Spatial navigation with a simulated prosthetic vision in a virtual environment

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Abstract

Blind people experience great difficulties to navigate in complex environment. Micro-navigation problems could be partially solved by learning mobility skills and how to use a white cane or a guide dog, but macro-navigation problems are more difficult to solve despite the variety of existing assistive devices. Most of these devices are based on satellite positioning, which is not available in street canyons and inside buildings. To help restore these navigation functions, missing visual information could be restored though a visual neuroprosthesis. Retinal implants are presently tested in clinical trials and first results show that they can elicit precisely localized visual perceptions (white/yellow dots called phosphenes). Experiments with these early implants are evaluating the visual functions -such as reading- that could be restored with a low number of electrodes. Very few studies are performed on the navigation capabilities that could be restored by these implants, probably for practical as well as safety reasons.

Here, we used simulated prosthetic vision (SPV) to investigate the navigation capabilities that could be restored through two different stimulation strategies. The first strategy consist in a reduction of the environment view to match the number of electrodes in the simulated retinal implant (defined as the scoreboard approach). The second strategy is relying on an object recognition algorithm (here simulated) in order to present recognized elements only (defined as the object recognition and localization approach). Six subject participated in the experiment. They were wearing a head mounted display to perceive phosphenes as seen by a retinally implanted blind person. In a virtual indoor environment, the subjects were following a path indicated by short verbal instructions. They were guided by the visual cues produced by the neuroprosthesis and their instruction was to navigate as fast and accurately as possible. The average time to complete the path was nine minutes for the localization approach and six minutes for the scoreboard approach. This difference was only marginally significant as one subject showed an opposite pattern compared to the others. Additional measurements from the experiments demonstrate that the scoreboard approach is more effective than the localization approach to navigate in indoor environments.

1. Introduction

Electrical stimulations of visual structures in order to restore vision has been started in the late 60's (Brindley & Lewin 1968). Patients implanted with an array of electrodes in the visual system report the perception of reproducible white spots in the visual fields (called phosphenes) after stimulation. Many stimulation sites have been explored, from the primary visual cortex (Dobelle & Mladejovsky 1974), to the optic nerve (Veraart et al. 2003) and the retina (Humayun et al. 1996). Nowadays, the more advanced research is related to retinal implants (see e.g Second Sight implants, Sylmar, California). 30 patients worldwide are currently implanted with the ARGUS II array (6*10 electrodes) for a clinical trial. The ARGUS III[1] retinal implant is currently under development (200+ electrodes array). However, because of the very low resolution of implanted arrays (60 pixels to be compared to the resolution of the biological retina), these neuroprosthesis are not currently usable. And, it is very difficult to design additional extensive experiments because of the small number of implanted patients.

In order to systematically explore the usability of such low resolution prosthetic vision, it is possible to rely on simulated prosthetic vision protocols. This system usually consists in a camera mounted on a virtual reality helmet. Sighted subjects have to perform various tasks in the absence of natural vision, while wearing the head mounted display. In the helmet, they only perceive a set of white spots mimicking the percepts elicited by a visual neuroprosthesis.

Simulated prosthetic vision is easy to design and can evolve to match the resolution of future neuroprosthesis. In a series of experiments, the image from a camera was displayed on a screen that was masked by an opaque perforated film in order to simulate the perception of a cortically implanted patient (Cha, Horch & Normann 1992b). The team performed ophtalmologic tests and measured the reading speed at different grid resolutions (Cha, Horch, Normann, et al. 1992). They also performed a mobility experiment (Cha, Horch & Normann 1992a) along a small indoor path with obstacles. After this first attempt, different teams created simulated prosthetic vision systems. They mainly focused on reading speed, object localization and grasping movements. A few experiments on navigation were performed, but the weight, the size and the power supply of the system prevented further investigations on navigation in real environments.

