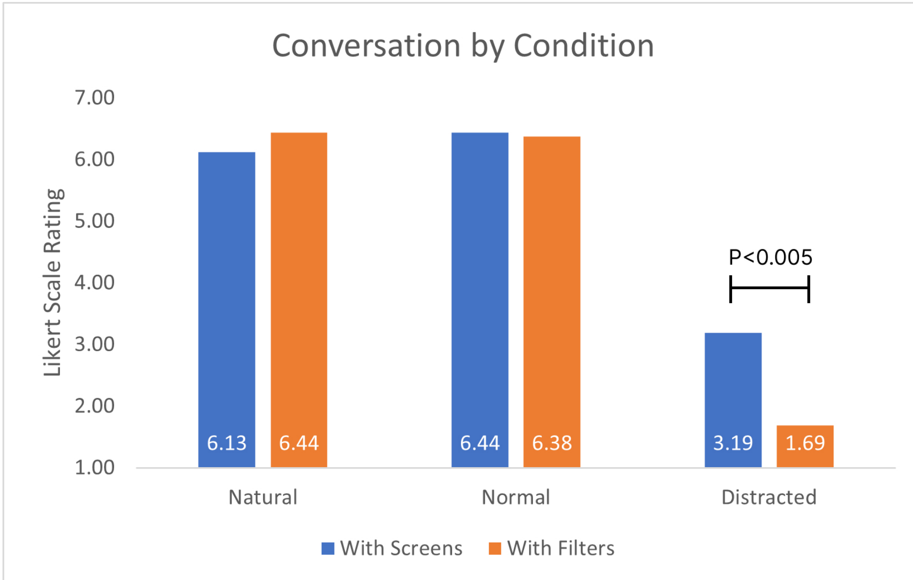


Figure 5.6: Conversation ratings by condition.

coded in NVivo [34], using a thematic analysis method. The observations were transcribed into digital format and grouped based on relevant themes.

Pre-Assessment

Most participants reported playing video games less than once a month (N = 7), two participants said they play every day, a few times a month, or once a month, and one participant reported never playing video games. Eight participants had experienced VR less than once a month (once or twice), six participants had never experienced VR before, one reported experiencing VR once a month, and another about once a week. Since most participants did not have considerable VR or gaming experience, I could not evaluate if there was any correlation between those aspects and performance on the Stroop task.

The levels for how comfortable participants were with a TV playing in the background while doing other tasks show that most participants felt very comfortable (N = 7); four felt comfortable, four were neutral, and only one participant reported feeling uncomfortable. When analyzing the interaction between comfort levels and task time, one can see almost no difference in the total task time speed for how comfortable they are with TVs. There is a slight trend towards those comfortable with TVs being slightly faster on the task (figure 5.7).

Post Stroop task interview

Most participants did not have significant issues or concerns with the task, but two mentioned that the task was too challenging, and three participants felt that in the beginning, it was "a little hard," but after a while, they got used to it. Two other participants mentioned

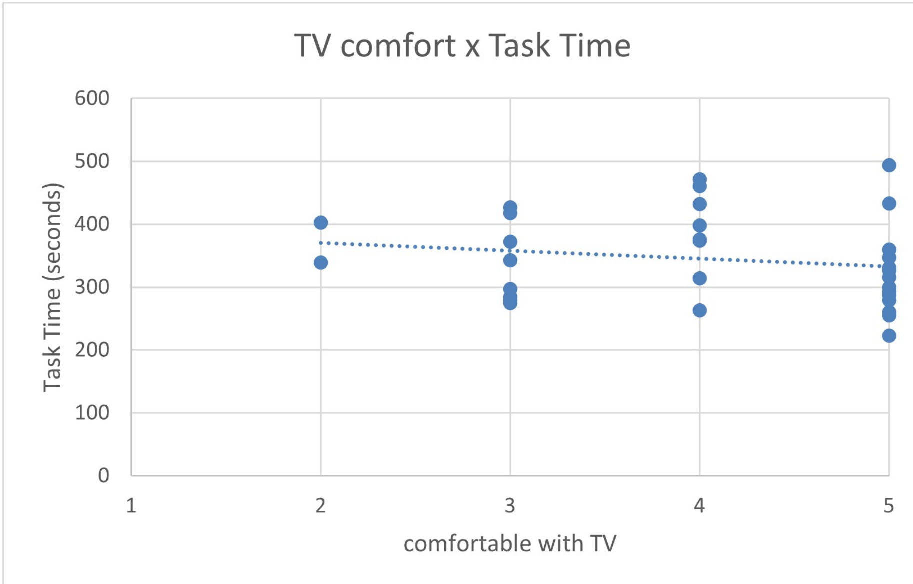


Figure 5.7: Correlation between how comfortable participants were with a TV playing vs. Stroop task time.

that they started to get mentally tired by the second condition. Five participants mentioned liking the task; some even compared it to a minigame.

When asked how they felt in each condition, participants generally had positive feedback for the filter condition (N = 5), "I felt less tired than in the first scenario with the TV present. I had the impression that the TV wasn't a distraction. But when they were removed, it was much easier" (P5). However, two participants felt that the filters were annoying or distracting. A couple of participants (N = 3) mentioned that even though they usually have screens playing while doing other tasks, they found themselves distracted by them: "When I was doing the TV one, I like didn't realize how like kind of visually distracting the TV's were until like I did the second task [with filters]. Like, I couldn't really tell that, though it was like I didn't think the TV was going to make a difference, but I feel like it was really mentally straining because like. There were so many colors popping up at you" (P11).

The opposite can be said for the screen's condition, where most of the feedback was negative (N = 7), with these participants mentioning explicitly that the screens were distracting: "It was too many videos happening for me to concentrate on the task. I felt that it was overwhelming"(P6). Only one participant said they felt more focused with the screens.

However, the most common answer for participants was that they did not feel much difference between the conditions or that after an initial adjustment phase, they were not bothered by the distractions (N = 9): "I didn't feel any difference. There was just some noise around, but I could just focus on the center of the screen where my tasks were" (P12).

Post conversation task interview

Participant's response to the conversation task was generally positive. Three participants mentioned explicitly that they enjoyed the task and thought it was interesting. However, two participants mentioned that the task felt weird because they were talking with someone who was not present in the virtual environment. One of them even suggested adding a model of a person so they would see someone to communicate with.

