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Improving human vision through artificial systems considering new capabilities found in animal models

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14. ABSTRACT
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Improving Human Vision through artificial Systems Considering New Capabilities found in Animal Models

Final Report

Period reported: November 2018 - October 2021

PI: Maria-Jose Escobar, Co-PI: Adrian G. Palacios
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Summary

This final report aims to summarize the main findings and research lines aligned with this grant. Unfortunately, given the pandemics, we encountered several concerns for experiments in the avian retina. This is the main reason why we shifted the objectives to the computational part artificially emulating retina response. We continued the efforts to understand retinal computations in mammalian retinas, ranging from predicting behaviors up to neural coding associated with neural assemblies activity. Similarly, we continue exploring one of the third year's goals: developing bio-inspired algorithms for artificial agents. We published one journal paper with a deep reinforcement learning (DRL) architecture that uses retina physiology knowledge to fed the convolutional neural network, avoiding the learning stage in the sensory input. An extension of this work is the proposed bio-inspired retinal architecture for a convolutional neural network to understand retina receptive field formation principles. Similarly, using a real and an artificial video sequence, we recover the emergence of several groups of retinal ganglion cells, all of them paving the entire visual field, following the mosaic structures found in many animal species. This grant has also allowed the team to apply for new research grants to improve retina physiology and cognitive robotics equipment. We now account for a 4096 multi-electrode array system and an iCub robotic platform arriving on January 2022. An essential part of this project is master and Ph.D. students involved in these research initiatives. Also, this grant strengthened our collaborations with other research labs in Chile, USA, and France.

1 Accomplishments

1.1 Research Objectives

This three years project aimed to achieve the following objectives

G1: *Record in-vitro electrical activity of hundreds of RGCs from two diurnal bird models: Columba livia and Gallus gallus domesticus. The retinas will be confronted to different artificial and natural visual stimuli.*

We performed avian experiments in numerous *Gallus gallus domesticus* animals. Nevertheless, retina fragility did not allow us to record evoked light activity of several retinal ganglion cells. We improved the dissection protocol during this research grant up to the pandemic, where we encountered trouble getting new animals or accessing the research labs. In several experiments, we only found uERG activity and pursuing a deeper analysis, a couple of retinal ganglion cells generated it.

The pandemic outbreak did not allow us to exchange practical experience with other labs worldwide. We decided to focus on the computational part of this research proposal, which is specified in the subsequent goals.

G2: *Use techniques of data analysis to classify different functional characteristics and features present in the retina of these two animal models.*

We developed several tools and libraries to process retinal data obtained from the 252-micro-electrode-array system. These tools were part of one of the articles published during the grant period [1], and two others in preparation.

G3: *To detect and to characterize populations of RGCs computing motion features: direction selectivity, differential and approaching motion.*

We characterized populations of retinal ganglion cells as specified in the previous objective (G3). But, since we could not generate new recordings due to the pandemics constraints, motion analysis could not be further implemented.

G4: *Simulate, in real-time, an artificial retina behaving according to the functional types previously encountered in the two animal models.*

Using retinal data previously recorded in rodents' retinas, we were able to simulate artificial neural networks emulating retinal ganglion cells responses. For this, we implemented two different types of networks trained by white noise visual stimulus and temporal variations obtaining models that could be used in several computational applications.

Furthermore, we also studied emerging properties in the retina given several networks and input constraints, such as signal-to-noise ratio or the level of compression in the optic nerve. The results obtained in this line are currently in preparation for a journal paper.

G5: *Implement an enhanced visual system in an artificial agent (such as a robot) and evaluate its performance in different navigation tasks to reveal the advantages of different visual front-ends.*

Also, using the linear models of rodents' retinal ganglion cells, we build a bio-inspired visual sensor to guide the navigation of an artificial agent in a complex environment. This bio-inspired visual sensor was inserted in a deep reinforcement learning architecture, obtaining promising results speeding up the learning rate and increasing the global collected reward [2; 3].

The challenge is to use the artificial neural networks trained with retinal data to guide agent navigation in complex environments. Moreover, the arrival of the iCub platform will provide a promising platform to test the bio-inspired visual sensors developed along with this research grant.

1.2 Research activities during the grant

1.2.1 Avian retina physiology

The first year of the project was focused on data acquisition and the development of computational and technical tools to stimulate and record retina activity in rodents and birds with a high temporal resolution (over 100fps). According to this, we progressed on:

1. We have mounted the setup to dissect and record avian retina activity.
2. We have established stimulation protocols following scotopic spontaneous activity, photopic spontaneous activity, light flashes, white noise, and chirp (see Fig 1). Besides, we tested several optical filters finding the highest uERG activity with ND2.
3. We have dissected several retinas being able to record uERG and spiking activity of some retinal ganglion cells.

During the next period, considering the pandemic outbreak, we improved the retinal dissection procedure for MEA preparation to obtain light-evoked responses. The last dissection was on March 13th, 2020, observing only uERG signal but no spikes. Being able to record the uERG, which is light-evoked and represents the activity of the retina's first cell layers (photoreceptors and bipolar cells), is an important signal indicating the retina's healthy state. Nevertheless, the absence of action potential suggests the electrical contact of retinal ganglion cells (RGC) with the electrodes could be not tight enough. This could be due to the presence of vitreous humor or not enough pressure on the micro-electrode array.

