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Towards Improving the Mobility of Patients with Peripheral Visual Field Defects with Novel Digital Spectacles

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Abstract

Purpose: To assess the efficacy of novel Digital spectacles (DSpecs) to improve mobility of patients with peripheral visual field (VF) loss.

Design: Prospective Case Series.

Methods: Binocular VF defects were quantified with the DSpecs testing strategy. We implemented an algorithm that generated personalized visual augmentation profiles based on the measured VF. These profiles were achieved by relocating and resizing video signals to fit within the remaining VF in real time. We tested 20 patients with known binocular VF defects with static test images, followed by dynamic walking simulations to determine if they could identify objects and avoid obstacles in an environment mimicking a real-life situation. We assessed the effect of the DSpecs on the visual/hand coordination with object grasping tests. Patients performed these tests with and without the DSpecs correction profile.

Results: The diagnostic binocular VF testing with the DSpecs was comparable to the integrated monocular standard automated perimetry based on point by point assessment with a mismatch error of 7.0%. Eighteen of 20 patients (90%) could identify peripheral objects in test images with the DSpecs that they could not previously. Visual/hand coordination was successful for 17 patients (85%) from the first trial. The object grasping performance improved to 100% by the third trial. Patient performance, judged by finding and identifying objects in the periphery in a simulated walking environment, was significantly better with the DSpecs ($P=0.02$, Wilcoxon rank sum test).

Conclusions: DSpecs may improve mobility by facilitating the ability of patients to better identify moving peripheral hazardous objects.

Keywords

Digital Glasses; Visual Field; Peripheral Visual Defects; Field Expansion; Simulation testing; mobility testing

INTRODUCTION

Peripheral visual field (VF) defects can be caused by several diseases, including glaucoma, cerebrovascular accidents, retinitis pigmentosa, and choroideremia. Over 75 million patients are projected to suffer irreversible VF loss secondary to glaucoma by 2020.¹ Visual impairments complicate the course of 72% of all cerebrovascular accidents.² Binocular VF losses are associated with reduced quality of life activities for many patients.^{3–5} Peripheral vision losses affect postural stability^{6,7}, motion estimation⁸, and the ability to avoid hazardous peripheral obstacles. Reduced VF total area and narrower visual fields worsen mobility performance.^{9–13} Despite recent advances, no medical or surgical treatment can reverse existing damage associated with either glaucoma or stroke. Visual aids attempt to maximize patient functionality^{14,15}, yet often fail to achieve this goal.^{16,17} Research to evaluate effectiveness of visual aids for patients with damaged peripheral visual field is limited.^{17,18}

Current visual aids relocate or minify the captured scenes to fit within the assumed intact VF. To achieve these goals, investigators have used both optical or electronic/digital solutions. Optical approaches use prisms or magnifying components to expand the field of view. These strategies have not been widely accepted because they result in reduced resolution, overlapping image effects, and require the patient to scan the environment with head rather than eye movements.^{19–22}

Electronic or digital based visual aids apply enhancement techniques to improve central vision by adjusting image contrast, brightness, color, and edge properties with head mounted displays (HMDs).^{17,21,23–25} Representative examples of this technology include Esight (Esight, Ontario, Canada), Jordy (Enhanced Vision Systems, CA, USA), Flipperport (Enhanced Vision Systems, CA, USA), and Oxsight (Oxsight, Oxford, UK) devices. Clinical trial results and studies performed with these aids are limited^{26,27}, and have focused on testing central vision tasks, such as writing, reading, and identifying objects. Although these tests showed improvements in central vision related tasks, the ability to avoid collisions and restore mobility did not improve.^{27,28} Failure to achieve this goal is likely related to the fact that current aids do not quantify patient specific visual field defects nor apply a unique strategy to augment visual function.^{16,21,27} Some investigators have used HMDs to measure or screen monocular VFs^{21,29–31}, but did not use this information to provide patient specific solutions. A uniformly applied criteria to define the benefit of a specific visual aid for improving mobility, independency, and safety would facilitate comparisons among devices.¹⁶ Consequently, a need exists for a new low vision aid to improve mobility.³²

We developed and used new Digital Spectacles (DSpecs) that measured binocular VF defects and applied a digital image processing strategy unique to each patient to create a visual augmentation profile. Real time augmentation was performed by rescaling and

shifting video images of patients' scene to fit within the remaining intact VF. To demonstrate the improved ability of patients to avoid and identify moving objects located in the periphery, we tested the device in a dynamic walking simulation environment specifically designed to assess mobility improvements.

