

Features of multiple phosphenes resulting from combined electrical stimulations of the optic nerve

C. Laloyaux, C. Archambeau, V. Lambert, J. Delbeke, B. Gérard & C. Veraart
Neural Rehabilitation Engineering Laboratory,
Université catholique de Louvain (UCL),
Avenue Hippocrate, 54 / GREN-54 46 / B-1200 Brussels, Belgium
E-mail: Cedric.laloyaux@gren.ucl.ac.be

Abstract

This study aims at understanding the perceptual effect of combined stimulations of a human optic nerve. Phosphenes were obtained by electrical stimulations through a 4-contact spiral cuff electrode previously implanted around the right optic nerve of a completely blind retinitis pigmentosa patient.

Simultaneous, interlaced or sequential stimulations resulted in the perception of multiple phosphenes whereas on single train stimuli, the patient usually perceived only a single phosphene. Moreover, when comparing the different types of combine stimulations, the synchronous paradigm more often yielded the corresponding expected number of phosphenes. A proper understanding of the rules governing these combination effects is essential to the development of pattern recognition abilities with a prosthesis system.

1. Introduction

Electrical stimulations of a human optic nerve have been attempted in the frame of two European projects (Optimization of a Visual Implantable Prosthesis' or OPTIVIP project which is in the continuity of the MIVIP project) [1, 2, 5 & 6].

When the optic nerve was stimulated through a four contact spiral cuff electrode, the patient perceived visual sensations in her visual field [6]. Such visual sensations, elicited in the absence of any light activation, are defined as phosphenes.

A model, based on physiological parameters of the optic nerve, has also been described and validated. This model predicts the localization, size and luminosity of phosphenes for single contact stimulations [3].

In previous investigations, a single contact was generally used to deliver the stimulation. Here we report on stimuli applied either synchronously, or with interleaving pulses or yet in rapid succession through several contacts and some preliminary results have already been provided [4].

2. Material and method

A spiral cuff nerve electrode was chronically implanted around the optic nerve of an retinitis pigmentosa completely blind volunteer and little charges of currents on the optic nerve produced phosphenes that the volunteer was able to describe accurately. Details about the blind volunteer and the implanted electrode have been provided previously [6]. The stimulations were composed of trains of charge balanced rectangular biphasic pulses with a charge recovery duration five times longer than the initial cathodic phase. The charge per phase was always kept under 100 nC/phase with a contact area of 0.2mm² [6].

The volunteer described the phosphenes she perceived when pointing the center of a Plexiglas hemisphere with her left index finger. She drawn the shape of the elicited phosphenes with her right hand. The number of phosphenes was mostly based on her description. For example, when she described two distant vertical bars at a distance one from the other, we considered that these were two different phosphenes.

More than 1200 description of stimulations effects were recorded and processed. The different parameters which varied were: number of pulses, pulse duration, frequency, and activated contact. A combination of one to four contacts could be activated in one stimulation frame. Each frame was arranged in synchronous, interlaced or sequential pulse trains. Pulse duration, pulse number and train frequency were kept identical for all pulse trains within a frame. Pulse duration were: 21.3, 42.6, 63.9 or 85.2 μ s; pulse number were: 1, 2 or 3; train frequency were: 60, 80 or 100 Hz.

Combined electrical stimulations were as follows: a stimulation was synchronous if the nerve was stimulated through 2, 3 or 4 contacts exactly at the same time. In the interlaced scheme, 2 or 3 stimulation trains were time-shifted so that their individual pulses were interlaced. Several shift times were used. For technical reasons, four contacts interlaced stimulations were not allowed. In a sequential stimulation, the first pulse of a second train followed the last pulse of any forerunner with a delay corresponding to the period of the train frequency.

3. Results

We computed a two way analysis of variance. The “number of contacts stimulating the nerve” N_c (2, 3 and 4) and the “type of combination” T_s (synchronous, interlaced and sequential) were chosen as independent variables, whereas the “Number of phosphenes” N_{ph} was chosen as dependant variable. Single contact stimulations were not considered here because the aim was to compare the three types of multiple stimulations. The results are thus based on 896 descriptions of stimulations.

We obtained a main effect for the ‘Number of contacts’ N_c [$F(2,888)=96.897;p<0.0001$] and for the ‘type of combination’ T_s [$F(2,888)=69.026;p<0.0001$]. We also observed a significant interaction between these two variables [$F(3,888) = 6.693;p<0.0001$]. These results mean, as figure 1 emphasizes, that the more the contacts stimulating the nerve, the more the synchronous stimulation elicited multiple phosphenes.

We also computed pairwise comparisons for the different number of contacts stimulating the nerve. All these conditions were significantly different ($p<0.001$). For the type of combination, the pairwise comparisons were significant between synchronous summation and the two others ($p<0.0001$) but not between interlaced and sequential stimulations. This means that, as suggested in figure 1, the synchronous stimulation produced more phosphenes than interlaced or sequential stimulations.

