COVER LETTER

UNIVERSITY OF WASHINGTON

DINA V. POPOVKINA
DEPARTMENT OF PSYCHOLOGY
119 GUTHRIE HALL, BOX 352515
SEATTLE, WA 98195

August 2, 2018

Dear Division of Receipt and Referral:

Please accept this proposed F32 application.

Application Title:

How does dividing attention limit object recognition and modify relevant neural activity?

Funding Opportunity Title:

Ruth L. Kirschstein National Research Service Award (NRSA) Individual Postdoctoral Fellowship (Parent F32)

Funding Opportunity Announcement Number:

PA-18-670

Please assign this application to the following:

Institutes/Centers: National Eye Institute – NEI

Study section: Sensory and Motor Neuroscience, Cognition and Perception (F02B)

List of Referees:

Anitha Pasupathy, Ph.D. – Associate Professor of Biological Structure, University of Washington
Wyeth Bair, Ph.D. – Associate Professor of Biological Structure, University of Washington
Ione Fine, Ph.D. – Professor of Psychology, University of Washington

Thank you for your consideration.

Sincerely,

Dina V. Popovkina, Ph.D.

OMB Number: 4040-0001
Expiration Date: 10/31/2019

APPLICATION FOR FEDERAL ASSISTANCE
SF 424 (R&R)

3. DATE RECEIVED BY STATE	**State Application Identifier**

1. TYPE OF SUBMISSION*

❍ Pre-application ● Application ❍ Changed/Corrected Application

4.a. Federal Identifier

b. Agency Routing Number

c. Previous Grants.gov Tracking Number

2. DATE SUBMITTED | **Application Identifier**

5. APPLICANT INFORMATION **Organizational DUNS*:** 6057994690000

Legal Name*: UNIVERSITY OF WASHINGTON
Department: Office of Sponsored Programs
Division: Office of Research
Street1*: Office of Sponsored Programs
Street2: 4333 Brooklyn Ave NE
City*: SEATTLE
County:
State*: WA: Washington
Province:
Country*: USA: UNITED STATES
ZIP / Postal Code*: 981959472

Person to be contacted on matters involving this application
Prefix: First Name*: Carol Middle Name: Last Name*: Rhodes Suffix:
Position/Title: Director
Street1*: 4333 Brooklyn Ave NE
Street2: Box 359472
City*: Seattle
County:
State*: WA: Washington
Province:
Country*: USA: UNITED STATES
ZIP / Postal Code*: 98195-9472
Phone Number*: 206-543-4043 Fax Number: 206-685-1732 Email: osp@uw.edu

6. EMPLOYER IDENTIFICATION NUMBER *(EIN) or (TIN)** 91-6001537

7. TYPE OF APPLICANT* H: Public/State Controlled Institution of Higher Education

Other (Specify):
Small Business Organization Type ❍ Women Owned ❍ Socially and Economically Disadvantaged

8. TYPE OF APPLICATION*

● New ❍ Resubmission
❍ Renewal ❍ Continuation ❍ Revision

If Revision, mark appropriate box(es).
❍ A. Increase Award ❍ B. Decrease Award ❍ C. Increase Duration
❍ D. Decrease Duration ❍ E. Other *(specify)* :

Is this application being submitted to other agencies?* ❍Yes ●No What other Agencies?

9. NAME OF FEDERAL AGENCY*
National Institutes of Health

10. CATALOG OF FEDERAL DOMESTIC ASSISTANCE NUMBER
TITLE:

11. DESCRIPTIVE TITLE OF APPLICANT'S PROJECT*
How does dividing attention limit object recognition and modify relevant neural activity?

12. PROPOSED PROJECT
Start Date* Ending Date*
04/01/2019 03/31/2022

13. CONGRESSIONAL DISTRICTS OF APPLICANT
WA-007

SF 424 (R&R) APPLICATION FOR FEDERAL ASSISTANCE

14. PROJECT DIRECTOR/PRINCIPAL INVESTIGATOR CONTACT INFORMATION

Prefix: First Name*: DINA Middle Name: V Last Name*: POPOVKINA Suffix: Ph.D
Position/Title: Research Associate
Organization Name*: UNIVERSITY OF WASHINGTON
Department: Psychology
Division: College of Arts and Sciences
Street1*: Guthrie Hall, Box 351525
Street2:
City*: SEATTLE
County:
State*: WA: Washington
Province:
Country*: USA: UNITED STATES
ZIP / Postal Code*: 981951525
Phone Number*: 2066166951 Fax Number: Email*: dina4@uw.edu

15. ESTIMATED PROJECT FUNDING

a. Total Federal Funds Requested*	$178,866.00
b. Total Non-Federal Funds*	$0.00
c. Total Federal & Non-Federal Funds*	$178,866.00
d. Estimated Program Income*	$0.00

16.IS APPLICATION SUBJECT TO REVIEW BY STATE EXECUTIVE ORDER 12372 PROCESS?*

a. YES ○ THIS PREAPPLICATION/APPLICATION WAS MADE AVAILABLE TO THE STATE EXECUTIVE ORDER 12372 PROCESS FOR REVIEW ON:
DATE:

b. NO ● PROGRAM IS NOT COVERED BY E.O. 12372; OR
○ PROGRAM HAS NOT BEEN SELECTED BY STATE FOR REVIEW

17. By signing this application, I certify (1) to the statements contained in the list of certifications* and (2) that the statements herein are true, complete and accurate to the best of my knowledge. I also provide the required assurances * and agree to comply with any resulting terms if I accept an award. I am aware that any false, fictitious, or fraudulent statements or claims may subject me to criminal, civil, or administrative penalties. (U.S. Code, Title 18, Section 1001)

● I agree*

** The list of certifications and assurances, or an Internet site where you may obtain this list, is contained in the announcement or agency specific instructions.*

18. SFLLL or OTHER EXPLANATORY DOCUMENTATION File Name:

19. AUTHORIZED REPRESENTATIVE

Prefix: First Name*: Carol Middle Name: Last Name*: Rhodes Suffix:
Position/Title*: Director
Organization Name*: University of Washington
Department: Office of Sponsored Programs
Division: Office of Research
Street1*: 4333 Brooklyn Ave NE
Street2: Box 359472
City*: Seattle
County:
State*: WA: Washington
Province:
Country*: USA: UNITED STATES
ZIP / Postal Code*: 98195-9472
Phone Number*: 206-543-4043 Fax Number: 206-685-1732 Email*: osp@uw.edu

Signature of Authorized Representative*
Completed on submission to Grants.gov

Date Signed*
06/28/2018

20. PRE-APPLICATION File Name:

21. COVER LETTER ATTACHMENT File Name:Cover_Popovkina_FINAL.pdf

424 R&R and PHS-398 Specific
Table Of Contents

OMB Number: 4040-0010
Expiration Date: 10/31/2019

Project/Performance Site Location(s)

Project/Performance Site Primary Location

❍ I am submitting an application as an individual, and not on behalf of a company, state, local or tribal government, academia, or other type of organization.

Organization Name: UNIVERSITY OF WASHINGTON
Duns Number: 6057994690000
Street1*: Office of Sponsored Programs
Street2: 4333 Brooklyn Ave NE
City*: SEATTLE
County:
State*: WA: Washington
Province:
Country*: USA: UNITED STATES
Zip / Postal Code*: 98195-9472
Project/Performance Site Congressional District*: WA-007

Project/Performance Site Location 1

❍ I am submitting an application as an individual, and not on behalf of a company, state, local or tribal government, academia, or other type of organization.

Organization Name: UNIVERSITY OF WASHINGTON
DUNS Number: 6057994690000
Street1*: Psychology Department
Street2: Guthrie Hall, Box 351525
City*: SEATTLE
County:
State*: WA: Washington
Province:
Country*: USA: UNITED STATES
Zip / Postal Code*: 98195-1525
Project/Performance Site Congressional District*: WA-007

Project/Performance Site Location 2

❍ I am submitting an application as an individual, and not on behalf of a company, state, local or tribal government, academia, or other type of organization.

Organization Name:	University of Washington
DUNS Number:	6057994690000
Street1*:	Integrated Brain Imaging Center
Street2:	Dept. of Radiology, Box 357115
City*:	Seattle
County:	
State*:	WA: Washington
Province:	
Country*:	USA: UNITED STATES
Zip / Postal Code*:	981957115
Project/Performance Site Congressional District*:	WA-007

Additional Location(s) File Name:

OMB Number: 4040-0001
Expiration Date: 10/31/2019

RESEARCH & RELATED Other Project Information

1. Are Human Subjects Involved?* ● **Yes** ❍ **No**

1.a. If YES to Human Subjects

Is the Project Exempt from Federal regulations? ❍ Yes ● No

If YES, check appropriate exemption number: _ 1 _ 2 _ 3 _ 4 _ 5 _ 6 _ 7 _ 8

If NO, is the IRB review Pending? ● **Yes** ❍ **No**

IRB Approval Date:

Human Subject Assurance Number 00006878

2. Are Vertebrate Animals Used?* ❍ **Yes** ● **No**

2.a. If YES to Vertebrate Animals

Is the IACUC review Pending? ❍ Yes ❍ No

IACUC Approval Date:

Animal Welfare Assurance Number

3. Is proprietary/privileged information included in the application?* ❍ **Yes** ● **No**

4.a. Does this project have an actual or potential impact - positive or negative - on the environment?* ❍ **Yes** ● **No**

4.b. If yes, please explain:

4.c. If this project has an actual or potential impact on the environment, has an exemption been authorized or an environmental assessment (EA) or environmental impact statement (EIS) been performed? ❍ Yes ❍ No

4.d. If yes, please explain:

5. Is the research performance site designated, or eligible to be designated, as a historic place?* ❍ **Yes** ● **No**

5.a. If yes, please explain:

6. Does this project involve activities outside the United States or partnership with international collaborators?* ❍ **Yes** ● **No**

6.a. If yes, identify countries:

6.b. Optional Explanation:

	Filename
7. Project Summary/Abstract*	Project_Summary_FINAL.pdf
8. Project Narrative*	Project_Narrative_FINAL.pdf
9. Bibliography & References Cited	Bibliography_FINAL.pdf
10.Facilities & Other Resources	Facilities_OtherResources_FINAL.pdf
11.Equipment	Equipment.pdf

PROJECT SUMMARY/ABSTRACT

The information that reaches our eyes doesn't always correspond to what we perceive. Attention strongly influences what we see and how we interpret the world. At the same time, our daily activities often require us to pay attention to more than one thing at once (divided attention). Previous studies quantifying how much divided attention degrades task performance have produced varying results, and the neural bases for these effects are poorly understood.

The focus of my proposed research is to understand how divided attention affects object shape recognition and brain activity associated with visual object processing. Specifically, I will pursue the hypothesis that a serial bottleneck in object processing accounts for the performance limits observed in divided attention. I plan to use a combination of theory-driven psychophysics and functional neuroimaging to investigate (1) how much divided attention impairs human ability to recognize objects, (2) how much divided attention changes neural activity, and where in the brain this takes place, and (3) whether divided attention can explain why patients with posterior cortical atrophy (a variant of Alzheimer's disease affecting visual areas) exhibit deficits in recognizing simultaneously presented objects.

Studying vision and attention together can have powerful implications for our understanding of the relationship between brain and behavior. My findings will make an impact by informing theories of how cognitive states relate to brain activity, and how these changes underlie the limits in our ability to make perceptual judgments. Beyond the benefit to advancing the fields of visual and attentional processing, the proposed research will also make an impact in understanding conditions involving deficits in perceptual and attentional processing functions, including aging and dementias such as Alzheimer's.

PROJECT NARRATIVE

Multitasking is ubiquitous in daily activities, but how can our brains make sense of two things simultaneously? In this proposal, I will study how dividing attention between two objects affects our ability to recognize them. My research will help investigate how human brains and behavior are linked, and will provide insights into conditions where perception and attention are impaired, including aging and Alzheimer's disease.

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White, A.L., Palmer, J., & Boynton, G.M. (2018b). Probing the serial bottleneck in visual word recognition. Vision Sciences Society Meeting Abstract.

White, A. L., Runeson, E., Palmer, J., Ernst, Z. R., & Boynton, G. M. (2017). Evidence for unlimited capacity processing of simple features in visual cortex. Journal of Vision, 17(6), 19. https://doi.org/10.1167/17.6.19 PMC5488877

FACILITIES AND OTHER RESOURCES

Scientific Environment: The University of Washington Psychology Department consists of an interdisciplinary group of faculty with expertise in a broad array of areas including Behavioral Neuroscience and Clinical, Developmental, and Quantitative Psychology. In addition to departmental breadth, the University of Washington provides access to excellent opportunities for interdisciplinary collaborations. The university is home to large and thriving communities of researchers in vision science, physiology, theoretical and computational neuroscience. Cross-departmental collaborations are encouraged, easy to establish, and ubiquitous in these diverse groups. A number of interdisciplinary institutes at UW provide an opportunity to obtain diverse perspectives and feedback, including the UW Institute for Neuroengineering, the Computational Neuroscience Center, and the Center for Sensorimotor and Neural Engineering. The Psychology Department provides travel money for one conference per year, which will support Dina to present this project at national conferences.

Dina is a member of the UW Vision & Cognition Group, which includes the labs of Drs. Geoffrey Boynton (Sponsor), Ione Fine (vision, audition, and cortical plasticity) and Scott Murray (spatial vision, attention, context). Graduate and postdoctoral training is a shared responsibility among these PIs. The shared lab space is co-localized with the lab of John Palmer (co-sponsor). We conduct a joint weekly lab meeting and share equipment. In this shared space, Dina has a ~110 square foot office. During her first 6 months in the lab, Dina has settled well and benefitted from this community.

MR Facilities: The UW has a research-dedicated 3T Philips Achieva scanner at the UW Health Sciences Center that is producing excellent data. The Sponsor of this project, Dr. Boynton, is a co-Director of the UW Center for Neuroimaging that administers this scanner. There is no concern whatsoever regarding access to this device. Our lab uses a 3T Philips Achieva with a 32- channel head coil. We also have a custom-build 8-channel occipital coil built by our in-house developer Cecil Hayes. Acquisition support (including acquisition protocol development, data storage and any specialized image pre-processing that is required) is provided by the imaging center, under the direction of Dr. Maravilla. Of particular importance to this project is the presence of Dr. Chris Gatenby, a physicist trained in developing state-of-the art structural and functional imaging protocols. The MR Research Laboratory provides an image viewing room equipped with computers and picture archiving and communications system (PACS) workstations, a physics laboratory for radiofrequency coil design, an electronics laboratory for component fabrication, a software development laboratory for image analysis, and office space for faculty, support scientists, staff and students.

Integrated Brain Imaging Center (IBIC): Additional support in data analysis is provided by IBIC, under the direction of Dr. Thomas Grabowski (contributor). The goal of IBIC is to provide support to multimodal imaging projects that use cutting edge neuroimaging techniques. IBIC offers a series of formal and informal neuroimaging seminars and lectures throughout the year (approximately 1-2/week) in acquisition and analysis techniques. In combination, the MR Research Lab and IBIC offer a variety of Linux, Macintosh, Sun, SGI and PC workstations. These workstations offer a broad array of analysis software including MEDx, Matlab, SPM, FSL, Brain Voyager, Measure, and Adobe Photoshop. IBIC also offers custom image analysis software developed in the laboratory.

Psychophysics Facilities: Each psychophysical testing room is equipped with computers, required software, and a calibrated CRT monitor. Two testing stations are equipped with eye-tracking systems (SR Research, Eyelink 2 & Eyelink 1000).

Computer resources: Dina has a high-end Microsoft laptop and access to all the software needed for word processing, experiment development, and data analysis, including BrainVoyager and Matlab. Dr. Boynton's laboratory also owns a very powerful Linux workstation with excellent graphics capabilities suitable for computational or graphics intensive processing. The laboratory has three printers (one high speed black and white, and two high quality color printers). The Psychology Department provides computer support services, including a computer and electronics shop staffed by two technicians.

EQUIPMENT

Equipment	Location	Capabilities
Philips Achieva 3T magnetic resonance scanner and 32 channel radio frequency head coil	UW Magnetic Resonance Research Laboratory. The scanner is located within a 10-15 minute walk from the Psychology Department.	Dedicated for research use. The UW Medical Center offers support, including an on-site physicist for development of new protocols.
Computer stations with CRT monitors	Boynton and Palmer labs in the Psychology Department.	
SR Research Eyelink eye-tracking systems (2)	Boynton and Palmer labs in the Psychology Department.	
Photo Research PR 650 Spectrophotometer	Palmer lab in the Psychology Department.	