The waveforms obtained from the uERG recordings were observed for rodents and avian retinas (see Fig. 1 and 2) under a visual stimulus of frequency-modulation (see chirp in Fig. 4A). Additionally, a spectrogram of the recordings was obtained to see the light-evoked oscillatory response capacity of both retinas.

A considerable decrease in the amplitude of the signals from bird retinas was observed. It is also expected that superposition signals will be seen since each entity (electrode) is measuring the light-evoked response from multiple cells, a situation that occurs recurrently in the analyzed records of the rodent's retinas but not in the avian ones. The spatial distribution of the electrodes that captured uERG of amplitudes over a threshold (10 uV) as shown in Fig. 3 was analyzed, and due to the absence of superposition signals in the bird records, it is feasible to conclude that the highlighted entities are measuring the same cell or the same couple of cells.

1.2.2 Retina inspired visual sensor for artificial agents

Aligned with **G5**, we proposed a visual system front-end using retinal features encountered in the **rodent retina** (*Octodon degus*)[4]. The bio-inspired visual sensor was inserted in an artificial agent guided by a deep reinforcement learning architecture.

An extended version of this approach was accepted and published in the IEEE Latin America Transactions:

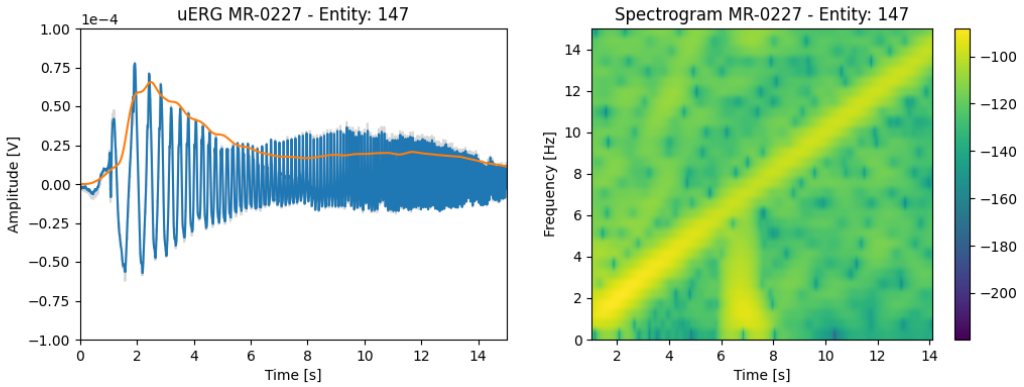

Figure 1: Signal captured by an entity of the MEA for the rodent retina from a frequency-modulated visual stimulus. (*left*) Light-evoked uERG signal. (*right*) Spectrogram of the signal obtained.

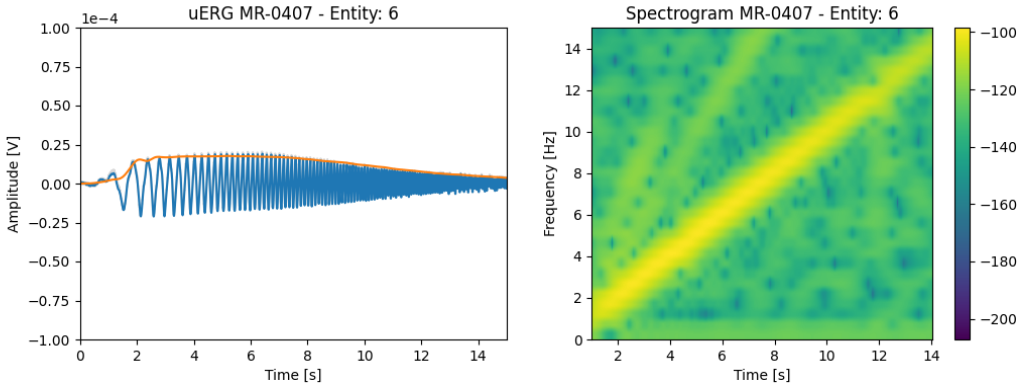

Figure 2: Signal captured by an entity of the MEA for the avian retina from a frequency-modulated visual stimulus. (*left*) Light-evoked uERG signal. (*right*) Spectrogram of the signal obtained.

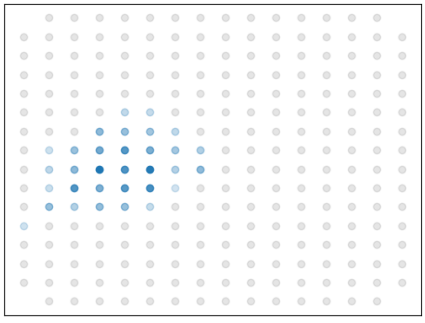

Figure 3: Entities of the MEA where the power of the signals captured for the frequency-modulated stimulus is concentrated. Transparency indicates lower intensity.

+ Lenhert H., Araya M., Carrasco-Davis R., Escobar M.J. (2020). Bio-Inspired Deep Reinforcement Learning for Autonomous Navigation of Artificial Agents. IEEE Latin America Transactions, Vol. 18, No. 12, pp 2028-2035. DOI: 10.1109/TLA.2019.9011549.

Getting inspired by the retina computations to implement visual sensors for an artificial agent, we implemented a neural network to emulate the temporal course of RGCs response. To do this, we firstly clustered the different RGCs, and then, we implemented an LSTM neural network to reproduce these cell responses.

We considered the RGCs responses to the chirp stimulus (see Fig. 4A), which contains light flashes with variable amplitudes and frequencies. This relatively complex stimulus is widely used to classify retinal ganglion cell types functionally. Considering the cell response to this visual stimulus, we computed several clusters to determine a given cell type's mean response.

We then used a Long-Short Term Memory (LSTM) to reproduce the chirp stimulus's temporal response. Using a total of 70 epochs, we were able to reproduce some cluster's temporal responses, acting as temporal RGCs without spatial selectivity (see Fig. 4B-C). The next step of this research is to emulate all the temporal clusters encountered in the retina and add them spatial selectivity of different zones inside the visual field.

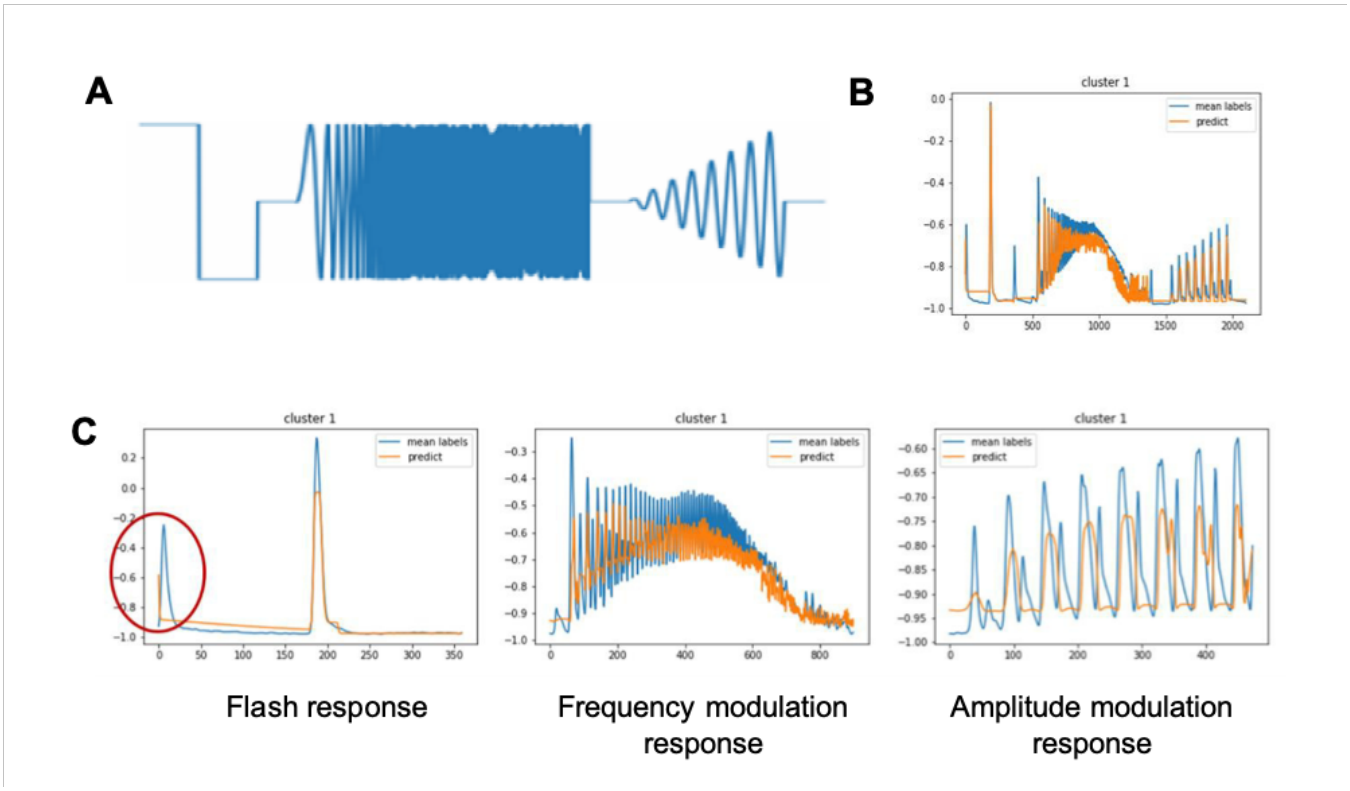

Figure 4: **A** Chirp stimulus used to obtain RGC temporal response. **B** Real response of the RGC cluster (blue) and the simulated response registered by the LSTM network (orange). **C** Details of the different stages of the chirp stimulus and the respective simulated response.

Continuing the track to create an artificially neural network behaving as the mammalian retina, we followed the work of [5] to implement a convolutional neural network reproducing retinal ganglion cells' response to checkerboard stimulus Fig. 5A.

In contrast with Baccus' paper [5], we have a long checkerboard stimulus instead of multiple repetitions of the same one. We generated 10000 sequences of 18 frames to feed the convolutional neural network. We considered 70% of the data for training and the remaining 30% for testing. The network performance is then evaluated considering the number of spikes generated within the 18 frames, i.e., the firing rate for a single cell (one training per cell). Fig. 5B shows the connection weights before (left) and after (right) the training procedures.

After the training, we asked whether it was possible to recover the receptive fields of RGCs from their artificial response. Using the Spike-triggered average (STA) algorithm, we were able to successfully recover the cell's receptive field as it is shown in Fig. 5D

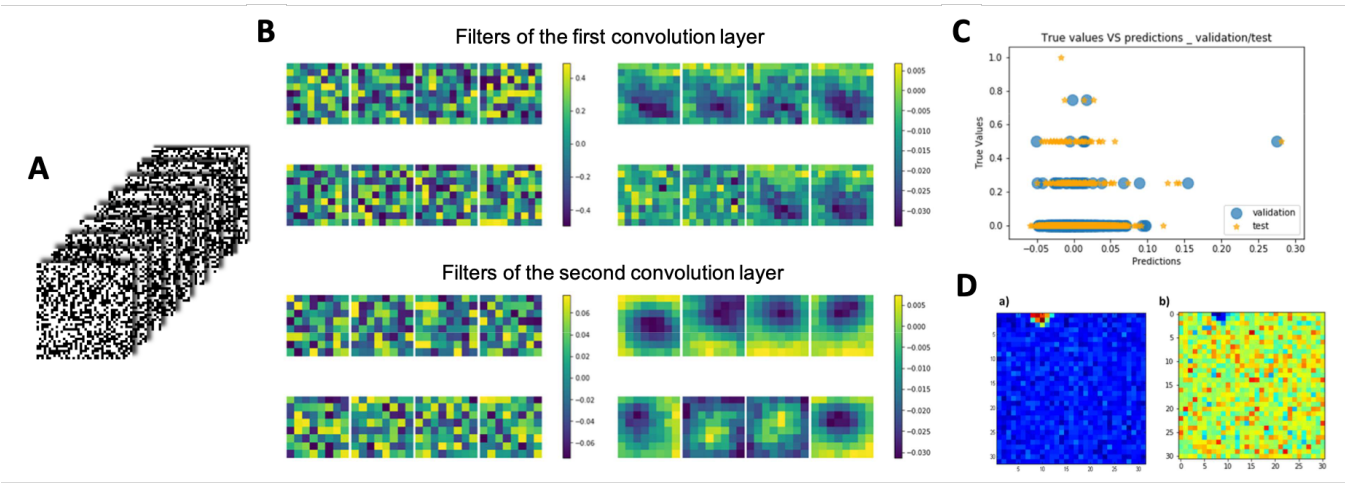

Figure 5: **A** Checherboard input stimulus used to train the artificial retina. **B** Filters obtained for the first and second convolutional layers of the neural network before (left) and after (right) the training. **C** Real (blue) versus artificial (orange) response of a single ganglion cell trained in the convolutional neural network. **D** Real receptive field (left) versus the receptive field obtained from the response of an artificial ganglion cell (right).

1.2.3 Understanding retina computations

An important part to transfer retina capabilities to artificial intelligence algorithms is to understand the principles underlying retina computations. In this case, we are interested in to an **emergent bio-inspired retinal architecture**. The goal is to study the emergence of midget and parasol cells' biological distribution in the retinal layer. The main characteristic of these kinds of cells is the size of their receptive fields (RF) and the frequency components of the time response. Parasol cells have large RF and high-frequency time response, while midget cells have small RF and low-frequency time response [6].

In this research, we hypothesize that it is possible to generate some of these RGCs properties through training by imposing some constraints on the learned parameters and task dependence. For this, we used two types of input stimulus (natural and artificial, see Fig 6) feeding a retinal convolutional layer in an autoencoder architecture similar to [7]. The network is then trained to match the input image with the reconstructed one. After the learning stage, we obtained the input stimulus for each cell in the retinal convolution layer, maximizing its response. Through this mechanism, we computed the cell's receptive fields.

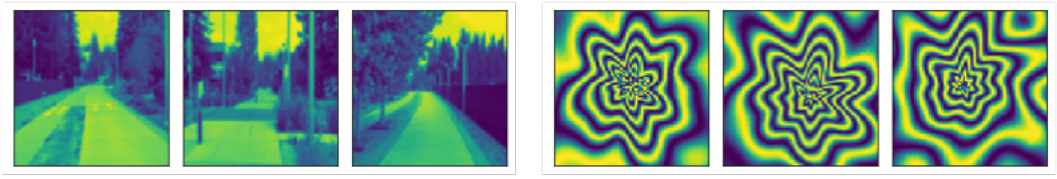

Figure 6: Snapshots of the natural (*left*) and artificial (*right*) stimuli to train the artificial retina network.

We have also explored the effect of the different regularization terms, such as noise and L1-norm. Through this, we can manipulate the impact of noise or the number of activated cells and evaluate the generated RFs. **The results here encountered are currently being part of a manuscript that should be submitted in the following months**:

+ R. Carrasco-Davis, M. Araya, Adrian G. Palacios and M.J. Escobar (2022). Space-Time Frequency Variability in Retinal Eccentricity under First-person View. *In preparation*.

In this second year's grant, we have also invested effort in exploring the retina's prediction capabilities motion. In particular, we are interested in the mechanisms underlying the detection of homogeneous stimulation periodic patterns and events related to these rhythms' disruption.

The omitted stimulus-response (OSR) is a phenomenon that has been described in the RGCs when stimulated with repetitive periodic light patterns. In brief, OSR is a response to a violation of the stimulus's periodicity, and its principal feature is the locking of the responses to a specific range of stimulus period. Similar to literature, our retina experiments report a wide variety of OSR at the single-cell level. For instance, we have encountered cells spiking for the repetition and others when the pattern's

rhythm is violated. From a population point of view, we can group the variety of cell responses in two broad classes: i) one associated with the predictable aspects of the stimuli, like the stimulus's period, and ii) another related to surprising elements of the stimulus, as the periodicity violation. **The results associated with these findings are currently being organized in a manuscript**.

Asking whether the prediction property is a global characteristic of the central nervous system, we performed a similar experiment with EEG measurements and periodic visual stimulus.

This research aims to explore the response's persistence of the visual cortex depending on the stimulus characterization, which is tightly related to neural entrainment. Focusing on alpha oscillations, we hypothesize that the persistence of entrainment is determined by the specific functional state of the entrained neural network at the time the stimulus ends. Visual stimulation consisted of a sinusoidally-varying light terminating at one of four phases: 0, $\pi/2$, π, and $3\pi/2$. The persistence duration of the oscillatory activity was analyzed as a function of the stimulus's terminating phase. Longer persistence durations were obtained when visual stimulation terminated towards the troughs of the alpha oscillations, while shorter persistence durations occurred when stimuli terminated near the peaks. Consequently, different states of the network at the end of the stimulation, corresponding to different states of intrinsic neuronal coupling, may determine the time windows over which the preceding oscillatory activity modulates coding of incoming sensory stimulation.

This research was published during this 2020, imposing an interesting question in the retina: is the retina response depending on the periodic stimulus's termination phase? Is the retina responsible for the persistence variable behavior?

- Otero M., Prado P., Weinstein A., Escobar M.J., El-Deredy W. (2020) Persistence of EEG alpha entrainment depends on stimulus phase at offset. Frontiers in Human Neuroscience, Vol. 14, pp 139. DOI: 10.3389/fnhum.2020.00139

1.2.4 Other collaborations and networking

We propose a novel, scalable, and accurate automated method for detecting neuronal ensembles from a population of spiking neurons. Our approach offers a simple yet powerful tool to study ensemble activity. It allows the participation of neurons in different ensembles, has few parameters to tune and is computationally efficient. We used spike trains of retinal ganglion cells obtained from multi-electrode array recordings under a simple ON-OFF light stimulus to test our method. We found a consistent stimuli-evoked ensemble activity intermingled with spontaneously active ensembles and irregular activity. Our results suggest that the early visual system activity is already organized in clearly distinguishable functional ensembles. To validate the performance and generality of our method, we generated synthetic data, where we found that our method accurately detects neuronal ensembles for a wide range of simulation parameters. Additionally, we found that our method outperforms current alternative methodologies. Finally, we provide a Graphic User Interface, which aims to facilitate our method's use by the scientific community.

- R. Herzog, A. Morales, S. Mora, J. Araya, M.J. Escobar, A.G. Palacios, R. Cofré. Scalable and accurate method for neuronal ensemble detection in spiking neural networks. PloS ONE. *Under Review*.

In collaboration with another research project related to the presence of biomarkers of Alzheimer's disease (AD) in the function of retinal ganglion cells, we explored the possibility to determine whether the 5xFAD transgenic mice, an AD's model, display changes in the function of RGCs during the temporal course of AD, linked to changes in the expression of glutamate (Glu) and gamma-aminobutyric acid (GABA) neurotransmitters.

To prove that, we recorded retina activity from one eye of young (2-3 months) and adult (6-7 months), 5xFAD, and WT mice, with a multielectrode array system (MEA). The dissected retina pieces were stimulated with white noise (WN), natural images (NI), photopic (PA), and scotopic (SA) condition, measuring the RGCs' activity through firing rates (FR) and Bursts (B/s). The contralateral eye was collected and fixed for immunogold-silver staining to detect Glutamate and GABA neurotransmitters in the retina's different layers. All methods used here comply with bioethical certification.

The RGCs from young 5xFAD had the highest FR and B/s values, compared with WT and older animals. In contrast, adults 5XFAD reported the lowest FR and B/s activity. These observations are consistent in all the stimuli and significantly different between 5xFAD and WT. Changes in RGCs' activity matches the increase of Glutamate staining in the (GCL), and also the increase of GABA staining in the inner nuclear layer (INL) observed in the 5xFAD retina.

+ J. Araya, F. Bello, G. Shivashankar, D. Neira, C. Duran, M.L. Acosta, M.J. Escobar, C. Hetz, M. Chacon, A.G. Palacios (2020). Functional changes on the retinal ganglion cells in a mouse model of Alzheimer's disease are Linked with Neurotransmitters Alterations. Journal of Alzheimer's Disease. *Under Review*.

1.2.5 Granted equipment

In parallel with this research grant, the PI of this project granted a FONDEQUIP EQM190008, which supports purchasing an iCub robotic platform.

iCub, whose appearance is that of a 3-year-old child, is a robot designed for collaborative research in cognitive development through autonomous exploration and social interaction. It has high sensory-motor capacities with many degrees of freedom and software architecture that encourages code reuse (OpenSource). Specifically, it has visual, vestibular, auditory, and tactile sensory systems.

More specifically, iCub is a 104cm tall humanoid robot originally conceived for social and cognitive robotics. iCub has a complete set of sensors and actuators in its body, allowing multidisciplinary research in all aspects. Within the hardware capabilities, we can mention 53 degrees of freedom, facial expressions, cameras, microphones, inertia sensors, encoders in all joints, force/torque sensors, a robotic-head with 6 degrees of freedom, capacitive touch sensors in hand and fingers (108 in total), full-body coverage, high-resolution encoders on all brushless motors.

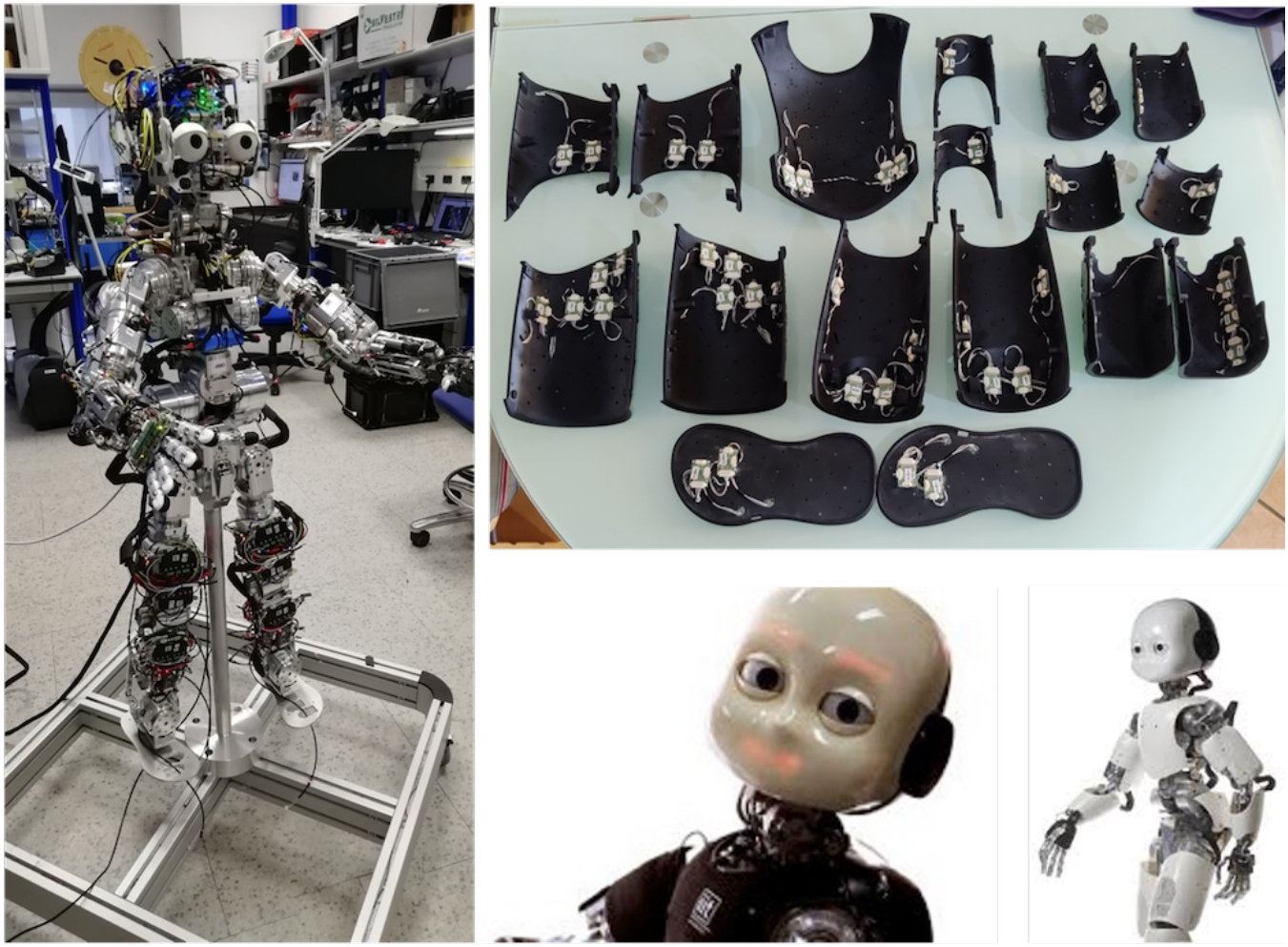

Figure 7: iCub platform designed for cognitive robotics.

The arrival of the iCub platform will allow testing the computational advantages of bio-inspired sensory systems. In particular, a retina-based visual system will be used to develop behavior in different scenarios and associated with various tasks. In addition, the interaction of the visual system with other sensory modalities is also one of the main iCub advantages (touch and audition).

Another project awarded during this period is a FONDEQUIP from ANID, which consists of a state-of-the-art CMOS Multielectrode system with 4200 high-density electrodes that will allow us to enhance our ability to study the behavior of hundreds of neurons simultaneously, which can be stimulated by a spatial light modulation system (SML) with Laser, as well as different

types of LEDs. We hope to study with sufficient precision the fine articulation of networks of neurons in terms of their ability to generate different types of neural code.

1.3 Dissemination activities

We have generated several scientific communications related to this research grant and the computational properties of mammalian retinas. Moreover, we have also participated in several invited talks to disseminate this research. See the Appendix for a full list.

2 Impacts

One of the current main challenges of AI is to cross lines with neuroscience. We learn from retinal computations to create bio-inspired visual sensors for artificial agents within this research. Moreover, the study in neuroscience also impacts developmental learning in robotic platforms, which we expect to be the next challenge in our group.

At the level of students, this grant supported three Ph.D. students and several undergraduate students, involving them in research and motivating them to pursue graduate school.

We have also developed computational tools to process retinal data, create functional groups, and train artificial neural networks that mimic retinal cell responses.

3 Changes

The main change of the research grant was due to the pandemic outbreak. Since we could not perform new retina experiments either in rodent or avian retinas, we should focus on using already collected data to develop and understand different retinal computation principles.

We also put the efforts into creating an artificial neural network emulating retina response that could be used as a bio-inspired visual sensor in artificial agents and robotic platforms.

In addition, we also worked on modeling how some of these computational principles are also present at different levels of neural systems, such as the visual cortex.

Appendix

A Scientific communications generated during or resulting from the grant

A.1 Journal Publications

+ Araya J., Bello F., Shivashankar G., Neira D., Durán-Aniotz C., Acosta M., Escobar M.J., Hetz C., Chacón M., Palacios, A.G. (2021) Retinal Ganglion Cells Functional Changes in a Mouse Model of Alzheimer's Disease Are Linked with Neurotransmitter Alterations. Journal of Alzheimer's Disease, vol. 82, no. s1, pp. S5-S18. DOI: 10.3233/JAD-201195

+ Torres F., Otrio P., Escobar M.J. (2021) Selection of stimulus parameters for enhancing slow wave sleep events with a Neural-field theory thalamocortical model. PLoS Comput Biol 17(7): e1008758 (link). DOI: 10.1371/journal.pcbi.1008758

+ Herzog R., Morales A., Mora S., Araya J., Escobar M.J., Palacios A.G., Cofre R. (2021) Scalable and accurate method for neuronal ensemble detection in spiking neural networks. Plos ONE, 16(7):e0251647. DOI: 10.1371/journal.pone.0251647

+ Lehnert H., Araya M., Carrasco-Davis R., Escobar M.J. (2020). Bio-Inspired Deep Reinforcement Learning for Autonomous Navigation of Artificial Agents. IEEE Latin America Transactions, Vol. 18, No. 12, pp 2028-2035. DOI: 10.1109/TLA.2019.9011549

+ Otero M., Prado P., Weinstein A., Escobar M.J., El-Deredy W. (2020) Persistence of EEG alpha entrainment depends on stimulus phase at offset. Frontiers in Human Neuroscience, Vol. 14, pp 139. DOI: 10.3389/fnhum.2020.00139

+ Reyes P., Escobar M.J.. (2019) NeuroEvolutive Algorithms for Learning Gaits in Legged Robots. IEEE Access, Vol. 7, pp 142406 - 142420. DOI: 10.1109/ACCESS.2019.2944545

A.2 In preparation

+ R. Carrasco-Davis, M. Araya, A.G. Palacios and M.J. Escobar. Space-Time Frequency Variability in Retinal Eccentricity under First-person View. In preparation.
+ J. Pérez-Ortega, J. Araya, C. Ibaceta, R. Herzog, M.J. Escobar, F. Peña-Ortega, L.Carrillo-Reid, and A.G. Palacios. Parallel processing of environmental images by overlapping retinal neuronal ensembles. In preparation new version.

A.3 Conferences

+ Lenhert H., Araya M., Escobar M.J. (2019). Retina-inspired Visual Module for Robot Navigation in Complex Environments. 2019 International Joint Conference on Neural Networks (IJCNN), Budapest, Hungry, 2019, pp. 1-8. Oral Presentation. DOI: 10.1109/IJCNN.2019.8851896
+ Otero M., Prado P., Weinstein A., Escobar M.J, El-Deredy W (2019). Entrainment of brain oscillations persists after the entrainer removal. Journal of Vision 2019;19(10):49. DOI: 10.1167/19.10.49.
+ Torres F., Orio P., Escobar M.J.. A search for slow-wave sleep events enhancer stimulation pattern with neural field theory. XIV Reunión Anual de la Sociedad Chilena de Neurociencia, Nov 2019, La Serena, Chile.
+ Becerra G., Atkinson J., Palacios, A.G., Escobar M.J. Neuro-mimetic lexical-semantic analysis for retinal data. XIV Reunión Anual de la Sociedad Chilena de Neurociencia, Nov 2019, La Serena, Chile.
+ Araya J., Palacios A.G., Durán-Aniotz C., Escobar M.J., Acosta M., Chacón M., Neira D., Shivashankar G., Bello F. Changes in the Physiological Activity and the Expression of Neurotransmitters in the Retinal Ganglion Cells from 5xFAD Alzheimer's Disease Mouse Model. Invest. Ophthalmol. Vis. Sci. 2020;61(7):2254.
+ Otero M., Prado P., Weinstein A., Escobar M.J, El-Deredy W (2019). Cortical mechanisms of the persistence of visual alpha entrainment. Human Brain Mapping (OHBM), Rome, Italy.

  item[+] Adrian Palacios. Lecture Trends in Sensory Ecology. First International Workshoop on Octodon degus: A natural model from Cellular Biology to Behavioral Ecology. 28-31 March. Puerto Williams, Chile, 2019.
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+ Cristobal Ibaceta, David Neira, Frederic Alexandre, Adrian G Palacios. A Hippoccampal network model to estimate Excitation / Inhibition balance from empirical data of Octodon degus. XVII Annual Meeting of the Chilean Society for Neuroscience. 3 Nov 2021.

+ Sebastián Garay Perez, Joaquín Araya-Arriagada, Cristobal Rojas, Adrián G Palacios, Max Chacón Leonel E. Medina. Multi-Scale Entropy Analysis of Retinal Signals in an Animal Model of Alzheimer's Disease. XVII Annual Meeting of the Chilean Society for Neuroscience. 2 Nov 2021.

A.4 Presentations

+ "Retina-Inspired Visual Module for Robot Navigation in Complex Environments", (2019). International Joint Conference in Neural Networks, Budapest, Hungry.

+ "Research spotlight: Neuroscience & AI", (2019). Khipu 2019 Latin American meeting in Artificial Intelligence, Montevideo, Uruguay, link.

+ "Seeing the retina as a computational Machine", (2019). Frontiers in Computer Vision. Khipu 2019 Latin American meeting in Artificial Intelligence, Montevideo, Uruguay, link.

+ "IA & Neurociencia: Algoritmos de IA Bio-Inspirados", (2020). Webinars part of the Chilean AI National Plan, available at the following link

+ "Ciencia para un Futuro IA", (2021). IA-LATAM Conecta Latinoamérica Summit 2021, link.

+ "IA & Neurociencia: Algoritmos de IA Bio-Inspirados", (2021). Chile-WIC (Women in Computing). Keynote Speaker.

+ "Hacia una Política de Inteligencia Artificial para Chile", (2021). Academia de Guerra, Armada de Chile, Viña del Mar, Chile.

+ "Neuroderechos", (2021). Alumni Universidad Andrés Bello, Chile.

+ Khipu Mentoring Event, "Neuroscience and Cognitive Robotics" room (2021), link.

+ Maquinas artificiales: Una visión desde la neurociencias. Adrian Palacios Seminario. Workshop: Sistemas Inteligentes y Complejidad. 6 Agosto 2021. giSCOM Industria Inteligente y Sistemas Complejos. Universidad del Bio-Bio.

+ Adrian Palacios. Article: Thompson, Palacios, Varela, "Ways of coloring: Comparative color vision as a case study for cognitive science" (1992)". 5 May 2021. Ouroboros Seminars 2021. https://metanoia.si/2021/05/12/ouroboros-4th-session/

B Collaborators on grant

+ **MAGMA INRIA Associated team**

  We have consolidated collaboration with INRIA through an associated team called MAGMA (webpage).

  MAGMA (Modelling And understandinG Motion Anticipation in the retina) Team looks forward to studying the mechanisms underlying anticipatory response and the predictive coding observed in the mammalian retina, with a particular emphasis on lateral connectivity (amacrine cells and gap junctions). Based on the importance of understanding how the visual system accumulates information and resolving problems inherent from neural computation, its dynamics, and implementations for simulations.

+ Recently we have established the first working meetings to collaborate in the area of neural coding and classification of RGCs, using convolutionary algorithms [8] together with Francisco Flores[1], and Demba Ba[2], from MIT and Harvard University.

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