Original Article

Use of augmented reality technology for improving visual acuity of individuals with low vision

Sarika Gopalakrishnan[1,2], Sanjana Chouhan Suwalal[3], Gnanapoonkodi Bhaskaran[3], Rajiv Raman[4]

Purpose: The objective of this study was to analyze the visual acuity improvement in patients with low vision using augmented reality device who presented to the low vision care (LVC) clinic at a tertiary eye care center. **Methods:** A prospective study of 100 patients with low vision who were referred to the LVC clinic between July and December 2018 was done. Demographic data and visual acuity improvement assessed using augmented reality (AR) technology paired with Samsung Gear headset were documented. **Results:** Out of 100 patients, 74 were male and 26 were female. The median age of the overall patients was 36 (25.5) years. In 100 patients, 21% patients were found to have central field loss (CFL), 35% patients have peripheral field loss (PFL), and 44% patients were found to have overall blurred vision (OBV). Majority of the subjects with CFL (47%) and OBV (37%) has a moderate visual impairment and in PFL group (26%), severe visual impairment was more. Cone dystrophy (9%) was found to be the major cause of CFL group, retinitis pigmentosa (22%) in the case of PFL group, and optic atrophy (10%) in the case of OBV group. The median distance visual acuity 0.9 log MAR improved to 0.2 log MAR ($P < 0.0001$) and median near visual acuity 0.4 log MAR improved to 0.1 log MAR with a P value of < 0.0001 using AR device. **Conclusion:** The use of an AR device can help patients with low vision to improve their residual vision for better visual performance.

Key words: Augmented reality, central field loss, Low vision care, overall blurred vision, peripheral field loss, Samsung Gear

Globally, there are about 285 million people who are visually impaired, in which 39 million people are blind and 246 million people have low vision. In India, there are about 63 million people who are visually impaired, in which 8 million people are blind and 55 million people have low vision.[1] Low vision is the disability which is caused due to ocular conditions such as refractive errors, cataract, glaucoma, diabetic retinopathy, retinal detachment, macular degeneration, retinitis pigmentosa, albinism, retinopathy of prematurity, and Stargardt's disease.[2,3] This leads to visual field defects such as peripheral field loss (tunnel vision), central field loss, and overall blurred vision.

In people with low vision, various visual functions will be affected; they might have difficulty in face recognition, reading, doing their day-to-day activities, education, work, and social life. Patients with low vision are referred to low vision care clinic and are examined thoroughly and suggested to use low vision devices (LVD) according to the need for the patients. But, these low vision devices have some limitations such as fixed levels of magnification, decreased field of view, narrow depth of field, heavy, and closer working distance. Inability to track the complete word due to restricted field of view and

higher magnification of the available low vision devices were also found to be difficulties.[4-9]

Although the conventional LVD has been very useful for patients with visual impairment, the newer technology like VR and AR have recently been adapted as LVD. One such technology is augmented reality (AR), which is a live direct view of a physical, real-world environment whose elements are augmented by computer-generated sensory input such as sound, video, and graphic data.[10,11] The three basic characteristics of AR are an overlay of the real and digital world, real-time interaction, and registration along with alignment in 3D.[12] The working principle of AR is that real-world image is captured with the input devices like camera and it will be sent to the processor for creating an augmented content. Then, the content will be sent to the AR browser which later displays the image on the screen such as head-mounted display or smartphone screen. It is used in data and architectural visualization, modeling, designing, training, education, and entertainment. In the medical field, it is used in surgeries, pain management, and psychological disease therapy.[13,14] Studies related to the application of AR for vision improvement are very limited.

[1]Department of Bio-Chemistry, Shanmugha Arts, Science, Technology and Research Academy (SASTRA) University, Thanjavur, [2]Optometrist, Low Vision Care Clinic, Sankara Nethralaya, [3]Medical Research Foundation, [4]Shri Bhagwan Mahavir Vitreoretinal Services, Sankara Nethralaya, Chennai, Tamil Nadu, India

Correspondence to: Dr. Rajiv Raman, Shri Bhagwan Mahavir Vitreoretinal Services, 18 College Road, Sankara Nethralaya, Chennai - 600 006, Tamil Nadu, India. E-mail: rajivpgraman@gmail.com

Therefore, the aim of the study is to analyze the visual acuity improvement in patients with low vision using an augmented reality device.