OMB Number: 4040-0001
Expiration Date: 10/31/2019

RESEARCH & RELATED Senior/Key Person Profile (Expanded)

PROFILE - Project Director/Principal Investigator

Prefix: First Name*: DINA Middle Name V Last Name*: POPOVKINA Suffix: Ph.D

Position/Title*: Research Associate
Organization Name*: UNIVERSITY OF WASHINGTON
Department: Psychology
Division: College of Arts and Sciences
Street1*: Guthrie Hall, Box 351525
Street2:
City*: SEATTLE
County:
State*: WA: Washington
Province:
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Zip / Postal Code*: 981951525

Phone Number*: 2066166951 Fax Number:

E-Mail*: dina4@uw.edu

Credential, e.g., agency login: dpopovkina

Project Role*: PD/PI Other Project Role Category:

Degree Type: PHD,BS Degree Year: 2017,2010

Attach Biographical Sketch*: File Name: Biosketch_Popovkina_FINAL.pdf

Attach Current & Pending Support: File Name:

PROFILE - Senior/Key Person

Prefix: First Name*: GEOFFREY Middle Name M Last Name*: BOYNTON Suffix:

Position/Title*: Associate Professor
Organization Name*: University of Washington
Department: Psychology
Division: College of Arts and Sciences
Street1*: Guthrie Hall, Box 351525
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County:
State*: WA: Washington
Province:
Country*: USA: UNITED STATES
Zip / Postal Code*: 981951525

Phone Number*: (206) 685-6493 Fax Number:

E-Mail*: gboynton@u.washington.edu

Credential, e.g., agency login: boynton

Project Role*: Other (Specify) Other Project Role Category: Sponsor

Degree Type: PHD,MS,AB Degree Year: 1994,1989,1987

Attach Biographical Sketch*: File Name: Biosketch_Boynton_FINAL.pdf

Attach Current & Pending Support: File Name:

PROFILE - Senior/Key Person

Prefix: First Name*: JOHN Middle Name Last Name*: PALMER Suffix:

Position/Title*: Research Professor
Organization Name*: University of Washington
Department: Psychology
Division: College of Arts and Sciences
Street1*: Guthrie Hall, Box 351525
Street2:
City*: SEATTLE
County:
State*: WA: Washington
Province:
Country*: USA: UNITED STATES
Zip / Postal Code*: 981951525

Phone Number*: (206) 543-0706 Fax Number: (206) 685-3157

E-Mail*: JPALMER@U.WASHINGTON.EDU

Credential, e.g., agency login: johnpalmer

Project Role*: Other (Specify) Other Project Role Category: Co-Sponsor

Degree Type: PHD,BS Degree Year: 1984,1976

Attach Biographical Sketch*: File Name: Biosketch_Palmer_FINAL.pdf

Attach Current & Pending Support: File Name:

OMB No. 0925-0001 and 0925-0002 (Rev. 09/17 Approved Through 03/31/2020)

BIOGRAPHICAL SKETCH

Provide the following information for the Senior/key personnel and other significant contributors.
Follow this format for each person. **DO NOT EXCEED FIVE PAGES.**

NAME: Popovkina, Dina Valentinovna

eRA COMMONS USER NAME (credential, e.g., agency login): dpopovkina

POSITION TITLE: Research Associate

EDUCATION/TRAINING *(Begin with baccalaureate or other initial professional education, such as nursing, include postdoctoral training and residency training if applicable. Add/delete rows as necessary.)*

INSTITUTION AND LOCATION	DEGREE *(if applicable)*	Start Date MM/YYYY	Completion Date MM/YYYY	FIELD OF STUDY
University of Maryland, Baltimore County (UMBC)	BS	06/2006	05/2010	Biochemistry and Molecular Biology
	BA	06/2006	05/2010	Ancient Studies
University of Washington (UW)	PhD	09/2010	12/2017	Neuroscience

A. Personal Statement

My early training as a neuroscientist was driven by a fascination with exploring the mechanisms by which the brain translates physical stimuli into electrical signals, and electrical signals to behaviors. In my undergraduate training, I learned to image the structure of neurons and analyze their morphology and function. In my graduate training, I learned electrophysiology in awake, behaving primates, as well as computational modeling of the visual system. This extensive methodological background has ultimately led me to develop a strong interest in studying the relationship between sensory encoding and cognitive functions. My career goal is to carry out research at the intersection of perception and cognition.

As an undergraduate student with Dr. Scott Thompson, I contributed to projects investigating how molecular factors affect the morphology of dendritic spines, small protrusions from neuron branches where synaptic connections between neurons are commonly established. I found that chronic application of the stress hormone corticosterone decreased dendritic spine density, suggesting that chronic stress reduces connectivity in the brain. In my graduate training, I wanted to explore not only how neurons establish and maintain connections, but also what information is being transmitted in their electrical signals. During my PhD work in the lab of Dr. Anitha Pasupathy, I investigated how visual objects are encoded in the cortical neurons of non-human primates, and how their computations contribute to our ability to recognize objects. I found that individual neurons carry complex information about multiple features of objects, and that this information encoding can change depending on the cognitive state on the animal.

My predoctoral research experiences have led me to an interest in understanding how cognitive processes such as attention affect sensory representations in the brain. Since beginning my current postdoctoral position, I have been conducting behavioral experiments to understand how attention affects object recognition in people. Here, I propose to study how dividing attention between two objects affects human ability to recognize them. I plan to take advantage of my expertise in studying the visual system of non-human primates to inform the questions I pose and models I build to understand the neural basis of visual processing and attention.

With support from the Ruth L. Kirschstein F32 NRSA award, I will acquire additional training in (1) large-scale approaches to studying the brain, specifically functional neuroimaging and associated models; (2) quantitative approaches to studying human cognition and perception, specifically psychophysics and theoretical modeling. Along with refinement of skills in experimental design and theoretical interpretations, these two complementary methodologies will round out the skillset that will help me transition into a career as an independent investigator. I look forward to using an arsenal of experimental, analytical, and computational techniques to answer challenging questions in systems and cognitive neuroscience, such as those at the interface of vision, attention, and cognition.

a. Pasupathy A, El-Shamayleh Y, Popovkina DV. 2018. Visual shape and object perception. Oxford Research Encyclopedia of Neuroscience. DOI:10.1093/acrefore/9780190264086.013.75
b. Popovkina DV, Bair W, Pasupathy A. Modelling diverse responses to filled and outline shapes in macaque V4. 2018. Under review.
c. Popovkina DV, Pasupathy AK. Behavioral relevance changes feature selectivity in area V4. Society for Neuroscience Annual Meeting, Washington DC, November 2014. Poster presentation.
d. Mattison HA, Popovkina D, Kao JPY, Thompson SM. 2014. The role of glutamate in the morphological and physiological development of dendritic spines. European Journal of Neuroscience, 39: 1761–1770. doi: 10.1111/ejn.12536 PMCID: PMC4043883

B. Positions and Honors

Positions and Employment

2018 - Research Associate, University of Washington

Professional Memberships

Phi Beta Kappa
Society for Neuroscience
Vision Sciences Society

Honors and Awards

2006 - 2010 Scholarship, Meyerhoff Scholars Program
2006 - 2010 Scholarship, HHMI Undergraduate Scholars Program
2008 - 2010 Traineeship, MARC U*STAR Program, UMBC (T34)
2010 Salutatorian, Class of 2010, UMBC
2010 B.S. *summa cum laude*, B.A. *summa cum laude*, UMBC
2010 Outstanding Graduating Senior, Department of Chemistry and Biochemistry, UMBC
2010 Outstanding Graduating Senior, Department of Ancient Studies, UMBC
2010 Departmental Service Award, Department of Chemistry and Biochemistry, UMBC
2011 - 2013 Traineeship, Computational Neuroscience Training Grant, UW (T90)
2012 - 2016 Fellowship, NSF Graduate Research Fellowship Program
2016 - 2017 Traineeship, Vision Training Grant, UW (T32)

C. Contributions to Science

1. Modelling diverse responses to filled and outline shapes in macaque V4**.** In visual area V4, a mid-level cortical area in the primate ventral pathway of object processing, neurons show responses related to the boundaries and surfaces of visual objects. Past studies have typically investigated selectivity for either boundary or surface properties, providing little understanding of how boundaries and surfaces may be represented together. Moreover, prominent computational models of recognition rely on boundary shape of objects, disregarding surface information. I recorded responses of single, well-isolated neurons in area V4 to the presentation of 2D shapes and their outlines, which share a common boundary, but differ in their interior fill. While computational models (e.g. Cadieu et al., 2007) predict the same responses for stimuli with the same boundaries, I found that responses of most V4 neurons were modulated by both boundary shape and interior fill. This finding was surprising given the prominence of boundary-based computational models, but consistent with physiological findings in other areas of the ventral pathway. Together with Dr. Wyeth Bair, I successfully modified the model proposed by Cadieu and colleagues to account for my experimental observations, and identified two key ways in which information in earlier visual areas may combine to produce V4 neurons' responses to object shape and fill. These findings have major implications for understanding the role mid-level stages of visual processing play in object recognition, and provide predictions for how representations of boundaries and surfaces in the brain may enable processes such as scene segmentation. The manuscript for this work is currently under review at the Journal of Neurophysiology.

a. Popovkina DV, Bair W, Pasupathy A. 2018. Modelling diverse responses to filled and outline shapes in macaque V4. Under review.
b. Popovkina DV, Pasupathy A, Bair W. Advancing models of shape representation for mid-level vision. Society for Neuroscience Annual Meeting, San Diego, CA, November 2016. Poster presentation.
c. Popovkina DV, Pasupathy A, Bair W. Advancing models of shape representation for mid-level vision. COSYNE, Salt Lake City, UT, March 2015. Poster presentation.

2. Influence of task on encoding of object shape and color in macaque V4**:** Typically, neuronal responses are collected while animals perform a passive task: looking at a small white dot on the screen while ignoring the peripherally presented object. Responses to the object can be used to measure neuronal selectivity, e.g. which shapes or colors elicit stronger responses from the neuron. However, responses of neurons in area V4 are also known to be affected by cognitive processes such as attention. I investigated whether the passively-determined neuronal selectivity for shape and color changes when animals switch to an active task: reporting whether the shape of two objects was the same or different. In both the passive and the active task, animals saw objects which were combinations of different shapes and colors. This design allowed me to record responses of V4 neurons to identical objects in two different contexts: where shape and color were irrelevant to the goal of the animal (passive task) and where only shape was relevant (active task). I found that in a majority of neurons, selectivity for shape and/or color was different during the active task, compared to the passive task. For some neurons, I also measured responses in a complementary active task: reporting whether the color of two objects was the same or different (ignoring shape). Although the two active tasks have opposite perceptual judgments, neuronal selectivity in the color task was similar to that in the shape task. Importantly, these results suggest that task context can change the shape and color selectivity of V4 neurons; however, these changes do not relate to the overall behavioral goal (e.g., discriminating shape or color). Differences in selectivity are observed only when comparing responses in passive and active task contexts, and may be related to higher-level task factors such as engagement. Since V4 is relatively early in the object recognition processing stream, an attention-related change in the brain's response means that later stages of processing are affected as if the stimulus physically changed; thus, my findings underscore that the nature of information available for decision-making may be context-dependent. I am currently preparing the manuscript for this work.

a. Popovkina DV, Pasupathy AK. Behavioral relevance changes feature selectivity in area V4. Society for Neuroscience Annual Meeting, Washington DC, November 2014. Poster presentation.

3. Investigating the timing of signals in area V4**:** The hierarchical nature of connections in primate visual cortex is reflected in the gradual delays of signal arrival (response onset latency) in successive stages of the visual system. For example, onset of responses in area V4 is typically observed later than those in primary visual cortex; these comparisons help constrain interpretations of the functions performed by different areas. A widely cited estimate of onset latency in area V4 (Schmolesky et al., 1998), derived from one anesthetized animal, is at odds with our observations from electrophysiology data collected in Dr. Pasupathy's lab. Together with Polina Zamarashkina, a research assistant with Dr. Pasupathy, we have confirmed that signals arrive substantially earlier than the original estimation. This finding results from a large-scale analysis of data from 6 experiments in awake macaques. Additionally, we found that response onset latency depended on both bottom-up (i.e., the size of the stimulus presented) and top-down factors (i.e., whether the animal performed a passive or active task). Similar to my analysis of selectivity in area V4 (see Contribution #2), these findings suggest that information content in mid-level visual areas is stimulus- and context-dependent, likely affecting later stages of visual processing. For this study, I collected 2 of the 6 data sets, assisted with data analysis, co-presented results at a national conference, and am currently helping prepare the manuscript.

a. Zamarashkina P, Popovkina DV, Pasupathy A. 2017. Stimulus and task dependence of response latencies in primate area V4. Vision Science Society Annual Meeting Abstract. Journal of Vision, 17:476. DOI:10.1167/17.10.476. Poster presentation.

D. Additional Information: Research Support and/or Scholastic Performance

YEAR	COURSE TITLE	GRADE
	UNIVERSITY OF MARYLAND, BALTIMORE COUNTY (*)	
2006	Principles of Chemistry I	A
2006	Calculus and Analytical Geometry I	A
2007	Principles of Chemistry II	A
2007	Calculus and Analytical Geometry II	A
2007	Concepts of Biology	A
2007	Molecular and General Genetics	A
2007	Organic Chemistry I	A
2007	Introductory Physics I	A
2008	Neuroanatomy	A
2008	Organic Chemistry II	A
2008	Introductory Physics II	A
2008	Cell Biology	A
2008	Analytical Chemistry	A
2008	Comprehensive Biochemistry I	A
2009	Ethics and Integrity in Scientific Research	Pass
2009	Comprehensive Biochemistry II	A
2009	Physical Chemistry for Biochemists	A
2009	Special Topics in Chemistry: Nanoparticles	A
2010	Microbial and Molecular Genetics	A
	UNIVERSITY OF WASHINGTON (**)	
2010	Intro to Neurobiology I	3.9
2010	Biophysics of Nerves, Muscles, Synapses	3.9
2011	Intro to Neurobiology II	3.9
2011	Cell Signaling	3.7
2011	Cognitive Neuroscience	3.6
2011	Neurobiology of Disease	3.5
2012	Computational Modeling of Biological Systems	3.9
2012	Vision	4.0

YEAR	COURSE TITLE	GRADE
	OTHER: COLD SPRING HARBOR SHORT COURSES (***)	
2009	Imaging Structure and Function in the Nervous System (teaching assistant)	N/A
2014	Computational Neuroscience: Vision (student)	N/A
2016	Computational Neuroscience: Vision (teaching assistant)	N/A
2017	Neural Data Analysis (teaching assistant)	N/A

* Courses counting toward the B.A. in Ancient Studies are omitted for brevity. All courses graded on the A-F scale, except Ethics and Integrity in Scientific Research (Pass/Fail, based on attendance and discussion participation). *Cumulative undergraduate GPA: 4.0*

** All courses graded on the 0.0-4.0 scale. *Cumulative graduate GPA: 3.8*

*** Special topic courses that did not result in a grade, but were paramount to my scientific development.

OMB No. 0925-0001 and 0925-0002 (Rev. 09/17 Approved Through 03/31/2020)

BIOGRAPHICAL SKETCH

Provide the following information for the Senior/key personnel and other significant contributors.
Follow this format for each person. **DO NOT EXCEED FIVE PAGES.**

NAME: Boynton, Geoffrey M.

eRA COMMONS USER NAME (credential, e.g., agency login): boynton

POSITION TITLE: Professor

EDUCATION/TRAINING *(Begin with baccalaureate or other initial professional education, such as nursing, include postdoctoral training and residency training if applicable. Add/delete rows as necessary.)*

INSTITUTION AND LOCATION	DEGREE *(if applicable)*	Completion Date MM/YYYY	FIELD OF STUDY
University of California, San Diego, CA	B.S.	06/87	Applied Mathematics
University of California, Santa Barbara, CA	M.A.	06/89	Mathematics
University of California, Santa Barbara, CA	PhD.	06/94	Psychology
Stanford University, Stanford, CA	Postdoc	06/98	Psychology

A. Personal Statement

I have been involved with functional brain imaging and brain imaging centers since 1994 when I began my postdoc with David Heeger at Stanford University. Since then, I have built a research program developing computational models to compare behavioral data with fMRI data, focusing on attention in the visual system. I have had continuous support since 1998 from NIH to study the effects of attention in human visual cortex using fMRI and visual psychophysics. I am currently focusing on computational models of divided attention that predict a range of behavioral and imaging results. The present proposal fits in well with the Specific Aims of my research program. However, this proposal's inclusion of object recognition and Alzheimer's patient populations provides the opportunity for the applicant to branch out into an independent research career.

All throughout my career I have held leadership roles with my current neuroimaging center. As a faculty member at the Salk Institute in 2000, I served on the original director's committee that oversaw the design, construction and development of the UCSD Neuroimaging center. In 2006 I was the PI on the NSF MRI grant that supported the purchase of the current Philips 3T scanner at the University of Washington's Diagnostic Imaging Service Center. During my transition to the University of Washington, I oversaw the installation of this device and have served on its director's committee ever since. I am therefore very familiar with the process of developing and maintaining a service center that supports access to high quality and reliable neuroimaging equipment.

B. Positions and Honors

1998 - 2004 Assistant Professor, Systems Neurobiology Laboratory, The Salk Institute for Biological Studies, La Jolla, California
1999 - 2007 Assistant Adjunct Professor, Department of Psychiatry, University of California, San Diego
1999 - 2007 Assistant Adjunct Professor, Department of Neurosciences, University of California, San Diego
2001 - 2007 Associate Director for Human Neuroscience Research, Center for Functional Magnetic Resonance Imaging, University of California, San Diego
2004 - 2007 Associate Professor, Systems Neurobiology Laboratory, The Salk Institute for Biological Studies, La Jolla, California

2007 – 2012 Associate Professor, Department of Psychology, University of Washington
2012 – Present Professor, Department of Psychology, University of Washington

Other Experience and Professional Memberships

2007- Editorial Board for the Journal of Vision
2005-2015 Editorial Board for Vision Research
2009- Elected Member of the Society for Experimental Psychologists
2009- Abstract Review Committee, Vision Sciences Society
2013- External Advisor, University of Nevada Reno COBRE grant
2013 Member, Local Organizing Committee, Human Brain Mapping Conference
2014- External Advisor, U.C. Davis Neuroscience Core Grant

C. Contributions to Science

Over the past two decades we've learned that what and where an observer is attending has a profound influence on the neuronal response to incoming visual stimuli. This is a remarkable shift in our understanding of the functional organization of the mammalian visual system. It means that attention alters the brain's interpretation of a stimulus as soon as it enters the cortex. While it was once thought that areas such as V1 maintained a veridical, movie screen-like representation of the visual scene, we now know that all cortical areas in the visual system are affected by what and where you are attending. My research has been focused on understanding how our brain's representation of the distal world is unavoidably altered by what we are trying to see.

Much of our knowledge about how attention alters neuronal responses in visual cortex comes from functional MRI (fMRI) studies in human subjects. As I will describe below, much of my work on attention has involved this method.

1. Research on the response properties of the fMRI signal

Functional MRI (fMRI) was in its infancy when I started my postdoc at Stanford University with David Heeger in 1994. It had been only a few years since the original papers were published showing that a blood oxygen level dependent (BOLD) signal could serve as a correlate of brain responses using standard clinical MRI scanners. The method was so new that almost nothing was known about the relationship between the BOLD signal and the underlying neuronal response. David Heeger and I wanted to apply fMRI to study the human visual system, but before we could get started we decided to run a series of experiments to determine if we were working with a well-behaved measure of neuronal activity. Specifically, we wanted to see if the BOLD response behaved linearly in time so that, for example, the response to two successively presented stimuli could be predicted from the response to single stimuli alone. To our surprise, we found that the BOLD signal was remarkably linear. This greatly simplified the interpretation of fMRI results – the linear model is the backbone of nearly all fMRI analysis software packages. Our publication of this result in the Journal of Neuroscience in 1996 formed the justification for nearly all fMRI analysis methods today (Boynton, Engel et al. 1996). More importantly, it meant that we could proceed with our original plans to investigate the human visual system with fMRI.
I have since maintained an interest in the 'hemodynamic coupling problem' and have published work on the effects of adaptation (Boynton and Finney 2003) and transients (Tuan, Birn et al. 2008) on the fMRI signal. I have also enjoyed writing a series of commentaries and reviews on the topic (e.g. Boynton 2005).

a. Boynton, G. M., S. A. Engel, et al. (1996). "Linear systems analysis of functional magnetic resonance imaging in human V1." J Neurosci 16(13): 4207-4221.
b. Tuan, A. S., R. M. Birn, et al. (2008). "Differential transient MEG and fMRI responses to visual stimulation onset rate." International Journal of Imaging Systems and Technology 18(1): 17-28.
c. Boynton, G. M. (2005). "Imaging orientation selectivity: decoding conscious perception in V1." Nat Neurosci 8(5): 541-542.

d. Finney, E. M. and G. M. Boynton (2003). "Orientation-specific adaptation in human visual cortex." J. Neurosci 23 (25): 8781-7.

