Final Progress Report for Research Projects Funded by Health Research Grants

Instructions: Please complete all of the items as instructed. Do not delete instructions. Do not leave any items blank; responses must be provided for all items. If your response to an item is "None", please specify "None" as your response. "Not applicable" is not an acceptable response for any of the items. There is no limit to the length of your response to any question. Responses should be single-spaced, no smaller than 12-point type. The report **must be completed using MS Word**. Submitted reports must be Word documents; they should not be converted to pdf format. Questions? Contact Health Research Program staff at 717-783-2548.

1. **Grantee Institution:** Carnegie Mellon University

2. **Reporting Period (start and end date of grant award period):** 1/1/2009-12/31/2011

3. **Grant Contact Person (First Name, M.I., Last Name, Degrees):** Jim Osborn, MS

4. **Grant Contact Person's Telephone Number:** 412-268-6553

5. **Grant SAP Number:** 4100047627

6. **Project Number and Title of Research Project:** 2: Computational and Neural Basis of Visual Inference

7. **Start and End Date of Research Project:** 01/01/2009-06/30/2011

8. **Name of Principal Investigator for the Research Project:** Carl Olson

9. **Research Project Expenses**.

   9(A) Please provide the amount of health research grant funds spent on this project for the entire duration of the grant, including any interest earned that was spent:

   $277,037

   9(B) Provide the last names (include first initial if multiple individuals with the same last name are listed) of **all** persons who worked on this research project and were supported with health research funds. Include position titles (Principal Investigator, Graduate Assistant, Post-doctoral Fellow, etc.), percent of effort on project and total health research funds expended for the position. For multiple year projects, if percent of effort varied from year to year, report in the % of Effort column the effort by year 1, 2, 3, etc. of the project (x% Yr 1; z% Yr 2-3).

Last Name	Position Title	% of Effort on Project	Cost
Olson	Principal Investigator	5%	$51,911
Lee	Co-Principal Investigator	10%	$31,803
Clark	Business Manager	25%	$44,482
Dorney	Administrative Assoc.	20%	$33,207

9(C) Provide the names of **all** persons who worked on this research project, but who *were not* supported with health research funds. Include position titles (Research Assistant, Administrative Assistant, etc.) and percent of effort on project. For multiple year projects, if percent of effort varied from year to year, report in the % of Effort column the effort by year 1, 2, 3, etc. of the project (x% Yr 1; z% Yr 2-3).

Last Name	Position Title	% of Effort on Project
Kelly	Graduate student	30%
Samonds	Post-doc	30%
Li	Graduate student	30%
Poole	Undergraduate student	10%
Lindsay	Undergraduate student	10%
Stepleton	Graduate student	30%
Potetz	Graduate student	30%
Meyer	Post-doc	10%

9(D) Provide a list of **all** scientific equipment purchased as part of this research grant, a short description of the value (benefit) derived by the institution from this equipment, and the cost of the equipment.

Type of Scientific Equipment	Value Derived	Cost
None		

10. Co-funding of Research Project during Health Research Grant Award Period. Did this research project receive funding from any other source during the project period when it was supported by the health research grant?

Yes_____X__ No_____

If yes, please indicate the source and amount of other funds:

Olson NIH 1R01EY018620
Olson NIH 1P50MH084053

Lee: NSF (CISE) IIS0713206. $450K. (2007-2010)
Lee: AFOSR: $300K (2009-2012).

11. Leveraging of Additional Funds

11(A) As a result of the health research funds provided for this research project, were you able to apply for and/or obtain funding from other sources to continue or expand the research?

Yes___x_____ No_____

If yes, please list the applications submitted (column A), the funding agency (National Institutes of Health—NIH, or other source in column B), the month and year when the application was submitted (column C), and the amount of funds requested (column D). If you have received a notice that the grant will be funded, please indicate the amount of funds to be awarded (column E). If the grant was not funded, insert "not funded" in column E.

Do not include funding from your own institution or from CURE (tobacco settlement funds). Do not include grants submitted prior to the start date of the grant as shown in Question 2. If you list grants submitted within 1-6 months of the start date of this grant, add a statement below the table indicating how the data/results from this project were used to secure that grant.

A. Title of research project on grant application	B. Funding agency (check those that apply)	C. Month and Year Submitted	D. Amount of funds requested:	E. Amount of funds to be awarded:
A new conceptualization of surface representation	☐NIH ■ Other federal (specify:__AFOSR (Air Force) _____) ☐ Nonfederal source (specify: _____)	2009	$ 300K	$ 300K
	☐NIH ☐ Other federal (specify:_____ _____) ☐ Nonfederal source (specify: _____)		$	$

11(B) Are you planning to apply for additional funding in the future to continue or expand the research?

Yes___x_____ No_____

If yes, please describe your plans:

Lee has applied for a CRCNS (Collaborative Research in Computational Neuroscience) grant from NSF-NIH to elucidate the neural encoding of higher order concepts in the visual systems.