Navigation is one of the major issues for blind people. Indeed, it greatly relies on visual or visuomotor processes (for example the memorization of landmarks and routes) that must be replaced in absence of vision. Thorndyke showed that blind people are able to build functional cognitive maps (Thorndyke & Hayes-Roth 1982). However, it is still unexplored if spatial cognition processes would be abolished, preserved or enhanced with a visual neuroprosthesis. We designed a simulated prosthetic vision connected to a virtual environment, which allowed us to systematically study spatial cognition based on prosthetic vision. The main issue is to determine the visual information which has to be presented through prosthetic vision in order to understand the environment and help in navigation tasks.

2. Methods

The experiment we designed compares two different strategies of visual information presentation to a blind patient implanted with a retinal implant. The first approach consists in a simple pixelisation. The resolution of the signal from the camera in the virtual environment was reduced to match the resolution of the -still under development- ARGUS III retinal implant (200+ electrodes array). This method called scoreboard, creates an ultra-low resolution image of the initial camera capture. The second approach relied on a recognition and localization approach. With the recent advances in computer vision algorithms, objects can now be recognized in real time on mobile

1 http://biotechstrategyblog.com/2011/03/argus-iii-is-the-next-generation-of-artificial-retina-from-lawrence-livermore-national-laboratory.html/

devices. When an object is recognized, its location within the camera image becomes available and its position relative to the user can be indicated. It is then possible to restore a sensorimotor loop between the subject and the perceived target. In grasping movements experiments, the object position can be indicated by the presence of one phosphene while all the others are switched off. In this approach, the subject only perceives the location of the target object when detected in the camera field of view. This second approach has been evaluated in an object grasping task (Macé et al. 2011). It is very effective to guide the hand of the user towards a specific object among many others. We made hypothesis that the localization approach could enhance the landmark perception by hiding the useless information, even though the mobility performance would be affected.

(a) Subjects

6 sighted subjects (4 males, 2 females) from 22 to 46 years old participated in this experiment. Every subject used a computer daily. 4 subjects were familiar with the hardware, 2 subjects were completely naïve.

(b) Materials

We connected the simulated prosthetic vision to a virtual environment. In this environment there was an automatic detection of identified objects (like posters or doors) in the field of view of the camera. This detection was used in the localization approach. The subjects navigated in the virtual environment with the arrow keys of a keyboard. Irrlicht 3D rendering engine handled the environment and the subjects' input. The environment was displayed via a head mounted display (Nvisor SX-60, NVIS, Reston, Virginia). An eye-tracker (ViewPoint PC-60, 60Hz Arrington research, Scottsdale, Arizona) was used within the head mounted display to get a gaze-locked visual rendering (the visual stimulus was moving on the helmet screen in accordance with eye movements to stimulate more closely what a blind user would perceive with a retinal implant). 3 main softwares made up the system : the Irrlicht 3D rendering engine, the phosphene renderer and the control board used by the experimenter. The perceptual array, was composed by a grid of 15*18 phosphenes. We decided to simulate an implantation in the central area. The phosphenes were white dots with a gaussian profile. In agreement with the stimulation studies (Humayun et al. 2003), we used a maximum of 8 gray levels which seems to be a perceptual limit with present day retinal implants.

(c) Protocol

Subjects followed simple vocal navigation instructions in order to move in the virtual environment. They were exploring the environment through different visual strategies. The control condition consisted in presenting the environment without any alterations, as it is rendered by the Irrlicht engine (Fig 1 a). It was called the ‘natural approach’. The other visual strategies used the simulated prosthetic vision (Fig 1 b&c). The first one was the scoreboard approach, where the resolution was reduced to fit the 15*18 array of electrodes. The last condition relied on the object recognition and localization approach where only the position of the recognized objects were displayed in the head mounted display. A simple visual code differentiated the objects of the environment (3 phosphenes for a door, 4 for a poster on a wall, etc...).