2. Effects of spatial attention in primary visual cortex (V1)

Around this time, the first studies were published showing that attention could affect the neuronal responses in higher areas of the macaque visual cortex such as area MT. It was natural to apply fMRI to see if we could find effects of spatial attention in the human visual cortex. We were surprised to find robust effects of spatial attention not only in higher visual areas, but also in V1 (Gandhi, Heeger et al. 1999). This result was so novel that we had some difficulty getting our results through the review process, but in the end two other laboratories had just discovered the same result (Martinez, Anllo-Vento et al. 1999; Somers, Dale et al. 1999). Since then, effects of attention on fMRI responses in V1 have been published hundreds of times (many in my own laboratory); this is now literally textbook knowledge.

A curious fact is that the effects of spatial attention on the BOLD signal in human V1 appear to be larger than what is expected from monkey electrophysiology studies, especially for weak or low contrast stimuli. My research back at the Salk Institute showed that the strength of these attentional effects did not depend on the strength, or contrast, of the physical stimulus (Buracas and Boynton 2007). This apparent discrepancy between human fMRI and monkey electrophysiology results has been an ongoing topic of my research. One intriguing explanation is that because the BOLD signal presumably reflects an aggregate response over a large pool of neurons, the BOLD signal may actually be more sensitive than single-unit measures. I've discussed this possibility and a variety of other possible explanations in a review (Boynton 2011).

a. Boynton, G. M. (2011). "Spikes, BOLD, attention, and awareness: a comparison of electrophysiological and fMRI signals in V1." J Vis 11(5): 12. PMC4124818

b. Buracas, G. T. and G. M. Boynton (2007). "The effect of spatial attention on contrast response functions in human visual cortex." J Neurosci 27(1): 93-97.

c. Gandhi, S. P., D. J. Heeger, et al. (1999). "Spatial attention affects brain activity in human primary visual cortex." Proc Natl Acad Sci U S A 96(6): 3314-3319. PMCID: PMC15939

3. Feature-based attention

Attention can be directed to locations in space (spatial attention, described above), or to different features such as toward directions of motion, or colors (feature-based attention). Early single-unit studies in macaque showed that attention to a specific feature enhanced the responses in neurons that are selective to that feature, and suppressed the response in neurons selective away from the attended feature. These effects of feature-based attention can be found in the responses of neurons with receptive fields far away from the spatial focus of attention.

We were able to find the first effects of such global feature-based attentional effects in humans using fMRI (Saenz, Buracas et al. 2002, 2003). We measured the fMRI response to an unattended moving stimulus while subjects attended to either a matching or un-matching direction in the opposite hemifield. Consistent with the electrophysiological study, we found a greater fMRI response to the unattended stimulus when it matched the direction of motion attended elsewhere. This 'global feature-based' attentional effect was found all over the visual cortex, including area V1. We also found that it applies to color so that attention to a color (say, green) on one side of the visual field enhances the responses to all stimuli in the visual field sharing the attended color, regardless of the spatial focus of attention. This mechanism has implications for tasks such as visual search which is greatly benefited by knowing the feature of an object that you are looking for.

In a later study, we applied a new method of fMRI data analysis called 'multi-voxel pattern analysis' (MVPA) to show that feature-based attention affected the pattern of responses across voxels in early visual areas, including V1, even in the absence of a stimulus (Serences and Boynton 2007). That is, just like for spatial attention, feature-based attention appears to modify neuronal responses in a way that is independent of the physical stimulus. One interpretation of these results is that spatial and feature-based attention is modulating baseline neuronal responses in the anticipation of an incoming visual stimulus, perhaps setting up the network to be particularly sensitive to incoming visual stimulation that matches the attended locations and features.

a. Serences, J. T. and G. M. Boynton (2007). "Feature-based attentional modulations in the absence of direct visual stimulation." Neuron 55(2): 301-312.

b. Saenz, M., G. T. Buracas, et al. (2003). "Global feature-based attention for motion and color." Vision Res 43(6): 629-637.

c. Saenz, M., G. T. Buracas, et al. (2002). "Global effects of feature-based attention in human visual cortex." Nat Neurosci 5(7): 631-632.

4. Automatic processing of unattended information

The flip side of studying the neuronal representation of attended stimuli is to see what happens to the rest of the unattended visual field. Recent work in my lab is showing that an unattended stimulus can slip through the attentional filter if it is threatening or if it shares features or temporal synchrony with an attended stimulus. For example, we have found that when a brief flash of color directs attention to one location in the visual field, subjects are better at detecting a subsequent target anywhere in the visual field as long as it has the same color as the cue (Lin, Hubert-Wallander et al. 2011). Also, when viewing a looming object on a computer screen, the object automatically attracts attention to its location only if it is on a collision course with the subject's head. Amazingly, this automatic capture of attention is sensitive to imperceptible changes in the trajectory of the looming object (Lin, Murray et al. 2009). Finally, we have discovered that unattended information in the peripheral field can be passed into memory if it occurs in time with a foveally presented target. We call this a 'screen-capture' mechanism that grabs all information in the visual field at behaviorally relevant points in time (Lin, Pype et al. 2010). All of these discoveries have been made through behavioral measurements in the lab. We are now pursuing the neuronal basis of these attentional effects using fMRI and EEG techniques.

a. Lin, J. Y., B. Hubert-Wallander, et al. (2011). "Rapid and reflexive feature-based attention." J Vis 11(12). PMC4106428

b. Lin, J. Y., S. O. Murray, et al. (2009). "Capture of attention to threatening stimuli without perceptual awareness." Curr Biol 19(13): 1118-1122. PMC2724068

c. Lin, J. Y., A. D. Pype, et al. (2010). "Enhanced memory for scenes presented at behaviorally relevant points in time." PLoS Biol 8(3): e1000337. PMC2838752

Complete List of Published Work in My Bibliography:

http://www.ncbi.nlm.nih.gov/myncbi/collections/bibliography/46317720/

D. Additional Information: Research Support and/or Scholastic Performance

Ongoing Research Support

RO1 EY02925 -12 Boynton (PI) 9/1/2014 – 8/31/2019
Attention Effects in the Human Visual Cortex
The goal of this study is to understand the neuronal basis of divided attention in the human visual cortex.

OMB No. 0925-0001 and 0925-0002 (Rev. 11/16 Approved Through 10/31/2018)

BIOGRAPHICAL SKETCH

Provide the following information for the Senior/key personnel and other significant contributors.
Follow this format for each person. **DO NOT EXCEED FIVE PAGES.**

NAME: John Palmer

eRA COMMONS USER NAME (credential, e.g., agency login): johnpalmer

POSITION TITLE: Research Professor

EDUCATION/TRAINING *(Begin with baccalaureate or other initial professional education, such as nursing, include postdoctoral training and residency training if applicable. Add/delete rows as necessary.)*

INSTITUTION AND LOCATION	DEGREE *(if applicable)*	Completion Date MM/YYYY	FIELD OF STUDY
University of Washington	B.S.	1976	Psychology
University of Michigan	Ph D.	1984	Psychology

A. Personal Statement

The goal of my research is to better understand the effects of divided and selective attention on both behavior and physiology. My largest body of research is on the behavioral effects of divided attention with the visual search and dual-task paradgims. In perception, divided attention occurs when a task requires information from multiple stimuli rather than a single stimulus. Much of my research has focused on quantifying the magnitude of divided attention effects using methods from visual psychophysics and theory from mathematical psychology. For a recent article, see White, Palmer and Boynton (2018) and for an older more detailed review see Palmer, Verghese and Pavel (2000). I have also investigated selective attention. In perception, selective attention occurs when a task requires using information from one stimulus and ignoring information from another stimulus. Most notable is a line of research beginning with Palmer and Moore (2009) that refines an existing paradigm to obtain very large effects of selective attention (from chance to perfect performance). We have used this improved paradigm to ask a variety of questions about the mechanism of selection. More recently, I have been collaborating with Dr. Geoffrey Boynton on the neural basis of attention. Our papers together have combined my prior research on divided attention in behavior with Dr. Boynton's research on divided attention in imaging (e.g. White, Runeson, Palmer, Ernst & Boynton, 2017). We continue to combine our expertise in behavior and physiology to identify the neural basis of the behavioral effects of attention.

1. White, A. L., Palmer, J. & Boynton, G. M. (2018). Evidence of serial processing in visual word recognition. *Psychological Science*, *29*, 1062-1071.

2. White, A. L., Runson, E., Palmer, J., Ernst, Z. R. & Boynton, G. M. (2017). Evidence for unlimited capacity processing of simple features in visual cortex. *Journal of Vision*, *17*, 1-20.

3. Palmer, J. & Moore, C. M. (2009). Using a filtering task to measure the spatial extent of selective attention. *Vision Research*, *49*, 1045-1064.

4. Palmer, J., Verghese, P., & Pavel, M. (2000). The psychophysics of visual search. *Vision Research*, *40*, 1227-1268

B. Positions and Honors

Positions and Employment

1973 - 1979 Research Technician, University of Washington
1979 - 1984 Graduate Training, University of Michigan
1984 - 1988 Assistant Professor, University of Washington
1988 - 1989 Visiting Assistant Professor, Stanford University
1989 - 1992 Assistant Professor, University of Washington
1992 - 2005 Research Consultant, University of Washington
2005 - present Research Professor, University of Washington

Other Experience and Professional Memberships

2001 - Member, Vision Sciences Society
1987 - Fellow, Psychonomic Society
2008 - Fellow, American Psychological Association
2004 Editor of a special issue of Spatial Vision on Visual Search and Attention
2005 - 2008 Editorial Board, Journal of Vision

Honors

1979-1982 National Science Foundation Graduate Fellowship
1982-1984 National Eye Institute Training Grant
1988-1989 Invited to Stanford University
1990 Invited to Attention and Performance XIV
2008 Davida Teller Distinguished Faculty Award
2008 Fellow in the American Psychological Society

C. Contributions to Science

1. **Divided attention for the perception of simple features.** I am perhaps best known for my work showing the lack of divided attention effects in the perception of simple features. In visual perception, divided attention refers to situations in which an observer must judge multiple aspects of a visual scene rather than a single aspect. For example, is it harder to simultaneously read two words at once compared to one? Divided attention effects are common for complex stimuli such as words. For the case of a simple feature, is it harder to detect a change from green to red among multiple warning lights on an instrument panel compared to a single warning light? The literature is not as clear on whether divided attention effects occur for the perception of simple features such as luminance, color or motion. The issue is complicated by whether an observed effect is due to divided attention in perception or in memory and decision. My studies have focused on isolating the perceptual contribution and have shown that such effects do not occur for a variety of simple features (Palmer, 1994), a variety of visual search tasks (Busey & Palmer, 2008) and for simple dual tasks (Ernst, Boynton & Palmer, 2012). Recent work continues to refine these measurements and explore the boundary conditions of this phenomenon (Attarha, Moore, Scharff & Palmer, 2014). The lack of divided attention effects with simple features forces one to reject many common theories of divided attention that predict effects for all kinds of stimuli.

    a. Attarha, M., Moore, C. M., Scharff, A. & Palmer, J. (2014). Evidence of unlimited-capacity surface completion. *Journal of Experimental Psychology: Human Perception and Performance*, *40*, 556-565.

    b. Ernst, Z. R., Palmer, J. & Boynton, G. M. (2012). Dividing attention between two transparent motion surfaces results in a failure of selective attention. *Journal of Vision*, *12*, 1-17. PMCID: PMC3587004

c. Busey, T. & Palmer, J. (2008). Set-size effects for identification versus localization depend on the visual search task. *Journal of Experimental Psychology: Human Perception and Performance*, *34*, 790-810.

d. Palmer, J. (1994). Set-size effects in visual search: The effect of attention is independent of the stimulus for simple tasks. *Vision Research*, *34*, 1703-1721.

2. Divided attention for the perception of objects and words. To complement the research with simple features, I have conducted a series of studies that measure divided attention effects for the perception of objects and words. We have found robust divided attention effects for the semantic categorization of words (Scharff, Palmer & Moore, 2011a), the categorization of animal pictures (Scharff, Palmer & Moore, 2011b), and shape judgments of "table-top" objects (Scharff, Palmer & Moore, 2013). More recently we have shown that masked words have the largest effects one might expect: one can process only one masked word at a time (White, Palmer & Boynton, 2018). All of these cases provide a sharp contrast to our previously studied judgments of simple features. Being able to predict exactly what stimuli and tasks result in divided attention effects is a critical test for general theories of divided attention. Current work in collaboration with Dr. Geoff Boynton explores the neural basis of such divided attention phenomena. We are also beginning to study how limits on divided attention across words constrain the processes of reading.

a. White, A. L., Palmer, J. & Boynton, G. M. (2018). Evidence of serial processing in visual word recognition. *Psychological Science*, *29*, 1062-1071. PMCID: PMC6050133

b. Scharff, A., Palmer, J. & Moore, C. M. (2013). Divided attention limits perception of 3-D object shapes. *Journal of Vision*, *13*, 1-24.

c. Scharff, A., Palmer, J. & Moore, C. M. (2011b). Extending the simultaneous-sequential paradigm to measure perceptual capacity for features and words. *Journal of Experimental Psychology: Human Perception and Performance*, *37*, 813-833.

d. Scharff, A., Palmer, J. & Moore, C. M. (2011a). Evidence of fixed capacity in visual object categorization. *Psychological Bulletin and Review*, *18*, 713-721.

3. Selective attention to simple features, objects and words. In collaboration with Dr. Cathleen Moore, I have begun a line of research on selective attention. Selective attention refers to situations in which an observer must use information from one stimulus and not another. In particular, filtering paradigms explicitly define some stimuli as relevant and others as irrelevant. One must "filter" stimuli to include the relevant and exclude the irrelevant. In Palmer and Moore (2009), we reinvented the filtering paradigm to reveal very large effects of attention (from chance to perfect). In the spatial filtering version of this task, we tell an observer that the stimulus at one location is relevant and the same stimulus at any other location is irrelevant. We also manipulate the separation between the relevant and irrelevant stimuli. If the relevant and irrelevant locations are very close together, the irrelevant stimulus cannot be ignored; if they are far apart, it is easy to ignore the irrelevant stimulus. Thus, by varying the location of the irrelevant stimulus we can measure the spatial selectivity of spatial attention. We have begun exploring the mechanisms of selective attention and find evidence for different mechanisms depending on the procedure (Yigit-Elliott, Palmer & Moore, 2011). Current research is examining a variety of stimuli (features, objects, and words) and a variety of similar paradigms to relate this improved paradigm to previous work. The large effects found with this paradigm enhance our ability to distinguish between the predictions of alternative hypotheses for how selective attention works.

a. Yigit-Elliott, S., Palmer, J. & Moore, C. M. (2011). Distinguishing blocking from attenuation in visual selective attention. *Psychological Science*, *22*, 771-780.

b. Palmer, J. & Moore, C. M. (2009). Using a filtering task to measure the spatial extent of selective attention. *Vision Research*, *49*, 1045-1064.

4. **Divided attention in visual memory.** Early in my career, I focused on divided attention effects in memory rather than in perception. In particular, Palmer (1990) quantified the capacity of memory using methods that bridged the worlds of perception and memory. In recent years, these methods have become commonplace and there is an active debate about the constraints of features versus objects in the capacity of visual memory. I returned to this topic in a recent study (Palmer, Boston & Moore, 2015) and continue to be interested in comparing attention phenomena in perception and memory.

   a. Palmer, J., Boston, B. & Moore, C. M. (2015). Limited capacity for memory tasks with multiple features within a single object. *Attention, Perception & Psychophysics*, *77*, 1488-1499.

   b. Palmer, J. (1990). Attentional limits on the perception and memory of visual information. *Journal of Experimental Psychology: Human Perception and Performance*, *16*, 332-350.

   c. Palmer, J. (1988). Very short-term memory for size and shape. *Perception & Psychophysics*, *43*, 278-286.

5. **Response time measures of visual perception and attention.** While the majority of my research uses accuracy measures of human performance, I have also developed methods to conduct similar studies using response time measures. A key problem is the need for common theories to interpret both accuracy and response time. To that end, one can relate models used with accuracy (e.g. signal detection theory) to models used in response time (e.g. random walks and diffusion). In Palmer, Huk and Shadlen (2005), we described a simple diffusion model that allows for many of the analyses of response time that we have performed in the past on accuracy using signal detection theory. In the future, I intend to extend this work to address the phenomena of selective and divided attention.

   a. Palmer, J., Huk, A. C. & Shadlen, M. N. (2005). The effect of stimulus strength on the speed and accuracy of a perceptual decision. *Journal of Vision*, *5*, 376-404.

   b. Palmer, J. (1998) Attentional effects in visual search: Relating search accuracy and search time. In R. Wright (Ed.), *Visual Attention*. New York: Oxford University Press.

D. Additional Information: Research Support and/or Scholastic Performance

R01 EY12925 Boynton (PI) 9/1/2014 - 8/31/2019
The effects of attention in human visual cortex
In this project, we examine the neural basis of divided attention using behavior, imaging and computational theory.
Role: Co-Investigator

PHS Fellowship Supplemental Form

OMB Number: 0925-0001
Expiration Date: 03/31/2020

Introduction

1. Introduction to Application
(for Resubmission applications)

Fellowship Applicant Section

2. Applicant's Background and Goals for Fellowship Training*	Background_GoalsforTraining_FINAL.pdf

Research Training Plan Section

3. Specific Aims*	Specific_Aims_FINAL.pdf
4. Research Strategy*	Research_Strategy_FINAL.pdf
5. Respective Contributions*	RespectiveContributions.pdf
6. Selection of Sponsor and Institution*	Selection_Sponsors_Institution.pdf
7. Progress Report Publication List (for Renewal applications)	
8. Training in the Responsible Conduct of Research*	Training_RCR.pdf

Sponsor(s), Collaborator(s) and Consultant(s) Section

9. Sponsor and Co-Sponsor Statements	Sponsor_Cosponsor_Statement_FINAL.pdf
10. Letters of Support from Collaborators, Contributors and Consultants	Popovkina_LOS_NRSA_TJG_8-31-2018.PDF

Institutional Environment and Commitment to Training Section

11. Description of Institutional Environment and Commitment to Training	Description_Institutional_Environment_FINAL.pdf

Other Research Training Plan Section

Vertebrate Animals

The following item is taken from the Research & Related Other Project Information form and repeated here for your reference. Any change to this item must be made on the Research & Related Other Project Information form.