MATERIALS AND METHODS

We used a commercial virtual reality (VR) HMD to develop the DSspecs visual aid (HTC Vive, Xindian District, New Taipei City, Taiwan). The HMD was integrated with an eye tracking system (Tobii Technology, Danderyd, Sweden) that fed gaze data to the VF testing algorithm (Figure 1.a). The visual aid was also equipped with two high definition (HD) 2 megapixels miniature cameras (Camera sensor: OmniVision, Santa Clara, California, USA) (Figure 1.b). The two cameras provided a binocular view. The cameras provided a field of view of about 85 degrees in diameter, which matched the 80-degree VF testing range of the DSspecs. The VR HMD and the eye tracking system permit a 100-degree field of view (FOV) for each eye. The DSspecs is controlled by a VR enabled laptop (Intel Core i7, 2.8GHz Quad core, NVIDIA 1070, 32GB RAM) that runs the binocular VF testing program and video processing algorithm. The developed algorithms were implemented with MATLAB R2018b (MathWorks, Inc., Natick, MA, USA) and C# under Unity (Unity Technologies, San Francisco, California, USA).

PARTICIPANTS RECRUITMENT:

The University of Miami IRB approved the study before patient recruitment. Patients signed informed consent forms before commencing the study. The design was in accordance with the Declaration of Helsinki and all HIPAA regulations.

We examined a test group consisting of 20 patients recruited from glaucoma and neuro ophthalmology clinics at the Anne Bates Leach Eye Center, Bascom Palmer Eye Institute, University of Miami Miller School of Medicine during their regular follow-up visits. All patients had previously performed either 24–2 or 30–2 testing strategy with the Humphrey Zeiss standard automated perimetry (SAP) (Carl Zeiss Meditec, California).

MEASURING THE BINOCULAR VISUAL FIELD:

The VF perimetry method with the DSspecs was based on the SAP static technique with a fast threshold strategy.³⁴ Locations of stimuli were determined by 52 points of a circular grid that covered the central 40-degree radius of both eyes, with an interspace of 10 degrees between each stimulus location. Four contrast staircase stimuli sequences were presented ranging between 32 dB to 20 dB in steps of 4 dB. A value of 0 dB was assigned to the stimuli locations where the patient could not respond. This testing method utilized a bright background with an illumination of 100 lux, and the stimuli were dark dots. This method of testing was relatively accurate for monocular and binocular VF testing (Digital Glasses for Visual Rehabilitation of Glaucoma Patients suffering from Visual Fields Defects", ARVO, BC, Canada, April 2019). The patient was asked to fixate on a central target, and the eye tracking system monitored fixation during the test. If the patient looked at the stimulus, the test was halted until fixation was restored based on feedback from the eye tracking system.

Based on a normal human FOV^{33–35}, the common binocular area covered by both eyes is approximately the central 60-degrees radius. Our VF test covers the central 40-degrees radius area, a subset region of the total binocular area. Our binocular VF test presented the stimuli to both eyes at the same visual location and time, so that either the left or right eye would detect the stimulus, and the patient would respond accordingly. The stimulus would only be marked as “unseen”, if both eyes were functionally defective at the same visual location in the binocular VF.

VISUAL FIELD MEASUREMENTS ACCURACY:

To assess the accuracy of the DSspecs binocular VF testing method, an estimated binocular VF was first constructed based on the monocular SAP VFs of 20 patients. The estimated binocular VF was constructed by integrating the right and left eyes monocular VF. Monocular integration was performed by selecting the maximum sensitivity value at each position of the monocular VFs. This merging process was based on the maximum sensitivity merging model reported by Crabb and associates³⁵ and the best location integrated binocular model reported by Nelson-Quigg and coworkers.³⁶ The predicted binocular VF was used as a reference to evaluate the accuracy of the DSspecs binocular test. We used the most recent monocular SAP VF tests to construct integrated visual field (IVF) binocular plots. The central 24 or 30 degrees area, depending on previous testing, were compared between the IVF and DSspecs binocular VF. Measurement errors were based on pointwise mismatches between the two methods.

