Development of Immersive Virtual Reality Environment for Assessment of Functional Vision in people with Low Vision: A Pilot Study

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ABSTRACT

Introduction: Virtual Reality technology helps in creating virtual environments for evaluation of visual performance of low vision individuals with holistic experience. The purpose of this study was to develop a virtual reality (VR) platform for the objective assessment of functional vision in patients with low vision in two categories, central and peripheral vision loss .

Materials and methods: Focus group discussions (FGD) were organized to understand the difficulties faced on a Day-to-day basis by patients with low vision. Based on the results of the focus group discussions, a virtual bank scenario incorporating specific visual tasks was developed. A pilot study was conducted which involved people with normal vision; low vision Patients secondary to central field loss (CFL) and peripheral field loss (PFL). Each subject completed all the tasks in the objective assessment; the data obtained from the assessment were further analyzed to understand the pattern.

Results: Comparing the three groups, there was a significant difference in distance (central field loss was lowest) and near visual angle, and three visual search tasks (peripheral field loss was lowest). In assessing the time taken, peripheral field loss group was again found to take the most time to complete tasks.

Conclusion: Based on a newly developed virtual reality platform, assessment of functional vision of specially abled persons could be tested and was inferior to that of normal sighted persons in a close to realistic environment. Multiple visual tasks were performed in the virtual environment and the visual performance was compared among all three groups of participants. Participants were matched for age and gender. Irrespective of the nature of tasks, visual performance of the normal group seemed significantly better than people with CFL and PFL.

Key words: Activities of daily living, Functional vision, Low vision, Virtual reality, Visual impairment.

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INTRODUCTION

There is a growing global burden in rehabilitating patients with low vision to live an independent and normal life (Pascolini et al, 2012). New and promising advanced technologies are rapidly evolving to help Patients with low vision to carry out their activities of daily living (Chader et al, 2009 et al). Virtual reality (VR) technology offers the potential to develop a human performance testing environment that is practical and can produce applications to assess patients at a level of realism unattainable by other techniques (Gourlay et al, 2000; Lee et al, 2003).

Clinical measures of functional vision facilitate the monitoring of disease severity but they offer less insight on the actual impact of the disease on the patient's quality of life and how they perceive the world (Lepri et al, 2009; Glen et al, 2011). Decreased functional vision leads to avoidance of activities that once seemed important to the patient and also leads to reduced confidence (Glen et al, 2011). Visual search is required for most of the activities on a day to day basis, impaired visual search might lead to failure to locate objects against a particular background and there is evidence that the performance in search tasks is reduced in individuals with visual loss (Smith et al, 2011, 2012; Taylor et al, 2017). Validated questionnaires report the patient's visual function, quality of life and measures visual functioning in various domains. Though these questionnaires have been very well validated to access visual function, they are inherently subjective (Massof et al, 2001). There are studies involving 'performance-based measures' as direct assessment of a person's ability to perform activities such as reading, mobility tasks, driving, searching for objects, and face recognition, using standardized conditions as an objective approach of assessment (Lovie-Kitchen et al,1990; Pardhan et al, 2011; Chung et al, 2016; Daga et al, 2017). More insight is needed to observe the patient's performance and difficulties faced in everyday tasks, under more real- world conditions for future successful rehabilitation.

VR environments have enabled researchers to conduct experiments in a simulated real-world, which may elicit responses from the patients similar to those in real situations (Gourlay et al, 2000; Lee et al, 2003; Klinger et al, 2013). There is a lack of studies on holistic assessment of functional vision in individuals with low vision in a VR environment. Therefore, in this study, we developed a virtual environment to assess the functional performance abilities of people with low vision disability and compared them to persons with normal sighted vision.

MATERIALS AND METHODS

The study was conducted at a tertiary eye care hospital in the year 2018, in adherence to the tenets of the Declaration of Helsinki, and was approved by the Institutional review board and ethics committee of the institution. All the individuals recruited for the study gave informed consent to participate in this study. This was a mixed method study.