Methods

A prospective study of 100 patients with low vision who were recruited from July 2018 to December 2018 from the Low Vision Care Clinic in a tertiary eye care Institute was done. The patients with low vision underwent a comprehensive low vision workup. The distance visual acuity was measured using the Bailey Lovie Log MAR chart and the near visual acuity was measured using the MN read acuity chart. The visual improvement was assessed with the best-corrected lenses using low vision devices and Samsung Gear VR. Data included the demographic data, best-corrected distance and near visual acuity, type of low vision device prescribed and visual improvement with it, and the visual acuity improvement with the AR. Patients with subnormal intelligence, claustrophobia, and Parkinson's disease were excluded. The low vision assessment and AR assessment were conducted by experienced optometrists. The study was approved by the Institutional review board and ethics committee and adhered to the tenets of the Declaration of Helsinki.

A person with low vision is the one who has impairment of visual functioning even after treatment and/or standard refractive correction and has a visual acuity of less than 6/18 to light perception, or a visual field less than 10° from the point of fixation, but who uses, or is potentially able to use, vision for the planning and/or execution of a task.[15]

Low vision was defined in the study based on recommendations by the World Health Organization relating to visual acuity of the better eye with the best possible correction: Category 0: Mild VI with visual acuity better than 6/18, Category 1: Moderate VI with worse than 6/18–6/60, Category 2: Severe VI with worse than 6/60–3/60, Categories 3 and 4: Profound VI with worse than 3/60 to perception of light, and Category 5: Blindness with no perception of light.[15]

The Samsung Gear VR® headset used in this study is a commercially-available, head-mounted audio-visual VR display developed by Samsung Electronics and Oculus. This portable and lightweight device pairs with a Samsung Galaxy Note® smartphone to provide a wireless audio-visual VR experience while an audio headset enabled sound. The dimension and weight of the Samsung Gear device are 207.1 × 120.7 × 98.6 mm and 345 g, respectively. It has a field of view 101° and interpupillary distance of 62 mm, which is fixed. It uses gyro and proximity sensor. The paired smartphone had been installed with an application in it to help the people with low vision.

Distance optical devices were used to magnify objects up to 3 m or more, whereas near optical devices were used to magnify printed materials and near objects.

Single or multiple optical devices of the following kinds were used to improve the visual acuity of patients with low vision: See TV Binocular telescopes, half-eye spectacles, hand-held magnifiers, stand magnifier, dome magnifier, and pocket magnifiers. Additional illumination was suggested in most cases for comfortable reading. Other devices given include portable video magnifier, Notex, and Clip-on filters.

The patients were given a trial of single or combination of low vision optical and nonoptical devices depending on their presenting visual acuity, and the maximum improvement in the visual acuity was noted.[16-18] The details of them are explained in the table.

Relumino is an Oculus VR mobile application that was developed by Samsung Electronics, which works together with Samsung Gear VR. The application processes the images from videos projected through the rear camera of a smartphone and makes the images visually impaired friendly. The main features of this are a variable magnification of the images, highlighting the outline, color contrast and brightness adjustment, reversing color, and screen color filtering. In this study, we are using only the variable magnification of the images.

Statistical analysis included descriptive statistic: percentage, medians according to the normal distribution, and interquartile range as appropriate. Friedman test was used for the comparison of non-normally distributed variables of groups. Wilcoxon sign rank test was used for the comparison of continuous non-normally distributed variables of the same group. All statistical analyses were performed using statistical package for the social sciences (SPSS) software version 20. The α (alpha) level was set at 0.05.