IMAGE REMAPPING:

Image remapping required shifting and resizing operations on the 85 degrees FOV input video signals to fit within the intact regions of the measured binocular VF to increase the functional FOV. The remapping method utilized VF test data to estimate a new scale and new center for the output video signals to be presented. Geometric image properties of the measured intact binocular VF were calculated, including the areas in pixels, bounding pixels, and the weighted center of mass. If multiple intact regions existed in the field, only the largest area was considered for remapping to maximize utilization of the remaining VF. The geometric calculations were fed to a mathematical function to calculate a new center and scale for the video signals to be specifically presented to each patient. Calculation of the patient unique remapping parameters and video processing (shifting and resizing) was performed in real time through the control program. Processed video signals were displayed at a speed of 24 frames per second.

Figure 2 shows an example application of the video remapping process to fit input images within the intact region of a certain VF automatically. (Figure 2.A) shows a scene of a shopping mall as seen through normal vision. (Figure 2.B) is a VF with peripheral defects. (Figure 2.C) shows the scene without remapping where the escalator's entrance could not be seen. (Figure 2.D) shows the remapped scene where the whole escalator can be noticed. VF was overlaid over the scenes in (Figures 2.C and D) for demonstration purposes only.

Before commencing the walking simulation, we tested the effectiveness of image remapping to augment the functional FOV with static test images of incoming cars in different image

quadrants. The test images were first presented without remapping, then with remapping activated. We asked patients to identify the exact nature of the object in the images.

WALKING SIMULATION TEST:

We designed and constructed a computer based walking simulator for testing of our visual aid. The walking simulator ensured the patient safety, where no fall could occur, before testing the use of DSspecs in a walking track.

Hand Coordination Test.—We determined if the DSspecs adversely affected hand coordination before performing the walking simulation test. Patient visual/hand coordination was tested with the DSspecs while activating the binocular video remapping strategy to ensure cognitive coordination between hand movements and visual perception with the remapped video signals. In this test, three objects with different sizes (Height × Width: 23×5, 13×4, and 7.5×3 cm, respectively), were randomly placed at different distances (51, 62, and 70 cm, respectively) on a table in front of the patient. Patients were required to grasp these three objects one at a time and the number of grasp trials was recorded for each object.

Walking simulation environment.—We constructed a walking computer simulation test environment to project a 80" × 60" image on the wall. The simulation environment was constructed geometrically with SketchUp software (Trimble, California, USA), and then converted to 3D and animated with SimLab VR software (Simulation Lab Software, Amman, Jordan). The image of the projector screen covered 80 degrees of the FOV, which matched the DSspecs VF testing range.

The participants performed the simulation while seated in front of the screen where a scene portrayed a long corridor with an equivalent length of 72 meters. Average simulated walking speed was 2.45 meters per second. The participants were able to navigate with a gaming joystick. All participants were instructed to look at the end of the corridor (center of the screen) as a fixation target to limit the confounding effect of eye and head movements scanning. We asked patients to identify the type and shape of eight peripheral objects located above the central horizontal line of sight in the walking corridor. These shapes were initially hidden, but appeared when the virtual walker was within approximately 2 meters of each object. The objects located on the walls included common shapes: a large clock and paintings with basic shapes (circles, triangles, and the letter 'X'). The shapes were projected to test the two superior VF quadrants, in which each quadrant was stimulated four times during the test, yielding eight static shapes (Figure 3.A).

We created six moving obstacles to block the passage of the patient from both sides (initially hidden obstacles: chairs, couches, and tables). The obstacles moved to block the virtual walker when within approximately 2 meters of each obstacle. Participants were asked to stop walking when they noticed the obstacle (Figure 3.B). The simulation software mimicked a collision situation and halted forward movements if the participant did not notice the moving obstacle. We used the moving obstacles to test functionality of the two inferior VF quadrants, where each quadrant was stimulated three times, therefore, the simulation environment had six moving obstacles.

We presented a demonstration version of the walking simulator that displayed sample obstacles and shape before performing the complete track, to demonstrate the test and describe the walking controls. The demonstration corridor was 28 meters long and patients took approximately 2 minutes to complete this learning phase, including explanations by the tester. The patients repeated the demonstration, two to four times, until they felt comfortable with the simulation environment and understood how to respond. We believed that this step minimized the potential learning effect on the recorded visual identification responses.