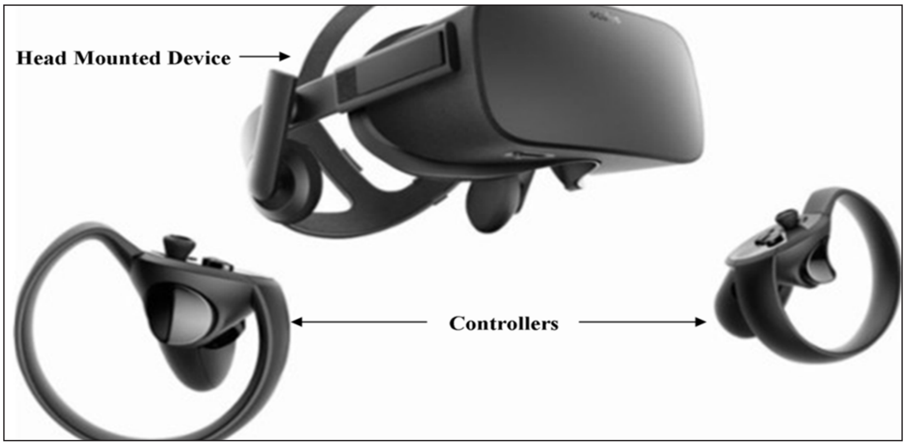
Focus- Group Discussion (FGD) to identify the tasks for the VR platform

In order to identify the problems faced by patients specific to central and peripheral vision loss keeping in mind their age as well, a FGD was conducted to gain better insight. Patients over 18 years of age with peripheral field loss (PFL) and central field loss (CFL), best-corrected visual acuity ranging from 6/6-6/60 and with no physical disabilities were included for the FGD. Patients were identified from the hospital database who had visited low vision clinics in the past. Patients were called over the phone and invited to participate in the discussion in person at a fixed date and time.

The FGD was facilitated by co-investigators who had previous experience in conducting such discussions. The FGD was open-ended and patients were invited to talk about the day-to-day activities throughout the day and explain any specific difficulty they faced. Some questions were asked to keep the discussion flowing but most of the discussion was patient driven. Data obtained from this discussion provided an in-depth insight in the problems faced by the Patients and this enabled the development of various tasks in a virtual environment.

Hardware/Software and the virtual environment

The Oculus Rift CV1 with Oculus Touch controllers, resolution of 2,160 x 1,200, with 90Hz refresh rate and head tracking and positional tracking (Figure 1) was the hardware used in this study. The Organic light-emitting diode (OLED) display was used in our study. The PC specifications for this study were: Processor: Intel i5-4590/AMD Ryz221 en 5 1500X, RAM: 16 GB, Graphics: NVIDIA GTX 1080 and OS: Windows. Tools like Maya (Autodesk.inc, Mill Valley, California, Version 2017) and Blender (Blender Foundation, Netherlands version 2.77) were used to design and animate 3D models.



Virtual Reality Head Mounted Display with controllers

Figure 1: Virtual Reality hardware.

Texturing was done using Adobe Photoshop (Adobe Systems, San Jose, California Version CC 2015) and Substance painter (Clermont-Ferrand, France, Version 2017.3). Unity game engine (Unity Technologies, San Francisco, 2017.2) was used for development. All programming logics were implemented in C#, a high end PC was used to provide realistic rendering that makes the experience immersive for patients.

The real-world bank setup was developed by analyzing the blueprint of existing banks and was made to look warm and uniformly lit. Algorithms were written to create artwork and 3D assets which were then put together to create a simulation and other algorithms were written to analyze, interpret and record the data into a report. The data obtained from the FGD, review of literature and opinion from low vision professionals helped in developing the virtual scenarios and the tasks relevant to both PFL and CFL (Table 1).

Table 1: Visual tasks involved in a Virtual Reality environment.

Sn	Scenario	Task	Visual parameters	Control levels
1	Outdoor Scenario	Read the signboard on the door	Distance Contrast	5%, 10%, 25%, 50%, 75% and 100%
2	Indoor Scenario	Read the text on the bank slip	Near Contrast	25%, 50%, 75% and 100%
3	Indoor Scenario	Report the preferred contrast of the font on the bank slip	Preferred contrast	Normal (Black text on white background) or reverse contrast (White text on black background)
4	Indoor Scenario	Read the details on the bank slip	Near visual angle	Varying font size
5	Indoor Scenario	Locate the Token Display	Visual Search	No control level
6	Indoor Scenario	Read the token number on the display	Distance visual angle	Varying font size
7	Indoor Scenario	Identify the fallen token	Visual Search	No control level
8	Indoor Scenario	Walk towards respective counter and avoid bumping into people	Hit rate	No control level
9	Indoor Scenario	Hand over the bank slip to bank authority	Spatial orientation	No control level
10	Indoor Scenario	Locate the exit door	Visual Search	No control level

The font sizes for distance tasks were equivalent to the measurement of the optotype sizes in the Bailey Lovie High Contrast Acuity chart and font size for near reading tasks were equivalent to the MN READ chart (Bailey, 2013). The readability of the text was improvised by choosing the right color and contrast value of the foreground and background. Contrast levels for distance tasks ranged from 5%, 10%, 25%, 50%, 75%, 100% and for near tasks 25%, 50%, 75% and 100%. Sound being an important factor for people to have an immersive experience, real bank environment sounds were incorporated.