Are Vertebrate Animals Used? ☐ Yes ☑ No

12. Are vertebrate animals euthanized?

If "Yes" to euthanasia
Is method consistent with American Veterinary Medical Association (AVMA) guidelines?

If "No" to AVMA guidelines, describe method and provide scientific justification

13. Vertebrate Animals

PHS Fellowship Supplemental Form

Other Research Training Plan Information

14. Select Agent Research

15. Resource Sharing Plan

16. Authentication of Key Biological and/or Chemical Resources

Additional Information Section

17. Human Embryonic Stem Cells

Does the proposed project involve human embryonic stem cells?* ☐ Yes ☑ No

If the proposed project involves human embryonic stem cells, list below the registration number of the specific cell line(s), using the registry information provided within the agency instructions. Or, if a specific stem cell line cannot be referenced at this time, please check the box indicating that one from the registry will be used:

Specific stem cell line cannot be referenced at this time. One from the registry will be used.

Cell Line(s):

18. Alternate Phone Number: 240-472-4955

19. Degree Sought During Proposed Award:

Degree:	If "other", indicate degree type:	Expected Completion Date (MM/YYYY):

20. Field of Training for Current Proposal*: 603 Cognitive Psychology & Psycholinguistics

21. Current or Prior Kirschstein-NRSA Support?* ☑ Yes ☐ No

If yes, identify current and prior Kirschstein-NRSA support below:

Level*	Type*	Start Date (if known)	End Date (if known)	Grant Number (if known)
Predoctoral	Institutional	09/16/2011	09/15/2013	T90 DA32436
Predoctoral	Institutional	09/16/2016	09/15/2017	T32 EY7031

22. Applications for Concurrent Support?* ☐ Yes ☑ No

If yes, describe in an attached file:

23. Citizenship*

U.S. Citizen — U.S. Citizen or Non-Citizen National? ☑ Yes ☐ No

Non-U.S. Citizen
- ☐ With a Permanent U.S. Resident Visa
- ☐ With a Temporary U.S. Visa

If you are a non-U.S. citizen with a temporary visa applying for an award that requires permanent residency status, and expect to be granted a permanent resident visa by the start date of the award, check here: ☐

24. ☐ Change of Sponsoring Institution — Name of Former Institution:*

PHS Fellowship Supplemental Form

Budget Section

All Fellowship Applicants:

25. Tuition and Fees*:

☑ None Requested ☐ Funds Requested

Year 1	
Year 2	
Year 3	
Year 4	
Year 5	
Year 6 (when applicable)	
Total Funds Requested:	$0.00

Senior Fellowship Applicants Only:

	Amount	Academic Period	Number of Months
26. Present Institutional Base Salary:			

27. Stipends/Salary During First Year of Proposed Fellowship:

a. Federal Stipend Requested:	Amount	Number of Months
b. Supplementation from Other Sources:	Amount	Number of Months
	Type (e.g.,sabbatical leave, salary)	
	Source	

Appendix

28. Appendix

APPLICANT'S BACKGROUND AND GOALS FOR FELLOWSHIP TRAINING

Doctoral Dissertation and Research Experience

Undergraduate Training: University of Maryland, Baltimore County (2007-2010)

PI: Dr. Scott Thompson, Dept. of Physiology, University of Maryland, Baltimore

Research support: Meyerhoff and HHMI Undergraduate Scholars Programs

Training grants: MARC U*STAR (T34)

In my undergraduate training at UMBC, I was supported by programs aimed at providing access to research experience for groups underrepresented in STEM fields. Although I was studying Biochemistry at the time, my research experience began in Dr. Thompson's lab because I was interested in applying molecular methods to study the brain. Dr. Thompson helped me develop a small independent project investigating how the stress hormone corticosterone affects the morphology of neurons in mouse hippocampus. I found that corticosterone reduced the density of dendritic spines, small projections from neuronal dendrites where synapses are commonly established; and this effect was mediated by the trkB neurotrophin receptor.

I carried out this research while learning principles of neuroscience, molecular techniques, fluorescent microscopy, and the basics of conducting animal work responsibly in a laboratory setting. I also contributed data collection, analysis, and interpretation to a collaboration with a graduate student in the lab (Dr. Hayley Mattison), which established a functional link between proposed precursors to dendritic spines, and morphologically distinct versions associated with mature synapses. This work resulted in a 2nd author publication.

Work in Dr. Thompson's lab also exposed me to electrophysiology methods, which lay the foundation for my interest in studying electrical signals in the brain and guided me in my choice of graduate training. My earliest experience in this lab (visualizing neuron morphology using fluorescent microscopy) also contributed to my current interest in visualizing large-scale activity in the brain.

Presentations:

Popovkina DV, Thompson SM. The effect of corticosterone and trkB receptor downregulation on dendritic spine density. Annual Biomedical Research Conference for Minority Students, Austin TX, November 2007. *Oral presentation.*

Popovkina DV, England PM, Thompson SM. TrkB receptor downregulation contributes to dendritic spine density decrease due to chronic elevation of corticosterone. Society for Neuroscience Annual Meeting, Chicago IL, October 2009. *Poster presentation.*

Publications:

Mattison HA, **Popovkina D**, Kao JPY, Thompson SM. 2014. The role of glutamate in the morphological and physiological development of dendritic spines. European Journal of Neuroscience, 39: 1761–1770. doi: 10.1111/ejn.12536 PMCID: PMC4043883

Graduate Training: University of Washington (2010-2017)

PI: Dr. Anitha Pasupathy, Dept. of Biological Structure, University of Washington

Research support: NSF Graduate Research Fellowship Program

Training grants: Vision (T32), Computational Neuroscience (T90)

Dissertation: Neural encoding of object properties and task-dependent changes in primate visual area V4

My goal for graduate training was to obtain a new perspective on understanding electrical signals in the brain, specifically using electrophysiology methods. I chose the graduate program in Neuroscience at the University of Washington because of its faculty's excellence in a variety of research areas and methods, and the collegial and

interdisciplinary environment. I joined the lab of Dr. Anitha Pasupathy after a rotation in the lab piqued my interest in sensory systems neuroscience. My dissertation work comprised two projects investigating how neurons in visual cortex of non-human primates represent information about visual objects.

In the first project, I investigated how neurons represented information about boundaries and surfaces of objects in area V4, a mid-level stage of visual processing in the primate brain. I found evidence that most neuronal responses were modulated by both boundary shape and object interior. This finding contradicted a prevalent assumption among computational models of object recognition in the primate brain: that neurons contributing to object recognition are modulated by object boundary shape alone, and responses are invariant to object interior. In collaboration with Dr. Wyeth Bair in the Dept. of Biological Structure, I discovered the critical components of a well-established computational model that can be changed to account for my experimental observations. This work resulted in a 1st author manuscript which is currently under review.

In the second project, I investigated whether the selectivity for object shape and color observed in responses of V4 neurons depended on the task the animals were performing. Most selectivity measurements are performed when an animal passively views peripherally presented stimuli; but it is well-established that V4 responses change in active tasks, i.e. attending to object shape. I found that many neurons in area V4 displayed changed selectivity for shape and/or color of objects in an active, compared to a passive task. Additionally, I found that this change did not depend on the goal of the active task, e.g. responses were similar in a task where the animal attended to object shape compared to a task attending to object color. This work also resulted in a 1st author manuscript, which is currently in preparation.

My graduate experience greatly motivated my current interest in vision and attention in humans. Dr. Pasupathy has been instrumental in my choice to continue a career in scientific research, and the choice to continue studying vision and object recognition. My graduate project examining behavior-related changes in neuronal encoding was especially reflective of my early interest in learning more about the relationship between vision and higher cognitive functions such as attention. My experience in the lab has also solidified my desire to leverage theory-driven interdisciplinary approaches to understand the brain, as I propose to do in my postdoctoral training with the guidance of Drs. Boynton and Palmer.

Presentations:

Popovkina DV, Pasupathy A, Bair W. Advancing models of shape representation for mid-level vision. Society for Neuroscience Annual Meeting, San Diego, CA, November 2016.

Popovkina DV, Pasupathy AK. Behavioral relevance changes feature selectivity in area V4. Society for Neuroscience Annual Meeting, Washington DC, November 2014.

Publications:

Pasupathy A, El-Shamayleh Y, **Popovkina DV**. 2018. Visual shape and object perception. Oxford Research Encyclopedia of Neuroscience.

Training Goals and Objectives

The goal of the fellowship proposal and associated training plan is to advance my research expertise and develop additional skills critical for an academic career in perceptual and cognitive neuroscience.

1. Psychophysics, experimental and analytical methods:

My prior experience with psychophysics included designing and carrying out behavioral experiments in non-human primates, including animal training. Probing human behavior provides a powerful opportunity to design rigorous experiments to gain insight into perceptual and cognitive processes, but also presents challenges that are distinctly different from psychophysics experiments in animals. My co-sponsor Dr. Palmer will train me in theory-driven psychophysics, including designing experiments, quantifying effects, and refining hypotheses related to human vision and attention.

2. Functional neuroimaging (fMRI), experimental and analytical methods:

In my graduate work, I performed electrophysiology experiments, collecting and interpreting data from individual neurons. fMRI methodology provides insights into a larger scale of neural activity, and allows the functional localization and simultaneous analysis of multiple brain areas, without the invasiveness of other approaches (e.g. electrocorticography). My sponsor Dr. Boynton will train me in state-of-the-art fMRI methodology, including analytical skills to interpret large-scale neural data and relate it to behavior.

3. Theory and model development:

In my graduate work, I particularly enjoyed combining experimental insights and computational modeling. My long-term career goal is to leverage interdisciplinary approaches to conduct research efficiently, comprehensively, and in a manner that maximizes impact on the field. Drs. Boynton and Palmer have a long-standing collaboration combining theory, behavior, and neuroimaging to develop quantitative models of perception and cognition. With their guidance, I will learn how to effectively develop theoretical frameworks to inform my experiment design and interpretation. This skill will not only shape my long-term independent research work, but also increase the significance of my work in bringing together the fields of vision and attention.

4. Written and oral communication:

I have foundational experience in writing and oral presentation, both of which are key communication skills necessary for an academic career. My sponsors will help me continue to develop these skills by teaching me how to disseminate my work in a variety of formats to diverse audiences. I will write all first drafts of abstracts and manuscripts, and improve them with help from my sponsors. I will also attend and present at local academic venues (e.g., Vision Journal Club and the Cognition and Perception seminar in the Psychology Department) as well as national and international venues (e.g. conferences such as annual meetings of the Vision Sciences Society, Society for Neuroscience, and Computational and Systems Neuroscience [CoSyNe]).

5. Teaching and mentorship:

In preparation for an academic career, I am dedicated to improving my skills as a mentor and leader. The collaborative environment in the Boynton and Palmer groups will allow me to mentor junior graduate students and undergraduate research assistants and train them in general research methods, as well as our specific areas of research expertise. I also plan to take part in the Science Teaching Experience for Postdocs (STEP) program at UW to develop effective pedagogy methods and learn to design course curricula.

6. Working with clinical populations:

A vast array of disorders result in dysfunctions in perceptual and cognitive processes; thus, my long-term goal to understand human vision and attention has the potential to make a substantial contribution through research in clinical settings. My research strategy includes a set of behavioral experiments with patients affected by posterior cortical atrophy (consulting with Dr. Thomas Grabowski, Director of the UW Alzheimer's Disease Research Center), which will allow me to gain valuable experience in working with a clinical population. Together with my sponsors, Drs. Boynton and Palmer, I will learn to integrate insights from my research with neurotypical individuals and patients to broaden our understanding of the human brain.

Activities Planned under this Award

The proposed timeline of the research is represented schematically below:

	Year 1	Year 2	Year 3
Study Design	X		
Participant Recruitment	X	X	
Data Collection	X	X	X
Data Analysis		X	X
Dissemination			X

The following is a detailed description of all research and career development activities planned under this award, and their relationship to the specific training objectives addressed above.

Year 1: Behavioral and fMRI data collection, analytical skill development

Behavioral study data collection (40%) – I will design and carry out psychophysical experiments to measure the effect of divided attention on object shape recognition. I will learn from co-sponsor Dr. Palmer how to fit mathematical models to the data to test competing hypotheses for attentional effects I observe. In addition to the proposed serial and parallel models, I will learn about related theories of attentional processing, such as limited resource models and stimulus interaction models. (*Training Objectives: 1,3*)

fMRI study design, training, and data collection (50%) – my sponsor Dr. Boynton, senior students, and post-docs in the lab will guide me through the steps of analyzing functional MRI data. First, I will learn the BrainVoyager software to apply motion correction to functional scans, align them to anatomical images, define regions of interest, implement general linear models, and export the data to MATLAB. I will practice these analysis steps on data previously collected in the lab for studies with designs similar to my own. I will write my own MATLAB code to extract signal changes and compare the resulting patterns to previous analyses. The Interdisciplinary Brain Imaging Center at the University of Washington offers certification courses and fMRI analysis seminars. I will also attend scanning sessions with other members of the lab to learn how to operate the equipment, interact with participants, and access the data. After this process, I will write code for my own experiments to test on the equipment in the fMRI imaging center, and then collect fMRI data. (*Training Objectives: 2,3*)

Meetings (10%) – I will attend lab meetings, journal club, and the Biomedical Research Integrity course to continue building my knowledge base. (*Training Objectives: 4*)

Year 2: Behavioral and fMRI data collection, communication skill development

Behavioral study data collection, modeling, and design (40%) – I will finish collecting data from healthy participants. At this points, the behavioral study will have produced interpretable results, and I will be ready to transition to studying behavior in PCA patients. I will use quantitative modeling skills from the previous year, and learn to place data from healthy participants in a theoretical context. I plan to spend a portion of this time refining the design of the behavioral study, including piloting in a few neurotypical participants, before beginning to collect data from PCA patients. (*Training Objectives: 1,3,6*)

MRI/fMRI data collection and modeling (30%) – I will finish collecting fMRI data in neurotypical participants, and collect or obtain the necessary structural MRI data in PCA patients. I expect to learn additional skills in distinguishing interpretations of functional and anatomical scans. At this time I will also begin quantitatively describing my fMRI results by developing models of visual and attentional interactions in the brain. (*Training Objectives: 2,3,6*)

Communication and manuscript preparation (30%) – I will begin preparing my results for dissemination at conferences and in peer-reviewed journals. As part of this process, I will present this work at both local (department- and university-wide seminars and meetings) and national venues (such as Vision Sciences Society and Society for Neuroscience annual conferences). I will also apply for the Summer Institute in Cognitive Neuroscience at U.C. Santa Barbara, another opportunity to learn from experts in related fields. Using feedback

from expert faculty within and outside my institution, I will begin drafting the manuscripts for publication. (*Training Objectives: 4*)

Year 3: Data collection, refinement of data analysis, publishing, grant and job applications

Data collection and analysis (30%) – By the 3rd year of the proposed work, we will have made substantial progress towards answering the primary research questions. Here, I anticipate the remaining follow-up experiments will continue to be conducted to refine our interpretations of the results, and connect our work more directly to relevant questions in other fields. (*Training Objectives: 3*)

Publishing (40%) – I will submit my results for publication in top-tier peer-reviewed journal. Building on analysis and writing in preceding years, I expect the manuscripts to be at the editing and submission stages by the third year. (*Training Objectives: 4*)

Career advancement (30%) – At this stage in the proposed training plan, I will prepare to transition to an independent position. I plan to apply to tenure-track faculty positions, combining research and teaching. In this final year I will acquire additional teaching experience, either as a guest lecturer in undergraduate and graduate-level courses, or formally through the Science Teaching Experience for Postdocs program at UW. I will further prepare for my faculty job application process by (1) attending academic conferences to share my research and network with other scientists, and (2) applying to career development grants such as NIH K99/R01. My sponsors Boynton and Palmer and the other outstanding faculty in the department will assist me in this process. I will practice job talks in our lab meetings and department seminars, and will seek additional career guidance from the University of Washington Office of Postdoctoral Affairs. (*Training Objectives: 4,5*)

SPECIFIC AIMS

Our ability to see and interpret the world is heavily influenced by visual attention. In particular, many common tasks such as driving and playing sports require one to pay attention to several things simultaneously (dividing attention). Intuitively, this can lead to a behavioral impairment: for example, it is much harder to understand two people speaking simultaneously than each one in isolation. Some perceptual tasks show such divided attention effects, while other tasks do not (Scharff *et al*., 2011b). A common explanation for this disparity is that some processes must act serially, while others can act in parallel; this depends on the extent that a task requires the use of serial processes (*e.g.* Treisman and Gelade, 1980).

Curiously, there are few laboratory tasks that show the large divided attention effects and other properties predicted by serial processing. Researchers in reading have long argued whether lexical processing is serial (*e.g.* Reichle *et al.*, 1998) or parallel (*e.g.* Engbert *et al.*, 2005). Recently, White, Palmer and Boynton (2018a) found evidence for serial processing for a task involving semantical categorization of masked words, revealing an attentional bottleneck - a critical limit in the ability to make perceptual judgments.

Our question is whether the attentional bottleneck found for words generalizes to objects. If the attentional bottleneck exists at the level of visual processing where representations of local features are bound into global objects (Kahneman *et al*., 1992), then an object recognition task should show the hallmarks of serial processing observed for word categorization. To test this hypothesis of an "object-level bottleneck", **I propose to leverage insights from behavioral experiments and functional neuroimaging to understand how divided attention limits the ability to recognize object shape.**

Aim 1. How does divided attention impair object shape judgments? To quantify the effect of dividing attention on the ability to recognize object shape, I will ask participants to perform a complex shape recognition task. Participants will see objects in two locations on the screen, and make a judgment about the shape of objects either in a given location (single task), or in both locations (dual task). I will measure performance accuracy in these conditions, and compare it against the predictions of two models: an "all or none" serial process, or an independent parallel process. This experiment should reveal whether an attentional bottleneck exists for whole object judgments.

