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CLINICAL INVESTIGATION

Night-vision aid using see-through display for patients with retinitis pigmentosa

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Abstract

Purpose From an early stage, retinitis pigmentosa (RP) patients suffer from night blindness which causes nocturnal mobility difficulties. We created a wearable visual aid that uses a high-performance see-through display, and added a high-sensitivity camera with a complementary metal-oxide-semiconductor sensor. Here, we evaluate the device's efficacy for helping night-blindness sufferers walk in the dark.

Study design Prospective clinical study.

Methods Twenty-eight subjects underwent binocular visual acuity testing in the dark without (power off) and with (power on) the device. The test was carried out in a darkened room. We recorded the number of trial errors and the time it took each subject to arrive at the goal both with and without the aid of our device.

Results Our device effectively assists walking in RP patients with mobility problems in the dark.

Conclusion Binocular visual acuity in the dark was significantly improved with the aid of our device. In the walking test, the number of errors decreased greatly with the device, and the travel time was significantly shortened.

Keywords see-through display · visual aids · night blindness · retinitis pigmentosa

Introduction

From the early stage of disease progression, individuals with retinitis pigmentosa (RP) suffer from night blindness and have mobility problems at night. Promising new therapeutic treatments such as gene therapy [1–4] and regenerative medicine [5, 6] are expected to be clinically available, but the night blindness of RP patients has not been a focus of research. A decline in RP patients' quality of life due to night blindness is apparent even before the alterations in visual acuity due to RP are manifested.

Since the 1970s, several types of devices have been evaluated to address mobility problems due to night blindness [7–14], but the devices were not convenient for daily use due to their large size, heavy weight and/or conspicuous design. We recently developed a wearable visual aid utilizing a see-through display to help individuals with night blindness walk in the dark [15]. Our device enables subjects to see objects that could not be detected by the unaided eye, which can assist RP patients with night blindness. However, the device's view was too small and the image quality was relatively low, and it was thus difficult for the wearer to walk

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smoothly. In addition, the device's production cost was too high for commercial availability.

Fig. 1 See-through display device. The device was designed as eyeglasses consisting of a see-through display (MOVERIO® BT-300; a) and a high-sensitivity camera (HOYA CMW01®; b)

We now developed a new night-vision aid (Fig. 1) that uses a high-performance see-through display (MOVERIO® BT-300; SEIKO EPSON Co., Ltd.), and added a high-sensitivity camera with a complementary metal-oxide-semiconductor (CMOS) sensor (HOYA CMW01®, HOYA Co., Ltd.). In the present study, we tested the effectiveness of this device for helping patients with RP walk in the dark.

Subjects and methods

Subjects

This subjects were 28 patients (12 men and 16 women; age: 45.61 ± 10.13 yrs; Table 1) who had been diagnosed with typical RP and were being seen at Kyushu University Hospital (Fukuoka, Japan). The investigation was carried out under approval from the Institutional Review Board of

Table 1 Ophthalmic data

Subject No.	Age (y)	Gender	Binocular visual acuity (LogMAR)	Binocular visual acuity in the dark (LogMAR)		Visual field
				power off	power on	
1	50	M	0.22	0.82	0.52	3
2	59	F	0.22	1.15	0.70	5
3	36	M	0.70	2.00	0.82	3
4	65	F	0.22	1.30	0.40	6
5	39	M	0.22	1.00	0.52	3
6	48	F	0.05	1.00	0.40	4
7	56	F	0.00	0.82	0.30	1
8	43	M	0.05	0.70	0.40	3
9	52	F	0.15	1.15	0.70	6
10	38	M	0.00	1.00	0.40	3
11	54	F	0.15	1.15	0.70	6
12	64	M	0.10	0.82	0.52	5
13	43	M	0.05	0.70	0.40	3
14	33	M	0.10	1.52	0.40	4
15	41	M	0.22	1.00	0.70	5
16	37	M	0.10	1.00	0.22	3
17	54	F	0.22	1.00	0.70	6
18	39	F	0.52	2.30	0.70	1
19	37	F	0.05	0.40	0.22	1
20	30	F	0.10	1.00	0.40	1
21	50	F	0.30	1.10	0.52	3
22	64	M	0.05	1.00	0.30	6
23	37	F	1.00	2.00	1.40	6
24	42	F	0.30	2.30	0.70	6
25	37	F	0.05	0.70	0.40	1
26	53	F	0.00	0.70	0.22	4
27	43	F	0.00	0.70	0.22	1
28	33	M	0.40	1.15	0.70	6

y years old, *M* male, *F* female

Kyushu University Hospital and conducted from August to December 2016, in accordance with the tenets of the Declaration of Helsinki on biomedical research involving human subjects. It was registered with the University hospital Medical Information Network <UMIN> ID: 000021945; 1st/May/2016). Informed consent to participate was obtained from all subjects. Furthermore, the informed consent for publication of identifying information/images in an online open-access publication was obtained from one subject (No. 3).

