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Perceptual abilities in case of low vision, using a virtual reality environment

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Abstract—Losing our relationship with our environmental conditions may reduce our cognitive abilities to understand them, and so to interact within. Through the SENSIVISE virtual space, we analyzed the perceptual abilities of 27 visually impaired people and 6 controls to perceive and interact while achieving requested tasks based on global or objects perception and recognition. We also tested the contribution of SENSIVISE's adaptations in improving performance and perception. Our results show a large variability of the performance among participants with low vision, according to visual deficiency, task features, and environmental conditions.

Keywords—low vision; perception; scene recognition; virtual reality

I. INTRODUCTION

According to the World Health Organization (WHO), "low vision" is an impairment of visual functioning that persists even after treatment or standard refractive correction, where visual acuity is less than 6/18 to light perception, or visual field less than 10 degrees from the point of fixation [1]. Unlike a person who is blind, a person with moderate or severe low vision has some useful sight that can be used for the planning and/or execution of a task [1]. The estimated number of people affected by low vision in the world is 246 million; 65% of these visually impaired people are 50 years and older; 1.5 million are living in France [2, 3]. Due to the increase of the life expectancy and the population's ageing, this prevalence is predicted to doubling in the next 25 years.

Eye diseases are often the main causes of visual impairments, among them cataract, glaucoma, or Age-related Macular Degeneration (AMD) [2]. Their consequences on vision are various and depend on the lesion localization: central, peripheral or both. In central vision loss, people feel a permanent loss of center of vision, called scotoma, affecting details perception [4, 5]. The narrowing of the peripheral visual field which leads to a perception of space through a "hole lock" is called tunnel vision and affects orientation and mobility [6]. When people do not present such central or peripheral loss, reducing of visual acuity is most often resulting from blurred vision often in bilateral way. These forms of low vision can present varying

degrees, in which the available visual field (central vs. peripheral residual visual acuity, level of contrast sensitivity are all factors that play a role in influencing cognitive performance [7] and behavior in daily life such as rupture with family, social and professional networks, isolation, depression [8, 9], accidents such as falling in the elderly [10]. These repercussions are often due to reduced perceptual abilities which lead to difficulties to accomplish daily life activities [11], like, reading [12], driving [13], orientation and mobility [14], or face recognition [15]. Furthermore, in other studies researchers have suggested a deficit in object and scene recognition which generates difficulties on tasks involving accuracy such as shopping (finding objects on shelves), preparing meals, performing light housework, especially in low level of contrast and illumination conditions [5].

Since, visual impairment severely affects quality of life, researchers tried to understand the contribution of the central or peripheral vision in daily life activities and also their impact whether impaired. In a recent study, Larson and Loschky (2009) studied the contribution of central vs. peripheral vision in scene recognition. They asked sighted participants to categorize, in 106 ms, photographs of natural scenes, where each scene was followed by a name (e.g., river), while information related to the central or the peripheral view was masked with different sizes of restriction. Results suggested that peripheral vision is more useful than central vision for scene gist recognition. In contrast, central vision is particularly useful for object recognition. The same result was observed when visually impaired participants experienced scenes recognition and categorization for natural versus urban scenes and indoor/outdoor [16]. In case of AMD, peripheral vision at low resolution was sufficient to recognize with precision two types of categorized photographs: natural versus urban scenes and indoor/outdoor [16]. However, to address these issues of the impact of low vision, researchers have mainly used photographs visualization [16, 17] or questionnaires about performing activities in daily life "ADLs" [5]. Furthermore, studies which have focused on objects recognition were carried out with objects presented in isolated manner on a uniform bottom [4, 18]. Whereas, in the natural environment objects rarely seem isolated.

In the present study, we aim to explore the impact of central or peripheral vision loss in scene or object recognition in simulated complex indoor situations closed to real life, while published studies investigated these issues with isolated photographs display. To address this research, we used a virtual reality (VR) approach that already gave positive results in various scientific fields like rehabilitation, learning, education [19, 20], notably in the fields of visual impairment for orientation and mobility [21, 22]. VR has many assets compared to real life situations, such as the easy delivery and control of appropriate stimuli within significant, familiar and secure contexts [20]. Our virtual environment, called “SENSIVISE”, reproduces an interior scene in an almost realistic manner; it was initially developed to raise awareness about visual impairment by providing the simulation of three graduated forms of visual impairments: central Scotoma, Blurred vision and Tunnel vision [23, 24]. It also proposes adaptations of the environment in order to improve perception.

