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Minireview

Simulating prosthetic vision: II. Measuring functional capacity

Spencer C. Chen [a,b,*], Gregg J. Suaning [a], John W. Morley [b,c], Nigel H. Lovell [a]

[a] Graduate School of Biomedical Engineering, University of New South Wales, Kensington 2052, Australia
[b] School of Medicine, University of Western Sydney, Penrith, NSW 1797, Australia
[c] School of Medical Sciences, University of New South Wales, Kensington 2052, Australia

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ABSTRACT

Investigators of microelectronic visual prosthesis devices have found that some aspects of vision can be restored in the form of spots of light in the visual field, so-called "phosphenes", from which more rich and complex scenes may be composed. However, questions still surround the capabilities of how such a form of vision can allow its recipients to "see" and to carry out everyday activities. Through simulations of prosthetic vision, researchers can experience first-hand many performance and behavioral aspects of prosthetic vision, and studies conducted on a larger population can inform the performance and behavioral preferences in general and in individual cases. This review examines the findings from the various investigations of the functional capacity of prosthetic vision conducted through simulations, especially on the topics of letter acuity, reading, navigation, learning and visual scanning adaptation. Central to the review, letter acuity is posited as a reference measurement so that results and performance trends across the various simulation models and functional assessment tasks can be more readily compared and generalized. Future directions for simulation based research are discussed with respect to designing a functional visual prosthesis, improving functional vision in near-term low-phosphene-count devices, and pursuing image processing strategies to impart the most comprehensible prosthetic vision.

1. Introduction

The human implantation of a visual prosthesis device by Brindley and Lewin in 1968 saw the successful elicitation of artificial visual perception, so-called "phosphenes", described as spots of light "the size of a grain of sago at arm's length" or "like a star in the sky". Similar visual sensations have been confirmed in subsequent human trials of past and modern visual prosthesis devices (for example, Brindley & Rushton, 1974; Dobelle 2000; Dobelle, Mladejovsky, & Evans, 1976; Dobelle, Mladejovsky, & Girvin, 1974; Humayun et al., 2003; Richard, Hornig, Keseru, & Feucht, 2007; Richard et al. 2005; Rushton & Brindley, 1978; Veraart et al., 1998; Zrenner et al., 2006, 2007). Elicitable in various sizes, luminance intensity and shapes, this rudimentary form of restored visual perception is considered to be the fundamental building block for creating visual scenes filled with rich and complex patterns described as "prosthetic vision".

Nevertheless, vision is more than the mere perception of spots of light in various sizes, luminance and shapes. A visual prosthesis may be able to elicit visual percepts from electrical stimulation at the retina, optic nerve or at the primary visual cortex, but the problem of visual comprehension lies in how the implant recipient interprets such information.

Using an idealized simulation of prosthetic vision as an example (Fig. 1), amongst many things, the most noticeable feature is the discreteness of the phosphenes; there are large gaps with no visual information in between the phosphenes, as opposed to a perceptually continuous visual image in normal vision. Consequently, separation of groups of phosphenes portraying one object over groups of phosphenes portraying another is required. In addition, current technology limits the elicitation of one or only a handful of phosphenes at any one instance, and even if all phosphene can be simultaneously perceived, the limited number of stimulating sites results in very low-resolution vision, the phosphenes are unevenly distributed over a reduced field of view, and the dynamic range of phosphenes limits the contrast presentable.

Many questions still surround how to best utilize such a form of vision to present an understandable visual perception. An intimately related problem is the training and rehabilitation routines to assist recipients in gaining the maximum benefit from a visual prosthesis device. Past attempts at developing aids for the blind by converting visual into auditory or tactile form has resulted in low acceptance due to the difficulty in interpreting the converted signals (Hungenahally, 1995). Therefore, it is crucial that prosthetic vision be approached from the functional

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* Corresponding author. Address: Graduate School of Biomedical Engineering, University of New South Wales, Kensington 2052, Australia. Fax: +61 (2) 9663 2108.
E-mail address: S.Chen@unsw.edu.au (S.C. Chen).