Again, more participants had positive attitudes toward the filters (N = 5), saying that it felt more manageable and they could think deeper before answering the questions, "It was easier to answer the questions because most of the questions I had to think a little and use the imagination, creativity" (P5). Yet, two participants felt that the filter condition was worse for them because it felt too serious or because they would not know where to focus, so they would keep looking around the environment. One of those was also the only one to mention that they liked the screen condition, saying they felt more relaxed like talking with a friend.

For the screen condition, most participants had negative thoughts about it (N = 9). They mentioned that the screen condition distracted them or that they would not be able to go as in-depth with their answers during this phase, and they would also mention specific content that the screens showed. Participants mentioned that this happened because they did not have a straightforward visual task, they needed to do it in this environment, leaving them "free" to pay attention to the screens. One participant said, "When selecting some colors [Stroop test], I have something to do. Then I'll just focus on what I'm doing, but while we make conversation, I'm just doing nothing. So I just focus on the TV. So yeah, it is definitely distracting" (P9).

For the conversation task, four participants felt like there was no difference between conditions. This number is substantially lower than for the Stroop task. The participants who mentioned they did not feel any difference often stated that this is a situation they are used to in their daily lives, "I didn't feel as distracted. Because like usually nowadays when people talk, they talk with an experience in front of you sometimes. It felt natural to me that the screens were present" (P10).

Post experiment interview

Most participants are used to having a second screen playing videos while doing other activities (N = 9). They mentioned that watching something helps them relax or that it is just a habit that they are used to, even if they recognize that this can lead them to be more distracted. "Sometimes, when I'm doing something really serious. [Follow-up question: Do you usually have a screen playing while doing another task?] Because I want to distract myself" (P13). Some participants are used to having another screen playing in their shared home environment, so someone else might be watching the TV while studying or working.

Finally, some participants reported feeling uncomfortable with silence, so they liked to have something playing just for the noise. However, an almost equal number of participants also prefer not to have a video playing in the background (N = 7). Still, like in the first study, more participants like to have some form of audio playing while working, studying, or doing chores (N = 11).

I asked participants about their work or study environment and potential distractions within that environment. Almost all participants (N = 14) study or work at home, where they have at least some control over most of the distractions in their environment. Thus, depending on their preference for the moment, they might have a second screen playing something or turn it off to have a quieter environment when working on a demanding task. One distraction a couple of participants mentioned was their phones, mainly due to constant phone notifications. Beyond that, two participants stated that they work in an office environment and that they get distracted by other screens at work. Five participants mentioned that sometimes they study at a library or in a cafeteria and that occasionally, they would get distracted by other people passing by.

In this experiment, participants produced a more diverse range of answers when asked about the potential uses of DR in their daily lives. Five participants mentioned that they would use such technology to diminish the distractions in their environment if they had to work in a public place like a restaurant, college, or library: "Probably like in a test or like a college. Sometimes when I was doing a test in college, someone was eating something or using the laptop and things like that got me very distracted" (P16), or "People around me can make me feel more uncomfortable with things I need to do, so I would probably use that once I need to work outside of home" (P2).

A couple of participants mentioned that they would like to use DR to hide sensitive situations (N = 5). "Yeah, like disturbing scenes. Sometimes when I go on the street, and I'm walking down, I'm kind of scared of encountering racist signs or something like that" (P10). These situations would range from blocking racist signs, patients suffering at a hospital, explicitly sexual or violent content, and even drug addicts.

Another common theme was wanting to use diminished reality to block advertisements or billboards (N = 5). "Yeah, I would block ads if I could. I feel like that would make life really better" (P11). Three participants felt that diminished reality could aid them in navigation tasks, like finding the correct airport gate, telling them which streets to take to a destination, or helping them find the correct groceries in a supermarket. Two participants could not think about any potential use of DR in their daily lives.

Experimental observations

I observed no significant issues during most of the tests. During the Stroop task, many participants (N = 10) spoke the task type out as a means of helping them shift their focus between WORD and COLOR. Another common situation was that participants would realize they had made a mistake (N = 5) and that they would then be more careful in subsequent trials. Some participants (N = 4) asked to do the practice trials twice to understand the task. Some minor problems during this phase were double-clicking a panel by mistake (N = 4) and missing the target (N = 3).

I asked the participants if there were any moments where they found it difficult to concentrate during the Stroop task. The most common answer was that when the task switched from one type to the other, the participants had trouble concentrating and had to take a moment to shift their mindset (N = 9). In contrast, other participants said after doing the task, they got tired or bored (N = 5).

During the conversation task, some participants turned slightly toward the researcher (N = 5), probably a reaction similar to what they would do in a normal conversation. Many participants were looking around the environment while in the filter conditions; since they were not looking at the screen, they were instead observing the virtual environment or the virtual clouds passing by the windows (N = 4).

Chapter 6

Discussion

In this chapter, I discuss the results of both of my user studies.

6.1 Perception of filter options

The first research question I aimed to investigate was how participants perceived different DR filter options for blocking screens and what kind of filter they preferred. The result of the first experiment shows that, among the options I presented, wallpaper and block were preferred over the others. The main reason for the preference was that users wanted a static filter; however, they also desired one that was aesthetically pleasing. I acknowledge that I should have also asked participants to rate their filter preference in a post-experiment questionnaire since their preference could have changed after the tasks.

During the first study, the block filter was used more than the wallpaper filter. I believe this behavior happened because a more straightforward filter was preferred, as blocking multiple screens was needed in this scenario. Therefore, while a visually pleasing filter might be preferred for a single screen, a more straightforward filter is better suited when users need to block several screens. Furthermore, my research shows that participants liked the control the filters gave them. When reflecting on the different conditions, many participants mentioned how they enjoyed the ability to select which screens were blocked. During the interviews, participants also mentioned different ways to use the filters and how they would like to control what precisely to block.

Regarding user perception of filters in the first study, an unexpected result was that many participants were indifferent about them after their initial contact. This was most likely because, in the training scenario, the screens were not a prevalent distraction, and participants were focused on the task. Moreover, during the actual test, some participants decided not to use filters, which indicates that, at least for some users, they did not feel like the filters would help them. This behavior could be a result of multiple factors. One reason for this behavior might be that the puzzle task was too challenging and demanded much cognitive effort, which might have taken the participant's focus away from the screens and filters. A second reason why this might have occurred is that when I interviewed participants about the use of TVs in the background while doing other tasks, most of them were used to having active screens as ambiance or at least for the sound, so participants might not be as distracted by screens as I initially anticipated.