Results

Out of 100 patients, 21% of patients were found to have central field loss, 35% of patients had peripheral field loss, and 44% of patients had overall blurred vision. The median age of the overall patients was 36 years, the median age of CFL group was 31 (22) years, PFL group was 33 (20.5) years, and OBV was 39.5 (31.5) years. In the case of CFL group, 14 (67%) were male and 7 (33%) were female, in PFL group, 27 (77%) were male and 8 (23%) were female, and in OBV group, 33 (75%) were male and the rest were female 11 (25%). There was no significant difference among CFL, PFL, and OBV groups in terms of age and gender ($P > 0.05$). Majority of the patients in CFL group and PFL group were between 18 and 40 years of age 9 (43%) and 18 (51%), respectively, belongs to working age group and in OBV group, majority of the patients were above 40 years of age 21 (48%).

Among CFL, PFL, and OBV groups, the employed were 11 (52%), 17 (49%), and 17 (39%) respectively, the unemployment was little more in the case of CFL (14%) than in PFL (11%) and OBV (7%). There were 27% of students in the OBV group, 19% in CFL, and 14% in PFL. Majority of the subjects with CFL (47%) and OBV (37%) has a moderate visual impairment, followed by severe, mild, and then profound visual impairment. In PFL group, severe visual impairment was (26%), followed by moderate and mild visual impairment. Around 76% of the subjects in CFL, 66% in OBV and 60% in PFL groups reported difficulty in both distance and near vision. Majority of the subjects in CFL (95%), PFL (74%), and OBV (55%) were phakic and 20% in PFL and 34% in OBV groups were pseudophakic. Invariably myopia was more common in all three groups when compared to hyperopia, yet myopic astigmatism was the most common refractive error in both CFL (38%) and PFL (40%) groups, whereas in OBV group, hyperopic astigmatism (36%) was noted as shown in Table 1.

The ocular conditions causing low vision are classified based on their visual field loss as CFL, PFL, and OBV which were

Table 1: Demographic details of patients with low vision

Characteristics	Category	CFL* (21) n (%)	PFL† (35) n (%)	OBV‡ (44) n (%)	Total n
Age	<18 years	4 (19%)	5 (14%)	9 (20%)	18
	18-40 years	9 (43%)	18 (52%)	14 (32%)	41
	>40 years	8 (38%)	12 (34%)	21 (48%)	41
Gender	Male	14 (67%)	27 (77%)	33 (75%)	74
	Female	7 (33%)	8 (23%)	11 (25%)	26
Occupation	Student	4 (19%)	5 (14%)	12 (27%)	21
	Discontinued studies	0 (0%)	1 (3%)	1 (2%)	2
	Unemployed	3 (14%)	4 (12%)	3 (7%)	10
	Employed	11 (52%)	17 (49%)	17 (39%)	45
	Discontinued job	0 (0%)	2 (5%)	2 (5%)	4
	Home maker	2 (10%)	3 (9%)	6 (13%)	11
	Farmer	1 (5%)	2 (5%)	0 (0%)	3
	Retired	0 (0%)	1 (3%)	3 (7%)	4
Visual impairment	Mild	5 (24%)	11 (32%)	12 (27%)	28
	Moderate	10 (47%)	8 (23%)	16 (37%)	34
	Severe	5 (24%)	9 (26%)	14 (32%)	28
	Profound	1 (5%)	5 (14%)	1 (2%)	7
	Near blind	0 (0%)	2 (5%)	1 (2%)	3
	Total blind	0 (0%)	0 (0%)	0 (0%)	0
Task difficulties	Distance	2 (10%)	4 (12%)	10 (23%)	16
	Near	3 (14%)	6 (17%)	5 (11%)	14
	Both	16 (76%)	21 (60%)	29 (66%)	66
Lens status	Phakia	20 (95%)	26 (74%)	24 (55%)	70
	Aphakia	1 (5%)	1 (3%)	4 (9%)	6
	Psuedophakia	0 (0%)	7 (20%)	15 (34%)	22
Refractive error	Myopia	5 (24%)	3 (9%)	6 (13%)	14
	Hyperopia	3 (14%)	2 (5%)	4 (9%)	9
	Myopic astigmatism	8 (38%)	14 (40%)	11 (25%)	33
	Hyperopic astigmatism	4 (19%)	9 (26%)	16 (37%)	29
	Astigmatism	0 (0%)	3 (9%)	6 (14%)	9

*CFL=Central field loss; †PFL=Peripheral field loss; ‡OBV=Overall blurred vision

further categorized into retina-related and optic nerve-related conditions. Of the 21 cases with CFL, myopic macular degeneration (9%) and cone dystrophy (9%) were the major retinal pathology of low vision followed by RPE alteration (3%) and Leber's hereditary optic neuropathy (3%) was optic nerve pathology. Out of 35 PFL cases, Retinitis pigmentosa (22%) was the major cause of low vision followed by glaucoma (10%). In 44 cases of OBV, optic atrophy (10%) was the major cause of low vision followed by retinal detachment (6%), diabetic retinopathy (5%), and others as given in Table 2.