Distance contrast: A signboard on the entrance door was placed 10 feet away from them. The examiner using external controls increased the contrast level (from 5%, 10%, 25%, 50%, 75% and 100%) and the level at which the participant read the signboard “ENTER HERE”. was recorded as the contrast.

Near Contrast: Two bank slips were placed 40cm away from them. The examiner using external controls increased the contrast level (from 25%, 50%, 75% and 100%) and the level at which the participant read “DEPOSIT” and “WITHDRAWAL” was recorded as the contrast.

Preferred Contrast: Two “WITHDRAWAL” bank slips were placed 40 cm away from them. The participants were given a preference to choose between normal contrast (black font against a white background) and reverse contrast (white font against the black background). Insert Figure 2b.

Visual Search: Participants had to locate objects like table lamps, furniture, token display board, entrance door, exit door, and token slip around. They were free to make head movements, body movements and move closer to objects and also were given time to look around and locate the objects. Participant responses were noted.

Mobility (Hit Rate): Participants had to avoid bumping into people approaching from the opposite direction while walking to the deposit counter. Number of people bumped into was recorded as the hit rate

Distance Visual Angle: The token display board was placed at 3 meters from the examiner using external control increased the font size until the participant could identify the token number on the display board which was recorded

Near Visual Angle:

A withdrawal bank slip was placed 40cm away from the participant. The examiner using external control increased the font size until the participant could read the details on the bank slip. The participant was allowed to move closer to the object to make reading easier and the smallest letter identified was recorded. The distance at which the participant completed the task was documented.

Spatial Orientation:

The participant had to place the bank slip in the center of the bank authority’s hand; failure to do so was recorded as an error.

a-Practice test, b-Distance contrast, c– Near contrast, d-Preferred contrast, e-Near visual angle, f-Distance visual angle, g-h Visual search, i-j; Hit rate, k-Error rate, l-Visual search

Figure 2: Snapshot of the tasks to be performed in the Virtual environment

Time:

Each task was being timed from the commencement of the task to the time the task was completed. Total time taken for completion of each task was noted in seconds.

The pilot study included five participants in each of the groups; 1) control group, people with normal visual acuity, 2) CFL and 3) PFL conditions that underwent a detailed ophthalmic evaluation. Patients could adapt to the virtual environment during a practice session before the test began. An audio input provided instructions regarding the task to be performed. Patients were asked to complete the tasks wearing habitual refractive correction. An excel sheet with all the matrices mentioned above was generated for each subject at the end of the assessment. (Gopalakrishnan, 2020)

Statistical Analysis

Descriptive statistics included median and Interquartile range (IQR) of the variables. Normality assumption was assessed using the Shapiro-Wilk test. Mann-Whitney test was used for group comparison of continuous non-normally distributed variables of two groups and Kruskal Wallis test was used for more than two groups. All statistical analyses were performed using the statistical package for the social sciences (SPSS) software version 20. The α (alpha) level was set at 0.05.

RESULTS

Since this was a pilot study, there were 15 patients altogether. There were 5 normal patients, CFL had 5, PFL had 5 patients. Of the ten patients with low vision, 4 patients had Retinitis pigmentosa, 1 had optic neuritis contributing to PFL group, 1 had cone dystrophy, 1 with rod cone dystrophy, 1 with foveal thinning and 2 with oculocutaneous albinism (CFL group) contributing to the reduced vision. All these patients had good general health and were given training for activities of daily living from a low vision care clinic. There was no statistical significance in the age at the reporting time across the groups. Of these 10 patients only 1 was female.

Based on the FGD, the difficulties faced by the Patients with CFL and PFL were listed out. The common problems faced were elicited and the factors that affect the performance of activities were tabulated. The themes for developing VR environments were decided based on the commonly cited problems mentioned in methods (Table 1).