In the second experiment, after the Stroop task phase, many participants also felt indifferent about using filters. This result corroborates my assumption that having a highly cognitively demanding task can make participants focus almost exclusively on it and disregard their surroundings. Still, for the final conversation task, the number of participants who felt like the filters had no effect dropped to just four, showing that a task that does not demand as much focus (at least visually) is more prone to be affected by environmental distractions.

6.2 The Potential of DR

This study also investigated which potential applications users could foresee for DR in their daily lives. As hypothesized, most participants felt receptive to the general idea of DR. Half of the participants in the first study and five in the second study could think about scenarios where they would want to use such technology to improve their study or work habits. Participants also mentioned a plethora of different places where such technology could be helpful for work and study. Most environments included ones that I had anticipated, such as offices, coffee shops, libraries, and their (shared) homes. More surprising mentions included classrooms and doctors' offices.

Aside from uses related to work and study, five participants in the second experiment imagined using DR to hide sensitive situations, including racist signs, violence, sexual content, drug use, and suffering patients. This use for DR technology is somewhat similar to ideas explored in other studies [5, 10], where the user would hide objects or environments that trigger negative emotions to improve their mental state. This is an interesting topic that could be a focus for future research.

Another theme that surfaced in the second experiment was using diminished reality to block advertisements or billboards. This use had already been foreseen in the initial work on DR by Mann and Fung [37]. Furthermore, participants mentioned how DR could help their lives in transit, reflecting potential uses already identified in previous work [32, 48]. Based on the interviews, I can claim that most participants could easily anticipate how DR can enhance their daily lives. This supports my hypothesis that users can see the value of minimizing distractions and (visually) uncluttering environments.

Although five participants in the first study and two in the second study could not think about a technical use for the technology in their daily lives, this can also indicate a trend where some of the users still do not feel comfortable with the technology or cannot see the value it might bring, even if they disregard the current hardware limitations.

6.3 DR screen filters' impact on performance

This research aimed to answer whether DR screen filters help participants perform tasks faster when distracted by screens. The results for task time showed no significant results in either of the two experiments, which does not support my hypothesis that the filters would make participants perform faster compared to a condition without filters to block screen distractions. Furthermore, a baseline condition that included no screens was also not significantly different from the other two conditions.

As identified in previous research [33, 46] when evaluating XR applications, the difference in secondary task performance is often more significant. A typical pattern in such work is to use a secondary task, which is more likely to present significant results. Still, there was no significant difference among the three conditions in my first user study. As the standard deviations of the means were high, this is likely an outcome of the problems observed with the task controls, how likely an error could occur, how time-consuming such errors were, and the VR environment itself.

For the Stroop task used in the second study, although the task itself was not prone to time-consuming errors, there was (unsurprisingly) a significant effect of the order of the conditions due to learning.

Furthermore, participants verbally mentioned that they could more easily ignore screen distractions when faced with a cognitively demanding visual task than on a conversation-based task.

6.4 DR screen filters impact on conversations

My second experiment aimed to answer if DR screen filters would reduce participants' distraction when engaged in a conversation task. The results of the subjective conversation ratings showed significant results for the level of distraction, supporting my hypothesis that the filters would indeed make participants less distracted during conversations when compared to a condition without filters to block the screens.

The results for the subjective conversation ratings showed similar levels for how natural the conversation was and how representative of a normal conversation the questions were across conditions. However, the reported level of distraction was considerably higher for the screen conditions. Furthermore, more participants explicitly identified that they felt more distracted by the screen condition, while only a few participants claimed to perceive no difference. Compared with the performance results, these results show that DR screen filters might better improve participants' concentration during linguistic tasks than in visual or motor tasks. As shown by Boiteau et al. [4], speech planning increases the cognitive attention load, and the un-filtered screens seem to have been distracting enough to reduce the participant's capacity to answer questions in depth.

As this research represents an initial inquiry into the user experience with DR screen filters I acknowledge that there could be potentially confounding variables in the experimental approach I selected for the conversation task or the methods used for its evaluation. Since my approach relies on a self-reported measure the results of the distraction ratings could be unreliable. Yet, I postulate that these limitations for my results still highlight the potential utility of these filters to improve the focus in daily conversations.

6.5 DR screen filters impact on task load

I used the NASA TLX questionnaire to study the impact of the DR screen filters on participants' cognitive load. In the first experiment, the results of the questionnaire did not show a significant difference between conditions. However, in the second experiment, the measures for how successful the participants perceived themselves exhibited a marginally significant effect. These results show no substantial evidence for my hypothesis that the filters would help reduce participants' cognitive load. It also identifies that the effect of DR screen filters potentially depends on the type of task that users are doing.

An intriguing aspect I uncovered during the interviews for the first experiment is that participants generally mentioned they felt like the condition with screens was worse and that filters helped by giving them the control to select which screens would show content. Still, while participants verbally mentioned that filters helped, that was not reflected in the NASA TLX results. This discrepancy between verbal and questionnaire feedback might have appeared due to the problems faced while performing the task. Participants verbally stated that they felt some conditions might have been more challenging because of the task and not because of the conditions themselves: "I don't know if it's directly related to the TVs or not, but [the task] was pretty more demanding" (Study 1, P9). Yet, there was no significant difference in task time for the puzzle task. The analysis for the NASA TLX also identified a high standard deviation, indicating that the responses are somewhat variable. This outcome could also be due to a Hawthorne effect, i.e., participants could have reported they preferred the filter condition due to the experimental procedure, even when they did not feel a difference during the experiment.

In the second experiment, participants also commented positively about the filter condition, mentioning that the screen condition was worse and that filters helped them concentrate. This is reflected to a degree in the TLX results, where the condition with filters had generally better means for all TLX results, albeit not significantly so, aside from the question about how hard the participants had to work to achieve their success, which exhibited a significant difference. Some metrics, like mental and physical demand, had only minor variations across conditions. However, the marginally significant difference in how successful participants rated themselves matches their interview responses, showing that although they had similar task times, they reported feeling more successful in the filter conditions.