Aim 2. Which visual processing areas in the brain are affected by divided attention? To find the anatomical location of the attentional bottleneck for object recognition, I will examine neural activity using fMRI while participants perform the task from Aim 1. I will compare activity in an early visual area (primary visual cortex), which encodes local features such as line orientation, and a later visual area (lateral occipital cortex), which encodes global features such as object shape. I will relate fMRI observations to the behavioral results and the two models from Aim 1 (White *et al.*, 2018b). This experiment will independently test the "object-level bottleneck" hypothesis, and additionally address how directly changes in brain activity underlie behavior.

Aim 3. Are cognitive impairments observed in patients with posterior cortical atrophy (PCA) due to an inability to divide attention? Patients diagnosed with PCA demonstrate an inability to recognize multiple objects simultaneously. This deficit has been long observed in clinical settings, but poorly understood in the context of attentional and perceptual processes. I will adapt the task from Aim 1 to investigate whether this behavioral effect is observed because PCA patients are unable to divide attention across simultaneous stimuli, as opposed to an inability to select relevant locations or to form perceptual representations of objects in two locations. I will also compare behavioral performance to the anatomical loci of atrophy in individual patients. This experiment will test the insights from the previous aims, and will provide further elucidation of the relationship between brain and behavior.

Project Innovation. By combining analyses from psychophysics and fMRI, I will be able to examine the evidence for an attentional bottleneck in visual judgments using two independent methods. This will significantly advance our understanding of how attentional processes limit our ability to make perceptual judgments. Importantly, relating behavioral performance to neural activity will help uncover functional links between brains and behavior, and will have a broad impact on our understanding of disorders which affect perceptual or attentional processes.

RESEARCH STRATEGY

Significance

Visual attention research has made significant progress in understanding how attending to locations, features, or objects affects both behavior and its neural basis. Simple computational models (Boynton, 2009; Reynolds and Heeger, 2009) capture results from a large collection of behavioral, electrophysiological, and neuroimaging studies to explain how selective attention affects neural responses in early visual cortex of macaques, and fMRI responses in humans.

In contrast, there is a substantial gap in understanding how we divide attention between multiple sources of information, and there is surprisingly little neurophysiological research on this topic. Decades of behavioral research have shown that divided attention can produce a wide range of effects on performance. These studies have put forward theoretical frameworks to describe how humans perform simultaneous perceptual judgments, which include the idea that attentional bottlenecks might exist in the processing of visual objects, semantic information, or in memory (Kahneman *et al*., 1992; Broadbent, 1958; Luck and Vogel, 1997).

Previous work in our lab has shown that dividing attention can have little effect on performance accuracy for making two simple judgments, *e.g*. Gabor detection (White *et al.*, 2017). However, a more recent study has shown that divided attention profoundly impairs the ability to categorize simultaneously presented words (White *et al.*, 2018a). In fact, observers are able to process only one of the two words, consistent with a serial model in which information can be extracted from only one location at a time. Thus, unlike previous methods, the word recognition paradigm used by White *et al*. (2018a) uncovered a severe behavioral limitation.

An attentional bottleneck in the formation of objects may account for these disparate findings. Divided attention paradigms described above have revealed a critical serial limit somewhere between local (feature-based, *e.g.* line detection) and global (object-based or semantic, *e.g.* word recognition) processing. In this proposal, **I will test the hypothesis that the attentional bottleneck occurs at the level of object formation** (Kahneman *et al*., 1992). Using a combination of psychophysics and functional neuroimaging (fMRI), I will study how dividing attention between two objects impacts human ability to recognize object shape.

First, I will test whether judgments of shape for simultaneously presented objects produce the same serial processing limits observed for words, which would support the “object bottleneck” hypothesis for behavior. Next, I will identify the anatomical location of the attentional bottleneck by using neuroimaging to examine changes in activity in brain areas involved in object processing. I will determine whether effects of divided attention on brain activity are directly responsible for the observed behavioral limits by quantitatively comparing psychophysics and fMRI results. Additionally, I will make use of a relevant clinical population to extend our insights about divided attention and object recognition, and functional principles linking brains and behavior. I will study perception and attention in patients with posterior cortical atrophy (PCA), an uncommon variant of Alzheimer’s disease marked by impairments in recognizing objects simultaneously. I will test whether this clinical presentation is due to an attentional bottleneck rather than global perceptual deficits, and examine how behavioral performance in PCA patients relates to the anatomical extent of Alzheimer’s-induced atrophy in their brains.

Our goal is to leverage the power of behavioral and neurophysiological approaches to reconcile mixed results about how dividing attention limits perceptual judgments, and to identify brain areas and levels of processing responsible for observed limits in behavioral performance.

Insights from the experiments in this proposal will clarify the constraints on human ability to make two simultaneous perceptual judgments. Our approach has an advantage over existing behavioral models, which have largely been descriptive and thus unable to account for the diversity of effects in divided attention tasks. Thus, our studies will fill a prominent gap in the understanding of divided attention. Identifying the neural bases of perceptual performance will also contribute towards developing comprehensive theories of visual attention and perception. By localizing the attentional bottleneck using both psychophysics and fMRI, this work will strengthen our understanding of the link between brains and behavior. Finally, we will make a substantial novel contribution by studying object processing and attention in PCA patients. Although the behavioral impairments in PCA are well-documented in clinical settings, the mechanisms by which they arise have never been investigated. Our insights about the existence of an object bottleneck in neurotypical subjects will enrich our ability to investigate and interpret the impact of attention on object recognition behaviors in PCA. Together, the findings from our proposed studies will further our understanding of impairments of perceptual and attentional processing, such as those found in aging adults and patients with Alzheimer’s disease.

Approach

General Methods.

Subjects: For each experiment, we will recruit 10-20 healthy adults with normal or corrected-to-normal vision. This number of subjects has provided sufficient statistical power in similar behavioral and fMRI studies in our lab before.

Stimuli: The collection of stimuli used in this experiment consists of grayscale photographs of abstract 3D objects (see **Fig. 1** for example); there are 3 sets with 6 exemplar objects each, and 6 different viewpoints represented for each object, for a total of 108 unique images. These stimuli have been used previously in our lab to study global object judgments (Scharff *et al*., 2013). Stimuli will be presented above and below a central fixation point, with each image centered at 4° away from fixation. We will present stimuli and record responses with custom MATLAB code using the Psychophysics Toolbox (Brainard, 1997; Pelli, 1997). For behavioral testing outside the scanner, stimuli will be presented on a gamma-corrected CRT screen while an Eyelink 1000 eye-tracker ensures gaze fixation.

Functional MRI: We will quantify changes in the blood oxygenation level-dependent (BOLD) signal while observers perform an object recognition task with the stimuli described above. Training sessions outside the scanner will ensure that behavioral performance reaches asymptote before scanning. We will obtain structural (T1) and functional (T2) images with the research-dedicated 3T Philips Achieva scanner and a 32-channel head coil. Typical functional scanning parameters will provide whole-brain images with a repetition time of 2 seconds, 32 contiguous slices at a 3x3x3mm resolution and 6 minute scan duration. An LCD projector (60 Hz, 1024x786 resolution) will present stimuli on a back-projection screen viewed through a mirror above the subject's eyes. The projector and monitors in the laboratory are calibrated to have matching linearized grayscale lookup tables. An Eyelink eye-tracker will ensure central gaze fixation during scanning. The subject will use an MRI-compatible four-button box to make perceptual reports. We will use BrainVoyager to perform motion and distortion correction of functional scans, and align them to a 1 mm isotropic T1–weighted structural MRI. Additional analyses will use custom software in MATLAB. Retinotopic maps will be obtained in a separate scanning session using slowly sweeping bar stimuli and Dumoulin and Wandell's population receptive field (pRF) method (2008). We will localize object-selective regions of interest by contrasting responses to images of objects and phase-scrambled objects (Kourtzi *et al*., 2003).

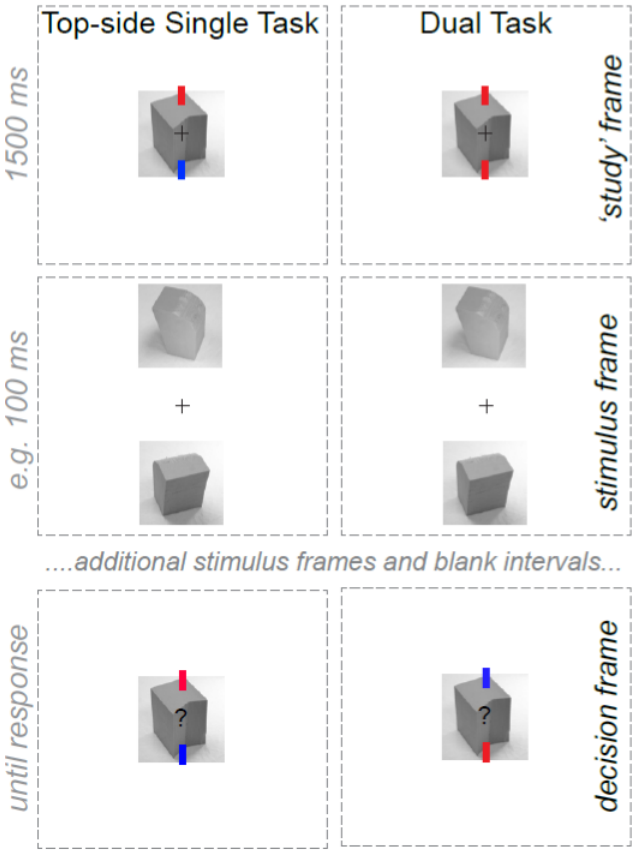

Fig. 1. RSVP task. Sample study, stimulus, and decision frames shown; left: typical durations. Red cue indicates attended side. In the dual task, there is a 2nd decision frame with opposite cues.

Aim 1. How does divided attention impair object shape judgments?

In this Aim, I will investigate whether the attentional bottleneck exists at the level of object formation by investigating how much divided attention impairs object shape recognition performance. To test the "object bottleneck" hypothesis, I will compare the results to the serial processing limit observed for word recognition.

Approach. Participants will perform a challenging 3D object shape recognition task (schematized in **Fig. 1**; following White *et al.*, 2018a). Participants will see a photograph of an object ('study'; *e.g.* top row, **Fig. 1**) and compare to subsequent stimuli: either the same object photographed from a different viewing angle ('match'), or different objects photographed at various angles ('distractors'; *e.g.* second row, **Fig. 1**). On each trial, the 'study' object will be followed by two simultaneously presented series of objects, with object presentation intervals separated by blank intervals (rapid serial visual presentation, hence RSVP). The participants will maintain fixation at the center of the screen and the two series will be located above and below fixation. Each series will contain 'distractor' objects, and one 'match' object with a 50% chance,

independently per series. Thus, on each trial there could be no 'match' objects; one 'match' object in either series; or two 'match' objects, one in each series.

The participant will report the presence of a 'match' object in two main conditions, shown in blocks of 20 trials:

(1) Single task: at the beginning of the trial, the participant sees a cue to attend to only one location (above or below fixation). The single task condition will balance and alternate pre-cueing of each location across blocks. The participant will report whether the object matching the 'study' was present in the cued location, and will not be asked to make any judgement about the uncued location.

(2) Dual task: at the beginning of the trial, the participant sees a cue to attend to both locations. After the RSVP stream, the participant will report whether the object matching the 'study' was present: first, for one of the series, and then for the other series. The dual task condition will balance and alternate the post-cueing order of locations.

Colored cues will be used to reinforce the task conditions (*e.g.* red line near fixation, **Fig. 1**). Participants will report their decision by pressing a keyboard button corresponding to 'yes' or 'no'. Participants will be asked to respond accurately rather than quickly, and will receive feedback on each trial (high or low frequency tone for correct and incorrect responses, respectively). RSVP speed will be adjusted for each subject to produce a consistent accuracy of ~80% in the single task condition (*e.g.* stimulus duration of 100ms in **Fig. 1**).

Along with the presence or absence of a 'match' object, participants will report how confident they are about their answer (high/low confidence). This additional measurement allows us to assess the area under a ROC curve (hence AUC). Like percent correct, this metric ranges from 0.5 (chance) to 1.0 (perfect); and like d', AUC is an unbiased estimate of performance. I will assess the behavioral effects of divided attention using a "**dual-task deficit**" metric, calculated by taking the difference between AUC for the single task and the dual task. This comparison quantifies the behavioral impact of dividing attention while taking into account the difficulty of the single task.

Model predictions and preliminary findings. I will compare the dual-task deficit measure to the predictions for "all or none" serial and independent parallel models. **Fig. 2A** represents behavioral results in the form of the attention operating characteristic (AOC; Green and Swets, 1966), with axes showing performance computed separately for each of the two locations where stimuli are shown. In a parallel process, judgment of object shape at each location is independent. If there is no dual-task deficit, the mean AOC values should fall at the intersection of the dashed lines (open square symbol, **Fig. 2A**). In an "all or none" serial process, judgment of object shape can only occur for one location at a time, with a guess for the other location. There should be a large dual-task deficit; on the AOC plot, data should fall along the negative diagonal (solid line, **Fig. 2A**), with exact position along this line estimating the proportion of trials for which one or the other side was attended.

If behavioral performance in the dual task falls along the negative diagonal, it suggests that global shape judgments, like words, are limited by an "all or none" serial process, which supports the "global object bottleneck" hypothesis. I collected preliminary data from 6 participants performing the object recognition task, who completed ~800 trials of each task condition. Participants performed the judgment well in the single task condition (blue circles along axes, **Fig. 2A**) and there was a large dual-task deficit (8±1%). This result (red, **Fig. 2A**) falls between the predictions for the "all or none" serial and independent parallel models, favoring a hybrid model.

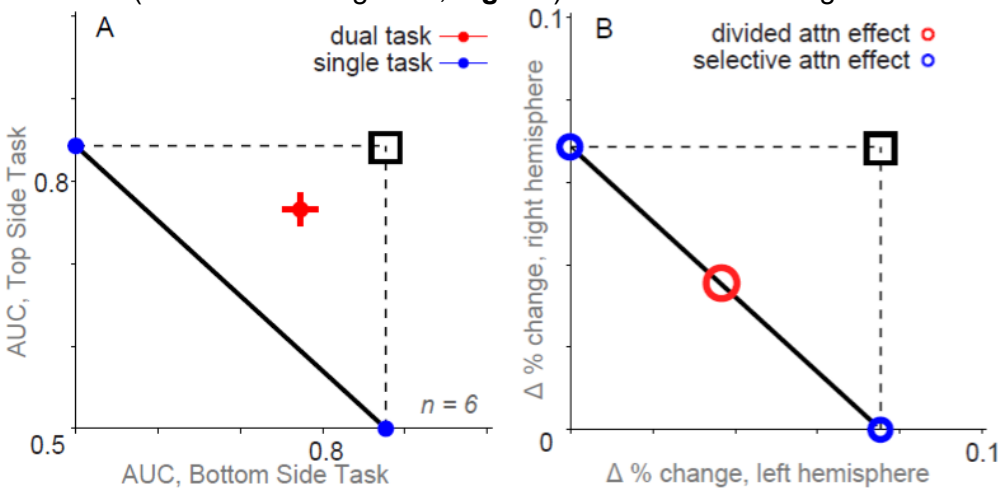

Fig. 2. All or none serial model: solid line. Independent parallel model: open square. (A) **Observed** behavioral performance in single (blue) and dual (red) tasks. Error bars: *s.e.m.* (B) **Predicted** fMRI result for a serial process. Selective attention effect (blue): difference in % signal change in single task for contra- and ipsilateral sides. Divided attention effect (red): difference in % signal change in single and dual task.

Alternative outcomes. The preliminary data presented here suggest that global shape judgments do not quantitatively match the predictions of the "all or none" serial model. More work is needed to statistically evaluate these models and reject those that do not fit the data. For example, we will confirm that subjects were indeed judging global object shape, and not relying on local features of the stimuli. We will examine this by probing recognition performance

with a larger set of stimuli that rule out local feature-based strategies for discrimination (*e.g.* an existing set such as Op de Beeck *et al.*, 2008; or a similar set developed *de novo*).

In the case that behavioral results continue to deviate from the "all or none" serial model predictions, we will consider an alternative hypothesis for the location of the attentional bottleneck. It is possible the bottleneck lies beyond global object shape judgments, specifically at the level of judgments requiring semantic processing (Broadbent, 1958; Lachter *et al*., 2004). In that case, we will change the stimuli to include nameable and categorizable images, *e.g.* animals, food, buildings (Sigala *et al*., 2002; Leibe and Schiele, 2003). Using these images, we will be able to assess whether divided attention limits the semantic categorization of objects in a serial fashion, as for words. These stimulus and task refinements will carry forward into the experiments described in the following Aims.

Aim 2. Which visual processing areas in the brain are affected by divided attention?

In this Aim, I will look for the neural basis of divided attention limits observed in behavior. Specifically, I will test the hypothesis that divided attention changes activity in brain areas that contribute to global object processing, and not in areas that contribute to processing of local stimulus features.

Approach. We will ask participants to perform the object recognition task from Aim 1 while we measure blood oxygenation level-dependent (BOLD) responses, which are a correlate of brain activity. In a blocked design, the participants will perform short runs of the same conditions as in Aim 1: the dual task, and both of the single tasks.

Since the stimulus presentation is the same in the single and dual task conditions, by comparing them we will measure the effect of divided attention rather than brain activity related to visual stimulus content (*e.g.*, sensitivity to orientation). To test the hypothesis that an attentional bottleneck exists at the level of object formation, **I will examine activity in brain areas that encode local features such as line orientation** (primary cortex, V1; Hubel and Wiesel, 1968; Boynton, 2005), **or global features such as object shape** (lateral occipital complex, LOC; Kourtzi and Kanwisher, 2000; Eger *et al*. 2008).

To define regions of interest (ROIs), we will first obtain retinotopic maps in a separate scanning session using slowly sweeping bar stimuli and Dumoulin and Wandell's population receptive field (pRF) method (2008). We will define the LOC ROI with a localizer scan that contrasts responses to objects and phase-scrambled objects, constrained by the anatomical location. The magnitude of activity measured by fMRI has been well-related to task accuracy (Boynton *et al*., 1999; Pestilli *et al.,* 2011); thus, I expect to find changes in brain activity when performance is impaired during the dual task.