See-through display device

We developed a device designed as eyeglasses consisting of a see-through display (MOVERIO® BT-300) and a high-sensitivity camera (HOYA CMW01®, HOYA Co., Ltd.) (Fig. 1). The see-through display is binocular. If the subject had a refractive error, a corrective lens was placed inside the device. The resolution of the display was high definition (1280 x 720 pixels). A high-sensitivity camera using a 1/2.9-inch CMOS sensor with 1280 (H)×720(V) resolution was mounted on the right side of the eyeglasses. The sensitivity of the camera was 0.05 lux with a field of view with a micro-lens (F2.8) of 44.1° (H)×33.6° (V). Thus, the display presented about a 2× minified color image of the real view (Fig. 2) that could assist a device's wearer with night blindness and peripheral visual field loss.

Ophthalmic data collection

We obtained the binocular best-corrected visual acuities at baseline and in the dark for all 28 subjects with full subjective refraction using a Landolt ring chart at 5 m. Visual acuity was converted to a logarithm of the minimal angle of resolution (logMAR) for statistical analysis. The visual fields were determined monocularly by Goldmann perimetry. The degree of visual field loss was classified into seven grades by the V4e indicator according to the reported classifications for RP patients as follows: grade 0, normal visual field; grade 1, some scattered scotomas in the mid-periphery; grade 2, ring scotoma; grade 3, constricted visual field within the central 30°; grade 4, constricted visual field within the central 15° with isolated peripheral visual islands; grade 5, constricted visual field within the central 15° without peripheral visual islands; and grade 6, constricted visual field within the central 10° [16].

Walking test (Fig. 3)

The walking test was carried out as described [15]. A spacious hall (approx. 17 m×16 m) with only two incandescent lamps covered with frosted glass shades was used in the darkened room. The illuminance level in the field where the subjects would walk was adjusted at the brightest point to under approx. 1.2 lux and at the darkest point to over approx. 0.2 lux, both horizontally and vertically.

For the test, the subject was instructed to walk to a goal 16 meters away from the starting point by passing through four 1.5-meter-wide gates consisting of pairs of black square carpet pieces, white poles, red and white traffic cones and cardboard boxes, in that order. The four gates and the starting point were located 4 meters apart from each other corresponding to the direction of the goal. At each trial, the three gates (except for the gate of boxes, which was the nearest to the goal) were randomly arranged along the perpendicular direction of travel.

Fig. 2 Image of the view of crosswalk at night as seen using the device. The middle of the screen is a brighter image of the zebra zone than that actually taken by the high-sensitivity camera. The size of the view is slightly reduced

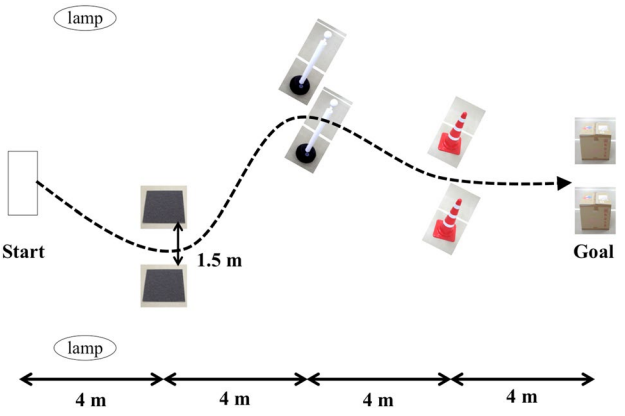

Fig. 3 Walking course schematic. The subject was instructed to arrive at a goal 16 meters away from the starting point by passing through four 1.5-meter-wide gates consisting of pairs of black square carpet pieces, white poles, red and white traffic cones and cardboard boxes, in that order. The four gates and the starting point were located 4 meters apart from each other corresponding to the direction of the goal. The dashed line indicates the path the subject was to walk

Before the walking test, we measured the baseline time it took each subject to arrive at the goal in a bright condition. To start the walking test, the hall was darkened. The examiner then familiarized the subjects with the device and confirmed that the subject could see the examiner standing directly in front of him/her, in the center of the screen on the display. After sufficient dark adaptation (>15 min), the subject was asked to walk the course twice with the device (power off) in a darkened condition. After two practice trials, the walking test was conducted in a darkened condition with the device (power off). The subject was asked to walk the course twice to practice using the device (power on). After two practice trials, the walking test was conducted in the darkened condition.