Many participants were also uncomfortable using a VR HMD for extended periods. Since most participants were novice VR users with little previous experience, this might have influenced the outcomes for physical demand and effort. The questionnaire results for how annoyed participants were indicate a tendency towards support for this hypothesis. Therefore, it might be the case that if the number of participants was increased or VR experts were recruited, one could see a difference in these factors. This seems worth investigating in further work.

Chapter 7

Conclusion

7.1 Contributions

I presented insights from two experiments that explored the potential for diminished reality filters to block screens. The results show that, after a training scenario where they could sample each filter option, participants preferred static filters with aesthetic wallpaper replacement. However, when there is a need for blocking multiple screens, blackout filters that mimic a screen turned off might be an even better choice as this filter was the one participants used the most. However, since I only asked participants about their preferred choice at the beginning of the experiment, a future study should investigate this preference in more depth. I also found that participants were generally highly receptive to the idea of DR filters in their daily lives and could imagine scenarios of using them for work, studying, blocking advertisements, removing sensitive information, and helping them navigate their surroundings on foot or while driving.

Another contribution of my research is identifying the fact that DR screen filters can potentially help reduce users' perceived distraction during a conversation. The results show that participants reported significantly lower levels of distraction when using the filters than in the scenario with active screens during the conversation task. Although these results came from self-reported ratings, participants' feedback reinforces this finding, showing that the distraction by screens leads them to be less thoughtful in their answers and that they had a more challenging time going in-depth on their responses.

While participants claimed that the filter condition was better than the screen condition, I could not observe any significant effect on task time for the 3D puzzle nor the Stroop task. Generally speaking, no significant differences were found in their TLX ratings, however, on the Stroop test, there was a marginally significant difference in the TLX level for perceived task success and generally better means for the filter condition. These results indicate that while there might not be a considerable impact on task time, filters could result in less cognitive load. Due to the minimal previous research that has explored this area, I faced many challenges during the design of this study. Therefore, the results here presented should be considered to be formative as they highlight the potential effects of this emergent technology. In the upcoming section, I further describe the limitations of my research and discuss directions for future work.

One possible explanation for my observation of the effect of screen filters during the conversation task but not during the puzzle or Stroop task comes from the dichotomy of the effect of distractions on different cognitively inducing tasks. Previous research [30] showed that participants are less likely to get distracted during *perceptual* load tasks as the cognitive load increases. This is highlighted by attention experiments where participants fail to notice even a huge distraction while being focused on a different task (see, e.g.: selective attention tests that feature an invisible gorilla [9]). The opposite effect happens during working-memory load tasks where the participant must remember or recall information, which is a constant activity during a conversation. This can be explained due to the difference in "early" and "late" perceptual processing. Previous research also corroborates most of the scenarios that participants mentioned for using this technology since they relate to common distractions in daily life (Education, Work, and Driving) [31].

7.2 Limitations

One limitation of this work is that I chose to emulate the DR screen filters in a VR environment instead of implementing them in AR. While this approach has proven successful in previous experiments, the ultimate goal for such technology is that it would be applied in a real-world environment. Therefore, I cannot be fully confident that the results portrayed here are guaranteed to transfer to a real-world scenario. While I have no reason to assume that replicating the experiment in AR will change its outcome, using an AR system would allow the experiment to be tweaked, giving the possibility for the participant to see a real person during the conversation task. Furthermore, as the field of view in optical see-through AR is wider than for VR, this could impact the likelihood of distraction, too.

Another major limitation is that, except for the conversation task, the different tasks used in this experiment do not represent real-world situations. While the tasks were chosen because they can be used as reliable measures for cognitive load, distraction, and focus, tasks more representative of daily activities could be used to see if participants would react differently to the filters, especially in activities which related literature has highlighted as common daily scenarios of inattention. Also, when I asked participants to imagine potential uses for the DR filters in their daily lives, and most participants could envision applications for the technology, I did not observe how they would use such technology had it been available to them in their daily activities. The experiments thus only identify short-term impressions of the DR filters and do not investigate how users would use such a technology in the long term. While such a long-term study is currently unrealistic, once DR technical constraints are lowered, it would be interesting to see the long-term effects of DR usage.

Considering the opposite effects of distractions on distinct cognitive tasks, one could also explore using increasing levels of cognitive load on both perceptual and working-memory tasks to check the effect of the screen filters.

Finally, the pool of participants could have included a larger audience, potentially leading to more solid results for the TLX questions. Furthermore, the participants were not generally familiar with VR technology in both experiments. While this is a good reflection of a more general population, it would be interesting to see if those familiar with VR and AR perceive these interactions differently. From my findings, I could also see a trend where the filters are impactful for some participants but not as much for others, but this distinction was not enough to generate a bi-modal outcome. While I tried to account for potential confounding variables, including participants' screen usage habits, it could be the case that other aspects I did not account for, such as personality traits, drastically change how susceptible a person is to being distracted by screens. Therefore, a psychometric type of evaluation where one considers looking at a single individual at a time could be an interesting approach to uncover more information about the potential susceptibility to screen distractions.

7.3 Future Work

Based on the topics I discussed in the study limitations, two potential directions for future work come to mind. One idea would be to implement the DR screen filters in a real AR system to see how that would impact user distraction. Another idea would be to focus on applying DR for real-world tasks and during a long period to identify DR's long-term effects on the participants' daily lives.

In this work, I asked participants about potential scenarios where they would use DR screen filters in their routines. This identified multiple scenarios that pose exciting directions for potential future work. Mainly, using DR to block advertisements could also lead to an intriguing study to evaluate how such a technology would impact consumers' buying habits. Furthermore, the idea of using DR to improve mental health by blocking sensitive situations is an emerging topic that could lead to fascinating discoveries.

While the current state of AR hardware is not yet entirely suitable for real-life implementation of DR screen filters due to lack of contrast, unreliable screen detection, and other technical issues, future work could explore potential user interactions with the DR filters in AR systems. In my VR-based implementation, I could easily guarantee 100% reliable detection of the screens and block them reliably. However, it would be interesting to see how these filters would work in a scenario closer to an actual AR-based implementation, allowing participants to block any region of (non-)interest with a blocking mechanism of their choice.