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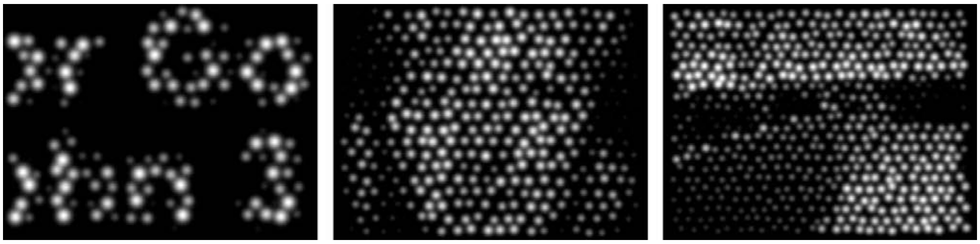

Fig. 1. Examples of phosphene vision. Left: Some text. Middle: A female face. Right: An office area.

point of view, acquiring information from the behavioral, psychological, perceptual and cognitive domains, so that the most comprehensible visual presentation and most effective rehabilitation routines can be formulated.

This review examines the methods by which researchers, using simulation studies of prosthetic vision, have assessed the level to which recipients can see and perform tasks. Two shortcomings of the current research are identified. Firstly, there needs to be better interoperability in the results between research groups, the various different forms of assessment techniques and prosthetic vision simulation models. Improved interoperability will allow researchers to more clearly describe the trends in functional prosthetic vision with respect to various contributing factors, rather than to simply view each investigation as a separate case study. Secondly, more attention is required in designing assessment protocols in light of the considerable learning trends observed in many SPV studies. Investigators should pay special attention to behavioral modification such as head and eye scanning movements. Finally, in the concluding section, simulation studies are related back to the need for driving aspects of visual prosthesis design and improving the functional capacity of the recipients implanted with near-term low-resolution devices.

2. Measuring functional capacity of prosthetic vision

Human performance can be assessed using a variety of psychophysical techniques. Psychophysical assessments are tasks designed to identify particular characteristics of human (or animal) perception, cognition and performance by manipulating physical sensory stimuli such as visual displays, sounds, and tactile texture, etc. These tasks are designed so a quantifiable performance measure can be analyzed – such as reaction time, perception threshold, or success rate – so as to reveal the psychological and neural mechanisms underlying the performance response.

In human trials, investigators have been interested in the ability of the implant recipients in recognizing simple characters, objects and patterns, and their ability to manipulate with their environment through hand-eye coordination and navigation tasks (Table 1). They demonstrate that given optimized conditions, implant recipients were able to successfully identify and differentiate between rudimentary patterns and objects, and conduct limited and assisted navigation about a high contrast environment.

The description of the visual perception reported by the implant recipients provides investigators with an opportunity to further study the functional capacity of current devices and devices

Table 1
List of human trials with visual tasks examined.

Year	Author + Notes	Exercises	References
1962	Button and Putnam	Light localization Navigation	Button and Putnam (1962)
1972	Brindley et al.	Visual Braille reading	Brindley and Rushton (1974)
1974	Dobelle et al.	Visual Braille reading	Dobelle et al. (1976)
2000	Dobelle et al. (1978 implants)	Character recognition Letter acuity Mobility	Dobelle (2000)
2001	Dobelle et al. (Portugal implants)	Object localization Navigation Driving a car	Unpublished
2002	Veraart et al.	Pattern recognition Orientation discrimination Object localization Object discrimination Hand-eye coordination (grasping)	Delbeke et al. (2002), Veraart et al. (2003), Veraart, Duret, Brelen, and Delbeke (2004), Brelen et al. (2005), Duret et al. (2006)
	Humayun et al.	Light detection Light localization Motion detection Object detection Object counting Object discrimination Orientation discrimination Movement direction detection	Humayun et al. (2003, 2004), Weiland et al. (2003, 2004), Yanai et al. (2007)
2007	Second sight (Argus II)	Movement direction identification Object localization	Ahuja et al. (2009), McMahon et al. (2009)
	Zrenner et al.	Letter acuity Orientation discrimination	Wilke et al. (2009), Zrenner et al. (2009)