Our objective was to investigate, by using SENSIVISE: 1) perceptual abilities of visually impaired participants and controls (full sighted people) while achieving requested tasks based on global and objects perception as well as recognition; 2) (in case of wrong answers) the efficiency of adaptations, such as contrast or lighting, in improving performance and perception.

II. METHOD

A. Participants

Thirty-three participants were recruited in a convenience sample and divided into research and control groups. The research group included 27 participants (fourteen men and thirteen women, mean age \pm SD = 40.79 \pm 18.19) who are visually impaired people. They were recruited and tested by professionals of low vision at IHT (Institute of Hauts Thébaudières) according to the following inclusion criteria: 1) best corrected visual acuity between 20/60 and 20/800; 2) field of view up to 8°; and 3) no history of cognitive impairment. The research group was heterogeneous in terms of visual disease origins such as: Optic atrophy, AMD, Albinism (nystagmus + achromatopsia), Retinitis pigmentosa (tubular stage), congenital Cataracts, Glaucoma, Myopia with myopic choroïdose. It was divided into three groups according to three main forms of low vision: Blurred vision (B), Central scotoma (S) and Tunnel vision (T) (see table 1). The control group of 6 participants (three men and three women, mean age \pm SD = 29.3 \pm 8.3) with normal visual acuity and normal visual field was tested at Arts et Métiers ParisTech institution. The control group allowed us to collect baseline data among young healthy people. The study was conducted in accordance with the tenet of the Declaration of Helsinki and all participants signed a consent form.

TABLE I. NUMBER OF THE PARTICIPANTS, MEAN AGE, STANDARD DEVIATION FOR PARTICIPANTS IN LOW VISION SITUATIONS AND CONTROL GROUP.

	Conditions			
	Control (CONT)	Blurred vision (B)	Scotoma (S)	Tunnel vision (T)
Participants number	6	11	12	4
Mean age \pm SD	29.3 \pm 8.3	44.9 \pm 20.7	35.4 \pm 16.3	45.5 \pm 15

B. The virtual tool : SENSIVISE

SENSIVISE is a VR-based application which simulates the entrance of a building and an apartment with a living room, a bedroom, a bathroom and a kitchen with a laundry room. All the rooms are equipped with 3D objects and furniture, as in a real apartment. Once into the virtual environment, participants use the arrows of the keyboard to move and the mouse to observe right and left, up and down.

Other virtual environments have been developed in the context of low vision [25], aiming at patient education, health care practitioner training, or understanding of low vision. These issues motivated our choice of low costs interfaces to ensure a large use of the tool, especially at home. The major particularity of SENSIVISE is the proposal of environmental adaptations in order to improve perception of scene and objects: contrast enhancement (e.g. between the walls and the bath), lighting adjustment (e.g. dim light in the bedroom), objects choice (alarm clock in the bedroom), etc. (see Figure 1).

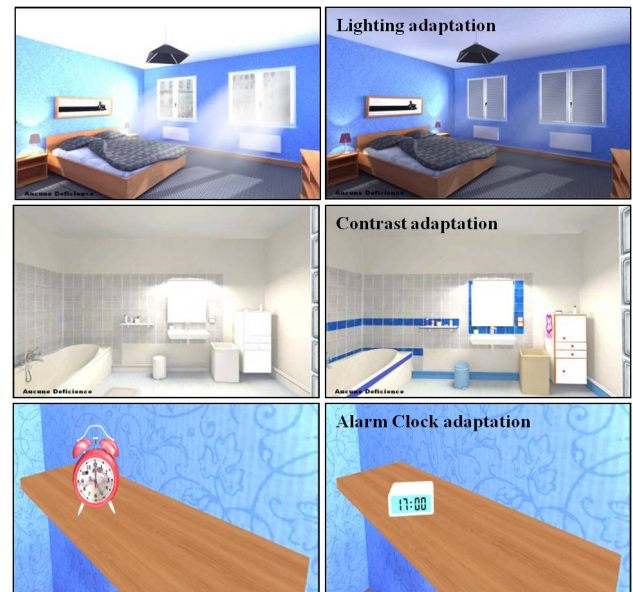


Figure 1. A snapshot of the rooms before and after adaptation: light adjustment in the bedroom (right top); contrast in the bathroom (middle); alarm clock adaptation (right down).

C. Objective of the study

The experimental study was conducted with two purposes: 1) to assess perceptual abilities of visually impaired participants and controls (full sighted people) while achieving requested tasks based on global and objects perception as well as recognition; 2) to test (in case of wrong answers) the efficiency of adaptations, such as contrast or lighting, in improving performance and perception.

D. Experimental Design

SENSIVISE application was displayed on a 22 inches screen which was located at 35 cm from the edge of the desk. The participants sat on a chair in front of the screen, with a mouse and a keyboard on the desk for navigation and interaction. Participants were allowed to adjust their position relative to the screen, forward or backward, according to their need or their own strategy. The evaluator sat close to the participant with a keyboard and a mouse also connected to the application in order to help the participant if needed and to select the adaptations during the test. In addition, the evaluator used a laptop in order to fill in an online questionnaire created for this experiment (see figure 2).

At the beginning of the experiment, all the participants had to answer a brief questionnaire (Q1) about their personal information (name, age, job ...) and to rate their abilities to use a computer (beginner, intermediate, advanced, expert). Then they performed a familiarization procedure with the virtual environment, in order to get familiar with the use of the mouse and the keyboard. Finally the participants began the testing phase in the apartment, at the entrance of each room (bedroom and bathroom). They had to follow a predefined scenario which was enunciated by the evaluator: global visual perception followed by object visual perception which involved displacements in the room.

In the global visual perception step, using the mouse for visual screening, participants had to recognize in which room they were (bedroom or bathroom). If beyond 15 seconds participants did not give a right answer, the evaluator activated adaptations: reduction of lighting at first, substituted by addition of contrast if the answer was always bad, and finally both together. The exposure timing of 15 seconds was decided by the therapists according to their knowledge of low vision behaviors.

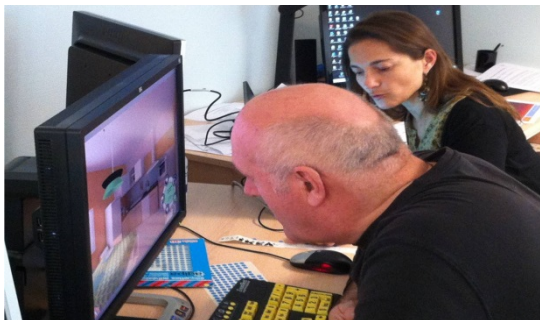


Figure 2. Experimental design: The participant in front of the screen and the evaluator on the right..

In the object visual perception step, participants had 60 seconds to perform the requested task while moving inside the room, using both mouse and keyboard. To define the exposure timing of 60 seconds we took into account the navigation time necessary to move to the right place. In the bedroom, participants had to find the alarm clock located on a shelf near the bed. Once in front of it, they were asked to read the time. If participants were unable to read the time displayed on an alarm clock with needles, two adaptations were tested: reduction of lighting and then changing the alarm clock to a digital one. In the bathroom, participants had to navigate to reach the tablet near the sink and to list all the objects that they perceived on it (e.g., toothpaste, toothbrushes, soap). Adaptations were activated if participants were unable to see all the 8 objects: reduction of lighting and then enhancing the color contrast. The relevance of the adaptations proposed on SENSIVISE was tested by the number of good answers obtained after adaptations activation.

Finally, the experiment was completed by post-test questionnaire (Q2) related to self-assessment on the usability of SENSIVISE (difficult, moderate, easy or very easy).

E. Data Analysis

The impact of visual impairment on perception was determined by comparing qualitative and quantitative parameters between low vision conditions and control condition. These parameters include: number of good responses to questions, response speed measured with a chronometer, number of item found. The time of response was the time elapsed between the end of the formulated question by the evaluator and the response provided by the participant. The statistical analyses were done using a non-parametric method of Kruskal-Wallis and the significant difference between conditions was analyzed using the Wilcoxon test ($p\text{Value} < 0.05$).

III. RESULTS

The purpose of this experiment was to compare the participants' performance between control condition and low vision situations in each step of the scenario. Results presented in this section were collected among 33 subjects: 6 controls, 11 with blurred visions, 4 with tunnel vision, 12 with central scotoma.

According to Q1 questionnaire participants consider themselves in the use of computers as beginners (9.1%), intermediate (18.2%), advanced (63.6%) and expert (9.1%). According to the post-test questionnaire Q2 participants rated the usability of SENSIVISE as very easy (18.8%), easy (40.6%), moderate (34.4%) and difficult (6.2%).

Now we present the results related to the impact of low vision on perception followed by the study of the relevance of the adaptations.

A. Impact of visual impairment on perception

Data analyses related to global and object visual perception are presented in the next two sections.

1) *Global Visual Perception:* As global visual perception scenario is common to both tested-rooms (bedroom and bathroom), data were analyzed in the same part. Individual performance in the global visual perception session was measured qualitatively by the success rate in answering the question “In which room are you?” and quantitatively by the time needed by the participants to answer. Results reported for time duration are only related to the good answers. These data were recorded and analyzed for each study group (Table II). In the bedroom, three participants from the tunnel vision group and only one with central scotoma had difficulties to recognize the bedroom in the allocated time. The participant from the tunnel vision group was the longest to answer. In the bathroom, the same results were observed and the difficulties concerned the same participants.

The Kruskal Wallis test applied on time duration revealed that the performance was significantly different between the groups. A post-hoc analysis realized by the Wilcoxon test revealed statistically significant difference for all groups in the bedroom: blurred vision (p Value= 0.02), central Scotoma (p Value= 0.001), tunnel vision (p Value= 0.04). By contrast, no significant result was found for the global visual perception in the bathroom.

2) *Object Visual Perception:* Data from the object visual perception step are presented separately for the bedroom and for the bathroom.

In the bedroom participants were asked to reach the alarm clock by moving through the VE. All participants from control and central scotoma condition reached the alarm clock, while one participant from the blurred and one from the tunnel vision groups failed (Table III).

TABLE II. VISUAL GLOBAL PERCEPTION, SUCCESS RATE (%), TIME DURATION IN SECONDS (MEAN ± STANDARD DEVIATION) AND TEST OF WILCOXON VALUES (P) ON THE RECORDED DATA FOR PARTICIPANTS IN LOW VISION SITUATIONS AND CONTROL.

In the bedroom	Conditions			
	CONT (6)	B (11)	S (12)	T (4)
Success rate (%)	100%	100%	90%	25%
Time duration (sec.)	1	2.4±1.5 <i>p</i> Value= 0.02	2.2±0.6 <i>p</i> Value= 0.001	10 <i>p</i> Value= 0.04

In the bathroom	Conditions			
	CONT (6)	B (11)	S (12)	T (4)
Success rate (%)	100%	100%	90%	25%
Time duration (sec.)	1.2±0.4	2.9±3.2	2.7±1.4	6

TABLE III. VISUAL GLOBAL PERCEPTION, SUCCESS RATE (%), TIME DURATION IN SECONDS (MEAN ± STANDARD DEVIATION) AND TEST OF WILCOXON VALUES (P) ON THE RECORDED DATA FOR PARTICIPANTS IN LOW VISION SITUATIONS AND CONTROL.

In the bedroom	Conditions			
	CONT (6)	B (11)	S (12)	T (4)
Success rate (%)	100%	90%	100%	75%
Time duration (sec.)	8.8 ± 3.8	27.8 ± 19.2 (<i>p</i> Value= 0.04)	39 ± 19.8 (<i>p</i> Value= 0.01)	54.3 ± 6.35 (<i>p</i> Value= 0.02)

The Wilcoxon test revealed significant differences between participants from the control and all low vision groups: blurred vision (p Value= 0.04), central scotoma (p Value= 0.01), tunnel vision (p Value= 0.02). Participants from the tunnel vision group were longest to reach the alarm clock compared to the other groups.