7.4 Final Words

This research constitutes another step toward better understanding how users perceive DR technologies, identifying the potential for DR in users' daily lives, and how it can reduce their perceived distraction in conversations. As the barriers for AR devices and applications keep getting lower, technological advancements will undoubtedly increase the adoption of DR applications, and we must study the possible impacts these technologies will have before they become widely available for general audiences.

Once such XR technologies are seamlessly integrated into our regular lives, many enhancements to people's lives seem possible by superimposing virtual information over the real world. However, in today's digital age, there is an overwhelming presentation of information, and DR as a technology focused on *reducing* those staggering amounts of content presentation can provide a much-needed solution. Further, innovative DR technologies should consider not only the user's productivity but also their mental health, well-being, and cognitive load. Ultimately, I hope my research contributes to a future where emerging technologies are not only pursued with the idea of going faster and further but are also designed with human welfare in mind.

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Appendix A

Study 1 Survey

Consent form

Who is conducting this study?
Principal Investigator:
Student Lead:

Who is funding this study?
The research is currently unfunded.

Why are we doing this study?
Screens are a prevalent distraction in many shared spaces such as offices, restaurants, and coffee shops. A potential solution to reduce the impact of such distractions is diminished reality filters, which alter the appearance or completely block real-world content in an Augmented Reality system. To understand and evaluate the use of such diminished reality filters, we simulate these filters within a Virtual Reality system and investigate how you perceive such diminished reality techniques, while you perform a puzzle task in different conditions. The results of this study will help us better understand how to design more comfortable and effective diminished reality experiences.

Your participation is voluntary.
You have the right to refuse to participate in this study. You should not feel pressured to participate due to an existing relationship with research team members, if applicable. If you decide to participate, you may still choose to withdraw from the study at any time without negative consequences to the education, employment, or other services to which you are entitled or are presently receiving.

How is the study done?
This is a one-time study, which will take approximately one hour of your time. If you decide to take part in this research study, here are the tests and procedures we will do: Before we start the experiment there is a quick pre-assessment questionnaire followed by a 6 minutes spatial abilities test. In the first part of the study, you will experience different diminished reality techniques for screen filters (e.g., blocking, replacing) in a virtual environment and evaluate them based on usefulness and comfort. You will be asked to rate each filter on a numerical scale and to provide feedback. In the second part of the study, you will complete puzzle tasks in virtual reality under varying conditions. We will measure task speed and success and after each task, you will be asked to fill out a short questionnaire. In the end, we will conduct a short interview about your experience.

Is there any way that being in this study could be bad for you?
There are no foreseeable risks for the participants, except for potential minor discomfort (e.g., eye strain, dizziness) associated with current commercial VR technologies.

What are the benefits of participating?
There are no foreseeable major benefits for the participants, except for experiencing novel user experiences with diminished reality technologies.

Will you be paid for your time/ taking part in this research study?
You will receive $15 for your participation in this research study, even if you chose to withdraw partway.

Measures to maintain confidentiality
You will not be required to provide your name or any other identifying information beyond the recruitment process. All other data, including questionnaires and interaction recordings, will use only anonymized identifiers, such as “Participant 1”/“participant1.log”, and will contain only de-identified information.

Data Security
All data will be kept as electronic files in a secure location, accessible only to the student lead and the principal investigator. Collected data or recordings will only be shared in aggregate form with collaborators and will not be shared with others outside of Dr. Stuerzlinger's lab. Files will be destroyed after publication, typically within two (2) years after completion of the study.

Future Use of Participant Data
No other uses of the collected data are foreseen

Withdrawal from the Study
If you wish you can ask to withdraw from the study and have their data removed at any time during the experiment. As we are keeping only de-identified data, it is infeasible to withdraw at a later time.

Study Results
The results of this study will be reported in a graduate thesis and also be made public through publication in a scientific conference, journal, or book chapter. Such publications will also be available through the lab webpage. Participants will never be identified by name in such publications of the results.

Questions About the Study
If you have any questions about the study or how you were treated, please contact the principal investigator.

Complaints or Concerns About the Study
If you have any concerns about your rights as a research participant and/or your experiences while participating in this study, please contact the Director, SFU Office of Research Ethics, at.

Participant Consent
Taking part in this study is entirely up to you. You have the right to refuse to participate in this study. If you decide to take part and later change your mind, you can withdraw from the study at any time without giving a reason and without any negative impact on your grades, or employment, or any services to which you are presently entitled to receive.

By agreeing to this form consent form, I acknowledge that understand the procedures, potential risks, and benefits of this research study and agree to participate. I have received an adequate opportunity to consider the information on this document and I voluntarily agree to participate. By consenting, I have not waived any rights to legal recourse in the event of research-related harm. I understand that I may register complaints with the Office of Research Ethics.

1. Please take your time to read the consent form and check the boxes bellow

- [ ] I consent to have my audio recorded
- [ ] I consent to have the experiment screen recorded

* 2. Do you wish to continue with the experiment?

- [ ] Yes – I have read and understood this Consent Form and agree to participate in the study.

Understanding Diminish Reality Effects for Screen Filtering

Thank you for agreeing to take part in our study!

Screens are a prevalent distraction in many shared spaces such as offices, restaurants, and coffee shops. A potential solution to reduce the impact of such distractions is diminished reality filters, which alter the appearance or completely block real-world content in an Augmented Reality system. To understand and evaluate the use of such diminished reality filters, we simulate these filters within a Virtual Reality system and investigate how you perceive such diminished reality techniques, while you perform a puzzle task in different conditions. The results of this study will help us better understand how to design more comfortable and effective diminished reality experiences.

This is a one-time study, which will take approximately one hour of your time. Here are the tests and procedures we will do: Before we start the experiment there is a quick pre-assessment questionnaire followed by a 6 minutes spatial abilities test. In the first part of the study, you will experience different diminished reality techniques for screen filters (e.g., blocking, replacing) in a virtual environment and evaluate them based on usefulness and comfort. You will be asked to rate each filter on a numerical scale and to provide feedback. In the second part of the study, you will complete puzzle tasks in virtual reality under varying conditions. We will measure task speed and success and after each task, you will be asked to fill out a short questionnaire. In the end, we will conduct a short interview about your experience.

* 1. **[For Researcher]** Participant ID

* 2. **[For Researcher]** Condition order

Pre-Assessment questionnaire

* 1. How old are you?