Two walking testing strategies with different obstacles and shapes distributions were displayed. Immediately after completing the virtual walk with one strategy with the DSspecs, the patient would proceed through the other theme without the DSspecs. This was chosen to minimize memory or practice effects, so that the patient would not memorize landmarks from the first completed course. Patients were asked to walk through the corridor twice for each setup (with/without DSspecs). They performed two different themes with the DSspecs and two additional themes without the DSspecs. The order of the walking trials was randomly assigned. Each trial was completed in 1–2 minutes depending on how many times the patient stopped during the test and responded to different obstacles/shapes appearance. Both types of scores (obstacle avoidance/stopping scores and object identification scores) were recorded and calculated for all participants' trials in both testing strategies by two observers to make sure that the correct scores are being recorded.

Descriptive and significance statistics were calculated using MATLAB R2018b (MathWorks, Inc., Natick, MA, USA). Means $\pm$ standard deviations (SD) were used to describe VF measurements errors. Wilcoxon rank-sum tests were used to test for significance between the patients walking simulation scores, with and without the DSspecs. We used Pearson's linear correlation tests to assess the correlation of three VF defect severity measures and the walking simulation average scores. We included the Mean Deviation (MD), Pattern Standard Deviation (PSD), and the Visual Field Index (VFI) metrics in the correlation analysis, as being commonly reported VF defects characterization parameters.^{37,38} For each measure we used the best eye's value in the analysis. P-values of less than 0.05 were considered to be statistically significant.

RESULTS

BINOCULAR VF MEASUREMENTS:

Patients age range was 13 to 89 years with a mean value of 63 ± 19 years old. The VF measurements were performed with SAP and DSspecs. The VF measurements of a patient with a residual left homonymous hemifield is shown for demonstration (Figure 4.A). The left blind spot is not detected, as the intact portion of the visual field in the right eye includes this area. A glaucomatous defect, where the superior hemifield of the left VF is intact, and nasal hemifield of the right eye exhibits moderate damage temporal to fixation is shown (Figure 4.B). Merging both fields revealed a common defect in the inferior-left quadrant, which was confirmed with the DSspecs VF measurements. Monocular SAP measurements supported the validity of using the DSspecs for defining binocular VFs.

The IVF was used as a reference for calculating the DSspecs binocular measurement error. The mean error and standard deviation was found to be 3 ± 2 points (range: 0 to 6) for the number of mismatched error points, and $7 \pm 4\%$ (range: 0 to 15 %) as a percentage of the total number of common test points between monocular SAPs and DSspecs VF methods.

IMAGE REMAPPING:

We initially tested the image remapping method with static images (Figure 5.B) to ensure potential benefit for each patient and the likelihood of improving the functional FOV. Eighteen out of 20 patients (90%) successfully identified the peripheral objects in the test images with the DSspecs remapping algorithm, while 2 patients (10%) correctly identified the objects without remapping. For example, in a patient with retinitis pigmentosa, he could not see the car before remapping (Figure 5.C) but could see the object after image remapping (Figure 5.D).

WALKING COMPUTER SIMULATION:

Hand Coordination Test.—Seventeen out of 20 patients (85%) were able to grasp the 3 objects on the first trial. For the other three patients: two patients grasped one object in the first trial and 2 objects in the second trial, the third patient grasped two objects from the second trial and one object in the third trial. Those three patients repeated the test (two patients repeated one time and the third patient repeated twice) until they became adapted to the new perspective of the DSspecs and grasped the three objects successfully from the first time. The use of DSspecs did not negatively affect visual/hand coordination, although training was needed to achieve a good coordination for some patients.

Walking Simulation Results.—We asked patients to perform the walking simulation experiment, and respond to the simulation events. Patients responded by stopping if they saw an obstacle or to verbally identify a sign or shape. Responses as percentage of successful obstacles avoidances and signs identifications were calculated (Figure 6). Improvements in the patient's ability to perform both tasks were calculated as the difference between the scores in the with and without DSspecs conditions. These calculations reveal average improvements of 13% in the obstacle avoidance task, and 15% for the shapes identification task. The use of DSspecs improved detection in 85% of subjects (17 out of 20 patients), but did not benefit three patients (patients 1,2 and 13 in Figure 6). To illustrate the difference between the walking simulation scores, with and without the visual aid, the effects were calculated for three response categories: obstacles avoidance, peripheral shapes identification, and combined responses calculated by averaging the first two response categories. Assuming no data normality, the Wilcoxon rank sum test was significant (*P*-value: 0.03, 0.04, and 0.02) for the three response categories, respectively.

