Analysis of Retinal Implants On Object Recognition Using Phosphene Distortion Model in Simulated Prosthetic Vision

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UC SANTA BARBARA Research Mentorship Program

Analyzing Phosphene Distortion

- Over 10 million people are affected by **degenerative retinal diseases** such as Age-Related Macular Degeneration and Retinitis Pigmentosa
- One treatment for these diseases is **Prosthetic Vision**, which stimulates surviving cells to restore vision
- Retinal Implant users perceive **distorted phosphenes** (spots of light), which greatly affects performance in visual tasks
- Develop and run an experiment on object recognition with prosthetic vision using phosphene distortion models
- **Object recognition** task in Simulated Prosthetic Vision with **phosphene distortion model** demonstrates greatly reduced accuracy compared to previous non-distorted models
- PRIMA Retinal Implant simulation provided greater accuracy than Argus II Retinal Implant simulation due to overall lower distortion parameters at equivalent electrode counts
- **Subchoroidal** implants provide greater accuracy than **subretinal** or **epiretinal** implants due to lessened activation of axon nerve fibers along retina
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Prosthetic Vision

What is Prosthetic Vision?

- Prosthetic Vision is a visual device intended to restore functional vision in those suffering from partial or total blindness
- Retinal Prostheses are forms of Prosthetic Vision used to treat degenerative eye diseases
- Retinal prostheses are made of 2 parts: [1]
  - Information collection device (camera)
  - Electrode array which stimulates neuronal cells in inner retinal layers

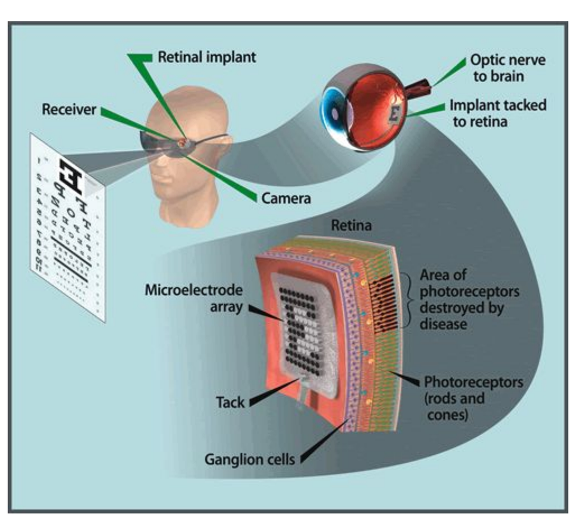

Figure 1: Prosthetic Vision Diagram (U.S. Department of Energy)

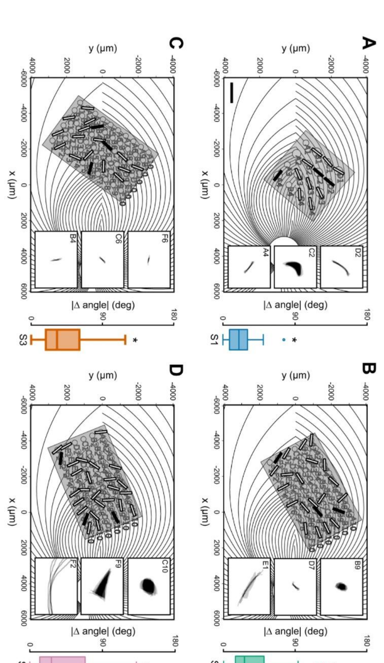

Figure 2: Distorted Phosphene drawings overlaid on Axon Map Model (UCSB Bionic VIsion Lab)

Phosphene Distortion

- Streaks in Phosphenes caused by activation of neuronal cells in optic nerve axon fibers [2]
- The position of electrodes along ganglion axon pathways can determine streak length and orientation [2]
- Past models of prosthetic vision did not consider phosphene distortion, referred to as 'scoreboard model'. [3]

Simulated Prosthetic Vision

- The use of computer-based simulation has been helpful in: [4]
  - understanding what users see
  - experimenting with higher resolutions
  - developing software solutions in order to increase clarity
- Past prosthetic vision simulations did not account for phosphene distortion [5]

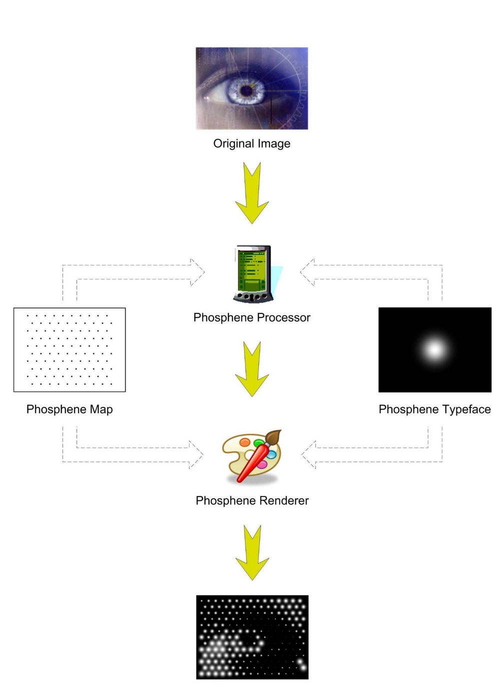

Figure 3: Simulated Prosthetic Vision using Scoreboard Model Diagram (Spencer C. Chen *et al.* 2009)