'Trial error' was defined as stepping on a black square carpet piece or a collision with any of the poles, pylons or boxes, as well as failure to pass through any of the gates. We recorded the number of trial errors and the time it took each subject to arrive at the goal (subtracting the baseline time in the bright condition). Eight subjects (Subjects No. 3, 4, 14, 18, 21, 23, 24 and 28) could not walk alone, so we counted the number of their trial errors as 4 times but could not record the travel time. All walking test trials were videotaped by a high-sensitivity video camera.

Statistical analyses

All values are expressed as the means ± standard deviations. The data were analyzed by two-tailed paired Student's *t*-test. P-values less than 0.05 were considered significant.

Results

The binocular visual acuity in the dark in all 28 subjects was poorer compared to that in the bright condition (Table 1). The subjects' binocular visual acuity in the dark was significantly improved with the aid of the see-through display device (Table 1; $p<0.001$).

The walking test results are summarized in Table 2. Without the aid of our device, eight of the 28 subjects (Subjects No. 3, 4, 14, 18, 21, 23, 24 and 28) could not walk alone without orientation (Supplementary Video 1). With the aid of the device, the eight subjects were able to walk the course without orientation (Supplementary Video 2). In the other 20 subjects, when our device was used, the number of trial errors decreased significantly compared to the trials of power off (power on: 0.57 ± 0.79 times, power off: 2.43 ± 1.20 times; $p<0.001$: n=28). The travel times were also significantly improved when our device was used (power on: 18.33 ± 11.84 seconds, power off: 28.32 ± 14.88 seconds; $p<0.004$: n=20).

Table 2 Results of walking test

Subject No.	Trial error (times)		Travel time (s)	
	power off	power on	power off	power on
1	2	0	11.8	7.3
2	3	0	37.9	6.2
3	4	0	n.d	7.6
4	4	1	n.d	37.3
5	2	0	12.6	8.9
6	2	0	21.8	20
7	1	0	0.7	10.4
8	1	1	17.2	12.2
9	3	0	29.2	23.5
10	2	1	45	19.3
11	3	0	65.8	31.8
12	1	0	34.8	32.8
13	1	0	15.9	8.5
14	4	1	n.d	19.3
15	2	0	23.2	12.9
16	2	0	34.7	31.2
17	2	1	42.7	40.1
18	4	1	n.d	4
19	1	0	25	9
20	1	0	27.2	30.7
21	4	2	n.d	23.2
22	2	0	40.9	-0.1
23	4	2	n.d	4
24	4	1	n.d	17
25	1	0	22.8	6.4
26	1	1	16.1	20
27	3	1	41.1	35.5
28	4	3	n.d	46.6

s seconds, *n.d* not done

Discussion

In the present study, we investigated the efficacy of our new visual aid that uses a high-performance see-through display and a high-sensitivity camera for RP patients who suffer from night blindness and, therefore, have mobility problems at night. The results of the visual acuity and walking tests demonstrate the following: with the aid of our device, 1) visual acuity in the dark significantly improved in all 28 subjects; 2) the subjects who could not walk the course alone were able to walk without orientation; 3) the number of trial errors significantly decreased; and 4) the travel time was significantly shortened. All this confirms that our new visual aid device can help RP patients who have mobility problems in the dark.

The present findings are thus similar to those in our previous study, in which we examined the use of a wearable visual aid with a see-through display and a high-sensitivity

camera [15]. With our new device, the view is notably wider (double the previous size) and the image quality is higher (Supplementary Fig. 1). In addition, our previous display was monocular, whereas our new see-through display (MOVERIO® BT-300) is binocular. Therefore, the performance of the new device is good. Moreover, this display costs less than the previous one, and thus production costs are reduced which makes the new device available commercially.

In conclusion, our new device using a see-through display assists in obstacle detection in a dark environment, and has the potential to assist patients with RP who have mobility problems when travelling at night. We are planning to put the new device on the market in the near future.

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