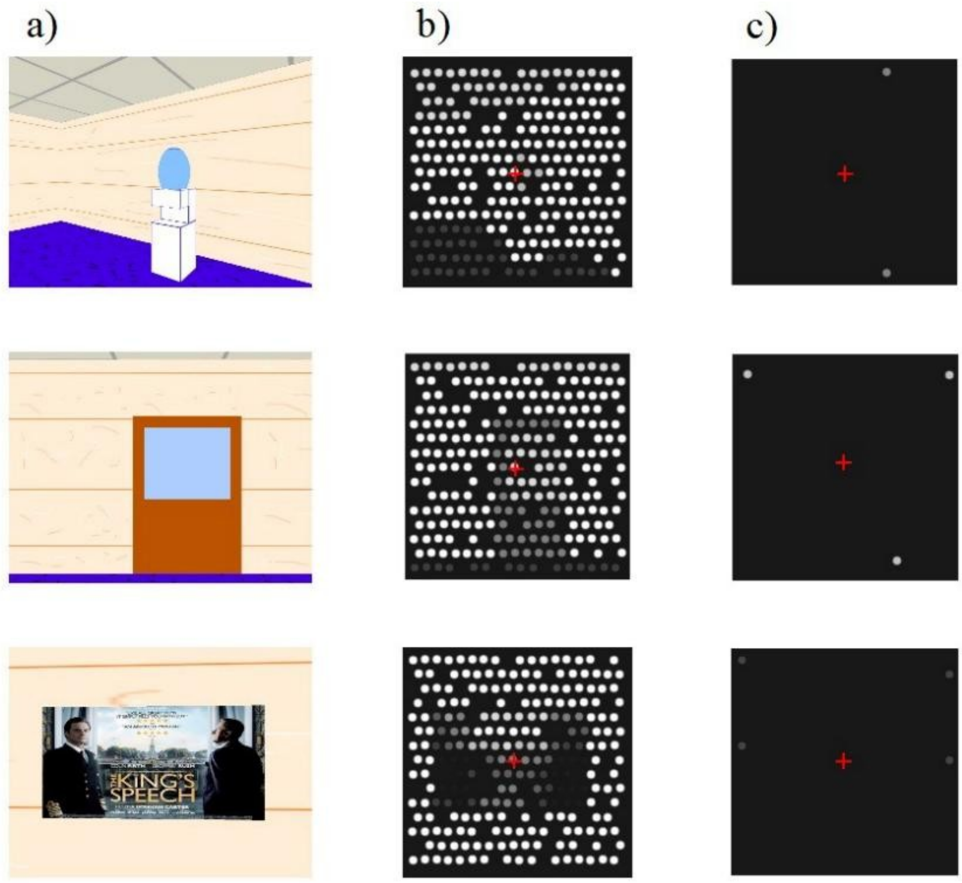

Figure 1 : Objects views in the virtual environment depending on the approach. a) Natural approach b) Scoreboard approach c) Localization approach.

Each itinerary was made of 7 doors that the subjects had to cross. When the subjects crossed a door, instructions were given to reach the next one. Each subject followed 3 different itineraries, one for each condition. Rendering and itineraries were randomized to decrease potential learning effects. Additional help was given to the subjects if they were lost or expressed difficulties. The number of additional helps was registered. The performance was assessed according to the time between crossing the first and the last door as well as the number of collisions with a wall (indicated with a sound). To evaluate the cognitive mapping of the environment, the subjects were asked to draw their route on a map of the environment after each condition. At the end of the experiment they evaluated (on a scale 1 to 5) the difficulty, the comfort and the tiredness for each approach.

3. Results

(a) Qualitative

Four subjects out of six evaluated the localization approach (LOC) as more tiring than the scoreboard approach (SC). Every subject evaluated the localization approach more difficult (average 4.7±0.47) than the scoreboard approach (average 3.1±0.18). No differences were found between the LOC drawings and the SC drawings. In the additive remarks, the subjects pointed out the difficulty to understand the environment in the LOC condition.

(b) Quantitative

All the results are presented as mean±standard deviation. The average time to complete the itinerary in LOC (551.6±154.1 sec) was longer than the average time in SC (324.5±154.6 sec). Both of these conditions were longer than the control condition (97.5±21.1 sec). In LOC, subjects used 10.7±6.8 helps. In SC, one subject used 6 helps, and none for the others. A Wilcoxon test (Z=2.023, p=0.043) showed that the number of helps is significantly higher in LOC than SC. In SC, subject didn't collide with any walls. In LOC, subjects frequently hit the walls (min=23; average 96.7±88.5).