12. Future of Research Project. What are the future plans for this research project?

We plan to continue our investigation of the neural basis of visual cognition – how information is represented at different levels of the visual hierarchy, how the different visual areas interact to perform visual inference, using a range of computational and neurophysiological techniques as fostered by this grant.

13. New Investigator Training and Development. Did students participate in project supported internships or graduate or post-graduate training for at least one semester or one summer?

Yes_____x____ No_____

If yes, how many students? Please specify in the tables below:

	Undergraduate	Masters	Pre-doc	Post-doc
Male	1		4	2
Female	1			
Unknown				
Total	**2**		**4**	**2**

	Undergraduate	Masters	Pre-doc	Post-doc
Hispanic				
Non-Hispanic				
Unknown	2		4	2
Total	**2**		**4**	**2**

	Undergraduate	Masters	Pre-doc	Post-doc
White	2		4	2
Black				
Asian				
Other				
Unknown				
Total	**2**		**4**	**2**

14. Recruitment of Out-of–State Researchers. Did you bring researchers into Pennsylvania to carry out this research project?

Yes___ No_____x_____

If yes, please list the name and degree of each researcher and his/her previous affiliation:

15. Impact on Research Capacity and Quality. Did the health research project enhance the quality and/or capacity of research at your institution?

Yes___x_____ No_____

If yes, describe how improvements in infrastructure, the addition of new investigators, and other resources have led to more and better research.

This project has lead to enhanced on-going collaborative investigation between Olson and Lee on the computational and neural basis of visual cognition. The exploration of the array recording techniques has increased the research capacity and quality in the CNBC primate electrophysiology facility.

16. Collaboration, business and community involvement.

16(A) Did the health research funds lead to collaboration with research partners outside of your institution (e.g., entire university, entire hospital system)?

Yes___X_____ No_____

If yes, please describe the collaborations:

Some of the findings of this grant lead to a new collaboration with Professor Alan Yuille at UCLA, and lead to the development of a new R01 project on the neural representation of higher order visual concepts in the brain, currently pending.

16(B) Did the research project result in commercial development of any research products?

Yes_____ No____x_____

If yes, please describe commercial development activities that resulted from the research project:

16(C) Did the research lead to new involvement with the community?

Yes_____ No_____x_____

If yes, please describe involvement with community groups that resulted from the research project:

17. Progress in Achieving Research Goals, Objectives and Aims.

List the project goals, objectives and specific aims (as contained in the grant application's strategic plan). Summarize the progress made in achieving these goals, objectives and aims for the entire grant award period. Indicate whether or not each goal/objective/aim was achieved; if something was not achieved, note the reasons why. Describe the methods used. If changes were made to the research goals/objectives/aims, methods, design or timeline since the original grant application was submitted, please describe the changes. Provide detailed results of the project. Include evidence of the data that was generated and analyzed, and provide tables, graphs, and figures of the data. List published abstracts, poster presentations and scientific meeting presentations at the end of the summary of progress; peer-reviewed publications should be listed under item 20.

This response should be a DETAILED report of the methods and findings. It is not sufficient to state that the work was completed. Insufficient information may result in an unfavorable performance review, which may jeopardize future funding. If research findings are pending publication you must still include enough detail for the expert peer reviewers to evaluate the progress during the course of the project.

Health research grants funded under the Tobacco Settlement Act will be evaluated via a performance review by an expert panel of researchers and clinicians who will assess project work using this Final Progress Report, all project Annual Reports and the project's strategic plan. After the final performance review of each project is complete, approximately 12-16 months after the end of the grant, this Final Progress Report, as well as the Final Performance Review Report containing the comments of the expert review panel, and the grantee's written response to the Final Performance Review Report, will be posted on the CURE Web site.

There is no limit to the length of your response. Responses must be single-spaced below, no smaller than 12-point type. If you cut and paste text from a publication, be sure symbols print properly, e.g., the Greek symbol for alpha (α) and beta (ß) should not print as boxes (□) and include the appropriate citation(s). DO NOT DELETE THESE INSTRUCTIONS.

The proposal's Specific Aims are:

Aim 1: Computational Models of Early Vision

We will analyze and model the computational mechanisms based on the principles of statistical inference for inferring object surfaces and extracting object figures from cluttered scenes, under the influence of top-down contextual information.

Aim 2: Computational Models of Object Perception

We will analyze and model the computational mechanisms based on the principles of statistical inference for object recognition to explore the paradigm of analysis by synthesis.

Aim 3: Neuronal Responses to Objects in V1, V4 and IT

We will monitor the visual responses of ensembles of neurons in areas V1, V4 and IT of the macaque monkey to object surfaces in cluttered scenes during object perception.