The presenting median distance visual acuity was 0.9 log MAR which improved to 0.8 (0.6) log MAR with LVD and 0.2 (0.3) log MAR using Samsung gear AR device and it was statistically significant with a P value of < 0.0001. The presenting median near visual acuity was 0.4 log MAR, which improved to 0.3 (0) log MAR with LVD and 0.1 (0) with Samsung gear AR with a P value of < 0.0001. There was a statistically significant improvement with both LVD and AR device.

The factors influencing the visual improvement with the Samsung gear device were analyzed. All the three age groups had more than four lines of improvement in distance visual acuity with the AR device and the improvement was statistically significant with a P value of < 0.0001. Though the 18–40 age group had little worse distance visual acuity when compared to the other two groups, yet the improvement with the AR device was significant. Irrespective of the gender, both

male and female had more than five lines of improvement with AR intervention with a P value of < 0.0001. The median presenting distance visual acuity was worse in the case of PFL, followed by overall blurred vision group and comparatively, it was a little better in the case of CFL patients. However, for all three CFL, PFL, and OBV categories, there was a statistically significant improvement in distance visual acuity with a P value of < 0.0001. Not only in mild, moderate, and severe visual impairment categories but also in profound and near-blind categories, there were more than four lines visual acuity improvement with AR device. Although the improvement was comparatively less in the case of profound visual impairment, all the categories had significant improvement with a P value of < 0.05.

Invariably patients with either myopia, hyperopia, or astigmatism had more than six lines of improvement in visual acuity, yet the difference was more significant in the case of myopia and hyperopia (P < 0.0001) when compared to astigmatism (P < 0.05). There was no influence of lens status over the AR device; therefore, patients those who are phakic, aphakic, and pseudophakic had significant visual acuity improvement (P < 0.05) as shown in Table 3. The adjustable brightness in AR device helped even patients with photophobia to improve their distance visual acuity significantly.

For near, all the age groups had more than two lines improvement in near visual acuity and it was statistically

Table 2: Conditions causing low vision

Visual field loss	Classification	Subclassification	n %
Central field loss	Retina Related	Scared Choroidal Neovascularised membrane	2%
		RPE Alteration in Fovea	3%
		Myopic Macular Degeneration	9%
		Cone Dystrophy	9%
		Stargardt's	2%
		BEST Disease	1%
		Retinal Schisis	1%
		ERM	1%
		Foveal Hypoplasia	1%
		CSME	1%
	Optic Nerve Related	Leber's hereditary optic neuropathy	3%
Peripheral field loss	Retina Related	Retinitis pigmentosa	22%
	Optic Nerve Related	Glaucoma	10%
Overall blurred vision	Retina Related	Albinism	2%
		Coloboma	1%
		Retinal Detachment	6%
		Diabetic Retinopathy	5%
		Posterior Staphyloma	1%
	Optic Nerve Related	Papilledema	1%
		Optic Atrophy	10%
		Traumatic Optic Neuropathy	2%
	Others	Microcornea	2%
		Aphakia	1%
		Prephthisical	2%
		Total Corneal Opacity	2%

Table 3: Factors influencing distance visual acuity improvement using augmented reality device

