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# Towards Developing an Immersive Virtual Reality Applications for Supporting Vision Screening – A User Study

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***Abstract:*** *Functional Vision Problems (FVPs) are problems related to eye musculature and/or eye coordination rather than visual acuity. Such problems are rarely diagonsed through standard vision control, and can get worse with age if not properly treated. However, a thorough vision screening of many requires enormous resources from society, which is not possible today. This paper illustrates current challenges to screen functional vision problems (FVPs) using immersive VR applications. For this, a laptop-based program for screening oculomotor difficulties (OMDs), which is a particular type of FVP, is transferred to a head-mounted display (HMD) with integrated eye-tracking technology (ET). The program records the participants' small eye movements via ETs, e.g., fixation stability, saccades, and smooth pursuits during task performance, and allows examining irregularities pointing to OMDs. The paper illustrates the iterative development of the immersive VR program based on continuous feedback from a vision expert. Data was collected from a vision expert and 7 end-users. The results include user experience and usability evaluation of the immersive VR program compared to the laptop version. It discusses the necessity for having vision expertise during specific faces of the development process and presents critical issues for further development of applications utilizing eye movements for more accurate support for vision screening, e.g., issues regarding measuring depth perception and hand-eye coordination.*

***Keywords:*** *Head mounted display (HMD); Virtual Reality (VR); Eye-tracking (ET); User Experience Questionnaire (UEQ); Functional Vision Problem (FVP); Oculomotor difficulty (OMD);*

 

## 1. Introduction

Vision problems can severely impact a person's daily life, and often degrade eyesight over time. This makes it hard for the affected party to notice something is wrong themselves, and we should attempt to provide mechanisms for obtaining screening services to those with limited access to specialized aid (Preslan, 1996). Standardized screening of vision is performed on children at age 4-5 in most European countries (Wallace, 118), however, FVPs can often be missed during these screenings (Willhelmsen, 2015) (Ali, 2020) (Heldal, 2021). As FVPs can lead to diseases such as amblyopia and strabismus, it is imperative that we provide a thorough screening of FVPs during standardized screening procedures (see e.g., (Lazarus, 2021)). Contemporary research shows that technologies such as VR and ET can have great effects for the detection and rehabilitation of vision problems (Nowak, 2018) (Backus, 2020) (Mishra, 2020).

A functional vision screening is performed to determine if the users' eyes are coordinated correctly. This is time-consuming and resource-intensive (Beauchamp, 2010). There are promises from technologies to support screening from accessible technologies with possibilities to measure eye coordination (Wallace, 2018) (Ali, 2021).

A previous study developed a computer-supported program (C&Look) for screening functional vision to determine such vision problems by registering fixation stability, saccades, and smooth pursuits (Wilhelmsen, 2015) (Wallace, 2018). This application was designed to complement manual vision screening by experts (Eide, 2019). The C&Look program needs a laptop computer and an eye-tracker (ET), and indicates possible oculomotor problems, a coordination problem between the two eyes. Its records movements from both eyes separately when the user is performing structural tasks on a computer screen. The objects (stimuli) may move with saccadic or smooth movements in a horizontal, vertical, or diagonal direction. By recording the gaze points following the stimuli on the screen, the eye gaze and coordination between the left and the right eye can be measured. Since many functional vision problems can be improved by training, a follow-up study developed programs including games supporting training to correct the problems (Heldal, 2021).

This study investigates how an ET-based immersive VR software can complement the current vision screening battery in relation to a computerized method and its current challenges. The first step towards this ambition is transferring the C&Look application (Eide, 2019) to immersive VR. Such an application would better support detection of functional vision problems which is a highly special problem, with many promises from added values from virtual reality and considering cognitive aspects (Wijkmark, 2021).