Progress in Aim 1:

The objective of this Aim is to develop computational models in the framework of Bayesian inference that can produce scene partitioning based on bottom-up visual features, as well as top-down contextual influence. We have developed state-of-the-art efficient Bayesian belief propagation algorithms for computing Bayesian network formulated in terms of factor graph (Potetz and Lee 2008). This new technique allows us to compute belief propagation messages in time linear with respect to clique size for a large class of potential functions over real-valued variables. It allows us to attack more difficult statistical inference problem involving higher order constraints, i.e. constraints involving three or more neurons simultaneously, which were computationally intractable earlier. This enables us to explore the use of a much richer set of prior knowledge of our visual experiences for visual inference. During the first year of the grant, we have explored these techniques for image denoising or removing noises from images, as well as for inference of shape from shading and produced state of the art results in denoising and shape from shading (Potetz and Lee, 2010). This study provides a theoretical foundation for us to carry out experiments in Aim 3.

Publications:

1. Potetz, B., Lee, T.S. (2009) Scene statistics and 3D surface perception. In *Computational Vision: From Surfaces to Objects. Chapman Hall.*
2. Potetz, B. and Lee, T.S. (2008) Efficient belief propagation for higher order cliques using linear constraint nodes. *Computer Vision and Image Understanding. 112(1): 39-54.*

Progress in Aim 2:

The objective of this Aim is to build a computational model for object recognition. During this grant period, we have explored two classes of models. The first class of models learn invariant representation of objects by linking many different views of an object together by virtue of our dynamic visual experience, without specifying how many views there are in advance, and yet maintaining the distinctness of the views of the different objects. We extended a class of

generative (graphical) models called infinite Hidden Markov Model (HMM) (Beal et al. 2002) or more generally known as Hierarchical Dirichlet processes (Teh et al. 2006) in object representation learning. We extended the infinite HMM model by introducing a block diagonal (BD) prior which will encourage the formation of distinct object representations, the views of each object can transit into other views of the same object, but not to views of another object. This is essentially a Bayesian clustering technique without the need of knowing how many object classes there are in the world. It dynamically adjusts and refines the representations as needed. The basic strategy to use this machinery for learning object representation is to track and analyze features in movies, segment and cluster the coherently co-varying features and parts together, taking into account the possible variations of the appearance of each type of features as objects move and rotate, and build object models based on these clusters. The computational complexity of the processing and learning procedure, which in some sense mimic the development of the visual system in a baby during its first few months of interacting with the environment. The outcome of this work, called Block-Diagonal iHMM, was published in a top machine learning conference called AISTAT, as reported in our second annual report (Stepleton et al. 2009).

A second class of models is designed o learn features for classification using a combination of generative models and discrimination models. Perceptual inference, such as recognizing objects or 3D surface geometry of objects, requires features that are both specific enough to allow for discrimination of different classes of objects, or different surface geometries, and yet able to tolerate image variations due to changes in viewpoint and illumination, as well as variations and deformation of shapes and texture within each class. Learning the appropriate features that are both specific and invariant for object discrimination has been a difficult problem. There has been proposals that perceptual inference in the brain is accomplished by the interaction of a bottom-up feed-forward discriminative process that *extracts* features for classification and a top-down generative process that produce "perceptual proposals" to *explain away* the features. An important question is to what extent the learning of the features used in the discriminative models are themselves influenced by the generative feedback process. In this study, we explored the use of generative models to derive a nonlinear mapping that map image input to a high dimensional nonlinear feature space based on the principle of maximizing the divergence of the posterior probabilities of the different classes. This work is published in IEEE Conference in Computer Vision and Pattern Recognition (CVPR) (Li et al. 2011). Establishing the computational competence of these object recognition models is important not just for computer vision, but also for neuroscience, as it is possible the brain might likewise utilize similar hybrid scheme of discriminative and generative models to learn features for classification. This class of hybrid methods for feature learning can provide concrete hypotheses of feature representation for testing neurons in the higher order visual cortex.

Publications:

3. Stepleton, T., Ghahramani, Z., Gordon G., Lee, T.S. (2009) The Block Diagonal Infinite Hidden Markov Model *Proceedings of the Twelfth International Conference on Artificial Intelligence and Statistics. AND Journal of Machine Learning Research: 5: 544-551.*
4. Li, X, Lee, T.S., Liu (2011) Hybrid generative-discriminative classifiers using posterior

divergence. IEEE Conference in computer vision and pattern recognition (CVPR). 2713-2720.