- ◯ Under 18
- ◯ 18-24
- ◯ 25-29
- ◯ 30-34
- ◯ 35-39
- ◯ 40-44
- ◯ 45-49
- ◯ 50+

* 2. Which gender do you identify as?

- ◯ Male
- ◯ Female
- ◯ Prefer not to say
- ◯ Other (please specify)

* 3. What is the highest degree or level of education you have completed?

- ◯ High School
- ◯ Post-Secondary Diploma/Certificate
- ◯ Bachelor's Degree
- ◯ Master's Degree
- ◯ Ph.D. or Higher
- ◯ Prefer not to say

* 4. How often do you play video games?

- ◯ Every day
- ◯ A few times a week
- ◯ About once a week
- ◯ A few times a month
- ◯ Once a month
- ◯ Less than once a month
- ◯ I never played video games before

* 5. How often do you use 3D software (e.g.: Blender, Maya, Auto CAD)?

- ◯ Every day
- ◯ A few times a week
- ◯ About once a week
- ◯ A few times a month
- ◯ Once a month
- ◯ Less than once a month
- ◯ I never used a 3D software before

* 6. How often have you experienced VR content?

- ◯ Every day
- ◯ A few times a week
- ◯ About once a week
- ◯ A few times a month
- ◯ Once a month
- ◯ Less than once a month
- ◯ I never experienced VR content before

7. How comfortable are you with TV playing while you do other tasks?

- ◯ Very Comfortable
- ◯ Comfortable
- ◯ Neutral
- ◯ Uncomfortable
- ◯ Very Uncomfortable

Paper-Folding Test Scoring

Please use the provided printed paper and fill the answers in this online formulary

* 1. Select the correct choice

- ◯ A
- ◯ B
- ◯ C
- ◯ D
- ◯ E
- ◯ No Answer

* 2. Select the correct choice

- ◯ A
- ◯ B
- ◯ C
- ◯ D
- ◯ E
- ◯ No Answer

* 3. Select the correct choice

- ◯ A
- ◯ B
- ◯ C
- ◯ D
- ◯ E
- ◯ No Answer

* 4. Select the correct choice

- ◯ A
- ◯ B
- ◯ C
- ◯ D
- ◯ E
- ◯ No Answer

* 5. Select the correct choice

- A
- B
- C
- D
- E
- No Answer

* 6. Select the correct choice

- A
- B
- C
- D
- E
- No Answer

* 7. Select the correct choice

- A
- B
- C
- D
- E
- No Answer

* 8. Select the correct choice

- A
- B
- C
- D
- E
- No Answer

* 9. Select the correct choice

- A
- B
- C
- D
- E
- No Answer

* 10. Select the correct choice

- A
- B
- C
- D
- E
- No Answer

* 11. Select the correct choice

- A
- B
- C
- D
- E
- No Answer

* 12. Select the correct choice

- A
- B
- C
- D
- E
- No Answer

* 13. Select the correct choice

- A
- B
- C
- D
- E
- No Answer

* 14. Select the correct choice

- A
- B
- C
- D
- E
- No Answer

* 15. Select the correct choice

- A
- B
- C
- D
- E
- No Answer

* 16. Select the correct choice

- A
- B
- C
- D
- E
- No Answer

* 17. Select the correct choice

- A
- B
- C
- D
- E
- No Answer

* 18. Select the correct choice

- A
- B
- C
- D
- E
- No Answer

* 19. Select the correct choice

- A
- B
- C
- D
- E
- No Answer

* 20. Select the correct choice

- A
- B
- C
- D
- E
- No Answer

Diminished Reality Filter Experience

* 1. Which technique did you prefer to filter the screen content (sort from top to bottom)?

- Block
- Dim (semi-transparent block)
- Wallpaper replacement
- Video replacement
- Freeze (Block with current image)

* 2. Please explain the reason for your most preferred choice in the last question:

* 3. Think about how useful such a technique would be if you wanted to block screen content. Please rate the **usefulness** of each technique

	1 - Not very useful	2	3	4	5 - Very useful
Block	○	○	○	○	○
Dim	○	○	○	○	○
Wallpaper replacement	○	○	○	○	○
Video replacement	○	○	○	○	○
Freeze	○	○	○	○	○

* 4. Think about how comfortable you would be using this technique for a long period of time. Please rate the **comfort** of each technique

	1 - Not very comfortable	2	3	4	5 - Very comfortable
Block	○	○	○	○	○
Dim	○	○	○	○	○
Wallpaper replacement	○	○	○	○	○
Video replacement	○	○	○	○	○
Freeze	○	○	○	○	○

Task Load Index - First condition

* 1. **[For Researcher]** condition:

* 2. How mentally demanding was the task?

1 - Very easy	2	3	4	5	6	7 - Very demanding
○	○	○	○	○	○	○

* 3. How physically demanding was the task?

1- Very easy	2	3	4	5	6	7 - Very demanding
○	○	○	○	○	○	○

* 4. How successful were you in accomplishing what you were asked to do?

1 - Failed	2	3	4	5	6	7 - Very successful
○	○	○	○	○	○	○

* 5. How hard did you have to work to accomplish your level of performance?

1 - Very easy	2	3	4	5	6	7 - Very hard
○	○	○	○	○	○	○

* 6. How insecure, discouraged, irritated, stressed, and annoyed were you?

1- Very low	2	3	4	5	6	7 - Very high
○	○	○	○	○	○	○

Task Load Index - Second condition

* 1. **[For Researcher]** condition:

* 2. How mentally demanding was the task?

1 - Very easy	2	3	4	5	6	7 - Very demanding
○	○	○	○	○	○	○

* 3. How physically demanding was the task?

1 - Very easy	2	3	4	5	6	7 - Very demanding
○	○	○	○	○	○	○

* 4. How successful were you in accomplishing what you were asked to do?

1 - Failed	2	3	4	5	6	7 - Very successful
○	○	○	○	○	○	○

* 5. How hard did you have to work to accomplish your level of performance?

1 - Very easy	2	3	4	5	6	7 - Very hard
○	○	○	○	○	○	○

* 6. How insecure, discouraged, irritated, stressed, and annoyed were you?

1 - Very low	2	3	4	5	6	7 - Very high
○	○	○	○	○	○	○

Task Load Index - Third condition

* 1. **[For Researcher]** condition:

* 2. How mentally demanding was the task?