Correlation analysis was performed between walking simulation mean scores, calculated by averaging the scores in columns 6 and 7 of (Figure 6), and three standard global parameters characterizing SAP VF tests (MD, VFI, and PSD). Pearson's linear correlation analysis demonstrated a significant correlation ($r = -0.55$; *P*-value 0.01) between the MD metric and DSspecs walking improvement scores. The analysis also showed a marginal significance of the VFI metric ($r = -0.45$; *P*-value 0.05). On the other hand, no significant correlation was

found between the PSD parameter and DSspecs improvements ($r = -0.18$; P -value 0.46). Patient's age was not correlated with the walking scores ($r = -0.02$; P -value 0.95).

DISCUSSION

We designed and tested the DSspecs, to measure binocular VF defects and accordingly generate a unique patient visual augmentation profile. We hypothesized that these personalized augmentation strategies may expand peripheral awareness and improve mobility.^{9,10} The ability of our patients to identify and avoid moving objects in a walking simulation environment was improved with the DSspecs. They could successfully coordinate their hand movements with the new visual aid.

Peli and coworkers^{39–42} used an HMD to augment restricted visual fields by displaying expanded contours of objects, but did not use real images. Their approach increased the FOV for patients with tunnel vision due to retinitis pigmentosa to less than 40 degrees. This technique did not improve the ability of the patients to avoid collisions nor improve mobility in a walking simulation experiment.²⁸ More recently, they reported expansion of vision with optical prisms that improved collision detection rates tested with virtual reality walking simulations.^{43,44} Binocular visual field expansion was limited to 11 to 39 degree through small apertures and binocular visual confusion due to the prismatic field expansion method was not tolerated by some patients.⁴³ Other available visual aids^{21,26,27,45,46} apply image magnification, brightness and contrast enhancements without considering the pattern of the VF defect. These aids were reported to provide limited benefits for many functional activities that rely on the peripheral VF.^{16,17,21} Wittich and coworkers investigated a modern visual aid where mobility tests did not show significant improvement.²⁷ Experimental validation of mobility improvements with HMDs has not been reported.

In review of current visual aids, we could not identify a similar approach to measure a VF defect pattern and apply a unique visual device to improve mobility. This feature has been reported as a possible future innovation.⁴⁶ Our method of binocular VF testing with DSspecs is advantageous over the standard Esterman method, that has been reported to underestimate the field defect extent, especially in the superior hemifield, due to fewer number of testing points in the superior hemifield.^{47,48} With Estermann binocular visual field testing, we believe that the results would have affected the accuracy of the image remapping process. Our device does not exhibit image overlap nor optical confusion artifacts, as the entire test image is remapped.

Not all patients benefitted with the use of the DSspecs, including three patients with relatively mild binocular defects. The first patient had monocular VF defects with the normal blind spots shown to be defective in the binocular VF, and the other two patients had moderately dense defects in the inferior and superior hemifields, respectively. It is worth mentioning that the DSspecs augmentation profile was not beneficial for the first two patients in Figure 6 in both the static images and walking simulation tests. This suggests that testing with static images was indicative of the walking simulation performance.

Although we instructed all patients to focus at the end of the corridor, center of the projector screen, while virtually walking and expect appearance of the objects, many continued to scan the environment with eye, head, and body movements to compensate for their VF losses. The efficient use of scanning likely explains the failure of the DSspecs to improve visual function in these patients. This behavior became an involuntary habit and controlling or stopping it was hard for them.^{49–52}

All other patients scored higher with the DSspecs, and some patients had very substantial improvements in both tasks. For example, two patients had much better avoidance and identification score with the DSspecs, and it was significantly different than without it: patient 15 (retinitis pigmentosa) and patient 20 (glaucoma). Therefore, two factors may have affected the performance of the DSspecs augmentation process. First, how profound the VF defect was regarding depth and pattern. More severe and homogeneous peripheral defects were found to be more beneficial, as can be clearly noticed in the objects detection improvement percentages shown in (Figure 6). Correlation analysis suggests that the MD and VFI metrics might be predictive factors for potential functional improvements with the DSspecs. Second, patients scanning behavior was responsible for not noticing improvements, as they compensate for their visual defects.

Our study has several limitations. The current prototype was based on a bulky and heavy VR HMD that isolates patients from their surroundings and is not socially acceptable. The application of augmented reality (AR) technology will likely address these VR technology limitations and provide a see-through, light-weight display. The image remapping algorithm was based on geometrical calculations to basically perform automatic image operations and create the required augmentation profile. The current process is a two degrees of freedom algorithm that involves both resizing and shifting of the images. The preliminary results have shown that this remapping method will likely not be sufficient to account for all the blind areas. An optimization method incorporating more degrees of freedom and considering different image transformations, such as fish eye transformation, may be required to maximize the usage of the remaining VF.