To take advantage of cortical retinotopy, we will arrange the stimulus locations in the left and right hemifields. To compare activity within each ROI, we will use 3 main conditions: dual task, single task on the contralateral side, and single task on the ipsilateral side. For area V1 in the right hemisphere, the "single contralateral" condition is when the participant attends only to the object series on the left. For each ROI, we will extract the average BOLD signal change in each condition relative to the baseline with no stimulus. We will then compute two key measures:

(1) The selective attention effect = single contralateral – single ipsilateral. This difference between responses to attended and unattended stimuli is usually strong in V1 (Pestilli *et al.*, 2011; Runeson *et al*., 2013). If we don't find it in V1, then our primary manipulation may have failed.

(2) The divided attention effect = single contralateral – dual. This is our primary measure, as it quantifies how divided attention weakens brain activity compared to selective attention. Conceptually, it is comparable to the behavioral 'dual-task deficit' measure in Aim 1.

Differences in spatial responses for left and right hemifields will make these analyses straightforward in area V1. Area LOC presents an interesting challenge. Although retinotopy has been observed in LOC (Larsson and Heeger, 2006), the spatial map in LOC is less distinct than in V1, and thus analyses relying heavily on spatial separation of information may fail. However, stimulus position can be accurately decoded from areas with poor retinotopy using multi-voxel pattern classifiers. We will use a related analysis technique known as "forward modeling" to recover responses to the left and right stimuli individually (Thomas *et al.*, 2015). The model posits that in area LOC, there are two "channels": one for stimuli on the left, and one for stimuli on the right side of fixation. Using a training set of data from the localizer scans, we will assign weights to capture how much the two channels contribute to each voxel's response. Then, after estimating voxel responses in different task conditions, we can use linear regression to invert the model to recover the responses in the two spatial channels.

Predictions. In area V1, simple feature detection tasks have produced no divided attention effects (Chen and Seidemann, 2012; White *et al*., 2017), but more demanding tasks have (Pestilli *et al*., 2011; Anderson *et al*., 2013). Given that the global shape recognition task is relatively complex, we predict that V1 will have significant divided as well as selective attention effects.

We have two main hypotheses for divided attention effects in V1 and LOC:

(1) Attention may be acting to filter out irrelevant (unattended) information, and distribute limited resources in early visual cortex. This may efficiently establish and pass stimulus representations for downstream processing in specialized areas. In this case, we expect to see similar divided attention effects in V1 and in LOC.

(2) The formation of object representations may be the primary limit for behavioral performance. In this case, divided attention effects will be relatively small in V1, but large in LOC. If only one of the two spatial "channels" is active at once in the dual task, this activity would be consistent with an "all or none" serial model.

If behavioral experiments in Aim 1 and neuroimaging experiments in Aim 2 both produce data consistent with "all or none" serial processing, this evidence would strongly favor the "object bottleneck" hypothesis.

In addition, matched magnitudes of attentional effects in behavioral and neuroimaging experiments would suggest that activity changes in the brain may directly underlie the dual-task deficit observed in behavior. We can test this similarly to how we test the "all or none" serial model of behavioral performance. We will calculate the selective and divided attention effects (Δ % signal change) separately for the two spatial "channels" (*i.e.* hemispheres), and plot them against each other in the same manner as the AOC (**Fig. 2B**). For an "all or none" serial process, the divided attention effect data should fall on the negative diagonal line (open red circle, **Fig. 2B**).

Alternative outcomes. The strength of our modeling approach is that we can test whether effects observed in the brain match those observed in behavior even if the dual-task deficit observed in Aim 1 is not as severe as for an "all or none" serial process. Our interpretation of the fMRI data rests on the well-established linking hypothesis that a smaller BOLD response leads to lower accuracy in the task. This is justified by a signal detection model: responses in neurons tuned to relevant stimulus attributes are compared against a criterion to produce a categorical decision (Green and Swets, 1966). We can interpret the imaging data using equivalent models to those described in Aim 1 for the behavioral data. By assuming that the BOLD response magnitude is proportional to the signal-to-noise ratio of the sensory evidence used by the observer, we can evaluate how well the activity in particular brain areas predicts the behavioral divided attention effects (White *et al.*, 2018b).

An alternative possibility is that we observe no divided attention effects in V1, nor in LOC. First, it may be possible that a downstream area is more suitable for the neural basis of the global object shape judgment. For example, we can examine responses in ventral temporal cortex, an area which has been implicated in more specialized object judgments such as face recognition (Haxby *et al*., 2001). Here, our forward model approach will be particularly useful, since retinotopic organization is poor or absent beyond LOC. Second, it may be that the attentional bottleneck occurs at the level of semantic processing, as discussed in Aim 1. In this case, we will shift our experimental focus to areas involved in semantic rather than shape-based processing, such as the anterior temporal lobe (Patterson *et al*., 2007).

Aim 3. Are cognitive impairments observed in patients with posterior cortical atrophy (PCA) due to an inability to divide attention?

Posterior cortical atrophy (PCA) is a less understood visual variant of Alzheimer's disease (Benson *et al*., 1988). While sharing commonalities with typical Alzheimer's pathology (*e.g.* plaques and tangles; Crutch *et al*., 2012), PCA progresses from the posterior portion of the brain rather than from the medial temporal lobe. As a consequence, PCA patients typically show impairments in visual function, and not memory, from the earliest stages of disease onset (Crutch *et al.*, 2012). Like patients with parietal and occipital lesions, PCA patients present with simultanagnosia, an inability to recognize objects presented simultaneously; however, they can typically direct their gaze to objects and correctly name them in isolation. The clinical profile of these patients presents a unique population for the study of how divided attention impacts object recognition processes.

Approach. I will examine object shape recognition behavior in 4-6 PCA patients using similar methods to those described in Aim 1. In addition to the single- and dual-task conditions, I will include a single-stimulus condition where there is no stimulus on the unattended side. Critically, this will allow me to distinguish between competing hypotheses that an inability to recognize simultaneously presented objects results from:

(1) An inability to form two distinct object percepts (a failure in perceptual organization),

(2) An inability to correctly select and attend to an object (a failure in selective attention), or

(3) An inability to divide attention across two objects (a failure in divided attention).

Our interpretation of the results will include a critical consideration of whether it is possible to equate performance for the single-stimulus or single-side tasks to neurotypical subjects (*e.g.* performance accuracy >80%). Due to variations in individual disease progression, the difference between the three hypotheses may only be revealed

once performance is equated to match neurotypical participants, *e.g.* by slowing down the rate of presentation or reducing the number of distractors in each location**.** For example, PCA patients may not be able to perform the paradigm as described in Aim 1 in any of the task conditions, due to additional deficits in working memory. To mitigate this effect, I can use a masked stimulus presentation instead of the RSVP paradigm (for word recognition, these produce similar results; White *et al*., 2018a). Dr. Thomas Grabowski, a contributor for this project, will oversee and advise us on the best way to approach behavioral paradigm adjustments given additional clinical history for individual patients.

Finally, I will compare each participant's behavioral performance with the localization of Alzheimer's-associated atrophy in their brain, obtained from structural MRI scans (or location of neurofibrillary tangles using tau-PET imaging; Okamura *et al*., 2014).

Predictions. The predicted performance under each of the three hypotheses is as follows:

(1) If simultanagnosia is the result of an inability to form distinct object percepts, we expect that it will be impossible to equate performance in the single-stimulus condition to neurotypical participants, and that performance will be below chance in all three conditions.

(2) If simultanagnosia results from an inability to attend to one of two objects, we expect to be able to obtain excellent performance (>80%) in the single-stimulus condition, but a drastic decrease in accuracy when it is necessary for a participant to select a location to attend to in the single task condition.

(3) If simultanagnosia reflects a critical inability to divide attention, we expect to see a dramatic dual-task deficit. When equating task parameters to match neurotypical participants in the single-stimulus and single-task conditions (>80%), dual task performance might even be lower than predicted by the "all or none" serial model (falling below the solid line in **Fig. 2A**).

In further experiments, we will assess behavioral performance based on formal theories related to the processing deficit supported by the prevailing hypothesis. For example, if the cognitive impairment observed in PCA patients appears to be due to an inability to form percepts of two objects, we will test additional aspects of visual function related to perceptual organization, such as crowding effects (Postman and Phillips, 1954; Pirkner and Kimchi, 2017).

Studying this unique population will allow me to test the linking hypothesis that I will develop in the preceding Aims, specifically regarding which brain activity underlies the effects of attention on object recognition. For example, results from Aims 1 and 2 may support the "object bottleneck" hypothesis and area LOC as the neural locus of divided attention effects for object recognition. In this case, I expect to see more severe dual-task deficits in patients with more atrophy localized to LOC. Insights from individual anatomy will help guide further investigations, *e.g.* if patients present with additional atrophy in dorsal brain areas which encode spatial information, we can direct follow-up experiments to more finely examine the interaction between spatial and object representations.

Potential Pitfalls

The methods for measuring attention effects in early visual cortex are straightforward, and my Sponsor Dr. Boynton has used them successfully many times. Previous research supports our linking hypothesis that higher BOLD responses in retinotopic cortex are associated with better perception (Pestilli *et al*., 2011). However, it is less clear whether LOC behaves similarly, and we may be the first to measure spatial attention effects there. The LOC's relatively weak spatial specificity will pose a challenge, which we will address using the "forward model" approach to recover separate responses to stimuli presented on the left and right side from spatial biases in individual voxels. The model may fail, however, if it incorrectly assumes that LOC contains separable spatial channels. To address this concern, we will validate the method under a range of conditions (*e.g.* when the objects are ignored, compared to when they are attended).

Conclusion

These experiments will answer important questions about the cortical mechanisms of attention and object recognition. To what extent can objects at two locations be recognized simultaneously? Is object recognition constrained in the same way as word processing? By measuring fMRI responses to objects while varying the task demands, we will clarify the nature of top-down modulations across occipital cortex and their effects on perception. Our ultimate goal, which we will advance by developing computational models for our data, is to link the attentional limits of behavior to patterns of brain activity. By extending our study to patients with PCA, we will not only be able to test our linking hypotheses about the relationship between brain and behavior, but also provide insights into the mechanisms underlying long-observed and poorly understood cognitive impairments.

RESPECTIVE CONTRIBUTIONS

This research training plan reflects a collaboration with my sponsor and co-sponsor, Drs. Boynton and Palmer. The plan was developed through a series of focused discussions about my interest in understanding the effects of attention on object recognition ability, and my desire to learn non-invasive methods of examining sensory and cognitive functions in humans (specifically, psychophysics and functional magnetic resonance imaging, fMRI). The objectives of the research program we developed are to (1) provide me with fMRI training; (2) contribute to ongoing studies and developing theory of divided attention; (3) apply my expertise in object recognition and the primate visual system to an independent project in human visual attention. The proposed project meets all of the objectives: the core experiment is suitable for adaptation to an fMRI study; it bridges a knowledge gap in previous and ongoing research about divided attention; and it applies the expertise of all collaborators to develop a comprehensive understanding of the neural bases of divided attention and recognition in healthy brains, and to test whether our insights can inform understanding of diseased brain states such as posterior cortical atrophy (PCA).

I developed the specific aims and corresponding research strategy after performing a thorough literature review and critical analysis of the known phenomenology of object recognition, divided attention, and visual processing deficits in PCA patients. With suggestions from my co-sponsors and our contributor Dr. Thomas Grabowski, I chose psychophysical paradigms that would address the research questions. I wrote the initial drafts of all components of this application, and refined them based on constructive feedback from the co-sponsors.

As the project moves forward, I will be responsible for all day-to-day tasks excepting during training periods. Drs. Palmer and Boynton will provide necessary equipment, including psychophysical testing stations (monitors, chin rests, eyetrackers, etc.). The necessary fMRI equipment is available at the Interdisciplinary Brain Imaging Center (IBIC) on campus, and the timeline to carry out the fMRI component of the application overlaps the period of current funding for my sponsor’s existing R01 grant.

I will write all necessary MATLAB code to perform the experiments (including presenting stimuli, collecting data, and analyzing results) using example scripts provided by Drs. Boynton and Palmer. Dr. Boynton and other senior members of the lab will train me in fMRI methods, including using existing data sets to develop analyses in BrainVoyager and MATLAB. I will also shadow other members of the lab during scanning sessions to learn in depth how to operate the equipment, interact with the IBIC staff, and recruit participants.

Once data collection begins, I will be responsible for scheduling and training participants, and running the experiments. Dr. Boynton will provide guidance for the technical aspects of fMRI scanning, together with onsite assistance from IBIC staff. Drs. Boynton and Palmer will supervise the analysis of collected data, and will assist in designing follow-up experiments. Dr. Grabowski will provide assistance with recruitment of patients with PCA, experimental design, and anatomical analyses related to this project component.

My responsibilities, as described above, correspond to a first-author contribution. While I will lead the conversion of findings into presentations, abstracts, and manuscripts, all co-authors will contribute to the preparation of this work for publication and dissemination. Through ongoing discussions, we will revise our approach according to needs arising from the peer review process.

After completing the training stages and carrying out the experiments in this proposal, I will be well-prepared for the faculty job market. I will have acquired the necessary experimental, technical, quantitative, leadership, and communication skills to establish and run an independent research lab.

SELECTION OF SPONSORS AND INSTITUTION

In my postdoctoral training, I want to build on the expertise I gained in my graduate training to learn important new skills in theory, methods, and analysis. Importantly, my research interests have transitioned from non-human animal models to understanding vision and attention specifically in humans, including in clinical populations. I am fortunate to have found an excellent sponsor and co-sponsor (Drs. Geoffrey Boynton and John Palmer, respectively) for the next step in my scientific journey. Their expertise makes them a clear choice as supervisors for the proposed collaborative project. Importantly, I am also confident that their mentorship strategies and scientific approaches will fill the critical gaps in my training as I prepare to transition to an independent research career. Although I completed my PhD at the University of Washington, the opportunity to work with experts at a new level of inquiry than my previous training, alongside faculty in a different department, will also contribute substantially to my ability to independently pursue questions in vision and attention.

Sponsor: **Dr. Geoffrey Boynton**. My proposed training is motivated by a long-standing interest in understanding functional differences between brain areas in the visual system, which lends itself particularly to using functional magnetic resonance imaging (fMRI). Dr. Boynton is a clear choice for sponsor not only because he is a recognized expert in fMRI approaches to studying the brain, but also because his work has long focused on the intersection between sensory and cognitive function. Through my interactions with Dr. Boynton during my graduate training, I was able to appreciate how his approach to science related to both my ongoing interest in sensory representations in the brain and newer interest in human cognition. Dr. Boynton will teach me all the necessary steps in designing and thoroughly planning the execution of fMRI experiments, including learning the relevant experimental and analytical techniques that represent cutting-edge usage of this technology. From my experience in working and interacting with Dr. Boynton in a variety of scientific settings, his mentorship style is also compatible with my needs as a mentee, namely his open-door approach to regular interactions and leaving room for trainees to make substantial thought contributions to projects in the lab. When I was choosing a lab to continue my scientific training as a postdoctoral fellow, it was clear that his quantitative and experimental expertise would complement my interests in extending my graduate interests to vision and attention in humans.

Co-sponsor: **Dr. John Palmer**. I wish to learn fMRI methods in my postdoctoral training with the intent to understand not only the difference between visual brain areas, but also how they contribute to behavior. Thus, in my training I also need to learn systematic approaches to understanding and quantifying human behavior. Dr. Palmer is a recognized authority in psychophysics methods, and has studied vision and attentional processing in a great variety of forms. He will train me in design of rigorous psychophysics experiments, and development of theoretical models to interpret results. In my graduate training, I regularly met with Dr. Palmer in an informal advising capacity while I was conducting my dissertation work, and these interactions were of utmost importance in shaping my interest in studying cognition. Like my sponsor Dr. Boynton, I also found Dr. Palmer's mentorship strategy to be conducive to developing the skills critical to my continued success in science. Namely, his approach is grounded in thorough dissection of decades of literature to identify critical theories and assumptions, from which development of the work is guided by regular interaction and collaboration with researchers both at UW and at other institutions. Additionally, he is dedicated to developing his trainees' written and oral communication skills, both of which will continue to be essential when I am running my own research group.

UNIVERSITY: The University of Washington in Seattle is home to a large, vibrant, and well-respected vision research community. I am a member of the Vision and Cognition Group, which is jointly directed by my sponsor Dr. Boynton, Dr. Ione Fine, and Dr. Scott Murray. This group is additionally affiliated with co-sponsor Dr. John Palmer, and lab meetings are held jointly within the group, including trainees at all levels. The university has a variety of relevant journal clubs, including the Vision Journal Club, Cognition and Perception Seminar, Cortical Neurophysiology Journal Club, and Computational Neuroscience Journal Club.

The group studies a diverse range of topics including attention, perceptual organization, and the effects of visual deprivation and disorders such as autism. Their methods include psychophysics, eye-tracking, fMRI, MR spectroscopy, DTI, and EEG. We have excellent on-site equipment and facilities to carry out this research. Our group has been successfully conducting studies at the University's MR Research Laboratory for many years, and the Interdisciplinary Brain Imaging Center provides additional training in advanced neuroimaging techniques. Faculty in the Neuroscience program study the primate visual system at a variety of levels, including Dr. Gregory Horwitz, Drs. Jay and Maureen Neitz, Dr. Ramkumar Sabesan, and Dr. Fred Rieke. Their work on sensory processing and circuit dissection of the visual system is tremendously important for me to be able to place my work within a larger context of visual system research. Also on campus is the Institute for Learning & Brain Sciences, which includes among its faculty Drs. Chantel Prat and Jason Yeatman, who use fMRI to study reading and language comprehension. All of the above resources at the University of Washington add to the expertise of my co-sponsors to produce a well-rounded training and research environment.

Training in the Responsible Conduct of Research

I have regularly taken part in courses in Responsible Conduct of Research, both as an undergraduate (at the University of Maryland, Baltimore County) and a graduate trainee (at the University of Washington).

The University of Washington offers RCR training through the Biomedical Research Integrity Program (BRI). This program consists of a series of lectures and discussion groups designed to meet NIH requirements and is obligatory for all PhD students and postdoctoral fellows.

Although I have participated in this series in the past, I will take part in the 2019 UW BRI series to continue educating myself about current issues in the ethical conduct of research. I will additionally complete training in the ethical principles for working with human research subjects, a course offered through the UW Human Subjects Division and conforming to the NIH guidelines on Human Subjects Protection Training.