## 2. Related literature

The laptop screening and training program (C&Look) faces challenges regarding the limited computer screen sizes where the stimuli can be represented, or regarding head movements during examination, and understanding how the gaze works for perceiving depth. This prohibits measuring important eye movements which can be approximated with manual screening, e.g., convergence or peripheral vision (Eide, 2019). If one could measure these aspects and address these challenges, vision screening could be achieved easier and could produce more evidence, i.e. measurements to illustrate problems and improvements.

Utilizing VR to better understand vision is challenging for several research teams (Bennett, 2019) (Lambooij, 2009) (Grassini, 2021). Such cases indicate a disconnect between researchers and vision experts, where cooperation with specialists from the domain of vision science could help direct research and development. By utilizing expert opinions from both fields, related research can achieve higher confidence in their results and measurments.

The primary goal of Human-Computer Interfaces (HCI) is to provide interfaces that enable efficient communication between computers and their users. Brain-computer interfaces (BCIs) are able to provide a kind of alternative communication channel between the human brain and some device that is intended to be used, controlled or controlled. Among other things, BCI interfaces can contribute to the investigation of human attention (Katona, 2014), memorization and indirectly the process of human learning, thereby serving as a kind of support and predictive system to increase the efficiency of human learning. (Katona & Kovari, 2018a, 2018b) In addition to BCI, the information processing process can also be examined using ETs, and even complex cognitive processes such as programming can be analyzed. More and more complex program systems result in more and more complex source codes, where possible error correction, maintenance and further development present challenges to developers, and may even mean the end of the application. For this reason, programmers use more and more new technologies, but the efficiency of development could be further increased if they could objectively examine which techniques can be used with less cognitive load for individuals, and even more so for development groups. From the eye movement parameters, it can be concluded that, for example, in which cases the use of the Language-Integrated-Query (LINQ) query syntax (Katona, et al., 2020, Katona, 2021b) means a lower mental load, as well as what algorithm description tools the developers can use easier to interpret (Katona, 2022), and the quality of the source code (Katona, 2021a) and its readability can also be objectively measured.

In relation to the importance of considering cognitive issues in VR for training and examination, cognitive aspects of recognition, learning, decision making and problem solving are adequately supported (Heldal, 2004). Literature within the field of visual perception can help possible VR screening programs take advantage of these unique benefits, and an interdisciplinary approach during development has the possibility to improve this aspect further (Wallace, 2018).

While VR has seen growing interest in multiple fields of research, its usage within the domain of vision therapy remains limited. Bibliometric analysis by Ali et al. (Ali, 2022a) shows that VR has seen increased attention within research, for example by utilizing games, see Ali et al (Ali, 2022b), although publications related to vision therapy and screening remain limited compared to other fields.

## 3. Study design

### *3.1. Methodology*

The design science research paradigm was used for the project, combined with a testing battery for data collection proposed by Heldal (Heldal, 2004). This includes a cyclical development strategy, where the application is revised based on results and feedback from evaluation with a domain expert regarding issues important for problem solving (task performance), the utilized social context (influences from the place and people involved), and technical issues (challenges from the applied technologies). By constructing an early prototype VR vision screening applicating and testing it on a vision expert, future development was influced through direct feedback collected via interviews. This led to changes to the user interfance, an implementation of a task replay system, and less focus on attempting to measure attention in VR. New development instead focused on utilizing peripheral vision, depth, and the added sense of presence in VR, as suggested by the vision expert.

A usability and user experience test was then performed on the revised application to determine how it compares to other available products on the market. This final evaluation test also focused on comparing the new VR solution to the original laptop version of C&Look. Data collection methods used during this test were open-ended questions, interviews, observations, User Experience Questionnaires (UEQs), and we asked some questions focusing on the users' presence during the VR experience. A total of 7 participants took part in the test, with each participant performing the same predefined screening tasks in each application. These participants were of varying ages, between 14 to 35, with different technological backgrounds and genders.

### *3.2. Technology Description*

To transfer C&Look into an immersive VR application using eye behavioural data, and to investigate how to complement manual vision screening and C&Look, the prospects and limitations of using a head-mounted display (HMD) are analysed. The HMD used is a Varjo VR2-Pro, as it is one of the leading VR headsets with embedded ET together with hand controls (see Fig. 1).