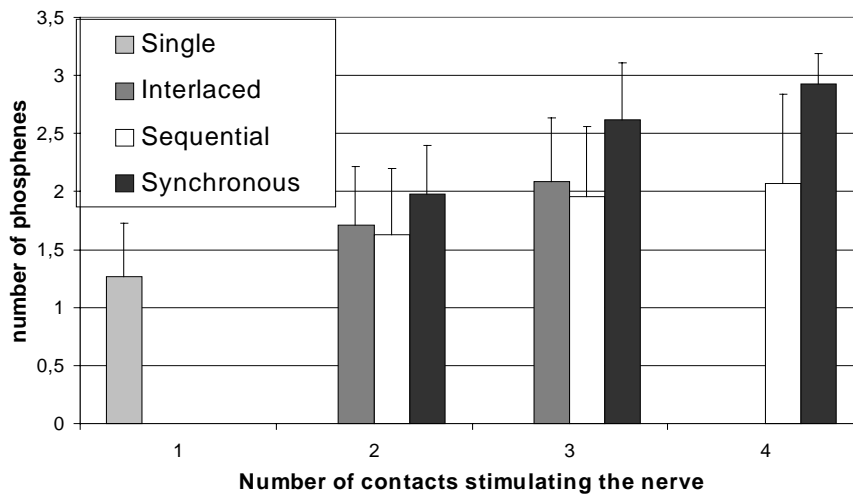


Fig. 1: Number of phosphenes as a function of stimulation characteristics

We also studied the phosphenes position depending on the combined stimulations because the eccentric character of phosphenes might be important for a visual field as large as possible. For this, we focused on the two-contact stimulations and we computed a mean eccentric value for the phosphene(s) produced. There were almost 400 two-contact stimulations from where two groups of data were extracted: a central one composed of the first quartile of eccentricity measurements and an eccentric one composed of the last quartile. Then, we compared the repartition of ‘eccentric’ and ‘central’ phosphenes according to the type of combinations as illustrated in fig. 2: synchronous stimulation produced more central phosphenes than the two other kind of stimulations [$\chi^2(2) = 11.9082 ; p<0.01$].

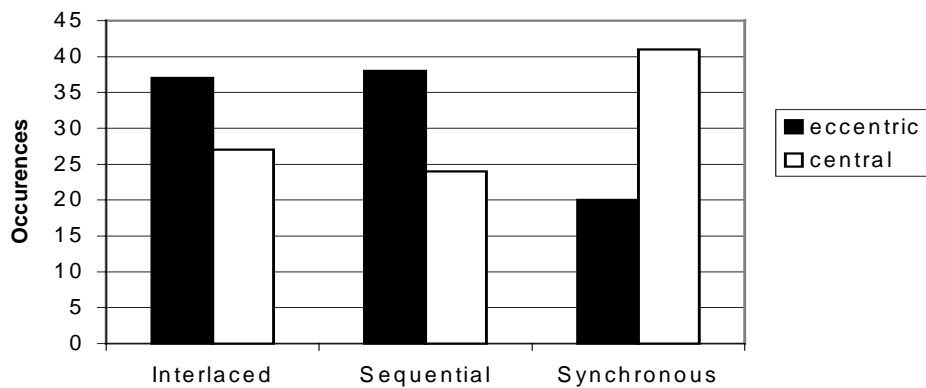


Fig 2 : Distribution of phosphenes eccentricity as a function of stimulation

4. Conclusion

This study clearly shows that the synchronous stimulation produces more phosphenes than the two other forms of combined activation but that these synchronous phosphenes are more central. However, this more central location might depend on lower perception thresholds with synchronous stimulation. Lower stimulation intensity with synchronous combination could produce more eccentric phosphenes with still a higher number than for interlaced or sequential combinations. A physiological model [3] predicts that for single-contact stimulations, a stronger current intensity should produce a more central phosphene and maybe that the same mechanism could be verified for synchronous combination.

Acknowledgment

We thank C. Schmitt for his useful help. This work was supported by the Commission of the European Union (OPTIVIP project, Information Society Technology - RTD: IST # 2000-25145) and FRSM Grant # 3.4590.02.

References

- [1] J. Delbeke, D. Pins, G. Michaux, M-C Wanet-Defalque., S. Parrini, and C. Veraart. Electrical Stimulation of Anterior Visual Pathways in Retinitis Pigmentosa. *Invest. Ophthalmol. Vis. Sci.*, 2001, 42: 291-297.
- [2] J. Delbeke, M-C Wanet-Defalque, B. Gérard, M. Troosters, G. Michaux, and C. Veraart. The microsystems based visual prosthesis for optic nerve stimulation *Artificial Organs*, 2002 Mar;26(3):232-4.
- [3] J. Delbeke, M. Oozeer., B. Gérard, and C. Veraart. Comparison between optic nerve activation and related phosphenes. *Invest. Ophthalmol. Vis. Sci.*, 2002, 43(6).
- [4] C. Laloyaux, V. Lambert, J. Delbeke, B. Gérard & C. Veraart. Simultaneous perception of phosphenes generated by direct stimulation of a human optic nerve. *Proc 7th Ann Conf International Functional Electrical Stimulation Society, Ljubljana, Slovenia, June 25-29,2002 (in press)*.
- [5] S. Parrini, J. Delbeke, V. Legat, and C. Veraart. Modelling analysis of human optic nerve fibre excitation based on experimental data. *Med Biol Eng Comput.* 2000 Jul;38(4):454-64..
- [6] C. Veraart., C. Raftopoulos, J.T. Mortimer, J. Delbeke, D. Pins, G. Michaux, A. Vanlierde, S. Parrini, and M-C Wanet-Defalque. Visual sensations produced by optic nerve stimulation using an implanted self-sizing spiral cuff electrode, *Brain Research*, 1998, 813: 181-186