Developing Object Recognition Task

Coding the Virtual Scene

- Developed in Unity 2021.1.12f1, using C# and ShaderLab software to code the virtual scene and the prosthetic vision simulation filter
- Program captures virtual scene information from camera and processes it into images

Simulating Prosthetic Vision

- Filter takes information from the image and inputs it into an algorithm which produces an electrode array configuration, which is displayed to the viewer
- The important parameters settings involved in producing the electrode array configuration are:
  - electrode array dimensions
  - activation sensitivity orthogonal to the axon (ρ, 'phosphene size and brightness')
  - activation sensitivity along the axon (λ, 'streak length')

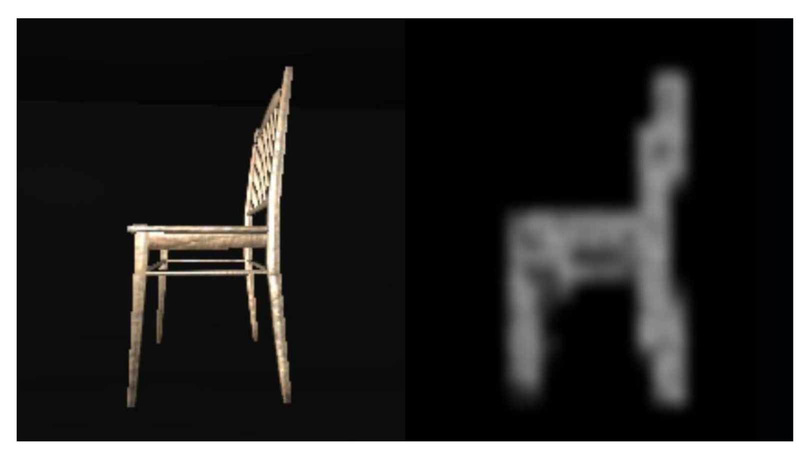

Figure 4: 'Chair' object with prosthetic vision filter turned off (left), 'chair' object with filter turned on (right, filter settings: 31x19 electrode array, ρ = 100, λ = 50)

Running the Experiment

Object Recognition Task

- Asked participants to identify objects 4 times for 30 settings
- 30 settings derived from combinations of different electrode arrays, λ, and ρ values:
  - electrode arrays: 10x6 (250 spacing), 31x19 (350 spacing), 50x50 (350 and 250 spacing), 100x100 (250 spacing)
  - ρ = 100, ρ = 300
  - λ = 50 ('scoreboard', PRIMA), λ = 1000, λ = 5000 (Argus II)
- The ρ value dictates how bright and large a phosphene is, whereas the λ value dictate how long the distortion streak is
- Presented objects were selected from a set of 22 common objects (Figure 5)

Figure 5: The 22 objects presented to participants during 'object recognition' task.

Effects on Accuracy

- Higher λ values (23.75% average decrease) played more significant role compared to higher ρ values (18.33% average decrease)
- On average, difference in accuracy between the scoreboard model and phosphene distortion model was 25% (Figure 6); Participants performed worse in over 80% of the settings with phosphene distortions (Figure 6)

Effects on Completion Time

- At low ρ values, correct answers on average took 16.59% longer for participants viewing objects with distortions applied (Figure 6); Participants took significantly longer to submit correctly in over 45% of settings with phosphene distortions (Figure 6)
- Higher λ values at low ρ values played significant role on completion time (27.93% longer); Higher ρ values did not play a significant role on completion time (8.08% shorter)

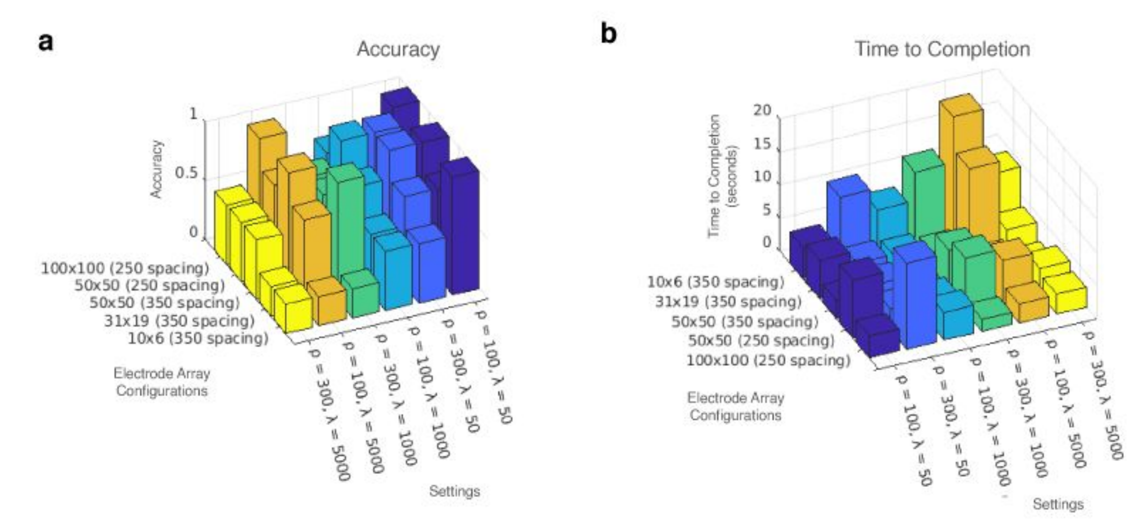

Figure 6: 3D bar graphs of average accuracy (a) and average time to completion for correct answers in seconds (b) as functions of electrode array configurations and ρ and λ settings.