Category	Sub category	Distance visual acuity				
		Presenting visual acuity Median (IQR§)	Best-corrected visual acuity Median (IQR§)	Visual acuity with low vision device Median (IQR§)	Visual acuity with augmented reality device Median (IQR§)	P
Age	<18 years	0.9 (0.4)	0.9 (0.6)	0.7 (0.6)	0.2 (0.3)	0.000
	18-40 years	1 (0.6)	0.9 (0.5)	0.9 (0.5)	0.2 (0.4)	0.000
	>40 years	0.8 (0.6)	0.7 (0.6)	0.7 (0.6)	0.2 (0.3)	0.000
Gender	Male	0.9 (0.5)	0.85 (0.6)	0.8 (0.6)	0.2 (0.3)	0.000
	Female	0.9 (0.5)	0.9 (0.5)	0.9 (0.5)	0.2 (0.1)	0.000
Visual field loss	CFL*	0.8 (0.4)	0.8 (0.3)	0.7 (0.4)	0.2 (0.2)	0.000
	PFL†	1 (0.7)	0.9 (0.8)	0.9 (1.3)	0.2 (0.5)	0.000
	OBV‡	0.9 (0.5)	0.9 (0.6)	0.9 (0.6)	0.2 (0.3)	0.000
Visual impairment	Mild	0.4 (0.3)	0.4 (0.3)	0.3 (0.3)	0 (0)	0.000
	Moderate	0.8 (0.2)	0.8 (0.2)	0.8 (0.3)	0.2 (0.1)	0.000
	Severe	1.1 (0.1)	1.1 (0.1)	1.1 (0.1)	0.2 (0.3)	0.000
	Profound	1.6 (0.2)	1.6 (0.2)	1.6 (0.2)	1.1 (0.3)	0.007
	Near Blind	1.9 (0.6)	1.9 (0.6)	1.9 (0.6)	0.6 (0.7)	0.029
	Total Blind	0	0	0	0	0
Refractive error	Myopia	0.8 (0.5)	0.7 (0.5)	0.7 (0.5)	0 (0.2)	0.000
	Hyperopia	1 (0.4)	1 (0.5)	1 (0.5)	0.2 (0.3)	0.000
	Astigmatism	0.8 (0.8)	0.5 (0.8)	0.5 (0.8)	0.1 (0.2)	0.046
Lens status	Phakia	0.8 (0.5)	0.8 (0.6)	0.8 (0.7)	0.2 (0.3)	0.000
	Aphakia	1.1 (0.1)	1.1 (0.1)	1.1 (0.1)	0.3 (0.7)	0.008
	Pseudophakia	1 (0.5)	0.9 (0.6)	0.9 (0.6)	0.2 (0.2)	0.000
Photophobia	Present	1 (0.7)	1 (0.7)	0.5 (0.7)	0.2 (0.2)	0.019
	Absent	0.9 (0.5)	0.9 (0.6)	0.8 (0.6)	0.2 (0.3)	0.000

*CFL=Central field loss; †PFL=Peripheral field loss; ‡OBV=Overall blurred vision; §IQR=Interquartile range

significant with a *P* value of <0.0001. Irrespective of the gender and the ocular conditions causing low vision, there was three lines of improvement in near visual acuity with AR device. All the visual impairment categories had significant improvement

in near vision with the use of Samsung gear device. Patients with myopia had two lines of improvement and those with hyperopia and astigmatism had four lines of improvement. Similar to distance vision, near-vision also had significant improvement with AR device irrespective of the lens status of the patients as given in Table 4. The list of low vision devices preferred by the patients are mentioned in Table 5.

Discussion

This study highlights the importance of using augmented reality technology in improving the visual ability of patients with low vision. The integrated approach of visual rehabilitation involves assessment of visual needs of the patient, dispensing of appropriate devices as per the needs, visual acuity improvement with the devices, and training of the patient in its use. This study compares the effect of AR among patients with various ocular conditions causing low vision. Although works of the literature have shown the uses of AR in the medical field, studies on the role of AR on patients with low vision are very limited. To the best of our knowledge, this is the first report on the application of augmented reality in enhancing the visual performance of people with central field loss, peripheral field loss, and overall blurred vision.