Progress in Aim 3:

Perceptual inference relies on statistical priors we learned from the natural environments. These priors allow surround contextual information to help disambiguate local inference computation. In computer vision, network encoding statistical priors are formulated in terms of Markov random field or factor-graph (see Aim 1), which are nodes with horizontal interactions. We hypothesized the local functional circuitries in the primary visual cortex can be modeled in terms of Markov random field. To evaluate these conceptualizations, we performed multi-electrode array recording studies in the primary visual cortex of monkeys to look into functional circuitry and coding of the neurons. We found that (1) neurons coding for depth interact in a way that is broadly consistent with the statistical constraints (specifically the continuity constraint and the uniqueness constraint) proposed by David Marr 30 years ago (Samonds et al. 2009, 2010). That is, neurons with similar disparity tunings cooperate across space, and neurons dissimilar in disparity tunings compete at each spatial location; (2) a neuron's activities can be predicted better by knowing the other neurons' activities than by the visual input in its receptive field, indicating extensive network interaction (Kelly et al. J. Comp Neuroscience 2009, Kelly et al. NIPS 2010). Both of these studies support the notion of extensive horizontal interaction between neurons in the visual cortex to mediate perceptual computation. Definitely elucidating the network structures and comparing them with constraints learned from natural scenes is a long-term goal of our research. The general idea behind the phase of Aim 3 concerned with inferotemporal cortex (IT) is that functional connections among neurons in IT change according to the statistics of visual experience so as to maximize the efficiency with which images are processed. The specific idea tested in these experiments was that if an image is highly predictable then IT neurons will cease to represent it strongly because it conveys no new information. We explored this possibility by exposing monkeys repeatedly to images presented in a certain sequence, so that the first became a strong predictor of the second, and then asking whether IT neurons responded less strongly to an image when it was predicted than when it was not. The answer was in the affirmative (Meyer and Olson 2010). We began by exposing two monkeys repeatedly to six pairs of images. On each trial, while the monkey looked at the center of the screen, two images appeared in succession at fixation for half a second each. The members of each pair were always presented in the same order so that the leading image became a strong predictor of the trailing image. Training involved viewing each sequential pair of images over 800 times. The training runs were distributed across three months in monkey 1 and one month in monkey 2. Following training, we began to collect data from single IT neurons in microelectrode recording sessions. The procedure employed during testing was identical to the training procedure with the exception that trials involving untrained sequences were interleaved among the trials involving trained sequences. An untrained sequence consisted of a leading image and a trailing image that belonged to different training pairs. So as to minimize any attenuation of the effects of training, we adopted a design in which each of the six trained sequences was presented eight times in a full run whereas each of the 30 untrained sequences was presented only once. Using this procedure, we collected data from 81 visually responsive IT neurons (46 in monkey 1

and 35 in monkey 2). IT neurons responded more strongly when the trailing image followed another image's predictor than when it followed its own. This effect achieved significance in 33/81 individual neurons (ANOVA with prediction status and stimulus identity as factors and firing rate 50-500 ms after stimulus onset as the dependent variable, $\alpha = 0.05$). The effect emerged clearly at the level of population activity. The firing rate elicited by the trailing image was greater on average when it was unpredicted (mean = 16.8 Hz) than when it was predicted (mean = 13.0 Hz) and the difference was highly significant (paired t-test, $n = 81$, $p = 1.5e^{-11}$; $p < 0.0005$ in each monkey). This effect depends on the order in which the two stimuli are presented (reversing their order eliminates it) and depends simply on the trailing image's being surprising (not on the degree to which it deviates in nature from the predicted image). Thus neurons in IT robustly signal when a prediction based on the statistics of past experience has been violated.

Publications:

1. Kelly, R.C., Smith, M.A., Kass, R.E., T.S. Lee (2010) Accounting for network effects in neuronal responses using L1 regularized point process models *NIPS -- Advances in Neural Information Processing Systems, 2010.* .
2. Kelly, R.C., Smith, M.A., Kass, R.E., T.S. Lee (2010) Local field potentials indicate network state and account for neuronal response variability. *J. Computational Neuroscience. 29: 567-579.*
3. Meyer, T., Olson, C.R. (2010) Inferotemporal neurons signal perceptual prediction errors. Program No. 372.11. Neuroscience 2010 Abstracts. San Diego, California: Society for Neuroscience, 2010. Online.
4. Samonds, J.M., Lee, T.S. (2010) Neuronal interactions and their role in solving the stereo correspondence problem. *In Vision in 3D Environments*, Ed. Laurence Harris, Michael Jenkin, Cambridge University Press, 2010. In Press.
5. Samonds, J.M., Potetz, B., Lee, T.S., (2009) Cooperative and competitive interactions facilitate stereo computations in macaque primary visual cortex_*J. Neuroscience 29(50):15780-15795, 2009.* .

18. Extent of Clinical Activities Initiated and Completed. Items 18(A) and 18(B) should be completed for all research projects. If the project was restricted to secondary analysis of clinical data or data analysis of clinical research, then responses to 18(A) and 18(B) should be "No."

18(A) Did you initiate a study that involved the testing of treatment, prevention or diagnostic procedures on human subjects?

_____Yes
____x__No

18(B) Did you complete a study that involved the testing of treatment, prevention or diagnostic procedures on human subjects?