Next step of the procedure was to read the time on the alarm clock with needles. In order to perform this step of the procedure, the two participants who failed to reach the alarm clock were placed in front of it after 60 seconds. All participants were asked to read the time on the clock. The participants succeeded in the task as follows: CONT (6/6), Blurred vision (9/11), Central Scotoma (8/12), Tunnel vision (2/4) (see table IV). Furthermore, for those who succeeded, the longest to answer were participants with central scotoma and blurred vision.

In the bathroom participants were asked to reach the tablet near the sink to list all the objects they perceived. Participants of the control group perceived all the eight objects. Results show that just few participants from the low vision groups were able to list them in full, especially for the tunnel vision group. In Table V, the success rate is the percentage of participants who were able to recognize the 8 objects. Number of items recognized by each group was as follows (mean ± SD): CONT (8 ± 0.0), Blurred vision (6 ± 1.9), Central scotoma (6 ± 1.2), and Tunnel vision (2.2 ± 0.5). Thus, the Wilcoxon test comparisons between the control group and each low vision groups revealed significant difference in the number of recognized objects, blurred vision group (p Value= 0.009), central scotoma group (p Value= 0.001), tunnel vision group (p Value= 0.005).

TABLE IV. OBJECT VISUAL PERCEPTION WHILE READING THE TIME, SUCCESS RATE (%), TIME DURATION IN SECONDS (MEANS ± STANDARD DEVIATIONS) WITH THE WILCOXON VALUES.

In the bedroom	Conditions			
	CONT (6)	B (11)	S (12)	T (4)
Success rate (%)	100%	80%	66%	50%
Time duration (sec.)	3	14.1 ± 18.7	14.1 ± 14.5 (<i>p</i> Value= 0.01)	3

TABLE V. OBJECT VISUAL PERCEPTION WHILE LISTING OBJECTS: SUCCESS RATE (%), TIME DURATION IN SECONDS (MEANS \pm STANDARD DEVIATIONS).

In the bathroom	Conditions			
	CONT (6)	B (11)	S (12)	T (4)
Success rate (%)	100%	27%	8%	0%
Time duration (sec.)	21.3 \pm 4.1	29.7 \pm 24.7	18	-

B. Relevance of adaptations

In order to attempt to improve participants' perception, adaptations of the VE were proposed to the participants who failed to give good answers. The adaptations were introduced one by one according to the room and then combined. During global visual perception in the bedroom, adaptations improved perception of participants with tunnel vision. Reducing lighting helped two participants, and then enhancing contrast helped the last one. However, none of the adaptations were helpful to the participant with central scotoma. In the bathroom, all participants were able to recognize the room when the evaluator has activated the adaptations: participant with central scotoma vision succeeded after enhancing contrast, the three participants with tunnel vision succeeded after reduction of lighting (1/3) and when combined both adaptations (2/2).

During the next step, objects perception, participants were asked to reach and recognize objects in the room. In the bedroom, eight participants failed to read the time on the clock alarm with needles (2B, 4S, 2T). When this alarm clock was replaced by a digital clock seven participants succeeded to read the time, however one participant with blurred vision was able to read the time only after combining both adaptations (dim lighting and digital clock). In the bathroom, almost all participants with low vision have failed in recognizing the eight objects (23/29). Reduction of lighting was helpful for 10 of them, enhancing the contrast was helpful for 4 persons, and when we combined both adaptations (reducing lighting and enhancing the contrast) two participants succeeded in the task. However, despite all the proposed adaptations, seven participants were not able to cite all objects: three participants with tunnel vision (75%), three participants with central scotoma (25%) and one participant with blurred vision (9%).