PRIMA Vs. Argus II

- The PRIMA device simulation (31x19 (350 spacing), λ = 50) performs better than Argus II device simulation (10x6 (350 spacing), λ = 5000)
  - 50.00% greater accuracy
  - Took 8.86 fewer seconds to submit correct
- At same electrode counts (31x19 (350 spacing))
  - 25.00% greater accuracy
  - Took 3.68 fewer seconds to submit correct

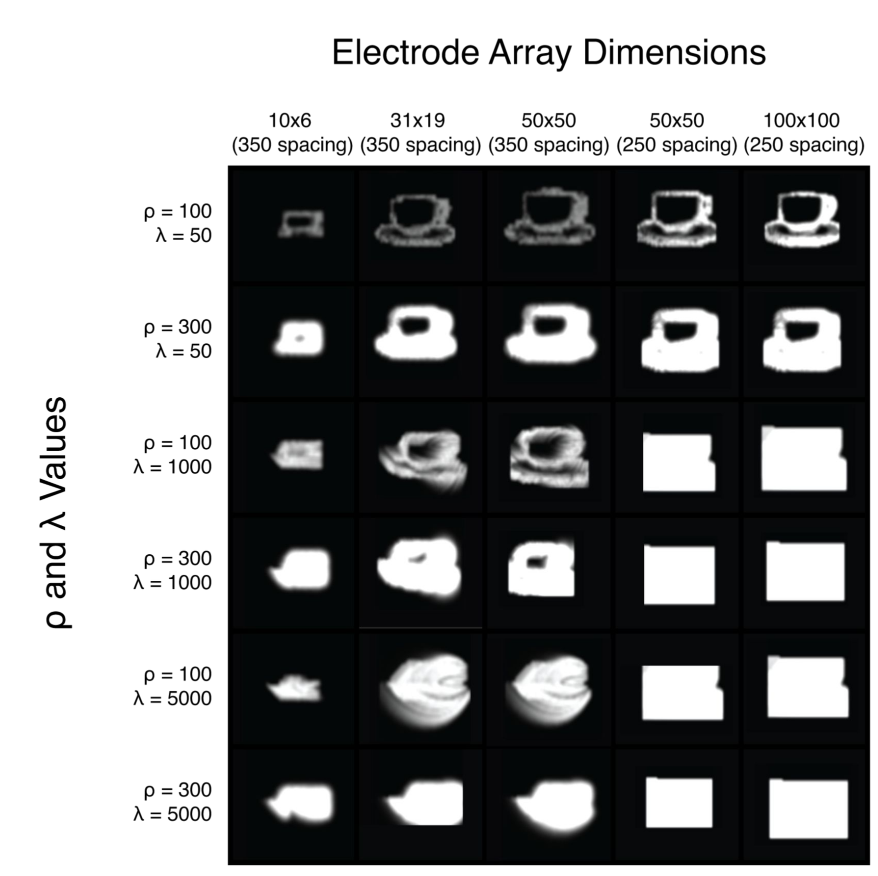

Figure 7: Rendering of 'tea cup' at equivalent distances under prosthetic vision simulation at different electrode array dimensions and ρ and λ values.

Conclusion

Summary

- Phosphene distortions play significant role in hindering the ability to recognize objects
- Increasing electrode array dimensions past 50x50 does not significantly increase object recognition capabilities compared to reducing phosphene distortion

Future Work

- Analyze phosphene distortion effects on other visual tasks
- Design hardware solutions and develop software to mitigate phosphene distortions
- Study phosphene distortion on cortical devices

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References:

[1] Ayton LN, Barnes N, Dagnelie G, et al. "An update on retinal prostheses." *Clin Neurophysiol.* 2020;131(6):1383-1398.
[2] Beyeler M et al. "A model of ganglion axon pathways accounts for percepts elicited by retinal implants." *Sci Rep.* 2019 Jun 24;9(1):9199.
[3] Yanai D et al. "Visual performance using a retinal prosthesis in three subjects with retinitis pigmentosa." *Am J Ophthalmol.* 2007 May;143(5):820-827.
[4] Eiber CD et al. " Attaining higher resolution visual prosthetics: a review of the factors and limitations." *J Neural Eng.* 2013 Feb;10(1):011002.
[5] Chen SC et al. "Simulating prosthetic vision: I. Visual models of phosphenes." *Vision Res.* 2009 Jun;49(12):1493-506.