Hand coordination tests were performed only with the DSspecs. Although, this confirmed a level of motor/visual coordination and accordingly we proceeded with the walking simulation experiment, it did not determine if the DSspecs affected or improved the baseline coordination before the DSspecs were used. Future studies will incorporate coordination assessments that include with and without DSspecs testing setups.

Future studies to improve peripheral awareness include increasing the DSspecs FOV. The current DSspecs prototype captures a VF of 80 degrees, and displays approximately 85 degrees FOV with images generated by the forward facing digital cameras. These field ranges cover a large portion of the mid-periphery VF, which is responsible for the highest collision risks⁵³, and they were adequate to demonstrate the feasibility of this proof of concept research to avoid obstacles. However, they are considered to be relatively limited ranges for daily life activities. A more useful FOV would be at least 110 degrees, which matches the FOV of prescription glasses. The walking computer simulation was a preliminarily effective and safe test to judge effectiveness of vision augmentation with the

DSpecs, but did not account for head and body coordination with the new visual aid. A standardized and validated real mobility track with physical objects that mimics the real world environment and permits measurements for all eye, head, and body kinematic movements while walking will be the subject of future studies.

We believe that our digital glasses technology may aid patients with peripheral VF defects improve their peripheral visual awareness. A virtual walking environment has been verified and found to be practical for assessing the effect of peripheral vision loss. The demonstrated results showed that the DSpecs detected different binocular VF defects. Functional tests demonstrated a successful hand coordination with the visual aid, and significant improvements to the ability to avoid obstacles and identify moving objects in the simulated walking test. These findings suggest the potential benefit of the DSpecs to improve recognition of peripherally moving objects, augment mobility, facilitate independence, and quality of life.

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United States Non-Provisional Pending Patent (Application No. 16/144,995) (MA) and United States Non-Provisional Filed Patents (Application No. 16/367,633, 16/367,687 and 16/367,751) (MA, AS).

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Figure 1:
Digital Spectacles prototype: A) Eye tracking infrared light emitting diodes integrated with the display lens shown from the patient view. B) Two high definition cameras mounted on the virtual reality head mounted display.

Figure 2:

An example showing the image remapping process: a) Example scene of a shopping mall as seen through normal vision. b) Visual Field (VF) with peripheral defects. c) The scene as shown without remapping: the escalator's entrance cannot be seen. d) Image with remapping: the escalator can now be noticed. VF was overlaid over the image in c) and d) for demonstration purposes only.

a) *b)***Figure 3:**

A) 3D model of the simulated walking corridor. B) A participant performing the rendered walking simulation test with real-world dimensions.

Figure 5:

A retinitis pigmentosa Patients' image remapping results: A) Measured binocular visual field. B) Test image showing an incoming car as a safety hazard. C) Test image as seen by the patient: patient could see only a road. D) Remapped image: patient could identify the car. Visual field was overlaid over the test image in the last two images for demonstration purposes only.

Patient #	With Visual Aid		Without Visual Aid		Average Detection Improvement %		Binocular VF
	Obstacles Avoidance %	Shapes Identified %	Obstacles Avoidance %	Shapes Identified %	Obstacles Avoidance %	Shapes Identified %	
1	100	100	100	100	0	0
2	100	100	100	100	0	0	
3	100	90	100	85	0	5	
4	85	85	50	70	35	15	
5	100	85	65	75	35	10	
6	100	100	100	85	0	15	
7	88	75	88	50	0	25	
8	92	83	83	58	9	25	
9	100	89	100	82	0	7	
10	92	100	92	86	0	14	
11	100	63	83	44	17	19	
12	100	44	75	38	25	6	
13	100	75	100	75	0	0	
14	100	75	100	55	0	20	
15	100	75	8	13	92	62	
16	100	100	100	93	0	7	
17	100	80	100	67	0	13	
18	75	86	75	55	0	31	
19	100	63	92	56	8	7	
20	100	56	67	44	33	12	
Average	97	82	84	67	13	15	
Obstacles Avoidance P-Value				0.03			
Shape Identification P-Value				0.04			
Combined Responses P-Value				0.02			

Figure 6:
Walking simulation test scores for 20 patients with and without the digital spectacles.