Table 2 shows demographic and clinical characteristics of included patients.

The median distance visual angle was worse for CFL group (0.83) than for PFL group (0.66) and the median near visual angle was worse for PFL group (1.80) than CFL group (1.26).

Table 2: Demographic and clinical characteristics of the study groups.

Variables	Normal Median (IQR) n=5	CFL † Median (IQR) n=5	PFL‡ Median (IQR) n=5	p
Distance Contrast (%)	25 (10-25)	25 (25-50)	50 (25-50)	0.191
Near Contrast (%)	25 (25-25)	50 (50-75)	50 (50-75)	0.005
Distance Visual Angle (deg)	0.32 (0.31-0.40)	0.83 (00.69-0.83)	0.66 (0.40-0.87)	0.021
Near Visual angle (deg)	0.71 (0.57-0.92)	1.26 (0.96-1.28))	1.80 (1.18-2.87)	0.034
Preferred contrast normal contrast(n)	5/5	4/5	5/5	0.253
Hit rate	4(4-4)	(5-7)	5(4-5)	
Visual search 1 (time taken)	0.09 (0.000069-0.00019)	0.19 (0.00014-0.0010)	1.06 (0.00053-0.00102)	0.039
Visual search 2	0.22 (0.00014-0.00033)	0.45 (0.00033-0.00057)	1.23 (0.00076-0.0010)	0.008
Visual search 3	0.14 (0.00010-0.0004)	0.14 (0.00014-0.00030)	0.32 (0.00022-0.00057)	0.005

* IQR: Interquartile range, †CFL: central field loss, ‡PFL: Peripheral field loss,

Kruskal-Wallis test showed that there was statistically significant difference ($P<0.05$) in near contrast ($\chi^2=10.44$, P = 0.005), distance visual angle ($\chi^2=7.76$, P = 0.021) and near visual angle ($\chi^2=6.74$, P = 0.034) between all three groups. Though there was significant difference between normal and low vision group in case of near contrast ($P<0.01$), distance visual angle

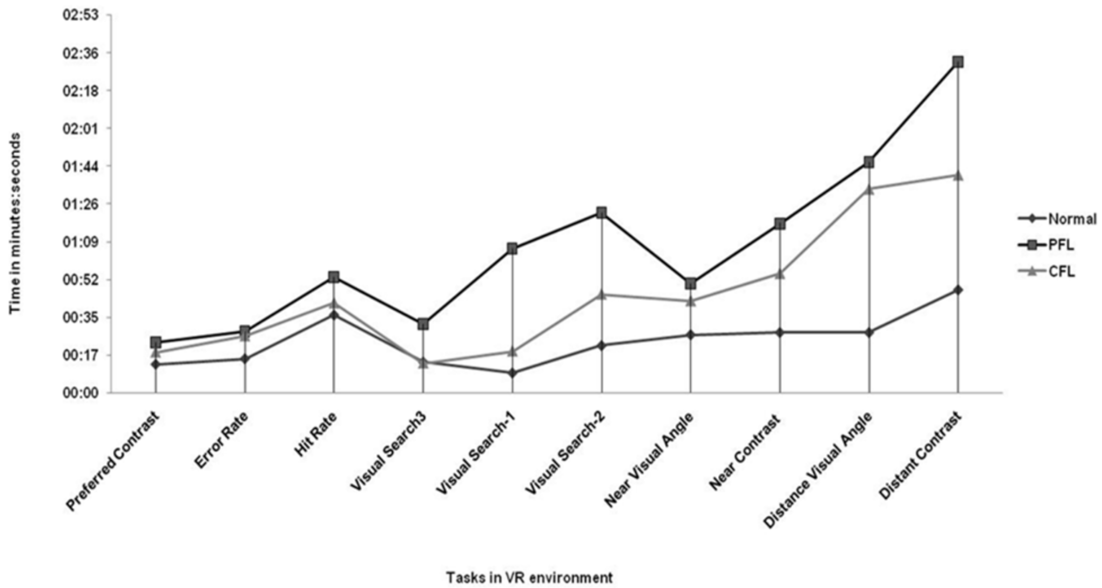


Figure 3: Time taken for various tasks in a VR environment.

(P<0.01) and near visual angle (P=0.01), there was no difference in case of distance contrast (P=0.07). Mann Whitney test showed that there was no significant difference between CFL and PFL (P>0.05) for all the variables.