In this study, though the patients with overall blurred vision were more when compared to peripheral field loss and central field loss, there was no significant difference in terms of age and gender among all the three groups. The age of the patients was categorized into less than 18 years, 18 to 40 years, and above 40 years; the number of patients under 18 to 40 and above 40 years were more in number when compared to the group of less than 18 years. Male preponderance was noted among all three groups which show accessibility of health care is

more among male when compared to female in this population. Nearly, 50% of the people were employed, which signifies their ability to get involved in independent earning skills, yet around 15% were unemployed who can be helped with low vision intervention and training to get a job according to their visual abilities. Many works of the literature have shown that moderate visual impairment was more in low vision studies which are similar to this study in an overall aspect.[19] Among the three categories, moderate visual impairment was more in CFL and OBV, whereas, in the case of PFL, mild visual impairment was more, which shows that patients with PFL will have better distance visual acuity when compared to rest of the groups.

Most of the patients in all three groups had difficulty in the distance and near visual activities, which is similar to the previous studies.[20,21] Myopia was found to be a more common refractive error when compared to a hyperopic error in all the groups, whereas hyperopic astigmatism was little more in OBV group when compared to the rest. The prevalence of refractive error among conditions causing central and peripheral field loss has not been studied in depth so far. In the case of CFL, myopic macular degeneration and cone dystrophy were the most common causes followed by Leber's hereditary optic neuropathy and in PFL group, retinitis pigmentosa was significantly followed by glaucoma. Although there were various conditions causing overall blurred vision, optic atrophy was more common followed by retinal detachment.

The visual acuity improvement was significant in all the categories as shown in Tables 3 and 4. Irrespective of age, gender, ocular conditions, refractive error, and severity of visual impairment, all patients with low vision had visual acuity improvement with the Samsung gear AR device for both distance and near. According to the previous studies, age

Table 4: Factors influencing near visual acuity improvement using augmented reality device

Category	Sub category	Near visual acuity				
		Presenting visual acuity Median (IQR §)	Best-corrected visual acuity Median (IQR§)	Visual acuity with low vision device Median (IQR§)	Visual acuity with augmented reality device Median (IQR §)	P
Age	<18 years	0.4 (0.2)	0.3 (0.1)	0.3 (0)	0.1 (0)	0.000
	18-40 years	0.4 (0.4)	0.3 (0.3)	0.3 (0)	0.1 (0)	0.000
	>40 years	0.4 (0.4)	0.3 (0.2)	0.3 (0)	0.1 (0)	0.000
Gender	Male	0.4 (0.4)	0.3 (0.2)	0.3 (0)	0.1 (0)	0.000
	Female	0.4 (0.4)	0.3 (0.1)	0.3 (0)	0.1 (0)	0.000
Visual field loss	CFL*	0.4 (0.2)	0.3 (0)	0.3 (0)	0.1 (0)	0.000
	PFL†	0.4 (0.5)	0.3 (0.4)	0.3 (0)	0.1 (0)	0.000
	OBV‡	0.4 (0.4)	0.3 (0.2)	0.3 (0)	0.1 (0)	0.000
Visual impairment	None	0.3 (0.1)	0.3 (0)	0.3 (0)	0.1 (0)	0.000
	Mild	0.4 (0.1)	0.4 (0)	0.3 (0)	0.1 (0)	0.000
	Moderate	0.6 (0.3)	0.6 (0.2)	0.3 (0)	0.1 (0)	0.000
	Severe	1 (0.4)	0.9 (0.3)	0.5 (0.4)	0.1 (0)	0.000
Refractive error	Myopia	0.3 (0.2)	0.3 (0.07)	0.3 (0)	0.1 (0)	0.000
	Hyperopia	0.5 (0.4)	0.4 (0.4)	0.3 (0)	0.1 (0)	0.000
	Astigmatism	0.5 (0.3)	0.4 (0.2)	0.3 (0)	0.1 (0)	0.000
Lens status	Phakia	0.4 (0.3)	0.3 (0.1)	0.3 (0)	0.1 (0)	0.000
	Aphakia	0.22 (0.2)	0.3 (0.3)	0 (0)	0.1 (0)	0.001
	Pseudophakia	0.5 (0.4)	0.3 (0.3)	0.3 (0)	0.1 (0)	0.000
Photophobia	Present	0.3 (0.3)	0.3 (0.2)	0.3 (0)	0.1 (0)	0.000
	Absent	0.4 (0.4)	0.3 (0.2)	0.3 (0)	0.1 (0)	0.000