Fig 1. The used Varjo HMD.

The sampling rate of integrated ET in the Varjo HMD is 100Hz. Varjo also allows investigating hand and eye coordination, and problems with how the eye is functioning is highly correlated with other functions, e.g. balance or hearing (Ali, 2021).

The 2-dimensional version of C&Look provides high-quality data when testing for oculomotor problems (OMD) but lacks the possibility of capturing important tasks performed during special performance that is included in manual vision screenings. The laptop used for testing the original version of C&Look had a screen size of 14 inches and utilized a Tobii 4C mobile eye-tracker with a sampling rate of 90Hz.

## 4. Application Overview

The foundation for implementing C&Look in VR is designed to be easy to use, similar to the computer application, and include possibilities to add new tasks to it. These applications point to several problems of understanding measurements in space for using VR in general, depending on where the user is looking, where they are in space and how they comprehend objects (Lambooij, 2009) (Grassini, 2021) as well as problems related to understanding depth (Wijkmark, 2021). A current shortcoming of the computer C&Look application is the functionality to approximate eye movements for depth perception. While this seems like a suitable task for VR since one can measure gaze, target position and depth, the problem lies in the accuracy of the ET integrated in the HMD. Therefore, the first step was to plan a screen into the VR environment. The program requires a scalable solution. Since the recording of eye-movement data is standardized, this makes the process of storing data easy. However, even for this step, the collection of eye-tracking data for the current technology can be inconsistent. While with closer targets, the errors are smaller, but the possible measurements may not measure accurately enough for increased distances needed to experience various depth. The measures of depth at the current stage are not reliable. Small changes to the actual gaze vector get significantly larger when objects are further away. The small errors from the eye tracker turn into data not close enough to the desired target. Inconsistency in the eye-tracker also leads to loss of data for some frames, reducing the reliability of data visualization even further.

A similar issue was discovered when attempting to measure hand-eye coordination using the hand-tracking technology of the Varjo VR2-Pro. While satisfactory on big hand movements and suitable for navigating menus, precise hand positioning and collision detection for this hand-tracking technology is inconsistent. This leads to unreliable data when attempting to measure small movements.

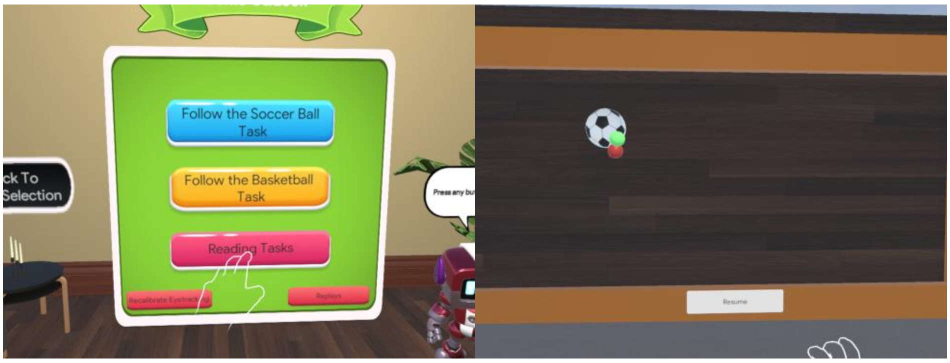


Fig. 2. A screenshot from the virtual reality C&Look with gaze points enabled.

Fig 2 contains two screenshots taken while the application is running and recording eye tracking data for the person using the application (see Fig. 1). The first screenshot is from the main menu where the user can select which task to perform. The second screenshot is from a replay of a task following a soccer ball where gaze points are being displayed. The red ball is a visual representation of the gaze point of the left eye, and the green ball is the gaze point of the right eye.