1 - Very easy	2	3	4	5	6	7 - Very demanding
○	○	○	○	○	○	○

* 3. How physically demanding was the task?

1 - Very easy	2	3	4	5	6	7 - Very demanding
○	○	○	○	○	○	○

* 4. How successful were you in accomplishing what you were asked to do?

1 - Failed	2	3	4	5	6	7 - Very successful
○	○	○	○	○	○	○

* 5. How hard did you have to work to accomplish your level of performance?

1 - Very easy	2	3	4	5	6	7 - Very hard
○	○	○	○	○	○	○

* 6. How insecure, discouraged, irritated, stressed, and annoyed were you?

1 - Very low	2	3	4	5	6	7 - Very high
○	○	○	○	○	○	○

Appendix B

Study 2 Survey

Consent form

Who is conducting this study?
Principal Investigator:
Student Lead:

Who is funding this study?
The research is currently unfunded.

Why are we doing this study?
Screens are a prevalent distraction in many shared spaces such as offices, restaurants, and coffee shops. A potential solution to reduce the impact of such distractions is diminished reality filters, which alter the appearance or completely block real-world content in an Augmented Reality system. To understand and evaluate the use of such diminished reality filters, we simulate these filters within a Virtual Reality system and investigate how you perceive such diminished reality techniques, while you perform a task in different conditions. The results of this study will help us better understand how to design more comfortable and effective diminished reality experiences.

Your participation is voluntary.
You have the right to refuse to participate in this study. You should not feel pressured to participate due to an existing relationship with research team members, if applicable. If you decide to participate, you may still choose to withdraw from the study at any time without negative consequences to the education, employment, or other services to which you are entitled or are presently receiving.

How is the study done?
This is a one-time study, which will take approximately one hour of your time. If you decide to take part in this research study, here are the tests and procedures we will do: Before we start the experiment there is a quick pre-assessment questionnaire. In the first part of the study, you will complete tasks to match a colour appearance with its name or vice versa in virtual reality under varying conditions. We will measure task speed and success and after each task, you will be asked to fill out a short questionnaire. In the second part of the study, you will participate in a conversation by answering some questions under the same conditions. In the end, we will conduct a short interview about your experience.

Is there any way that being in this study could be bad for you?
There are no foreseeable risks for the participants, except for potential minor discomfort (e.g., eye strain, dizziness) associated with current commercial VR technologies.

What are the benefits of participating?
There are no foreseeable major benefits for the participants, except for experiencing novel user experiences with diminished reality technologies.

Will you be paid for your time/ taking part in this research study?
You will receive $15 for your participation in this research study, even if you chose to withdraw partway.

Measures to maintain confidentiality
You will not be required to provide your name or any other identifying information beyond the recruitment process. All other data, including questionnaires and interaction recordings, will use only anonymized identifiers, such as “Participant 1”/“participant1.log”, and will contain only de-identified information.

Data Security
All data will be kept as electronic files in a secure location, accessible only to the student lead and the principal investigator. Collected data or recordings will only be shared in aggregate form with collaborators and will not be shared with others outside of Dr. Stuerzlinger's lab. Files will be destroyed after publication, typically within two (2) years after completion of the study.

Future Use of Participant Data
No other uses of the collected data are foreseen

Withdrawal from the Study
If you wish you can ask to withdraw from the study and have their data removed at any time during the experiment. As we are keeping only de-identified data, it is infeasible to withdraw at a later time.

Study Results
The results of this study will be reported in a graduate thesis and also be made public through publication in a scientific conference, journal, or book chapter. Such publications will also be available through the lab webpage. Participants will never be identified by name in such publications of the results.

Questions About the Study
If you have any questions about the study or how you were treated, please contact the principal investigator.

Complaints or Concerns About the Study
If you have any concerns about your rights as a research participant and/or your experiences while participating in this study, please contact the Director, SFU Office of Research Ethics, at.

Participant Consent
Taking part in this study is entirely up to you. You have the right to refuse to participate in this study. If you decide to take part and later change your mind, you can withdraw from the study at any time without giving a reason and without any negative impact on your grades, or employment, or any services to which you are presently entitled to receive.

By agreeing to this form consent form, I acknowledge that understand the procedures, potential risks, and benefits of this research study and agree to participate. I have received an adequate opportunity to consider the information on this document and I voluntarily agree to participate. By consenting, I have not waived any rights to legal recourse in the event of research-related harm. I understand that I may register complaints with the Office of Research Ethics.

1. Please take your time to read the consent form and check the boxes bellow

- ☐ I consent to have my audio recorded
- ☐ I consent to have the experiment screen recorded

* 2. Do you wish to continue with the experiment?

- ☐ Yes – I have read and understood this Consent Form and agree to participate in the study.

* 3. Do you have normal or corrected-to-normal vision?

- ○ Yes
- ○ No

* 4. Do you have a colour vision deficiency?

- ○ Yes
- ○ No

Understanding Diminish Reality Effects for Screen Filtering

Thank you for agreeing to take part in our study!

* 1. **[For Researcher]** Participant ID

* 2. **[For Researcher]** Condition order

Pre-Assessment questionnaire

* 1. How old are you?

- ◯ Under 18
- ◯ 18-24
- ◯ 25-29
- ◯ 30-34
- ◯ 35-39
- ◯ 40-44
- ◯ 45-49
- ◯ 50+

* 2. Which gender do you identify as?

- ◯ Male
- ◯ Female
- ◯ Prefer not to say
- ◯ Other (please specify)

* 3. What is the highest degree or level of education you have completed?

- ◯ High School
- ◯ Post-Secondary Diploma/Certificate
- ◯ Bachelor's Degree
- ◯ Master's Degree
- ◯ Ph.D. or Higher
- ◯ Prefer not to say

* 4. How often do you play video games?

- ◯ Every day
- ◯ A few times a week
- ◯ About once a week
- ◯ A few times a month
- ◯ Once a month
- ◯ Less than once a month
- ◯ I never played video games before

* 5. How often have you experienced VR?

- Every day
- A few times a week
- About once a week
- A few times a month
- Once a month
- Less than once a month
- I never experienced VR content before

6. How comfortable are you with a TV playing while you do other tasks?

- Very Comfortable
- Comfortable
- Neutral
- Uncomfortable
- Very Uncomfortable

Task Load Index - First condition

* 1. **[For Researcher]** condition:

- ◯ With TV
- ◯ With Filters

* 2. How mentally demanding was the task?