4. Discussion and perspective

In this exploratory experiment, the main objective was to anticipate the development of neuroprosthesis and explore how wayfinding may be enhanced with advanced phosphene rendering. The 'localization' approach which seems very promising to identify and grasp objects in the peri-personal space did not seem particularly adapted to a navigation task. According to the results, it induces a lot of confusion as the subjects needed active help and were longer to complete the task. In addition 4 out of 6 subjects evaluate the localization approach as more tiring than the scoreboard approach. These results lead us to conclude that the localization approach is less effective than the scoreboard approach for a navigation task.

However, the results of the scoreboard approach will tend to be more impaired than those of the localization approach as the simulation of the retinal implant takes into account additional characteristics from real implants such as noise on the phosphenes shape and brightness level. In addition, the virtual environment was very simple compared to a real environment. Strong contrasts were present between the floor, the walls and the ceiling. Therefore, in the scoreboard approach, it was easier than in reality to discriminate these structures that are essential to correctly execute a navigation task. In a real environment, contrasts are weaker and the scoreboard approach would probably not be as effective. For the localization approach, a few types of objects were recognized and displayed to the subjects. The repetition of these objects in the virtual environment was confusing the subjects and they were rapidly lost. A solution could be to further reduce the amount of information presented to the user by limiting to one or two objects presented at the same time.

5. Bibliography

Brindley, G.S. & Lewin, W.S., 1968. The sensations produced by electrical stimulation of the visual cortex. *The Journal of physiology*, 196(2), pp.479–93. Available at: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=1351724&tool=pmcentrez&rendertype=abstract [Accessed August 6, 2011].

Cha, K., Horch, K.W., Normann, R.A., et al., 1992. Reading speed with a pixelized vision system. *Journal of the Optical Society of America. A, Optics and image science*, 9(5), pp.673–7. Available at: http://www.ncbi.nlm.nih.gov/pubmed/1588454.

Cha, K., Horch, K.W. & Normann, R.A., 1992a. Mobility performance with a pixelized vision system. *Vision research*, 32(7), pp.1367–72. Available at: http://www.ncbi.nlm.nih.gov/pubmed/1455709 [Accessed September 20, 2011].

Cha, K., Horch, K.W. & Normann, R.A., 1992b. Simulation of a phosphene-based visual field: visual acuity in a pixelized vision system. *Annals of biomedical engineering*, 20(4), pp.439–49. Available at: http://www.ncbi.nlm.nih.gov/pubmed/1510295.

Dobelle, W.H. & Mladejovsky, M.G., 1974. Phosphenes produced by electrical stimulation of human occipital cortex, and their application to the development of a prosthesis for the blind. *The Journal of physiology*, 243(2), pp.553–76. Available at: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=1330721&tool=pmcentrez&rendertype=abstract [Accessed September 16, 2011].

Humayun, M.S. et al., 1996. Visual perception elicited by electrical stimulation of retina in blind humans. *Archives of ophthalmology*, 114(1), pp.40–6. Available at: http://www.ncbi.nlm.nih.gov/pubmed/8540849 [Accessed August 22, 2011].

Humayun, M.S. et al., 2003. Visual perception in a blind subject with a chronic microelectronic retinal prosthesis. *Vision research*, 43(24), pp.2573–2581. Available at: http://www.sciencedirect.com/science/article/pii/S0042698903004577 [Accessed December 6, 2011].

Macé, M.J.-M., Guivarch, V. & Jouffrais, C., 2011. Brain-computer interface for the blind: The benefits from a computer-based object recognition approach. *Perception*, 40, p.51. Available at: http://www.perceptionweb.com/abstract.cgi?id=v110567.

Thorndyke, P.W. & Hayes-Roth, B., 1982. Differences in spatial knowledge acquired from maps and navigation. *Cognitive Psychology*, 14(4), pp.560–589. Available at: http://dx.doi.org.gate6.inist.fr/10.1016/0010-0285(82)90019-6 [Accessed March 22, 2012].

Veraart, C. et al., 2003. Pattern recognition with the optic nerve visual prosthesis. *Artificial Organs*, 27(11), pp.996–1004.