_____Yes
____x__No

If "Yes" to either 18(A) or 18(B), items 18(C) – (F) must also be completed. (Do NOT complete 18(C-F) if 18(A) and 18(B) are both "No.")

18(C) How many hospital and health care professionals were involved in the research project?

_____Number of hospital and health care professionals involved in the research project

18(D) How many subjects were included in the study compared to targeted goals?

_____Number of subjects originally targeted to be included in the study
_____Number of subjects enrolled in the study

Note: Studies that fall dramatically short on recruitment are encouraged to provide the details of their recruitment efforts in Item 17, Progress in Achieving Research Goals, Objectives and Aims. For example, the number of eligible subjects approached, the number that refused to participate and the reasons for refusal. Without this information it is difficult to discern whether eligibility criteria were too restrictive or the study simply did not appeal to subjects.

18(E) How many subjects were enrolled in the study by gender, ethnicity and race?

Gender:
_____Males
_____Females
_____Unknown

Ethnicity:
_____Latinos or Hispanics
_____Not Latinos or Hispanics
_____Unknown

Race:
_____American Indian or Alaska Native
_____Asian
_____Blacks or African American
_____Native Hawaiian or Other Pacific Islander
_____White
_____Other, specify:_____
_____Unknown

18(F) Where was the research study conducted? (List the county where the research study was conducted. If the treatment, prevention and diagnostic tests were offered in more than one county, list all of the counties where the research study was conducted.)

19. Human Embryonic Stem Cell Research. Item 19(A) should be completed for all research projects. If the research project involved human embryonic stem cells, items 19(B) and 19(C) must also be completed.

19(A) Did this project involve, in any capacity, human embryonic stem cells?
_____Yes
___x___ No

19(B) Were these stem cell lines NIH-approved lines that were derived outside of Pennsylvania?
_____Yes
_____ No

19(C) Please describe how this project involved human embryonic stem cells:

20. Articles Submitted to Peer-Reviewed Publications.

20(A) Identify all publications that resulted from the research performed during the funding period and that have been submitted to peer-reviewed publications. Do not list journal abstracts or presentations at professional meetings; abstract and meeting presentations should be listed at the end of item 17. **Include only those publications that acknowledge the Pennsylvania Department of Health as a funding source** (as required in the grant agreement). List the title of the journal article, the authors, the name of the peer-reviewed publication, the month and year when it was submitted, and the status of publication (submitted for publication, accepted for publication or published.). Submit an electronic copy of each publication, listed in the table, in a PDF version 5.0.5 format, 1,200 dpi. Filenames for each publication should include the number of the research project, the last name of the PI, the number of the publication and an abbreviated research project title. For example, if you submit two publications for PI Smith for the "Cognition and MRI in Older Adults" research project (Project 1), and two publications for PI Zhang for the "Lung Cancer" research project (Project 3), the filenames should be:

Project 1 – Smith – Publication 1 – Cognition and MRI
Project 1 – Smith – Publication 2 – Cognition and MRI
Project 3 – Zhang – Publication 1 – Lung Cancer
Project 3 – Zhang – Publication 2 – Lung Cancer

If the publication is not available electronically, provide 5 paper copies of the publication.

Note: The grant agreement requires that recipients acknowledge the Pennsylvania Department of Health funding in all publications. Please ensure that all publications listed

acknowledge the Department of Health funding. If a publication does not acknowledge the funding from the Commonwealth, do not list the publication.

Title of Journal Article:	Authors:	Name of Peer-reviewed Publication:	Month and Year Submitted:	Publication Status (check appropriate box below):
1. Hybrid generative-discriminative classifiers using posterior divergence	Li, X, Lee, T.S., Liu, Y.	IEEE Conference Proceeding in computer vision and pattern recognition	November 2010.	☐Submitted ☐Accepted ☐x Published
2. Cooperative and competitive interactions facilitate stereo computations in macaque primary visual cortex	Samonds, J.M., Potetz, B., Lee, T.S.,	*J. Neuroscience*	May 2009	☐Submitted ☐Accepted ☐xPublished

20(B) Based on this project, are you planning to submit articles to peer-reviewed publications in the future?

Yes_____x____ No_____

If yes, please describe your plans:

Research begun under this project gave rise to some partial data sets (consisting of data collected from a single monkey) which will be supplemented outside the project period (with data from a second monkey) as required for confirmation of the findings leading to publication.

21. Changes in Outcome, Impact and Effectiveness Attributable to the Research Project. Describe the outcome, impact, and effectiveness of the research project by summarizing its impact on the incidence of disease, death from disease, stage of disease at time of diagnosis, or other relevant measures of outcome, impact or effectiveness of the research project. If there were no changes, insert "None"; do not use "Not applicable." Responses must be single-spaced below, and no smaller than 12-point type. DO NOT DELETE THESE INSTRUCTIONS. There is no limit to the length of your response.