*CFL=Central field loss; †PFL=Peripheral field loss; ‡OBV=Overall blurred vision; §IQR=Interquartile range

Table 5: Preference of low vision devices

Types of LVD*	Details	n (%)
Distance LVD*	SEE TV binocular telescope	1 (1%)
	4× monocular handheld telescope	5 (5%)
Near LVD*	Half eyes spectacle magnifier	21 (21%)
	Aspheric spectacle magnifier	1 (1%)
	Dome magnifier	18 (18%)
	Cutaway stand magnifier	13 (13%)
	Illuminated stand magnifier	2 (2%)
	Pocket magnifier	2 (2%)
	Handheld magnifier	2 (2%)
	Illuminated magnifier	4 (4%)
Assistive devices	Niki CCTV†	10 (10%)
	Senorita CCTV†	3 (3%)

*LVD=Low vision devices; †CCTV=Closed circuit television

was a major factor influencing the choice of low vision device, wherewith increase in age, the magnification required also increased. Our study shows that the variable magnification feature of the AR device eases all the age groups.[22] Various studies have described that patients with low vision get benefited from a single or combination of low vision devices either for near or distance.[23] In this study, the AR device helps for improving the visual performance both for distance and near; this makes it more preferable when compared to other low vision devices. AR technology benefits the low vision patients who have unique functional needs that may not be adequately addressed by existing treatment options. Similar to other studies, our study shows that augmented reality technology offers an advantage over conventional low vision devices.[19,24] Patients expressed that the image seen through the AR device was very clear and they were happy to see the real world much better when compared to be seen through naked eyes or any other low vision device.

Do *et al.* showed that patients who received low-vision devices showed a significant increase in the quality of life than those who did not.[17,25] Robinson *et al.* have studied the use of i-phone and i-pad by patients with visual impairment, yet analysis of visual improvement was not done.[26] From this study, the most commonly used vision accessibility features were large text and zoom magnifier. The previous studies have shown that the awareness of assistive technology among patients with low vision is very less. This may be due to several possible factors, including lack of clinician recommendations, lack of knowledge by the patient, and lack of the knowledge of these features by the doctor.

Kinateder *et al.* found that when participants used augmented vision, their visual performance was higher compared with baseline documentation, which is similar to our study.[27] This study has revealed that both artificially impaired participants and participants with near-complete vision-loss performed tasks that they would not do without the AR system. The AR application was associated with substantially improved accuracy and confidence in object recognition (all *P* <.001) and to a lesser degree in gesture recognition (*P* <.05).

Large sample size and innovative intervention for patients with low vision are the strengths of this study. Further

analysis can be done with other visual parameters tested with the augmented technology. Head-mounted displays with augmented reality technology would be promising in bringing changes in quality of life in patients with visual impairment. Thus, the augmented reality device can be successfully used as a low vision device in a selected group of patients. However, it has certain limitations like difficulty in mobility and affordability. The visual acuity improvement with Samsung gear AR device was incomparable with any other low vision device for distance in this study. However, the application of augmented reality technology while performing daily living activities need to be explored in future studies. Low vision rehabilitation with the latest assistive technology, apart from improving visual function, also has a positive influence on social functioning.

Conclusion

The use of an AR device can help patients with low vision to improve their residual vision for better visual performance.

Conflicts of interest
There are no conflicts of interest.