 

## 5. Results

After collecting data from the participants during the final test, UEQ answers for both the laptop and VR version were analysed using the UEQ benchmark proposed by Schrepp et al. (Schrepp, 2017). This resulted in scores in 6 categories ranging from -3 to 3. These scores led to classifications of either bad, below average, above average, good or excellent for each category. Fig 3 shows the scores for each category, while Table 1 depicts their final rankings.

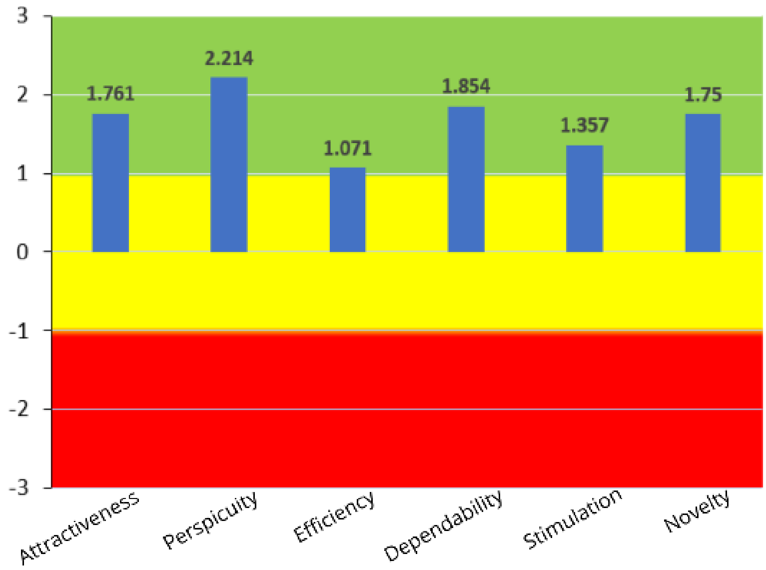


Fig 3. UEQ Scores from C&Look in VR

Table 1. UEQ classification from C&Look in VR

| Category | Attractiveness | Perspicuity | Efficiency | Dependability | Stimulation | Novelty |
|---|---|---|---|---|---|---|
| Value<br>Classification | 1.761<br>Excellent | 2.214<br>Excellent | 1.071<br>Below Average | 1.854<br>Excellent | 1.375<br>Above Average | 1.75<br>Excellent |

These results show that efficiency and stimulation are current weakness in the VR application which needs to be addressed, as their classification results in below and above average. Compared to the scores produced by the laptop application, these areas are the only ones to receive a lower classification. This indicates a need for better optimization of the application, as well as the addition of more interactive features to increase stimulation. These points were echoed in interviews, observations, and other data collection methods used during the evaluation.

 

To evaluate the users' experiences in the VR application, we collected data about their experiences in the two environments using the application on the laptop and the VR technologies. These questionnaires ask each participant to rate elements of the application on a scale from 1 to 7, where 7 feels very similar to being examined professionally, and 1 the opposite. Figure 4 shows average scores of experienced presence related to the users' overall experiences, engagement, involvement, the focus of attention, their experiencing time, and how they related the experiences in the application compared to real memories when they had eye screening. The VR version scores higher in almost every single category, indicating the added feeling of presence. "Compared to real memories" is the only exception, as those who had already been examined before founding the low confidence in results and lower quality replay function distracting.