Findings obtained in this project cast light on how the visual system adapts to the statistics of the natural environment in order to optimize processing of visual information. The findings

have long-term significance for understanding visual system plasticity during normal development and disease.

22. Major Discoveries, New Drugs, and New Approaches for Prevention Diagnosis and Treatment. Describe major discoveries, new drugs, and new approaches for prevention, diagnosis and treatment that are attributable to the completed research project. If there were no major discoveries, drugs or approaches, insert "None"; do not use "Not applicable." Responses must be single-spaced below, and no smaller than 12-point type. DO NOT DELETE THESE INSTRUCTIONS. There is no limit to the length of your response.

None.

23. Inventions, Patents and Commercial Development Opportunities.

23(A) Were any inventions, which may be patentable or otherwise protectable under Title 35 of the United States Code, conceived or first actually reduced to practice in the performance of work under this health research grant? Yes_____ No___X_____

If "Yes" to 23(A), complete items a – g below for each invention. (Do NOT complete items a - g if 23(A) is "No.")

a. Title of Invention:

b. Name of Inventor(s):

c. Technical Description of Invention (describe nature, purpose, operation and physical, chemical, biological or electrical characteristics of the invention):

d. Was a patent filed for the invention conceived or first actually reduced to practice in the performance of work under this health research grant?
Yes_____ No____

If yes, indicate date patent was filed:

e. Was a patent issued for the invention conceived or first actually reduced to practice in the performance of work under this health research grant?
Yes_____ No____
If yes, indicate number of patent, title and date issued:
Patent number:
Title of patent:
Date issued:

f. Were any licenses granted for the patent obtained as a result of work performed under this health research grant? Yes_____ No____

If yes, how many licenses were granted?_____

g. Were any commercial development activities taken to develop the invention into a commercial product or service for manufacture or sale? Yes__ No___

If yes, describe the commercial development activities:

23(B) Based on the results of this project, are you planning to file for any licenses or patents, or undertake any commercial development opportunities in the future?

Yes_____ No____X_____

If yes, please describe your plans:

24. Key Investigator Qualifications. Briefly describe the education, research interests and experience and professional commitments of the Principal Investigator and all other key investigators. In place of narrative you may insert the NIH biosketch form here; however, please limit each biosketch to 1-2 pages. *For Nonformula grants only – include information for only those key investigators whose biosketches were not included in the original grant application.*

NAME	POSITION TITLE
Carl R. Olson	Professor, Center for the Neural Basis of Cognition
eRA COMMONS USER NAME COLSON	

EDUCATION/TRAINING *(Begin with baccalaureate or other initial professional education, such as nursing, and include postdoctoral training.)*

INSTITUTION AND LOCATION	DEGREE *(if applicable)*	YEAR(s)	FIELD OF STUDY
Harvard University, Boston, MA	BA	1966	English Literature
Columbia University, New York, NY	MA	1967	English Literature
University of California at Berkeley, Berkeley, CA	PhD	1979	Neurobiology

A. Personal Statement

B. Positions and Honors

Positions and Employment

1982-1989 Assistant Professor, Psychology, Princeton University
1989-1991 Associate Research Professor, Psychology, George Mason University
1989-1991 Guest Researcher, Laboratory of Sensorimotor Research, NIH
1991-1996 Associate Professor, Anatomy, University of Maryland, Baltimore
1996-2001 Senior Research Scientist, Carnegie Mellon University, Pittsburgh
1996-2001 Research Associate Professor, Neuroscience, University of Pittsburgh
1996- Director, CNBC Primate Neurophysiology Laboratory, Pittsburgh
2001- Adjunct Professor, Neuroscience, University of Pittsburgh
2001- Professor with tenure, Center for the Neural Basis of Cognition, Carnegie Mellon University, Pittsburgh
2006-present Courtesy appointment, Department of Biological Sciences, Carnegie Mellon University, Pittsburgh
2006-2009 Acting Co-Director, Center for the Neural Basis of Cognition, Carnegie Mellon University, Pittsburgh

Other Experience and Professional Memberships

1976- Member, Society for Neuroscience
1996- Member, International Neuropsychological Symposium
1995 NIMH study section, ad hoc reviewer
1995-99 National Institutes of Health Reviewers Reserve
1996 NIMH Board of Scientific Councilors, ad hoc member
1997 NIMH Board of Scientific Councilors, ad hoc member
1999 NIH VISB study section, ad hoc member
2001-05 NIH VISB/CVP study section, member, 2001-2005
2009 NIH National Center for Research Resources RCMI-COBRE Review Panel
2010 NIH National Center for Research Resources RCMI-COBRE Review Panel

C. Selected Peer-reviewed Publications

Spatial working memory

1. Moorman, D.E., and Olson, C.R., 2007, Combination of neuronal signals representing object-centered location and saccade direction in macaque supplementary eye field. J. Neurophysiol. 97: 3554-3566.
2. Moorman, D., and Olson, C.R., 2007, Impact of learning on representation of object-centered space in macaque supplementary eye field. J. Neurophysiol. 97: 2159-2173.
3. Roesch, M.R., and Olson, C.R., 2004, Neuronal activity related to reward value and motivation in primate frontal cortex. Science 304: 307-310.
4. Olson, C.R., 2003, Brain representation of object-centered space in monkeys and humans. Annual Review of Neuroscience 26: 331-354.
5. Olson, C.R., and Gettner, S.N., 1995. Object-centered direction selectivity in the supplementary eye field of the macaque monkey. Science 269: 985-988.