According to the BRI program mission:

“Upon program completion, BRI participants will be able to:

1. Recognize ethical issues and challenges to integrity that arise in the course of routine research practice;

2. Formulate a justified response to research challenges, using select ethical decision-making tools; and

3. Identify a sense of professional responsibility to take action and make good judgments that work to support good research practices.”

This course is offered yearly, and is structured as follows:

(1) **Format**: face-to-face lectures and small discussion groups.

(2**) Subject Matter**: Conflict of interest; Data acquisition and ownership; Peer review; Responsible authorship; Research misconduct. Additionally, speakers are asked to incorporate explicit reference to researcher/trainee responsibilities *and/or* collaborative science.

(3) **Faculty Participation**: the lectures are given by distinguished faculty, sometimes from other institutions. The discussion sections are led by UW faculty.

(4) **Duration**: This year there are 5 hour-long lectures, three of which are followed by one-hour small discussion groups. (8 total contact hours).

(5) **Frequency**: Participation in this program is required at least once per career stage (doctoral, post-doc) and at least once every four years.

Section II -- Sponsor and Co-Sponsor Information

a. Research Support Available

	Funding Source	Funding Type and Identifying #	Title	PI	Dates	Amount
Current						
Available to support proposed fMRI work	National Institute of Health	R01, EY12925-14	The effects of attention in human visual cortex	Boynton	9/1/2014 – 8/31/2019	$1,250,000

b. Sponsor's/Co-Sponsor's Previous Fellows/Trainees

Sponsor – Boynton
Predoctoral: 8, Postdoctoral: 5

(1) Postdoctoral: John Serences
Current position: Assistant Professor, UCSD
(2) Postdoctoral: Robert Duncan
Current position: Assistant Professor, CUNY
(3) Postdoctoral: Vivian Ciaramitaro
Current position: Assistant Professor, UMass Boston
(4) Predoctoral: Melissa Saenz
Current position: Principal Investigator, Université de Lausanne
(5) Predoctoral: Edward Hubbard
Current position: Assistant Professor, University of Wisconsin, Madison

Co-Sponsor - Palmer
Predoctoral: 5, Postdoctoral: 6

(1) Postdoctoral: Karen Dobkins
Current position: Professor, UCSD
(2) Postdoctoral: Alex Huk
Current position: Associate Professor, University of Texas, Austin
(3) Predoctoral: Alex Scharff
Current position: Scientist, Google, WA
(4) Predoctoral: Serap Yigit-Elliott
Current position: Scientist, Exponent, WA

c. Training Plan, Milestones, Environment and Research Facilities

Training Plan

We believe that we have the ideal training environment for Dr. Dina Popovkina that will enable her to achieve her goal of becoming an independent academic researcher. Dina's past training and research experience in electrophysiology, psychophysics, and object perception make her a welcome addition to our community of highly collaborative and accomplished visual neuroscientists. Sponsor Boynton and co-sponsor Palmer are

long-time collaborators and have an established track record of joint publications. The sponsor and co-sponsor have overlapping research expertise using behavioral and neuroimaging (fMRI) and computational methods to investigate visual perception and attention. Including Dr. Thomas Grabowski and his expertise with Alzheimer's brings a translational aspect to this proposal that will broaden Dina's education and research skills.

We designed the specific training plan to meet the following **objectives**:

(1) To train Dr. Dina Popovkina in the methods of **functional magnetic resonance imaging (fMRI)**. Dina has already made contributions to the study of vision and object perception with her graduate work on electrophysiological measures in non-human primates. However, she has not yet learned fMRI, a powerful tool that will significantly expand her potential as a scientist. We feel that our lab is the perfect place to do so, and we have previously had success training students and post-docs in our fMRI studies. By combining this powerful tool with her existing expertise, Dina will be well prepared to continue her research in an independent faculty position.

(2) To involve Dina in our larger ongoing project on the effects of **divided attention in visual cortex**. Sponsor Boynton and co-Sponsor Palmer are co-PIs on an R01 grant to carry out this research, which can support Dina's fMRI experiments. This ongoing project overlaps nicely with the topics that Dina is most interested in, and through her previous research she has become well-versed in the relevant literature. An important part of this work is to use **computational models** of visual processing to test theoretical hypotheses for the attentional effects we measure in behavior and in the brain. These modeling efforts are also an important component of the training plan.

(3) To give Dina experience with clinical populations by studying divided attention with a special population of patients with Alzheimer's that have a visual dysfunction without cognitive or memory impartments. With the support of Dr. Thomas Grabowski, the proposed experiments on divided attention in this special population will satisfy Dina's desire to advance the interests of public health.

In her first six months in the lab, Dina hit the ground running and has already conducted behavioral experiments that lead up to the proposed research. As detailed below, one main goal for the first year is to train her in fMRI and have her practice analysis on existing data sets before beginning her own fMRI studies. Dina will be supported by our **collaborative research group**, which will provide formal and informal training, as well as opportunities to practice communicating empirical results. All of these resources will also be on hand when, towards the end of her post-doctoral fellowship, Dina prepares to transition to her own faculty position.

Our vision research group places a strong emphasis on **training for public scientific presentations**. At our combined weekly lab meetings, students give presentations on their current research and give practice talks for upcoming conferences and job interviews. These are dynamic meetings in which PIs and members from the 5 vision research labs (including 4 other postdocs) provide useful feedback on slides and presentation style. Participating in these meetings will allow Dina (already an accomplished public speaker) to draw from the combined expertise of the vibrant and collaborative vision research community that is unique to UW. In addition, Dina will attend and contribute to weekly seminars in order to expand and consolidate her knowledge of vision science and to keep up to date on recent publications. This will include the Psychology Department's Vision Journal Club, a weekly meeting run by Dr. Steve Buck where vision researchers discuss a particular scientific article. Dina will also attend and present at our weekly Cognition and Perception Seminar run by Dr. Chantel Prat, which hosts presentations from researchers across multiple disciplines. Dina will also take part in regular Vision Seminars, and present her research at the annual Department of Ophthalmology Retreat. Dina has additionally expressed an interest in seminars hosted by the UW Graduate School and the Postdoctoral Association, which cover topics such as grant writing or finding faculty positions, and allow trainees to practice research job talks. Finally, as part of her training in the responsible conduct of research, Dina has already participated in the **UW Biomedical Research Integrity Program** seminars and discussions.

Training Milestones

The training plan we have developed has a number of **specific milestones** for the proposed research project as well as specific objectives for the development of Dina's academic career.

Her first year will involve conducting **behavioral experiments, testing models against the data, and mastering fMRI techniques**, the most significant development of her technical training. Initially, Dina will receive instruction in the BrainVoyager software for the pre-processing and initial analysis of structural and functional MR images. She will use existing data sets (from studies with designs similar to her own) to practice exporting the BOLD data to Matlab, and write her own analysis code, following existing software in the lab. Dina will then adapt her psychophysical paradigm to run in the scanner, test it, and collect pilot data. Dr. Boynton will supervise these training steps and ensure that Dina is ready to begin data collection as soon as possible.

In addition to the traditional event-related and blocked design methods that are part of standard fMRI analysis software, we will train Dina on more **sophisticated analysis methods** including the forward modeling technique described in the proposal. That analysis requires writing and editing custom in-house Matlab software. By the end of the first year we plan to have collected sufficient pilot data for Dina to train on.

In addition to the instruction provided by Dr. Boynton, other members of the lab, and Dr. Palmer, Dina will supplement her fMRI training with **courses** offered on campus. **The Integrated Brain Imaging Center**, directed by Dr. Thomas Grabowski, offers a series of formal and informal neuroimaging seminars and lectures throughout the year (approximately 1-2 per week) in acquisition and analysis techniques. Formal or informal classes that have been provided to date include use of B0 maps, FSL and AFNI training, Fiber tracking analysis, MR operating training, and image analysis. Dr. Popovkina will also join IBIC special interest groups including Multi-voxel pattern fMRI, Acquisition Methods, and Diffusion Tensor Imaging. These groups focus on advancing technical understanding and facilitating scientific collaborations. Meeting formats include presentation of works in progress, discussion of joint projects, and journal club.

Additional formal training will be provided by Sponsor Boynton's graduate class on visual processing and Fine and Boynton's two-quarter course on Matlab programming for the behavioral sciences. This course covers topics relevant to Dina's training that range from experimental design and implementation, stimulus generation, efficient coding techniques, aesthetic figure generation, linear systems analysis (including GLM fMRI analysis) and bootstrapping.

The second year of the project will be focused on collecting fMRI data, completing psychophysical data collection and analysis, and preparing our findings for publication. Dina will develop her scientific writing and presentation skills during this time, and will present her research at multiple conferences, including the Vision Sciences Society and Society for Neuroscience meetings. With her new technical skills, Dina will be able to develop her **mentorship skills** by helping to train other students in the lab. We will encourage Dina to recruit undergraduate research assistants and train them in neuroimaging and psychophysics. This will help her learn how to manage a lab and guide less-experienced researchers, which will prove valuable when she establishes herself as a PI in the future.

Dina will also apply for the Summer Institute in Cognitive Neuroscience at U.C. Santa Barbara, which would be another opportunity to learn from experts in related fields.

The third year will focus on collection and analysis of additional behavioral and fMRI data, and submitting manuscripts for publication. We expect that her proposed research project will result in a **set of high-impact first author publications** investigating the neuronal mechanisms associated with divided attention and reading. We also expect Dina to begin developing a K99 **grant proposal for obtaining an independent faculty position**. Boynton and Palmer will provide feedback and guidance during the grant writing process,

helping to further refine Dina's technical and written communication skills. Boynton and Palmer have had recent success with this process by working with their postdoc, Dr. Alex White on a successful K99 application.

We will also support Dina as she prepares job talks, which she will practice for an audience of Boynton, Palmer, Murray, Fine, and Buck lab members. These PIs and fellow researchers will give feedback regarding the scientific content and presentation style of these talks. We feel that this plan will provide Dina with the support, training, experience and resources she will need to attain her goal of becoming an independent and productive faculty researcher.

Environment and Research Facilities

The University of Washington Psychology Department consists of an **interdisciplinary group of faculty** with expertise in a broad array of areas including neuroscience, clinical psychology, perception and cognition, social/personality, and developmental psychology. Consequently, Dr. Popovkina will receive an excellent interdisciplinary training with breadth in addition to her focus in advanced neuroimaging of vision and attention.

Dr. Popovkina will become a member of the UW Vision & Cognition Group, which includes the labs of professors Sponsor Dr. Boynton, Dr. Ione Fine (visual plasticity), and Dr. Scott Murray (spatial vision, attention, context). The shared lab space is co-localized with the labs of Dr. Steve Buck (color vision) and co-Sponsor Dr. John Palmer. Overall there is a **strong sense of shared responsibility for training** graduate students and postdocs. During her six months in the lab, Dina has already fit in perfectly with, and benefited from, this community. Together, the VisCog PI's Buck, Murray, Fine, Boynton and Palmer, supervise a total of seven graduate students and six postdocs (including Dr. Popovkina). The two other postdocs in Boyton and Palmer labs are Alex White, who is working with Drs. Palmer and Boynton on studying divided attention effects in reading and dyslexia, and Dr. Michael Beyeler, who is working with Drs. Fine and Boynton on electrical prosthetics. All postdocs and have regular contact (and neighboring offices) with Dr. Popovkina.

The VisCog group conducts a joint weekly lab meeting and share lab space and equipment. Dr. Popovkina has access to several **high-quality psychophysical testing stations**, complete with calibrated display devices, eye-tracking systems (SR Research), photometers, etc. In this shared space, Dina will have her own ~110 square foot **office** with a workstation and laptop.

The University of Washington has strong expertise and an international reputation for neuroimaging research, and our lab has acquired excellent data from the research-dedicated Phillips 3T MR scanner at the **Interdisciplinary Brain Imaging Center** (IBIC). Dr. Boynton and Dr. Scott Murray were co-PIs on a $2M NSF instrumentation grant in 2008 that was used to purchase the scanner and have served on the directors committee for the scanner since its installation. A second $2.6M NSF instrumentation grant has recently been acquired to obtain a Siemens Prisma 3T scanner to supplement the current device. The imaging facility at UW brings together MR experts from many different departments. The appointment of Dr. Thomas Grabowski to the IBIC has resulted in a thriving collaborative neuroimaging community that includes a strong training component. As mentioned above, the IBIC offers courses and seminars in advanced neuroimaging techniques, which Dina will take partake in.

d. **Number of Fellows/Trainees to be Supervised During the Fellowship**

Sponsor – Boynton
Predoctoral 2
Postdoctoral 2 (Alex White and Dina Popovkina)

Co-Sponsor – Palmer
Predoctoral 1
Postdoctoral 1 (Alex White and Dina Popovkina)

(Note that the larger Vision & Cognition research group is home to another postdoc, Dr. Michael Beyeler, supervised by Dr. Ione Fine).

e. Applicant's Qualifications and Potential for a Research Career

Dina comes to us with **ideal qualifications** for learning the fMRI techniques we use in our lab and advancing our shared research interests. Her formal education in non-human primate electrophysiology in area V4 *provides a solid background for the proposed work on divided attention to objects.* Dina also has a strong background in computational neuroscience, including first attending and then TA'ing the Cold Spring Harbor summer course on Computational Neuroscience: Vision (for which PI Boynton has served as an instructor and organizer since 2008).

Dr. Popovkina's education demonstrates her remarkable scholarship. She earned a B.S. in Biochemistry and Molecular Biology (summa cum laude) in 2010. During this time she worked as an undergraduate research assistant with Dr. Scott Thompson stuying the effect of chronic stress on dendritic spine density of CA1 pyramidal cells in mouse hippocampus. She then completed a PhD in 2017 with Dr. Anitha Pasupathy, using electrophysiological measures in non-human primates to study neural encoding of object perception in area V4.

This education has provided Dina with excellent training with a wide array of methods and statistical techniques for problem solving and model predictions. Dina is proficient with Matlab, and has used it to generate stimuli and experimental software and for analyzing behavioral data. Dina is now becoming familiar with Brain Voyager, an analysis and visualization tool for structural and functional magnetic resonance imaging data. We feel that she has the background in programming, knowledge of vision research and computational tools that form the foundation of an accomplished neuroimager. Sponsor Boynton and PI's Murray and Fine have trained from scratch a number of students who have gone on to successful academic careers using fMRI. Dina shows all of the signs that she will do at least as well. Dina has excellent training, works hard, has great ideas, and most importantly she gets things done. Working with her to prepare this application has been a sincere pleasure.

Dina's interest in object perception and attention dovetails nicely with the ongoing work on divided attention by Boynton and Palmer. The methods in the proposed work overlap with the Sponsor and Co-sponsor's work, but the topic of object perception and Alzheimer's is different enough to allow Dina to branch out in an independent direction.

To close, Dina has had an excellent start in behavioral research on attention. This proposed interdisciplinary training plan will allow her to expand her research to include the neuroscience of attention in neurotypical and patient populations using fMRI. Our goal is to transition Dina into an accomplished interdisciplinary researcher with the skills to span both behavior and neuroscience.

UW Medicine
SCHOOL OF MEDICINE

July 30, 2018

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To: NIH Center for Scientific Review
Fellowship study section F02B: Sensory and Motor Neurosciences, Cognition, and Perception

Re: PA-18-670 Ruth L. Kirschstein National Research Service Award (NRSA) Individual Postdoctoral Fellowship (Parent F32)

Dear members of the study section,

I am writing this letter to support the NRSA F32 application of Dr. Dina Popovkina, a postdoctoral fellow in the Psychology Department. Dr. Popovkina proposes to understand functional links between brain and behavior by studying recognition and attentional processing in patients diagnosed with posterior cortical atrophy (PCA), an unusual clinical variant of Alzheimer's disease, in which the profile of cognitive impairment is dominated by impairment of higher visual processing, especially in integration of vision and space.

I am a behavioral neurologist, and the Director of the UW Medicine Memory and Brain Wellness Center (MBWC), Alzheimer's Disease Research Center, and Integrated Brain Imaging Center. Our centers combine medical and research activities to diagnose, treat, and support patients living with memory loss or dementia. The MBWC has encountered more than 4000 patients suffering from a range of neurodegenerative disorders since its inception in 10/2013. I am pleased to assist her access to research participants with well-characterized PCA, supporting this component of her research and training plan.

My laboratory in particular uses functional MRI and other MRI-based approaches to investigate the cortical neural systems basis of cognition, and explores new therapeutic and diagnostic strategies. Dr. Popovkina's proposed study fits perfectly with the research in our center: she will combine behavioral and anatomical/neuroimaging approaches to understand how divided attention may underlie the impairments in visual recognition exhibited by patients with PCA. Although visual impairments in recognizing simultaneously presented objects are well-described in these patients in the medical setting, the underlying contribution

of attention has not been carefully examined. This proposal is important not only for the advancement of science, but also for patient well-being: understanding this behavior and its neural basis can help develop strategies to leverage intact visual and attentional functions.

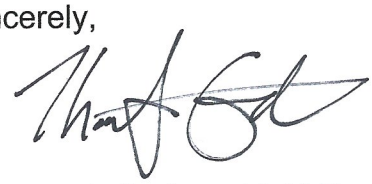
I know and have worked together with Dr. Popovkina's sponsor, Dr. Geoffrey Boynton. I believe we can provide her with excellent training in working with a clinical population. Her academic and research background in neuroscience is both comprehensive and diverse, and she has a strong interest in learning about perceptual processing in degenerative disease backgrounds. Because of this, we are confident that she will be able to tackle the challenges of conducting this research.

My role in this project will be to facilitate the following activities Dr. Popovkina will undertake in her study: (1) learning to recruit and interact with PCA patients; (2) developing experimental paradigms suitable for the abilities of PCA patients; and (3) obtaining and interpreting anatomical profiles for the patients in her study.

We systematically invite patients in the MBWC to participate in a research Registry, which allows us to connect researchers at UW with potential research participants. The Registry will facilitate Dr. Popovkina's work with this unique population. It currently includes 7 immediately contactable patients with PCA, and we are now making a concerted effort to recruit additional PCA patients. These patients have had high resolution (3D 1mm resolution T1-weighted) structural MRI scans performed to assess and localize the progression of atrophy in their disease.