Figure 3 shows the time taken for performance of tasks; the normal group had taken minimum time (4:43 min) to perform the tasks in the VR environment when compared to other groups. However, irrespective of the nature of tasks, the time taken by Patients with PFL (11:32 min) was longer than patients with CFL (8:42 min) to complete the tasks. All of the patients in the normal and CFL group preferred normal contrast, however two patients in the PFL group preferred reverse contrast.

Although patients with normal vision had a smaller number of hit rates, there was no statistically significant difference among all three groups.

DISCUSSION

We report the development of a VR platform to assess and understand the barriers faced by low vision Patients in performing activities of daily living. It also measured various visual parameters incorporated within the tasks such as distance contrast, near contrast, preferred mode of contrast, distance visual angle, near visual angle, hit rate, error rate and visual search behavior and also estimated the time taken for performing each of these tasks. The low vision patients were found to perform significantly worse than normal group. Depending upon the nature of the task, the performance of Patients with CFL and PFL varied. The performance of distance contrast did not vary among all three groups which may be due to the familiarity curve or because that was the first task and only task performed in an outdoor environment with different illumination settings in the VR environment.

The advantage of VR includes an objective way of assessment; a safe environment, complete control over content and personalized performance analysis for every subject over time to ensure if the subject has made any progress. The strength of this study includes assessing and understanding the barriers in the performance of activities of daily living in Patients with low vision in a relevant, real-world scenario. This form of assessment gives the clinician a better understanding of how the Patients performed the task, if they used any adaptive strategies to cope with the difficulties caused due to their condition and is useful for further planning of rehabilitation services which may prove to be beneficial in future.

The FGD revealed detailed difficulties of Patients with CFL and PFL while performing a task. The examiners encouraged the stakeholders to explain their intricacies involved in handling daily activities. As expected, the CFL group hypothesized that their most common difficulty was face recognition, searching for objects in a crowded environment and the PFL group reported on mobility issues. The FGDs helped in understanding the visual discomforts and demands of Patients in an organized way. The themes derived from FGDs lead to the decision of visual tasks to be developed in the VR environment.

In the pilot data, the age and gender of the Patients were almost matched to understand the effect of ocular conditions on the performance of Patients in the VR environment.

Angle of visual field

Lovie-Kitchen et al (1990) found that the smaller the solid angle of visual field subtended at the eye the poorer the performance on a navigation task for Patients with peripheral field loss, which is well correlated with the current study wherein the distance visual angle was smaller in case of PFL group. Though there was significant difference between normal and low vision group while performing certain visual tasks, there was no significant difference between CFL and PFL tasks which might be due to the nature of pilot study. Study with more Patients in all three groups will elicit better understanding of the nature of ocular deficit.

Peripheral field

The peripheral vision helps provide information about the global structure of the environment such that when an object appears in the periphery, eye and head movements can bring it to the fovea for further processing and localization (Chung et al, 2016). Loss of peripheral vision may hinder the ability to perform effective visual search and navigation tasks (Diniz-Filho et al, 2015). In the current study, participants with low vision took longer time in completing the tasks when compared to normal Patients, despite the fact that few used their habitual adaptive strategies to perform tasks. A similar observation was seen in a study conducted by Lam et al (2020) and suggested that VR simulation may enable the translation of clinical assessment results into relevant real-world performance measures which can help monitor vision-related disability. This VR tool can be used to monitor the visual performance of people with deteriorating ocular disease causing low vision. As a future scope of this study, the VR tool would be used to understand the visual abilities of patients before and after a laser procedure or injection or surgeries.

However, this study represents the need for developing more VR scenarios to understand the visual demands of people with low vision. Further research with more Patients is required to analyze factors such as types of visual impairment, duration of immersion, etc., and can be used for visual rehabilitation in the near future. This kind of VR tool can be recommended for assessing visual performance of people with low vision and can be compared with the assessments in the real-life clinical scenario.

Our study has its own limitation, although we have tried to design the VR assessment testing platform as close to the real-world as possible, it still can't attain the real-world realism due to factors like pixelation, resolution, and surface texture modulations. The eye movements could not be tracked and visual field could not be assessed. Since the study was a pilot study the number of patients in each group was small. Additionally, only patients affected with central and peripheral vision problems were included in the Focus group study and tailored the construction of the VR accordingly. Its extension to other low vision patients has not been explored.

CONCLUSION

VR simulating environments are a promising tool for evaluating the functional ability of people with low vision.

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