Executive control

1. Berdyyeva, T.K., and Olson, C.R., 2010, Rank signals in four areas of macaque frontal cortex during selection of actions and objects in serial order. J. Neurophysiol. 104: 141-159.
2. Berdyyeva, T.K., and Olson, C.R., 2009, Monkey supplementary eye field neurons signal the ordinal position of both actions and objects. J. Neurosci. 21: 591-599. PMC 2761674
3. Nakamura, K., Roesch, M.R., and Olson, C.R., 2005, Neuronal activity in macaque SEF and ACC during performance of tasks involving conflict, J. Neurophysiol. 93: 884-908.
4. Olson, C.R., and Gettner, S.N., 2002, Neuronal activity related to rule and conflict in macaque supplementary eye field. Physiology and Behavior 77:663-670.
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Vision

1. Sripati, A.P., and Olson, C.R., 2010, Responses to compound objects in monkey inferotemporal cortex: the whole is equal to the sum of the discrete parts. J. Neurosci. 30: 7948-7960.
2. Sripati, A.P., and Olson, C.R., 2010, Global image dissimilarity in macaque inferotemporal cortex predicts human visual search efficiency. J. Neurosci. 30: 1258-1269.
3. Sripati, A.P., and Olson, C.R., 2009, Seeing the forest before the trees: A global advantage effect in monkey inferotemporal cortex. J. Neurosci. 29: 7788-7796. PMC 2744217
4. Baker, C.I., Behrmann, M., and Olson, C.R., 2002, Impact of visual discrimination training on the representation of parts and wholes in monkey inferotemporal cortex. Nature Neuroscience 5:1210-1216.
5. Rollenhagen, J.E., and Olson, C.R., 2000. Mirror image confusion in single neurons of macaque inferotemporal cortex. Science 287: 1506-1508.

D. Research Support

Ongoing Research Support

P50 MH084053 Lewis (PI) 07/01/08 – 06/30/13
Inhibition, Oscillations and Information Processing in Schizophrenia

Project 3, Cognition-Related Cortical Oscillations in the Behaving Monkey
The goal of this project is to characterize cognition-related oscillatory activity in the cerebral cortex of the behaving monkey at the level of neuronal action potentials, local field potentials and the electrocorticogram and to investigate its dependence on GABA neurotransmission.
Role: Project director

RO1 EY018620 Olson (PI) 12/01/07 – 11/30/12
Inferotemporal Cortex and Object Vision
The goal of this project is to characterize the code in which neurons of inferotemporal cortex represent object identity and to analyze its dependence on learning and its relation to visual discrimination ability in the behaving monkey.
Role: PI

NAME	POSITION TITLE
Tai Sing Lee	Associate Professor
eRA COMMONS USER NAME TAISING	

EDUCATION/TRAINING *(Begin with baccalaureate or other initial professional education, such as nursing, and include postdoctoral training.)*

INSTITUTION AND LOCATION	DEGREE *(if applicable)*	YEAR(s)	FIELD OF STUDY
Harvard College, Cambridge, MA	B.S.	1986	Engineering Sciences
Harvard University, Cambridge, MA	M.S.	1988	Engineering Sciences
Harvard University, Cambridge, MA	Ph.D.	1993	Engineering Sciences
Harvard-MIT Div. HST, Cambridge, MA	Ph.D.	1993	Medical Engineering & Medical Physics

Personal Statement

I am an associate professor of Computer Science at Carnegie Mellon University and a member of the CNBC. My research expertise is in computational vision, and primate electrophysiology using single and multi-electrode array recording techniques. The goal of my research is to elucidate the computational principles and the neural mechanisms underlying visual perception, which requires the application of statistical, computational methods in conjunction with electrophysiological and behavioral studies. Over the course of my career, I have mentored 5 predoctoral trainees and 4 postdoctoral trainees in my laboratory and have served on the committees of 18 additional trainees. Two of my predoctoral trainees and two of my postdoctoral trainees have now become assistant professors. I am the director of the inter-college Minor in Neural Computation at Carnegie Mellon and am the coordinator of the CMU-Pitt undergraduate fellowship in Neural Computation. I am committed to training undergraduate students to pursue interdisciplinary research in computational neuroscience and to fostering diversity in this quantitative discipline. I have trained over 20 undergraduate students in my laboratory. Seven of my female undergraduate trainees have went on to graduate schools in public policy, medicine, robotics and neuroscience.