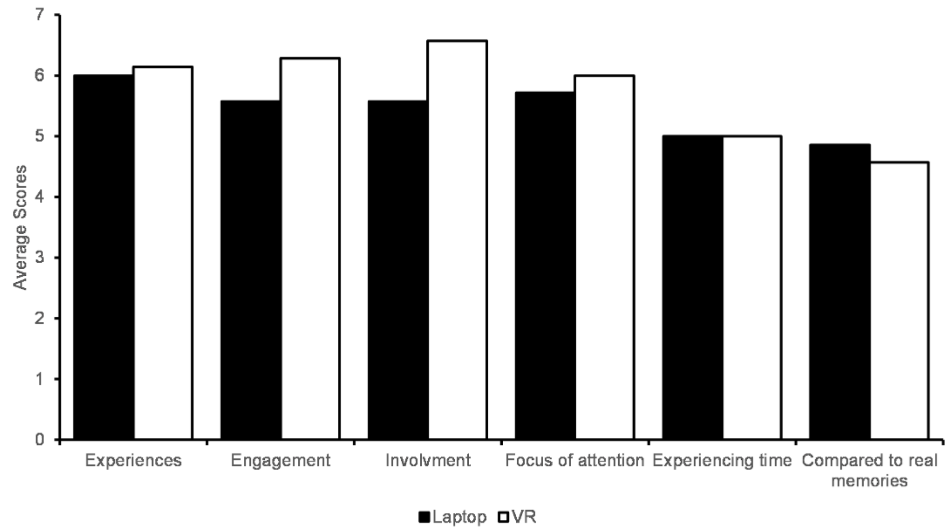


Fig 4. Average scores of presence from C&Look on a laptop and in VR.

## 6. Discussion and Limitations

The main goal of this project was to examine the possibilities of using immersive VR to assist a vision screening in detecting functional vision problems. This is done by developing a vision screening suite for VR and comparing it to a previously developed and utilized laptop solution developed for the same purpose.

Today, measuring small eye movements combining HMD and ET via applications meets several hinders for measuring exact distances in space, especially eye-movements for identifying depth, but also understanding peripheral vision. It is not a direct correlation between the capability of HMD and eye-tracking and understanding the space through the eyes. Therefore, as a first step, we implemented C&Look in immersive VR, allowing it to work on a visualized plan-screen in the HMD and perform the eye measurements only based on that screen. Experimental development of depth perception and hand-eye coordination testing was also performed during this projecter, however, these solutions proved unreliable and difficult to implement due to low quality ET and hand-tracking data. Depth perception testing has been proven to be compatible with VR by VividVision (Backus, 2020) but would require a larger development team and more time.

Interdisciplinary cooperation with a vision expert proved effective when choosing a direction for future development after the initial prototype. This communication was lost in later stages of the project. For the future this should be prioritized to a greater extent, having the possibility to lead to exact demands for quality and confidence of measurements. When data quality is poor, other possible avenues for screening in VR could be proposed by someone with a background in vision science.

Several limitations were discovered during this study. Firstly, the eye-tracking hardware of the Varjo VR-2 Pro lacks the ability to provide accurate positions of gaze points while returning no missing data. This gives less confidence to the results produced by the application. Secondly, the current database transaction methods in the application rely on a separate server and custom API. This was the result of a lack of Unity SDKs compatible with PostgreSQL, resulting in significant technical debt if the current solution is to be developed further. Thirdly, access to only one HMD for testing led to a smaller participant pool than suggested by Schrepp et al. (Schrepp, 2017). Testing of each participant lasted between 1-2 hours and a larger pool of participants would necessitate being able to test multiple subjects at the same time. The final limitation comes from the lack of available resources and prior research related to the Varjo VR2-Pro HMD. Very few publications and online resources related to this HMD exists, making development for this environment time-consuming and difficult when utilizing features such as eye-tracking and gaze point visualization.

## 7. Conclusion

This study presents a prototype version of a VR application that, if developed further, can help assess functional vision problems. Results from user experience and usability testing show that the current version suffers from a low score in efficiency, while performing well in most other categories. These efficiency problems, as well as other limitations, are closely related to the used HMD, so utilizing a more researched and reliable HMD should be prioritized for the future. Test participants report an added sense of presence in VR, highlighting the unique immersive elements provided by HMDs. Experimental development for accurate depth perception and hand-eye coordination measurements highlight the need for high precision data concerning both gaze and hand positioning. More communication with researchers from the vision science domain have the ability to identify such problems early, while also being able to propose alternative directions when data quality suffers. The current prototype lays the foundation for developing a VR application that can help vision experts diagnose functional vision problems in a real-world screening.

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