1 - Very easy	2	3	4	5	6	7 - Very demanding
◯	◯	◯	◯	◯	◯	◯

* 3. How physically demanding was the task?

1- Very easy	2	3	4	5	6	7 - Very demanding
◯	◯	◯	◯	◯	◯	◯

* 4. How successful were you in accomplishing what you were asked to do?

1 - Failed	2	3	4	5	6	7 - Very successful
◯	◯	◯	◯	◯	◯	◯

* 5. How hard did you have to work to accomplish your level of performance?

1 - Very easy	2	3	4	5	6	7 - Very hard
◯	◯	◯	◯	◯	◯	◯

* 6. How insecure, discouraged, irritated, stressed, and annoyed were you?

1- Very low	2	3	4	5	6	7 - Very high
◯	◯	◯	◯	◯	◯	◯

* 7. How focused were you when performing the task?

1- Very distracted	2	3	4	5	6	7 - Very focused
◯	◯	◯	◯	◯	◯	◯

* 8. How do you rate your performance on the task?

1- Very slow	2	3	4	5	6	7 - Very fast
◯	◯	◯	◯	◯	◯	◯

9. Where there any moments where you find it difficult to concentrate? If so when?

10. Did you feel any external factors distracted you during the task?

Task Load Index - Second condition

* 1. **[For Researcher]** condition:

- ◯ With TV
- ◯ With Filters

* 2. How mentally demanding was the task?

1 - Very easy	2	3	4	5	6	7 - Very demanding
◯	◯	◯	◯	◯	◯	◯

* 3. How physically demanding was the task?

1 - Very easy	2	3	4	5	6	7 - Very demanding
◯	◯	◯	◯	◯	◯	◯

* 4. How successful were you in accomplishing what you were asked to do?

1 - Failed	2	3	4	5	6	7 - Very successful
◯	◯	◯	◯	◯	◯	◯

* 5. How hard did you have to work to accomplish your level of performance?

1 - Very easy	2	3	4	5	6	7 - Very hard
◯	◯	◯	◯	◯	◯	◯

* 6. How insecure, discouraged, irritated, stressed, and annoyed were you?

1 - Very low	2	3	4	5	6	7 - Very high
◯	◯	◯	◯	◯	◯	◯

* 7. How focused were you when performing the task?

1- Very distracted	2	3	4	5	6	7 - Very focused
◯	◯	◯	◯	◯	◯	◯

* 8. How do you rate your performance on the task?

1- Very slow	2	3	4	5	6	7 - Very fast
◯	◯	◯	◯	◯	◯	◯

9. Where there any moments where you find it difficult to concentrate? If so when?

10. Did you feel any external factors distracted you during the task?

Conversation Exercise - First condition

* 1. **[For Researcher]** condition:

- ◯ With TV
- ◯ With Filters

* 2. The conversation was natural

1 - Strongly Disagree	2	3	4	5	6	7 - Strongly Agree
◯	◯	◯	◯	◯	◯	◯

* 3. The questions were representative of a normal conversation

1 - Strongly Disagree	2	3	4	5	6	7 - Strongly Agree
◯	◯	◯	◯	◯	◯	◯

* 4. How distracted were you during the conversation?

1 - Very focused	2	3	4	5	6	7 - Very Distracted
◯	◯	◯	◯	◯	◯	◯

Conversation Exercise - Second condition

* 1. **[For Researcher]** condition:

- With TV
- With Filters

* 2. The conversation was natural

1 - Strongly Disagree	2	3	4	5	6	7 - Strongly Agree

* 3. The questions were representative of a normal conversation

1 - Strongly Disagree	2	3	4	5	6	7 - Strongly Agree

* 4. How distracted were you during the conversation?

1 - Very focused	2	3	4	5	6	7 - Very Distracted

Appendix C

Study 2 Conversation Questions

1. What's your favorite type of music, and do you have a favorite song?
2. What's a hobby you enjoy doing on weekends?
3. Describe a trip you've taken.
4. Share a story about a memorable gift you've received.
5. What place would you love to visit for a vacation?
6. What's a movie you can watch over and over again?
7. Do you have any pets? If not, what kind of pet would you like to have?
8. If you could travel anywhere in the world right now, where would you go?
9. What's your favorite food and why?
10. Do you enjoy watching sports, and if so, which is your favorite?
11. What's your go-to dessert when you have a sweet tooth?
12. If you could have any superpower, what would it be and why?
13. What's your favorite season of the year, and what do you like about it?
14. What's your preferred way to spend a lazy Sunday afternoon?
15. Do you have a favorite type of movie genre, like comedy or action?
16. If you could be any fictional character for a day, who would you choose?
17. What's your all-time favorite book, and why do you love it?
18. If you could have a meal with any celebrity, who would it be?
19. What's your favorite holiday, and how do you celebrate it?
20. If you could meet any historical figure, who would you want to meet?

21. What's a hobby or activity that instantly cheers you up?
22. Are you a morning person or a night owl?
23. What's your favorite thing about the place you currently live?
24. If you could learn any new skill in an instant, what would it be?
25. What's your preferred way to relax after a long day?
26. If you could have any animal as a pet, what would you choose?
27. What's your favorite way to exercise or stay active?
28. If you could visit any fictional world from a book or movie, where would you go?
29. If you could time travel for a day, which time would you visit?
30. What's your favorite outdoor activity, like hiking or biking?
31. What's the most interesting place you've ever visited?
32. Do you enjoy gardening or have any favorite plants?
33. If you could attend any historical event, which one would you choose?
34. If you could live in a different time, when would you choose?
35. What's your preferred mode of transportation?
36. What's your favorite board game or card game?
37. If you could have any job for a day, what would you like to try?
38. What's your favorite type of weather, like sunny or rainy days?
39. If you could explore any natural wonder, like a waterfall or canyon, where would you go?
40. What's your favorite way to spend a summer day?
41. If you could visit any famous landmark, which would you choose?
42. What's your favorite way to unwind and de-stress?
43. What hobbies do you enjoy, and how did you get started?
44. If you could have a meal from any cuisine right now, what would it be?
45. What's your favorite type of candy or sweet treat?