Positions and Honors

2004-now Associate Professor with tenure, Computer Science Department and Center for the Neural Basis of Cognition, Carnegie Mellon University, Pittsburgh, PA.
2004-now: Associate member of the Canadian institute for Advanced Research.
2002-2004 Associate Professor, Computer Science Department and Center for the Neural Basis of Cognition, Carnegie Mellon University, Pittsburgh, PA.
2000 NSF CAREER award in Robotics and Computer Vision/Computational Neuroscience.
1996-2002 Assistant Professor, Department of Computer Science & the Center for Neural Basis of Cognition, Carnegie Mellon University, Pittsburgh, PA
1996 McDonnell-Pew Cognitive Neuroscience Investigator Award.

1993-1996 Post Doctoral Fell, Department of Brain and Cognitive Sciences, MIT, Cambridge, MA and Division of Engineering and Applied Science, Harvard University, Cambridge, MA

1986-1993 Graduate Student, Division of Applied Sciences, Harvard University, Cambridge, MA and Harvard-MIT Division of Health Science and Technology, Harvard Medical School and Massachusetts Institute of Technology, Cambridge, MA

Selected Peer-Reviewed Publications

Kelly, R.C., Smith, M.A., Kass, R.E., T.S. Lee (2010) Local field potentials indicate network state and account for neuronal response variability. *J. Computational Neuroscience. 29:567-579.*

Samonds, J.M., Potetz, B., Lee, T.S., (2009) Cooperative and competitive interactions facilitate stereo computations in macaque primary visual cortex *J. Neuroscience 29(50):15780-15795, 2009.*

Stepleton, T., Ghahramani, Z., Gordon G., Lee, T.S. (2009) The Block Diagonal Infinite Hidden Markov Model *Journal of Machine Learning Research: 5: 544-551.*

Potetz, B., Lee, T.S. (2008) Efficient belief propagation for higher order cliques using linear constraint nodes. *Computer vision and image understanding. 112(1): 39-54.*

Smith, M.A., Kelly, R.C., Lee, T.S. (2007) Dynamics of response to perceptual pop-out stimuli in macaque V1. J. Neurophysiology. *98: 3436-3449.*

Yu, Y., Romero, R., Lee, TS (2005) Preference of sensory neural coding for 1/f signals. *Physics Review Letters*, 94, 108103, 1-4.

Deco G, Lee TS (2004) The role of early visual cortex in visual integration: a neural model of recurrent interaction. *European Journal of Neuroscience*, 20: 1089-1100.

Yu, Y., Potetz, B, Lee, T.S. (2004). The role of static nonlinearity in contrast gain control and information transmission, *Vision Research*, 45(2005): 111-116.

Lee, T.S., Mumford, D. (2003). Hierarchical Bayesian inference in the visual cortex. *Journal of Optical Society of America, A.* 20(7):1434-1448.

Potetz, B, Lee, TS. (2003) Statistical correlations between 2D images and 3D structures in natural scenes. *Journal of Optical Society of America,A* 20(7): 1292-1303.

Yu, Y, Lee, TS (2003) Dynamical mechanisms underlying contrast gain control in single neurons. *Physics Review E*, 68(1): 1901-1907.

Lee, TS, Yang, C., Romero, R., Mumford, D. (2002). Neural activity in early visual cortex reflects behavioral experience and higher order perceptual saliency. *Nature Neuroscience*. 5(6): 589-597.

Lee, TS, Nguyen, M. (2001) Dynamics of subjective contour formation in early visual cortex. *Proceedings of the National Academy of Sciences, USA*, 98(4) 1907-1911.

Lee, T.S., Mumford, D., Romero, R., & Lamme, V.A.F. (1998). The role of primary visual cortex in higher level vision. *Vision Research* 38, 2429-2454.

Lee, T.S. (1996). Image representation using 2D Gabor wavelets. *IEEE Transactions of Pattern Analysis and Machine Intelligence*, 18, 959-971.

Ongoing Research Support

NSF IIS-073206 Lee (PI) 9/01/07 – 8/30/11
NSF CISE IIS (Robust intelligence – computational neuroscience)
Title: Computational and neurophysiological investigation of robust visual inference

The goal of this study is to understand how neurons in the visual cortex represent statistical information and perform Bayesian inference in the context of 3D inference.
Role: Principal Investigator

Air Force (AFOSR): Tyler (PI). 9/1/09-8/30/12
Title: A new conceptualization of surface representation.
The goal of this project is to study neuronal connectivity in V1 and V2 pertinent to 3D surface interpolation using multi-electrode physiological technique and computational modeling.
Role: co-PI.