IV. DISCUSSION

Visual Acuity and field of view are undoubtedly important information in clinical assessment of visual impairment. However, alone, they do not predict visual function and thus perceptual abilities. Many objective and subjective factors must be taken into account, that are related to viewing conditions and task requirements, such as a low lighting, contrast sensitivity and crowded complex scene, ...etc. Under these conditions, we aim to understand how perceptual abilities of a global or detailed scene are

affected by peripheral or central vision loss or both. In our study, results indicate that participants with blurred vision and central vision loss were able to recognize an interior global scene, nevertheless with a longest answer time compared to the control group. This result is in agreement with previous studies conducted with sighted participants with a simulated scotoma [17] and patients with AMD [16] on scene recognition of natural vs urban or interior vs outdoor, using photographs. These studies suggest that central vision is not essential for global perception and therefore the performance is equal to that of an image completely seen.

In contrast, perception in case of peripheral vision loss was very difficult. In our experiment three out of four participants with tunnel vision did not succeed to recognize the bedroom and the bathroom during the allocated time of 15 seconds. And when they were requested to reach the alarm clock, they accomplished the task with a longest time compared to the other groups. Larson and Loschky (2009) demonstrate the same result with sighted participants who were asked to recognize photographs with only the central component, while hiding the peripheral information with different degrees of restriction. Their results showed that participant's perceptual abilities were better when peripheral restriction was low.

In the next step of the scenario, we investigated the impact of low vision on details perception. We asked participants to read the time in the bedroom and to list several objects in the bathroom. Our results show that times to execute the task are longer with central scotoma and blurred vision compared to the control and tunnel vision groups. However, participants with a central scotoma have a lower success rate, compared to the other groups. Only two out of four participants with tunnel vision gave a good answer in the allocated time of 60 seconds. Several works have pointed the impact of central vision in detail perception. In the bedroom, participants with central vision loss felt difficulty to read the time displayed on the alarm clock and reported having difficulty perceiving needles on a little contrasted background. In the bathroom, only 3 participants with blurred vision and one participant with a central scotoma succeeded in the task: recognition of eight objects on a small shelf. Studies conducted on objects recognition, such as animals in natural scene, showed that, perception performances of participants with a central vision loss were reduced with the decrease in contrast level [16, 17]. In the same manner, studies with sighted participants showed that performance is also dependent of the light level, however for the visually impaired people it is very difficult to provide standardized optimal levels due to many factors such as inter-individual differences, age, and the task [26]. Other studies with AMD patients showed their difficulty to find objects (e.g., lamp, coffee cup, bicycle, animals), especially when located in a crowded environment. Results from these studies showed that these patients recognize objects easily when they were presented in an isolated manner [4, 18, 27]. In our experiment, we suggest that the lack of contrast and the high level of lighting reduced the perception ability in case of low vision. Indeed, adaptations, such as reducing the

light and contrast enhancement, lead to perception improvement for most participants with low vision. However, for participants with peripheral loss, the adaptations proposed in our study present limitations.

Our results show a large variability of the performance among participants with low vision, according to visual deficiency, task features, and environmental conditions. The age of the control group may be considered as a limitation in our study, if we assume that young healthy adults are more efficient than older healthy people. This issue will be checked in a further study.

V. CONCLUSION AND FUTURE WORK

Scene and objects recognition have been studied in the literature on the basis of isolated photographs display, and a significant drop of performance was reported in case of central and/or peripheral vision loss. In our work, we aimed to assess in which manner these processes are affected while performing simulated tasks, being immersed in a virtual environment, close to indoor conditions of real life. Besides, as contrast and lighting are essential factors in objects or scene recognition improvement, we tested them through the use of SENSIVISE tool. Results were inconclusive except in case of peripheral vision loss, due perhaps to a very narrowed visual field. More investigations should be conducted with a larger number of participants representing the visual impairment studied in this work.

We are currently analyzing the quantitative and behavioral outcomes of our study, and we are investigating the supplements they provide to the understanding of the impact of visual impairment on abilities and behaviors. We think that using SENSIVISE tool, low vision professionals may explore ways to more accurately evaluate low vision whose assessment currently largely focuses on visual acuity. Better understanding of the relationship between lighting and contrast adaptations in objects or scene recognition may lead to improvement of rehabilitation of visually impaired people, and to better adjustment of the environment in order to prevent domestic accidents, and to increase quality of life through a best spatial perception.

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