References

1. Pascolini D, Mariotti SP. Global estimates of visual impairment: 2010. Br J Ophthalmol 2012;96:614-8.
2. Sharma P, Gaur N. How do we tackle a child's spectacle?. Indian J Ophthalmol 2018;66:651-2.
3. Evans K, Law SK, Walt J, Buchholz P, Hansen J. The quality of life impact of peripheral versus central vision loss with a focus on glaucoma versus age-related macular degeneration. Clin Ophthalmol 2009;3:433-45.
4. Copolillo A, Teitelman JL. Acquisition and integration of low vision assistive devices: Understanding the decision-making process of older adults with low vision. Am J Occup Ther 2005;59:305-13.
5. Peli E. Vision multiplexing: An engineering approach to vision rehabilitation device development. Optom Vis Sci 2001;78:304-15.
6. Peli E. Limitations of image enhancement for the visually impaired. Optom Vis Sci 1992;69:15-24.
7. Peli E. Wide-band image enhancement for the visually impaired. Invest Ophthalmol Visual Sci Suppl 1998;39:s398.
8. Peli E. Augmented vision for patients with tunnel vision. Optom Vision Sci 1999;76(Suppl):102.
9. Vargas-martin F, Peli E. Augmented vision for tunnel vision: Device testing by patients in real environments. Dig Tech Pap Plant Cell Environ 2001;32:602-5.
10. McKalin V. Augmented Reality vs. Virtual Reality : What are the differences and similarities?. Tech Times 2015;5:1-6.
11. Yuen SC, Yaoyuneyong G, Johnson E. Augmented reality: An overview and five directions for AR in education. Journal of Educational Technology Development and Exchange (JETDE) 2011;4:119-40.
12. Azuma R, Baillot Y, Behringer R, Feiner S, Julier S, MacIntyre B. Recent advances in augmented reality. IEEE Comput Graph Appl 2001;21:34-47.
13. Mazuryk T, Gervautz M. "Virtual Reality in the real world-History, Applications, Technology, Future," 1996.
14. Castleman KR. Digital Image Processing Prentice-Hall. NJ: Englewood Cliffs; 1979.

15. Dandona L, Dandona R. Revision of visual impairment definitions in the International Statistical Classification of Diseases. Biomed Chromatogr 2006;4:1-7.

16. Cohen JM, Waiss B. Visual field remediation. Remediation and Management of Low Vision. St. Louis: Mosby; 1996. p. 1-25.

17. Renieri G, Pitz S, Pfeiffer N, Beutel ME, Zwerenz R. Changes in quality of life in visually impaired patients after low-vision rehabilitation. Int J Rehabil Res 2013;36:48-55.

18. Faye E. Clinical Low Vision. Boston: Little, Brown; 1976. p. 233-54.

19. Ehrlich JR, Ojeda LV, Wicker D, Day S, Howson A, Lakshminarayanan V, *et al.* Head-mounted display technology for low-vision rehabilitation and vision enhancement. Am J Ophthalmol 2017;176:26-32.

20. Pardhan S, Scarfe A, Bourne R, Timmis M. A comparison of reach-to-grasp and transport-to-place performance in participants with age-related macular degeneration and glaucoma. Invest Ophthalmol Vis Sci 2017;58:1560-9.

21. Gottlieb DD, Allen CH, Eikenberry J, Ingall-Woodruff S, Johnson M. Living with Vision Loss. Atlanta, GA: St. Barthelemy Press; 1996.

22. Das K, Gopalakrishnan S, Dalan D, Velu S, Ratra V, Ratra D. Factors influencing the choice of low-vision devices for visual rehabilitation in Stargardt disease. Clin Exp Optom 2018;102:428-33.

23. Gopalakrishnan S, Muralidharan A, Susheel SC, Raman R. Improvement in distance and near visual acuities using low vision devices in diabetic retinopathy. Indian J Ophthalmol 2017;65:995-8.

24. Holzel T. Are head-mounted displays going anywhere?-Just as most of the growth of LCDs has been in new applications, the early growth of consumer-friendly HMDs will be in enabling new packaging of. Inf Disp1999;15:16-21.

25. Do AT, Ilango K, Ramasamy D, Kalidasan S, Balakrishnan V, Chang RT. Effectiveness of low vision services in improving patient quality of life at Aravind Eye Hospital. Indian J Ophthalmol 2014;62:1125-31.

26. Robinson JL, Braimah Avery V, Chun R, Pusateri G, Jay WM. Usage of accessibility options for iPhone and iPad in a visually impaired population. Semin Ophthalmol 2017;32:163-71.

27. Kinateder M, Gualtieri J, Dunn MJ, Jarosz W, Yang XD, Cooper EA. Using an augmented reality device as a distance-based vision aid—Promise and limitations. Optom Vis Sci 2018;95:727-37.