Our group is also developing and evaluating new technologies, such as PET imaging using tau tracers, to identify the aggregate pathology associated with Alzheimer's disease. These anatomical approaches will greatly benefit Dr. Popovkina in her interpretation of the results of her study. In summary, I am supporting Dr. Popovkina's proposal and training plan, and look forward to working together to contribute to our understanding of human vision and attention.

Sincerely,



Thomas J. Grabowski, M.D.

Professor of Neurology and Radiology
Director: Integrated Brain Imaging Center (IBIC)
Director: Memory and Brain Wellness Center
Director: UW Alzheimer's Disease Research Center
tgrabow@uw.edu

DESCRIPTION OF INSTITUTIONAL ENVIRONMENT AND COMMITMENT TO TRAINING

Dina's scientific interests span across multiple topics in neuroscience and psychology. Her research plan focuses on understanding how divided attention affects object recognition processing, and proposes to investigate this using several interrelated approaches: psychophysics, functional magnetic resonance imaging (fMRI), and quantitative modeling. Our goal in her training plan is to provide her with (1) training in conducting visual attention research from the perspectives of human behavior and neural activity, and (2) comprehensive training in psychophysics, fMRI, and computational modeling methods.

The University of Washington (UW) has exceptional resources available to support the proposed work. UW is the top funded public institution in the country and is consistently ranked among the top biomedical research institutions in NIH funding annually. The MR facility is excellent, complete with a mock scanner and staff with vast experience with clinical populations. As described in detail in the Facilities and Other Resources attachment, the MR facility provides ample support for researchers with an in-house physicist, trained technicians, computing resources and training and advising in data analysis. Importantly, the sponsor has an established collaboration with Dr. Thomas Grabowski, Director of the UW Alzheimer's Disease Research Center, which will greatly facilitate the research component proposing to examine visual attention in patients diagnosed with posterior cortical atrophy (PCA). Dr. Grabowski provides long-term care to a number of PCA patients, and an established database exists to facilitate recruitment of these patients by researchers affiliated with the center and/or UW.

The sponsor and co-sponsor's labs and department provide an ideal environment to support Dina's training. The Boynton and Palmer labs are part of a well-established vision and cognition group which also includes the labs of Dr. Ione Fine and Dr. Scott Murray. The collective research efforts of this group comprehensively cover human vision in both normal and clinical contexts, and this joint model enables trainees to interact with multiple PIs and benefit from their feedback and mentoring. The environment in the labs is highly collaborative, and the big group of fellow post-docs (currently five others) is vibrant and supportive. Within the Psychology Department, the Vision Journal Club and the Cognition and Perception seminar provide an opportunity to develop communication skills and receive external feedback. Both are held on a weekly basis throughout the school year, and are complementary: while the journal club discusses seminal and contemporary papers, and is joint by researchers from neurophysiology, the cognition-perception seminar is dedicated to talks by faculty and post-doctoral fellows from the Psychology department about their own research, and is shared with cognitive researchers.

Beyond the immediate lab environment, the scientific community at UW supports and promotes collaboration and innovation. The University of Washington has large and thriving communities of researchers in vision science, theoretical and computational neuroscience, and neuroengineering. Cross-departmental collaborations are encouraged, easy to establish, and ubiquitous in these diverse groups. The neuroimaging community at UW interacts regularly with the Integrated Brain Imaging Center (IBIC) and the eScience Institute. IBIC holds bi-weekly seminars in a variety of topics with local experts and invited speakers, and organizes special interest groups; for example, past subjects include multi-voxel pattern analysis, diffusion MRI, and acquisition protocols. The eScience Institute holds meetings and workshops in broader topics related to data science, many of which are relevant to neuroimaging community. Both IBIC and the eScience Institute provide open shared work spaces that all researchers are invited to use to benefit from the collaborative environment. A number of other interdisciplinary institutes at UW provide an opportunity to obtain diverse perspectives and feedback, including the UW Institute for Neuroengineering, Computational Neuroscience Center, and the Center for Sensorimotor and Neural Engineering. There are also opportunities to engage with international scholars; for example, UW most recently co-hosted the Organization for Computational Neurosciences annual conference together with the Allen Institute for Brain Science. Access to these perspectives will be especially important for Dina as she continues to build her computational skills in a new research field and using new methods, as proposed in this application. In summary, interactions within and outside our lab group will serve as a critical resource for Dina as carries out the proposed research and career development activities, and help her further refine the long-term research plan for her independent career beyond the NRSA training period.

PHS Human Subjects and Clinical Trials Information

OMB Number: 0925-0001 and 0925-0002

Expiration Date: 03/31/2020

Are Human Subjects Involved	● Yes ○ No
Is the Project Exempt from Federal regulations?	○ Yes ● No
Exemption Number	❑ 1 ❑ 2 ❑ 3 ❑ 4 ❑ 5 ❑ 6 ❑ 7 ❑ 8
Other Requested Information	

Human Subject Studies

Study#	Study Title	Clinical Trial?
1	How does dividing attention limit object recognition and modify relevant neural activity?	No

Section 1 - Basic Information (Study 1)

OMB Number: 0925-0001 and 0925-0002

Expiration Date: 03/31/2020

1.1. Study Title *

How does dividing attention limit object recognition and modify relevant neural activity?

1.2. Is this study exempt from Federal Regulations * ❍ Yes ● No

1.3. Exemption Number ❑ 1 ❑ 2 ❑ 3 ❑ 4 ❑ 5 ❑ 6 ❑ 7 ❑ 8

1.4. Clinical Trial Questionnaire *

1.4.a. Does the study involve human participants?	● Yes	❍ No
1.4.b. Are the participants prospectively assigned to an intervention?	❍ Yes	● No
1.4.c. Is the study designed to evaluate the effect of the intervention on the participants?	❍ Yes	● No
1.4.d. Is the effect that will be evaluated a health-related biomedical or behavioral outcome?	● Yes	❍ No

1.5. Provide the ClinicalTrials.gov Identifier (e.g. NCT87654321) for this trial, if applicable

Section 2 - Study Population Characteristics (Study 1)

2.1. Conditions or Focus of Study

- Neurotypical individuals
- Individuals diagnosed with posterior cortical atrophy

2.2. Eligibility Criteria

Exclusionary criteria for all groups will include seizures, neurological disease, history of serious head injury, sensory or motor impairment that would impede completion of the study protocol, implanted medical devices such as pacemakers which pose a risk for fMRI, or medication known to affect brain responses as measured with fMRI.

2.3. Age Limits	Min Age: 18 Years	Max Age: 65 Years
2.4. Inclusion of Women, Minorities, and Children	Incl_Women_Minorities_Children.pdf	
2.5. Recruitment and Retention Plan	Recruitment_Retention_FINAL.pdf	
2.6. Recruitment Status	Not yet recruiting	
2.7. Study Timeline	Study_Timeline.pdf	
2.8. Enrollment of First Subject	04/01/2019	Anticipated

INCLUSION OF WOMEN AND MINORITIES

We will recruit subjects from the University of Washington student population and the surrounding community. Our subject group will therefore reflect the demographics of the local population. The 2010 census showed that Seattle is approximately 70% White, 14% Asian, 8% Black, 1% Native American, 2% Other races, 5% More than one race, and 7% Hispanic or Latino of any race, with approximately equal distribution of males and females. The UW student population is 52% female, 48% male, 2% American Indian, Hawaiian or Pacific Islander, 23% Asian, 3% Black, 6% Hispanic or Latino, 14% International, and 50% White.

50% of our participants will be women. However, as noted above (4.1.1a), pregnant women will not be included in fMRI experiments due to the potential for unknown risk factors for a developing fetus entering a high magnetic field. No exclusion of subjects will occur on the basis of gender or minority group or subgroup.

INCLUSION OF CHILDREN

All participants in the proposed experiments will be volunteers 18 years old and older. A fair number of the subject population will be students between 18 and 21 years of age. We believe it is necessary to exclude children under the age of 18 from these studies because the neuroimaging experiments require lying still for several hours and concentrating on sometimes-tedious tasks, something that adult subjects do better than most children and adolescents. Moreover, since PCA only affects older adults, the overall comparisons in the study will not be appropriate for individuals under 18 years of age.

RECRUITMENT AND RETENTION PLAN

Most participants will be recruited from the University of Washington student and faculty population. University of Washington has a vibrant community of research engagement with the public, especially in the Psychology Department. Thus, we are confident that we will be able to recruit our target of 30-50 healthy participants.

Participants with PCA will be recruited through existing, well-established connections from Dr. Thomas Grabowski. Dr. Grabowski is the Director of the UW Medicine Memory and Brain Wellness Center as well as the UW Alzheimer's Disease Research Center. These centers and Dr. Grabowski himself provide medical care and support to individuals with memory loss and neurodegenerative disorders, including at least 7 immediately contactable patients with PCA. The centers maintain a participant database to connect patients willing to participate in research studies with UW researchers. We are confident that we can recruit our target of 4-6 individuals with PCA over the duration of the proposed study.

We have a "subject-first" approach to helping subjects adjust to behavioral and MRI experimental conditions, emphasizing subject comfort and safety over all other considerations. This strategy has led both our experimental paradigms to have a typically high participant retention rate. Additionally, the intuitively relatable nature of tasks related to object recognition and attention, combined with the interest of our subjects in contributing to scientific knowledge, further improves our retention rates.

STUDY TIMELINE

	Year 1	Year 2	Year 3
Study Design	X		
Participant Recruitment	X	X	
Data Collection	X	X	X
Data Analysis		X	X
Dissemination			X

Inclusion Enrollment Reports

IER ID#	Enrollment Location Type	Enrollment Location
Study 1, IER 1	Domestic	University of Washington

Inclusion Enrollment Report 1

Using an Existing Dataset or Resource* : ❍ Yes ● No

Enrollment Location Type* : ● Domestic ❍ Foreign

Enrollment Country(ies): USA: UNITED STATES

Enrollment Location(s): University of Washington

Comments: These numbers reflect the approximate ethnic composition of the local Seattle and UW community.

Planned

Racial Categories	Ethnic Categories				Total
	Not Hispanic or Latino		Hispanic or Latino		
	Female	Male	Female	Male	
American Indian/ Alaska Native	0	0	0	0	0
Asian	2	2	0	0	4
Native Hawaiian or Other Pacific Islander	0	0	0	0	0
Black or African American	0	1	0	0	1
White	12	12	0	1	25
More than One Race	0	0	0	0	0
Total	14	15	0	1	30

Cumulative (Actual)

Racial Categories	Ethnic Categories									Total
	Not Hispanic or Latino			Hispanic or Latino			Unknown/Not Reported Ethnicity			
	Female	Male	Unknown/ Not Reported	Female	Male	Unknown/ Not Reported	Female	Male	Unknown/ Not Reported	
American Indian/ Alaska Native	0	0	0	0	0	0	0	0	0	0
Asian	0	0	0	0	0	0	0	0	0	0
Native Hawaiian or Other Pacific Islander	0	0	0	0	0	0	0	0	0	0
Black or African American	0	0	0	0	0	0	0	0	0	0
White	0	0	0	0	0	0	0	0	0	0
More than One Race	0	0	0	0	0	0	0	0	0	0
Unknown or Not Reported	0	0	0	0	0	0	0	0	0	0
Total	0	0	0	0	0	0	0	0	0	0

Section 3 - Protection and Monitoring Plans (Study 1)

3.1. Protection of Human Subjects	Protection_Human_Subjects.pdf
3.2. Is this a multi-site study that will use the same protocol to conduct non-exempt human subjects research at more than one domestic site?	❍ Yes ● No ❍ N/A
If yes, describe the single IRB plan	
3.3. Data and Safety Monitoring Plan	
3.4. Will a Data and Safety Monitoring Board be appointed for this study?	❍ Yes ● No
3.5. Overall structure of the study team	

4.1 PROTECTION OF HUMAN SUBJECTS

4.1.1 Risks to Human Subjects

a. Human Subjects Involvement, Characteristics, and Design

We will recruit human subjects to participate in experiments that involve behavioral tests of visual perception and functional magnetic resonance imaging (fMRI). Human subjects are necessary because our research concerns the functioning of the healthy human brain, specifically the mechanisms of object recognition. Subjects will make judgments of visual stimuli presented on a computer screen and respond by pressing a button on an input device (button box).

We plan to recruit 30-50 participants between the ages of 18 and 65, with normal or corrected-to-normal vision. The participants will be drawn from the University of Washington community, including undergraduates, graduate students and post-docs. Further, subjects will be excluded from MR scanning for the same reasons as patients are excluded from clinical MRI exams: e.g. pacemakers, known metal fragments embedded in the body, and pregnancy.

Additionally, we plan to recruit 4-6 participants with a diagnosis of posterior cortical atrophy (PCA). These patients will be drawn from a participant pool made available by our study contributor Dr. Thomas Grabowski. PCA typically affects older individuals, thus we anticipate their ages to range from 40 to 65.

The Sponsor (Dr. Boynton) and Co-Sponsor (Dr. Palmer) have obtained approval for all aspects of this study from the University of Washington. This approval includes recruitment of subjects, confidentiality issues, and all MR procedures. All subjects sign a consent form (approved by UW) that includes all procedures in this study. Participants will be paid $30/hour for the MR studies and $20/hour for purely behavioral testing sessions. No special vulnerable populations will be included in this study.

b. Sources of Materials

Each subject will fill out a consent form, indicating their name, birth date, gender, race, and ethnicity, and will be assigned a unique non-identifying number. These records will be stored in a locker that only the applicant and the PIs will have access to. The data collected include perceptual reports in psychophysical tasks, eye movement traces, and functional brain scans. Same kinds of data will be collected for both healthy participants and those with PCA; all data will be labeled only with a de-identified subject number. At no time will any individually identifiable private information be associated with any kind of experimental data collected for this project.

c. Potential Risks

The risks posed by the behavioral experiments are minimal. They include minor psychological fatigue and minor physical strain (e.g., tired eyes) caused by performing a demanding psychophysical task.

There are no known harmful effects from magnetic resonance imaging, but some subjects do become anxious during testing, since participation can involve some discomfort, for example from the loud banging noise of the machine. It will be made clear to all subjects that they can end participation at any time. The subjects' comfort will be monitored over an intercom between scans. Subjects will be able to signal to experimenters that they wish to stop an ongoing scan through the use of a squeeze ball, which sets off a signal in the control room.

The presence of any ferromagnetic objects near the scanner could pose a risk, so all subjects will be screened for medical implants or any metal in the body, and neither participants nor experimenters are allowed inside the room until all objects have been removed from their pockets and person.

4.1.2 Adequacy of Protection Against Risks

a. Recruitment and Informed Consent

Recruitment plans are outlined in the Involvement section (4.1.1a) above. Researchers listed on the IRB protocol that will cover this project will describe the experiments to all potential research subjects, including potential risks and benefits. We will provide subjects with a copy of the consent form that they sign.

b. Protections Against Risk

We will mitigate fatigue risks from the behavioral studies by allowing subjects to take frequent breaks and resume testing when ready. During MR scanning, subjects will be able to signal to experimenters that they wish to stop an ongoing scan through the use of a squeeze ball, which sets off a signal in the control room. For both experimental settings, it will be made clear to all subjects that they can end participation at any time.

4.1.3 Potential Benefits of the Proposed Research to Human Subjects and Others

The only potential benefit for our participants is educational: the chance to participate in a scientific experiment. There is minimal risk, beyond temporary discomfort, for participants. By participating, our subjects will help advance our knowledge of the visual functions of the human brain and the neural mechanisms of object recognition.

4.1.4 Importance of the Knowledge to be Gained

This knowledge will improve our understanding of visual and attentional deficits in patients with PCA, and could lead to development of strategies to improve well-being and comfort in daily activities. Given that the risks for participating are low, this knowledge will be very valuable.

Section 4 - Protocol Synopsis (Study 1)

4.1. Brief Summary

4.2. Study Design

4.2.a. Narrative Study Description

4.2.b. Primary Purpose

4.2.c. Interventions

Type	Name	Description

4.2.d. Study Phase

Is this an NIH-defined Phase III Clinical Trial? ❍ Yes ❍ No

4.2.e. Intervention Model

4.2.f. Masking ❍ Yes ❍ No

❑ Participant ❑ Care Provider ❑ Investigator ❑ Outcomes Assessor

4.2.g. Allocation

4.3. Outcome Measures

Type	Name	Time Frame	Brief Description

4.4. Statistical Design and Power

4.5. Subject Participation Duration

4.6. Will the study use an FDA-regulated intervention? ❍ Yes ❍ No

4.6.a. If yes, describe the availability of Investigational Product (IP) and Investigational New Drug (IND)/ Investigational Device Exemption (IDE) status

4.7. Dissemination Plan

Delayed Onset Studies

Delayed Onset Study#	Study Title	Anticipated Clinical Trial?	Justification
The form does not have any delayed onset studies			

PHS Assignment Request Form

OMB Number: 0925-0001

Expiration Date: 03/31/2020

Funding Opportunity Number: PA-18-670

Funding Opportunity Title: Ruth L. Kirschstein National Research Service Award (NRSA) Individual Postdoctoral Fellowship (Parent F32)

Awarding Component Assignment Request *(optional)*

If you have a preference for an awarding component (e.g., NIH Institute/Center) assignment, use the link below to identify the appropriate short abbreviation and enter it below. All requests will be considered; however, assignment requests cannot always be honored.

Awarding Components: https://grants.nih.gov/grants/phs_assignment_information.htm#AwardingComponents

	First Choice	Second Choice	Third Choice
Assign to Awarding Component:	NEI		
Do Not Assign to Awarding Component:			

Study Section Assignment Request *(optional)*

If you have a preference for study section assignment, use the link below to identify the appropriate study section (e.g., NIH Scientific Review Group or Special Emphasis Panel) and enter it below. Remove all hyphens, parentheses, and spaces. All requests will be considered; however, assignment requests cannot always be honored.

Study Sections: https://grants.nih.gov/grants/phs_assignment_information.htm#StudySection

	First Choice	Second Choice	Third Choice
Assign to Study Section: *(only 20 characters allowed)*	F02B		
Do Not Assign to Study Section: *(only 20 characters allowed)*			

Tracking Number:

Funding Opportunity Number: . Received Date:

PHS Assignment Request Form

List individuals who should not review your application and why *(optional) Only 1000 characters allowed*

Identify scientific areas of expertise needed to review your applications *(optional)*

Note: Please do not provide names of individuals

1	2	3	4	5

Expertise:

Only 40 characters allowed

Tracking Number:

Funding Opportunity Number: . Received Date: