Aristotle University of Thessaloniki
Faculty of Sciences
Department of Physics

Bachelor Thesis

Author:
Kasapakis Nikolaos[1]

Supervisor:
Prof. Theodoros Samaras[2]

Insert Title Here

June 20, 2024

Aristotle University
of Thessaloniki
SCHOOL OF PHYSICS

[1] nkasapak@auth.gr, *https://github.com/kasapakis-nk*
[2] theosama@auth.gr

mythesis

Nikos Kasapakis

May 2024

This page intentionally left blank.

Abstract

Insert title here

Kasapakis Nikolaos

Insert my abstract text here.

This page intentionally left blank.

Περίληψη

Βάλε τίτλο εδώ

Κασαπάκης Νικόλαος

Βάλε κείμενο εδώ.

This page intentionally left blank.

Acknowledgements

I want to thank Proffessor Samaras, Dimitris Stoupis (include all titles), Ioanna K.

This page intentionally left blank.

Contents

This page intentionally left blank.

List of Figures

This page intentionally left blank.

List of Tables

This page intentionally left blank.

Listings

Chapter 1

Introduction

The significance of the sense of vision for humans, in our contemporary everyday lives as well as in our evolution as a species, cannot be understated. While there is no clear consensus that vision is our most important sense, since that is dependent on one's cultural, societal and technological influences, there exists a large body of data drawn from cross-sectional observational research and surveys, as well as expert opinion of practitioners and researchers that leans towards the fact that vision is considered the most valued sense to the general public.

Since prehistoric times, it is our vision that has aided us in our survival, by means of allowing us to advantageously select healthy mates, forage ripe fruit against a green foliage and detect predators through their natural camouflage, just to name a few benefits. Even in today's world, the majority of the information we process hails from our eyesight, whether it originates from the envirorment or from a computer screen.

However controversial the topic of the superiority of vision over our other senses might be, what is truly undebatable is that our evolution and eventual dominance as a species has been a consequence of the capabilities of our brain. It is the current form of the human brain after all, displaying an astonishingly intricate way in which it processes visual stimuli, that was preferentially chosen through natural selection to translate visual information to fit the species' best interests. Thus, it could be argued that to achieve a holistic understanding of the sense of vision, we need to delve into the patterns of activation induced in the brain by visual stimulation.

is it necessary to cite these above? or just unofficial?

1.1 Visual Information Flow In The Brain

Light entering the eye creates a cascade of neuronal events throughout the optic pathway, which describes the anatomical pathway by which electrical signals generated by the retina are sent to the brain.

1.1.1 The Optic Pathway

The optic pathway begins in the retina, which is a complex structure made up of ten different layers. Noteably, the photoreceptor layers consist of the rods and cones, which generate action potentials with the help of rhodopsin through photosensitive cycles. The ganglion cell layer and nervefiber layer serve as the foundation of the optic nerve; the former contains the cell bodies, and the latter contains the axons as they stream across the retina. The nerve is surrounded by the dura, which is a continuation of that of the brain, allowing free movement of Cerebrospinal Fluid (CSF) between the eye and the intraclanial vault. The axons exit the orbital part of the optic nerve through the orbital foramen, simultaneously with the ophthalmic artery and sympathetic fibers.

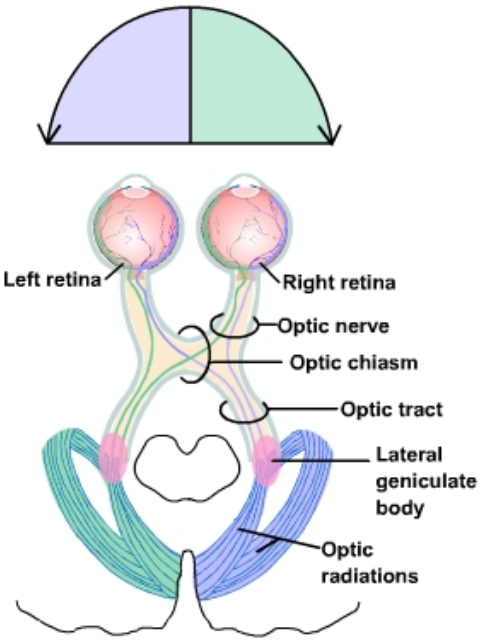

Figure 1.1: Illustation of the Visual Pathway and its components, including the course of information flow from the right (green) and left (blue) hemifields of the two eyes' visual fields. **no DOI cite Neuroscience Online Tsuchitani and Dragoi Ph.D.**

They then enter the optic canal, a bone-encased tunnel intended to protect the nerve, exit into the middle cranial fossa to form the intracranial part of the optic nerve, which continues till the two optic nerves join together to form the optic chiasm directly behind and above the pituitary stalk. Beyond the chiasm, the pathway continues as two distinct tracts, each carrying the temporal fibers from the other eye. The optic tract then passes posteriorly where most of the axons synapse in the layers of the Lateral Geniculate Body (LGB) of the midbrain, which is a posterolateral extension of the thalamus.

The majority of the fibers pass posteriorly to become the genico-calcarine tracts, which have both parietal and temporal loops and terminate into the cuneus gyrus and lingual gyrus of the primary visual cortex, respectively Figure 1.1. Perception of sight ultimately derives from processing within this and adjacent areas of the brain [1].

1.1.2 Information Processing In The Visual Cortex

The modules that compose the visual pathway from the retina to higher visual centers follow two diverging streams in the cortex: one pathway extends dorsally to terminate within the parietal lobe, including the motion detection area, Middle Temporal visual area (MT), and the visual areas of the posterior parietal cortex; the other pathway extends ventrally to terminate in the temporal lobe, including V4 and Inferior Temporal cortex (IT). It is suggested [2] that these two pathways serve different functions: the dorsal pathway is concerned with *where* an object is in visual space (motion, distance); the ventral pathway is concerned with *what* an object is (form, color, texture, all of which are involved in object recognition) Figure 1.2.

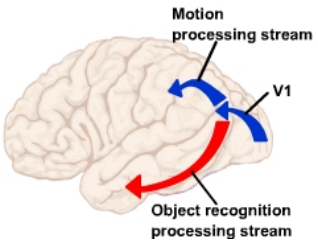

Figure 1.2: Distinction in the flow of visual information from the V1 to other cortical areas. The ventral stream transfers information to the inferior cortical areas, whereas the dorsal stream tranfers it to the more superior cortex.

The V1 area of the brain is involved in the initial cortical processing of all visual information necessary for visual perception. The color, shape and movement information from the thalamus are sent to different neurons within V1 for further processing and then sent onto different areas of the extrastriate visual cortex.

Within V1, information processed by blob cells is used in color perception, color discrimination and the learning and memory of the color of objects. The blob cells are the "color" processing cells of the V1. On the other hand, V1 interblob cells belong in one of two categories: The first are location specific cells, which respond best when the stimulus is in a specific location of the receptive field. The information processed by these cells is used in object perception, discrimination, learning and memory, or in spatial orientation. These cells are the "shape, form and location" cells of the V1; The second kind of interblob cells is the movement sensitive ones, which respond best to moving stimuli and are utilized to detect object movement, direction and velocity and to guide eye movements. These are the "motion detecting" cells of V1.

The V1 sends input to the extrastriate visual cortex, which includes all of the occipital lobe areas surrounding the V1. The extrastriate cortex in non-human primates has been subdivided into as many as three functional areas V2, V3 and V4. The information corresponding to each of the afformentioned categories of neurons in the V1 is sent to different areas of the extrastriate

visual cortex.

Specifically, the neurons in the inferior temporal visual association cortex, i.e., the ventrally located neurons accessed by the ventral stream, are responsible for processing information necessary for our abilities to recognize objects and colors, read text and learn and remember visual objects. It can thus be concluded that, in the context of this thesis, which investigates task-evoked visual stimulation, this area of the brain will be the region of interest. More deliberately, four regions of extrastriate cortex are of utmost importance for the purposes of this current dissertation: the Fusiform Face Area (FFA), the Parahippocampal Place Area (PPA), the Lateral Occipital Cortex (LOC) and the Extrastriate Body Area (EBA).

1.1.3 Category-Specific Information Processing Areas In The Extrastriate Visual Cortex

In the early 1990s, Positron Emission Tomography (PET) demonstrated activation of the ventral visual pathway, especially the Fusiform Gyrus (FG), in a variety of face perception tasks [3] [4]. fMRI studies of the specificity of these cortical regions for faces began with demonstrations of fusiform regions that responded more strongly to faces than to letter strings and textures [5], flowers [6] and other mixed stimuli [7]. Although face-specific fMRI activations could also be seen in many subjects in the region of the Superior Temporal Sulcus (fSTS) and in the occipital lobe in a region named the Occipital Face Area (OFA), the most consistent and robust face-selective activation was located on the lateral side of the mid-fusiform gyrus, within the IT, in a region consequently named the FFA. With the methods currently used, this region can be functionally identified in almost every normal subject in a short "localizer" fMRI scan contrasting the response to faces versus objects [8].

Another well studied category-selective region of cortex is the PPA, responding strongly to a wide variety of stimuli depicting places and/or scenes (e.g. outdoor and indoor scenes and houses) compared to various control stimuli such as faces or scrambled scenes [9]. Additionally, it has been found that PPA activity is not affected by the subject's familiarity with the place depicted, does not increase when subjects experience a sense of motion through the scene, and is greater when viewing novel versus repeated images [10]. Using sets of scenes that had viewpoint changes, it was demonstrated that the PPA treated scenes with viewpoint changes as different [11], suggesting that this area represents scenes as individual snapshots of each view rather than as a broader scene that integrates multiple similar snapshots. However, when subjects saw different snapshot views from panoramic scenes, which represented clearly different views but appeared to come from the same scene, fMRI showed no attenuation for panoramic repeats in the PPA, suggesting viewpoint-specificity [12].

The LOC is located on the lateral bank of the FG, extending both ventrally and dorsally, consisting of the Middle Occipital Gyrus (MOG) and the Inferior Occipital Gyrus (IOG) as well as the Lateral Occipital Sulcus (LOS) between them. This region has been shown to respond more strongly when subjects passively view photographs of common everyday objects than when they view visual textures without obvious shape interpretations [13]. Importantly, the magnitude of the response was no different for familiar objects and unfamiliar ones with clear three-dimensional shape interpretations (e.g. Henry Moore sculptures). A similiar result was found using line drawings [14]: stronger responses to three dimensional objects depicted in line drawings, whether familiar or novel, compared to scrambled line drawings. Several more studies provide evidence that the entire LOC region responds more strongly to intact objects with clear shape interpretations, than to control stimuli that do not depict clear shapes [15] [16] [17].

Since the turn of the twentieth century, neuroimaging studies have identified two brain regions of the extrastriate visual cortex that are highly sensitive to the perception of human bodies and body parts in comparison to other classes of stimuli. These regions are the EBA, which is a body-selective focal region located partly at both the posterior inferior temporal sulcus and the middle temporal gyrus [18] and the Fusiform Body Area (FBA) found ventrally in the fusiform gyrus [19]. Evidence derived from fMRI studies has shown that both areas become significantly activated in response to body and body parts stimuli visually presented in different formats such as photos, line drawings, stick figures and silhouettes compared to control stimuli

like faces, tools and scenes [20] [21] [22]. Additionally, research seems to suggest that the EBA also participates in more complex functions like body discrimination of self versus others. [23]. It has been suggested that EBA and FBA can be functionally dissociated, with a more selective activation for local body parts in EBA relative to more holistic images of the human body in FBA [24].

While it has been clearly established that certain areas of the extrastriate visual cortex process category-specific information, another critical inquiry, particularly in the context of fMRI Multi-Variate Pattern Analysis (MVPA) of contrasts among different classes of stimuli, is whether each region is exclusively selective for target-speific stimuli or if there is overlap between regions, especially considering the close proximity among them. One such case is the FFA and FBA, which have been found in many subjects to be adjacent or overlap with one another. However, in Regions of Interest (ROIs) that ommit overlapping voxels it has been demonstrated [25] that, FFA showed no response above control objects for body stimuli and FBA showed no response above control objects for face stimuli, confirming strong selectivities in distict but adjacent regions in the FG. Similar conclusions of high selectivity have been reached [26] in regards to the FFA and the PPA, where results revealed distinct response properties between the two regions for faces and houses respectively, implying a combination of spatially discrete domain-specific and relatively distributed domain-general organization mapping in the human ventral temporal cortex.

1.2 The mechanisms of Functional Magnetic Resonance Imaging

1.2.1 Blood Oxygen Level Dependent Signal *(BOLD)*

The BOLD signal , captured in fMRI detects changes in HbR driven by localized changes in brain blood flow and blood oxygenation, which are coupled to underlying neuronal activity by a process termed neurovascular coupling. fMRI relies upon the measurement of T2* relaxation, which is sensitive primarily to local concentrations of paramagnetic HbR in venous blood, rendering the latter a naturally occurring contrast agent. Interpretation of the fMRI BOLD signal is intrinsically linked to understanding the underlying physiological and metabolic processes in the brain that modulate blood flow.

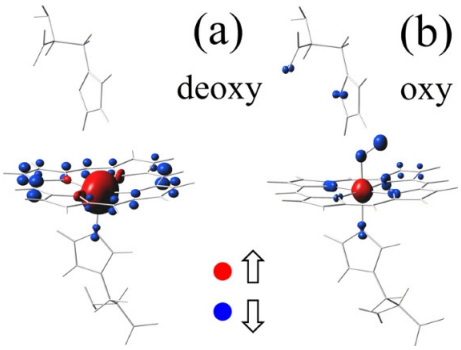

Figure 1.3: Illustation of magnetic-moment density **M(r)** for the **(a)** HbR and **(b)** HbO heme clusters at $T = 150K$. The magnitude of **M(r)** at an atomic site is proportional to the volume of the bubble at that site [27] Fig. 2 p.2).

The BOLD effect related to neural activity arises because of two distinct phenomena. The first is that when hemoglobin (Hb)-the molecule in blood that carries oxygen-lose the oxygen to become HbR, its magnetic properties change in a subtle way: HbR is paramagnetic, and alters the magnetic susceptibility of blood, whereas HbO and the surrounding tissue H_2O are diamagnetic Figure 1.3. The difference in susceptibility between blood vessels and the surrounding tissue creates local magnetic field distortions that decrease the net Magnetic Resonance (MR) signal. In the brain, a typical Oxygen Extraction Fraction (OEF)-the fraction of O_2 carried by an element of blood that is removed in passing through the capillary bed-is approximately 40% and in a 3 T magnetic field this level of HbR in the veins and capillaries is sufficient to reduce the MR signal by about 10% in the baseline state, compared to what it would be if no HbR was present.

The combination of the aforementioned with the biophysical phenomenon, that when a brain area is activated, the blood flow increases-via a process called the haemodynamic response-to a greater degree than the oxygen metabolic rate, produces a useful basis for an experimental signal aqcuisition technique. The second phenomenon leads to a reduction in the OEF, a seemingly

paradoxical scenario in which the venous blood is more oxygenated, despite the increase in oxygen metabolic rate, because the blood flow has increased to a greater extent. Taken together, these two phenomena produce the BOLD effect, a local increase in the MR signal due to a reduction in the OEF during increased neural activity. [28]

A prevailing misconception is that BOLD provides a direct measurement of neuronal oxygen consumption. However, this is generally not the case; classic positive BOLD signals, seen in response to functional stimuli, represent a decrease in HbR and thus an overoxygenation of the responding region [29]. These positive BOLD responses correspond to a local, actively actuated, increase in blood flow and volume, which brings blood in sufficient excess to increase local oxygenation levels [30]. This response typically begins within about 500ms and peaks 3-5 seconds after stimulus onset Figure 1.4, even for short stimuli lasting less than 1 second, with more complex dynamics for prolonged stimuli.

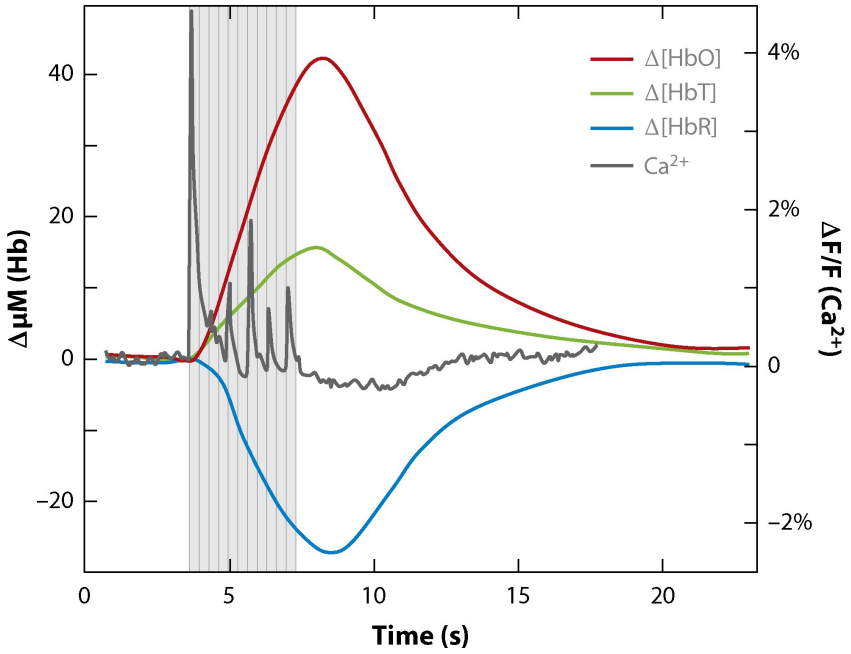

Figure 1.4: Stimulus-evoked response in somatosensory cortex of rats. Noteably, there is a distinct increase in HbT corresponding to vessel dilation and an increase in the number of red blood cells per unit volume of cortex, consistent with an increase in blood flow. HbO increases while HbR decreases, indicating a net overoxygenation of the region. The fMRI BOLD is sensitive to changes in HbR, where stimulus-evoked "positive BOLD" corresponds to the decrease in HbR shown here [31] Fig. 2 p.4).

A range of cellular mechanisms, including astrocytes, pericytes, and interneurons, have been proposed to play a role in neurovascular coupling.[32]. For classical interpretation of BOLD signals, it is assumed that neurovascular coupling is so robust that any increase in neuronal activity generates a proportional increase in local blood flow, irrespective of brain region, brain development, and pathological state [33].

1.2.2 The HCP WM task experiment

The data manipulated in this project has been obtained from the Human Connectome Project (HCP) database, whose overarching purpose is to acquire and share data about the structural and functional connectivity of the human brain. One of the major categories of data in the HCP refers to Task-Evoked Functional Magnetic Resonance Imaging (tfMRI) which assesses seven domains that sample the diversity of neural systems of interest, to a wide range of individuals in the field: 1) visual, motion, somatosensory, and motor systems; 2) category specific representations; 3) working memory or cognitive control systems; 4) language processing

(semantic and phonological processing); 5) social cognition (Theory of Mind); 6) relational processing; and 7) emotion processing. **cite Barch2013, cite HCP somehow?**

The domain which is presently being examined is that of WM tasks which is combined with category specific representation tasks into the following, single task paradigm. Stimuli were projected onto a computer screen behind the subject's head within the imaging chamber. The screen was viewed by a mirror positioned approximately 8 cm above the subject's face. Participants were presented with blocks of trials that consisted of pictures of places, tools, faces and body parts (non-mutilated parts of bodies with no "nudity"). Within each run, the four different stimulus types were presented in seperate blocks. Also, within each run, half of the blocks use a 2-back WM task and half use a 0-back WM task (as a working memory comparison). A 2.5 second cue indicated the task type (and target for 0-back) at the start of the block. Each of the two runs contains eight task blocks (10 trials of 2.5 seconds each, for 25 seconds) and four fixation blocks (15 seconds). On each trial, the stimulis is presented for 2 seconds, followed by a 500ms inter-task interval (ITI). The procedure is showcased in order in Figure 1.5.

Segment Type	Duration (s)	N-Back Paradigm	Target Category
Setup	10	-	-
Cue	2.5	-	-
Task	25	2-Back	Body
Cue	2.5	-	-
Task	25	0-Back	Face
Fixation	15	-	-
Cue	2.5	-	-
Task	25	2-Back	Tools
Cue	2.5	-	-
Task	25	0-Back	Body
Fixation	15	-	-
Cue	2.5	-	-
Task	25	0-Back	Place
Cue	2.5	-	-
Task	25	2-Back	Face
Fixation	15	-	-
Cue	2.5	-	-
Task	25	0-Back	Tools
Cue	2.5	-	-
Task	25	2-Back	Place
Fixation	15	-	-

Figure 1.5: Display of the exact sequece of events during the WM task paradigm.

Chapter 2

Category-Specific Data - MVPA

Add procedure explanation text here.

This page intentionally left blank.

Chapter 3

Software Architecture

Add pipeline explanation text here.

This page intentionally left blank.

Chapter 4

Classification Results

Add results text here.

This page intentionally left blank.

Chapter 5

Discussion & Conclusions

Add conclusion text here.

This page intentionally left blank.

Glossary

blob cells V1 cells that resemble kLGN neurons. They are monocular, color sensitive, characterized by small, concentric receptive fields and are found in clusters, hence the name.

interblob cells V1 cells, the majority of which are binocular, not color sensitive, characterized by elongated receptive fields, exhibit ocular dominance and orientation specificity, while they are found around the clusters of V1 blob cells.

V1 Visual area V1, the striate cortex or primary visual cortex.

V2 Visual area V2, or secondary visual cortex, also called prestriate cortex.

V3 Visual area V3, which communicates directly with the respective dorsal and ventral subsystems of V2. It is less well-defined compared to other areas of the visual cortex.

V4 Visual area V4, a midtier cortical area in the ventral visual pathway.

This page intentionally left blank.

Acronyms

BOLD Blood-Oxygen-Level-Dependent

CSF Cerebrospinal Fluid

EBA Extrastriate Body Area

FBA Fusiform Body Area

FFA Fusiform Face Area

FG Fusiform Gyrus

fMRI Functional Magnetic Resonance Imaging

fSTS Superior Temporal Sulcus

Hb hemoglobin

HbO Oxyhemoglobin

HbR deoxyhemoglobin

HbT total hemoglobin

HCP Human Connectome Project

IOG Inferior Occipital Gyrus

IT Inferior Temporal cortex

ITI inter-task interval

LGB Lateral Geniculate Body

LOC Lateral Occipital Cortex

LOS Lateral Occipital Sulcus

MOG Middle Occipital Gyrus

MR Magnetic Resonance

MT Middle Temporal visual area

MVPA Multi-Variate Pattern Analysis

OEF Oxygen Extraction Fraction

OFA Occipital Face Area

PET Positron Emission Tomography

PPA Parahippocampal Place Area

tfMRI Task-Evoked Functional Magnetic Resonance Imaging

WM Working Memory

Bibliography

[1] M. Gupta, A. C. Ireland, and B. Bordoni, *Neuroanatomy, Visual Pathway*. StatPearls Publishing, Dec. 2022.

[2] M. Mishkin, L. G. Ungerleider, and K. A. Macko, "Object vision and spatial vision: Two cortical pathways," *Trends in Neurosciences*, vol. 6, pp. 414–417, C Jan. 1983, ISSN: 0166-2236. DOI: 10.1016/0166-2236(83)90190-X.

[3] J. V. Haxby, C. L. Grady, B. Horwitz, *et al.*, "Dissociation of object and spatial visual processing pathways in human extrastriate cortex.," *Proceedings of the National Academy of Sciences*, vol. 88, pp. 1621–1625, 5 Mar. 1991, ISSN: 00278424. DOI: 10.1073/PNAS.88.5.1621. [Online]. Available: https://www.pnas.org/doi/abs/10.1073/pnas.88.5.1621.

[4] J. Sergent, S. Ohta, and B. Macdonald, "Functional neuroanatomy of face and object processing: A positron emission tomography study," *Brain*, vol. 115, pp. 15–36, 1 Feb. 1992, ISSN: 0006-8950. DOI: 10.1093/BRAIN/115.1.15. [Online]. Available: https://dx.doi.org/10.1093/brain/115.1.15.

[5] A. Puce, T. Allison, M. Asgari, J. C. Gore, and G. McCarthy, "Differential sensitivity of human visual cortex to faces, letterstrings, and textures: A functional magnetic resonance imaging study," *The Journal of Neuroscience*, vol. 16, p. 5205, 16 Aug. 1996, ISSN: 02706474. DOI: 10.1523/JNEUROSCI.16-16-05205.1996. [Online]. Available: /pmc/articles/PMC6579313/%20/pmc/articles/PMC6579313/?report=abstract%20https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6579313/.

[6] G. Mccarthy, M. Luby, J. Gore, and P. Goldman-Rakic, "Infrequent events transiently activate human prefrontal and parietal cortex as measured by functional mri," *Journal of neurophysiology*, vol. 77, pp. 1630–1634, 3 1997, ISSN: 0022-3077. DOI: 10.1152/JN.1997.77.3.1630. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/9084626/.

[7] N. Kanwisher, J. McDermott, and M. M. Chun, "The fusiform face area: A module in human extrastriate cortex specialized for face perception," *The Journal of Neuroscience*, vol. 17, p. 4302, 11 Jun. 1997, ISSN: 02706474. DOI: 10.1523/JNEUROSCI.17-11-04302.1997. [Online]. Available: /pmc/articles/PMC6573547/%20/pmc/articles/PMC6573547/?report=abstract%20https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6573547/.

[8] N. Kanwisher and G. Yovel, "The fusiform face area: A cortical region specialized for the perception of faces," *Philosophical Transactions of the Royal Society B: Biological Sciences*, vol. 361, p. 2109, 1476 Dec. 2006, ISSN: 09628436. DOI: 10.1098/RSTB.2006.1934. [Online]. Available: /pmc/articles/PMC1857737/%20/pmc/articles/PMC1857737/?report=abstract%20https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1857737/.

[9] R. Epstein and N. Kanwisher, "A cortical representation of the local visual environment," *Nature 1998 392:6676*, vol. 392, pp. 598–601, 6676 Apr. 1998, ISSN: 1476-4687. DOI: 10.1038/33402. [Online]. Available: https://www.nature.com/articles/33402.

[10] R. Epstein, A. Harris, D. Stanley, and N. Kanwisher, "The parahippocampal place area: Recognition, navigation, or encoding?" *Neuron*, vol. 23, pp. 115–125, 1 May 1999, ISSN: 0896-6273. DOI: 10.1016/S0896-6273(00)80758-8.

[11] R. Epstein, K. S. Graham, and P. E. Downing, "Viewpoint-specific scene representations in human parahippocampal cortex," *Neuron*, vol. 37, pp. 865–876, 5 Mar. 2003, ISSN: 08966273. DOI: 10.1016/S0896-6273(03)00117-X. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/12628176/.

[12] S. Park and M. M. Chun, "Different roles of the parahippocampal place area (ppa) and retrosplenial cortex (rsc) in panoramic scene perception," *NeuroImage*, vol. 47, p. 1747, 4 Oct. 2009, ISSN: 10538119. DOI: 10.1016/J.NEUROIMAGE.2009.04.058. [Online]. Available: /pmc/articles/PMC2753672/%20/pmc/articles/PMC2753672/?report=abstract%20https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2753672/.

[13] R. Malach, J. B. Reppas, R. R. Benson, *et al.*, "Object-related activity revealed by functional magnetic resonance imaging in human occipital cortex.," *Proceedings of the National Academy of Sciences*, vol. 92, pp. 8135–8139, 18 Aug. 1995, ISSN: 00278424. DOI: 10.1073/PNAS.92.18.8135. [Online]. Available: https://www.pnas.org/doi/abs/10.1073/pnas.92.18.8135.

[14] N. Kanwisher, M. M. Chun, J. McDermott, and P. J. Ledden, "Functional imaging of human visual recognition," *Cognitive Brain Research*, vol. 5, pp. 55–67, 1-2 Dec. 1996, ISSN: 0926-6410. DOI: 10.1016/S0926-6410(96)00041-9.

[15] K. Grill-Spector, T. Kushnir, T. Hendler, S. Edelman, Y. Itzchak, and R. Malach, "A sequence of object-processing stages revealed by fmri in the human occipital lobe," *Human Brain Mapping*, vol. 6, no. 4, pp. 316–328, 1998, ISSN: 1065-9471. DOI: 10.1002/(sici)1097-0193(1998)6:4<316::aid-hbm9>3.0.co;2-6. [Online]. Available: http://dx.doi.org/10.1002/(SICI)1097-0193(1998)6:4%3C316::AID-HBM9%3E3.0.CO;2-6.

[16] S. Murtha, H. Chertkow, M. Beauregard, and A. Evans, "The neural substrate of picture naming," *Journal of Cognitive Neuroscience*, vol. 11, pp. 399–423, 4 Jul. 1999, ISSN: 0898-929X. DOI: 10.1162/089892999563508. [Online]. Available: https://dx.doi.org/10.1162/089892999563508.

[17] K. Grill-Spector, Z. Kourtzi, and N. Kanwisher, "The lateral occipital complex and its role in object recognition," *Vision Research*, vol. 41, pp. 1409–1422, 10-11 May 2001, ISSN: 0042-6989. DOI: 10.1016/S0042-6989(01)00073-6.

[18] P. E. Downing, Y. Jiang, M. Shuman, and N. Kanwisher, "A cortical area selective for visual processing of the human body," *Science*, vol. 293, pp. 2470–2473, 5539 Sep. 2001, ISSN: 00368075. DOI: 10.1126/SCIENCE.1063414. [Online]. Available: https://www.science.org/doi/10.1126/science.1063414.

[19] M. V. Peelen and P. E. Downing, "Selectivity for the human body in the fusiform gyrus," *Journal of Neurophysiology*, vol. 93, pp. 603–608, 1 Jan. 2005, ISSN: 00223077. DOI: 10.1152/JN.00513.2004/ASSET/IMAGES/LARGE/Z9K0010543090003.JPEG. [Online]. Available: https://journals.physiology.org/doi/10.1152/jn.00513.2004.

[20] M. Spiridon, B. Fischl, and N. Kanwisher, "Location and spatial profile of category-specific regions in human extrastriate cortex," *Human Brain Mapping*, vol. 27, pp. 77–89, 1 Jan. 2006, ISSN: 10659471. DOI: 10.1002/HBM.20169.

[21] K. S. Weiner and K. Grill-Spector, "Sparsely-distributed organization of face and limb activations in human ventral temporal cortex," *NeuroImage*, vol. 52, pp. 1559–1573, 4 Oct. 2010, ISSN: 1053-8119. DOI: 10.1016/J.NEUROIMAGE.2010.04.262.

[22] L. Amoruso, B. Couto, and A. Ibáñez, "Beyond extrastriate body area (eba) and fusiform body area (fba): Context integration in the meaning of actions," *Frontiers in Human Neuroscience*, vol. 5, p. 13143, Nov. 2011, ISSN: 16625161. DOI: 10.3389/FNHUM.2011.00124/BIBTEX.

[23] A. Pann, M. Bonnard, O. Felician, and P. Romaiguère, "The extrastriate body area and identity processing: An fmri guided tms study," *Physiological Reports*, vol. 9, 8 Apr. 2021, ISSN: 2051817X. DOI: 10.14814/PHY2.14711. [Online]. Available: /pmc/articles/PMC8090840/%20/pmc/articles/PMC8090840/?report=abstract%20https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8090840/.

[24] J. C. Taylor, A. J. Wiggett, and P. E. Downing, "Functional mri analysis of body and body part representations in the extrastriate and fusiform body areas," *Journal of Neurophysiology*, vol. 98, pp. 1626–1633, 3 Sep. 2007, ISSN: 00223077. DOI: 10.1152/JN.00012.2007/ASSET/IMAGES/LARGE/Z9K0090783830004.JPEG. [Online]. Available: https://journals.physiology.org/doi/10.1152/jn.00012.2007.

[25] R. F. Schwarzlose, C. I. Baker, and N. Kanwisher, "Separate face and body selectivity on the fusiform gyrus," *The Journal of neuroscience : the official journal of the Society for Neuroscience*, vol. 25, pp. 11 055–11 059, 47 Nov. 2005, ISSN: 1529-2401. DOI: 10.1523/JNEUROSCI.2621-05.2005. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/16306418/.

[26] M. Li, H. Huang, B. Guo, and M. Meng, "Distinct response properties between the ffa to faces and the ppa to houses," *Brain and Behavior*, vol. 12, e2706, 8 Aug. 2022, ISSN: 2162-3279. DOI: 10.1002/BRB3.2706. [Online]. Available: https://onlinelibrary.wiley.com/doi/full/10.1002/brb3.2706%20https://onlinelibrary.wiley.com/doi/abs/10.1002/brb3.2706%20https://onlinelibrary.wiley.com/doi/10.1002/brb3.2706.

[27] S. Mayda, Z. Kandemir, N. Bulut, and S. Maekawa, "Magnetic mechanism for the biological functioning of hemoglobin," *Scientific Reports*, vol. 10, 1 Dec. 2020, ISSN: 20452322. DOI: 10.1038/s41598-020-64364-y. [Online]. Available: https://www.nature.com/articles/s41598-020-64364-y.

[28] R. B. Buxton, "The physics of functional magnetic resonance imaging (fmri)," *Reports on Progress in Physics*, vol. 76, 9 Sep. 2013, ISSN: 00344885. DOI: 10.1088/0034-4885/76/9/096601.

[29] D. Attwell and C. Iadecola, "The neural basis of functional brain imaging signals," *Trends in neurosciences*, vol. 25, no. 12, pp. 621–625, 2002.

[30] M. E. Raichle, *Neuroimaging of human brain function*, 1998. [Online]. Available: www.pnas.org..

[31] E. M. C. Hillman, "Optical brain imaging in vivo: Techniques and applications from animal to man," *Journal of Biomedical Optics*, vol. 12, p. 051 402, 5 2007, ISSN: 10833668. DOI: 10.1117/1.2789693.

[32] E. M. Hillman, *Coupling mechanism and significance of the bold signal: A status report*, 2014. DOI: 10.1146/annurev-neuro-071013-014111.

[33] N. K. Logothetis, "Neurovascular uncoupling: Much ado about nothing," *Frontiers in Neuroenergetics*, vol. 2, 2010. DOI: 10.3389/fnene.2010.00002.