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14. ABSTRACT
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in understanding some of the biological markers of novelty detection in both human subjects (EEG) and in single

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Final report for 58760LS

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Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Received		Paper
06/02/2014	3.00	Jonathan Sussman-Fort, Elyse Sussman. The effect of stimulus context on the buildup to stream segregation, Frontiers in Neuroscience, (04 2014): 0. doi: 10.3389/fnins.2014.00093
TOTAL:	**1**	

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

Received	Paper
TOTAL:	

Number of Papers published in non peer-reviewed journals:

(c) Presentations

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received   Paper

TOTAL:

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received   Paper

TOTAL:

(d) Manuscripts

Received   Paper

08/16/2012   1.00   Stephanie C Wissig, Carlyn A Patterson, Adam Kohn. Adaptation improves performance on a visual
                   search task,
                   (submitted) Jounal of Vision (08 2012)

09/26/2012   2.00   Ruben Coen-Cagli, Odelia Schwartz. The impact on mid-level vision of statistically optimal divisive
                   normalization in V1.,
                   PLoS Computational Biology (09 2012)

TOTAL: **2**

Number of Manuscripts:

Books

<u>Received</u>   <u>Book</u>

    TOTAL:

<u>Received</u>   <u>Book Chapter</u>

    TOTAL:

Patents Submitted

Patents Awarded

Awards

N/A

Graduate Students

NAME	PERCENT_SUPPORTED	Discipline
Amin Zandvakili	0.33	
Michoel Snow	0.33	
Jon Sussman-Fort	0.33	
FTE Equivalent:	**0.99**	
Total Number:	3	

Names of Post Doctorates

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Faculty Supported

NAME	PERCENT_SUPPORTED	National Academy Member
Adam Kohn	0.05	
Elyse Sussman	0.05	
Odelia Schwartz	0.05	
FTE Equivalent:	**0.15**	
Total Number:	**3**	

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Student Metrics
This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: 0.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:...... 0.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):...... 0.00

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense 0.00

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields:...... 0.00

Names of Personnel receiving masters degrees

NAME
Total Number:

Names of personnel receiving PHDs

NAME
Total Number:

Names of other research staff

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Sub Contractors (DD882)

Scientific Progress and Accomplishments

(1) Foreword: Our project aimed to understand the strategies used by sensory cortex to adapt to complex environments, and to signal the appearance of novel events in those environments. This knowledge can be used to develop novel computational algorithms that employ the same strategies. The algorithms can in turn be used to better integrate man and machine. In the second year of our grant, we built on our initial finding to understand the biological markers of novelty detection in both human subjects (EEG) and in single unit recordings in non-human primates. Further, we developed a computational algorithm that mimics this type of learning or adaptation.

(2) Table of Contents: N/A

(3) List of Appendices, Illustrations, and Tables: N/A

(4) Statement of the problem studied: The goal of our project was to identify fundamental principles of how the human brain adapts to complex visual and auditory environments and to develop novel algorithms that use this information to integrate man and machine so as to enhance performance on the battlefield. Previous work on sensory adaptation has focused on environments with simple stimuli and no competition from other sources. It is not clear if the information they provide extrapolates to complex, real world, environments. We conducted parallel perceptual and physiological experiments to extract principles of how sensory systems dynamically adapt to detect violations of statistical regularities in the environment, which guides behavior to important points of interest. In the first year, we developed and applied a novel paradigm for dissecting markers that signal the violation of statistical regularity. We used this paradigm to probe the adaptive strategies of cortical circuits in the visual cortex of non-human primates using microelectrode arrays, and to probe human performance and EEG-based signals in visual and auditory experiments. In year 2, we completed data collection for this paradigm and developed a computational framework that can employ similar learning strategies.

(5) Summary of the most important results:

(a) Adaptation and salience in a visual search task: As detailed in our previous report, we conducted a perceptual study of whether prior experience or adaptation affects the ability of human subjects to detect the appearance of a novel, target stimulus in a visual search task. More specifically, we tested the possibility that adaptation can enhance stimulus salience by measuring the effects of prolonged (40 s) adaptation to a counterphase grating on performance in a search task in which targets were defined by an orientation offset relative to a background of distracters. We found that, for targets with small orientation offsets, adaptation reduced reaction times and decreased the number of saccades made to find targets. Our results provide evidence that adaptation may function to highlight features that differ from the temporal context in which they are embedded. The student who conducted that work defended her PhD dissertation (which included this work). This student (Stephanie Wissig) did not receive salary support from this grant because she was paid by an MSTP training grant to the MD/PhD program at Einstein. Her work has now been published in the Journal of Vision (Wissig et al., 2013).

(b) Adaptation and neuronal correlates of deviance detection: To probe how cortical circuits detect statistical regularity in sensory input, and signal deviation from this regularity, we recorded from populations of neurons in the primary visual cortex (V1) of anesthetized, paralyzed monkeys. We recorded both extracellular spiking activity from single neurons (and small multiunit clusters) and local field potentials (LFPs). The latter signal is intermediate in spatial specificity between single neuron recordings and the EEG-based recordings we have conducted in human observers (see below); LFPs are thought to reflect the summed electrical activity in a spherical volume of tissue around the electrode tip, of radius 0.25-3 mm.

We explored the ability of cortical circuits to detect and encode several forms of regularity. First, we used a simple omission paradigm in which the same visual stimulus (a sinusoidal grating of a particular orientation and contrast) was presented repeatedly, with a constant interstimulus interval. After 5, 10 or 30 presentations, we stopped the stimulus sequence. Previous work in the retina has shown a robust response to the omitted stimulus--the retina appears to expect the following presentation, and continues to respond, even if the stimulus is not actually presented (Schwartz et al., 2007, 2008). We found no evidence for this form of pattern detection in the spiking activity of cortical circuits or in the LFP.

In our second paradigm, we used a classic oddball paradigm. One stimulus (a grating of a particular orientation or contrast) was used as the standard and presented in either 90% or 95% of trials. In the remaining trials, an oddball stimulus, having either a different orientation or contrast, was presented. We counterbalanced the design so that each stimulus could serve as either the standard or deviant on different blocks of trials. We found that a stimulus evokes a stronger spiking response when it is an oddball than standard, and the response is greater when the oddball is presented 5% of the time as compared to 10%. These results are consistent with well-established mechanisms of stimulus specific adaptation (SSA) and are consistent with previous work in the auditory system (Ulanovsky et al., 2003, 2004). LFP responses showed a similar behavior. We have extended this paradigm to investigate the rate of adaptation when a stimulus switches from being rare (5% of trials) to common (e.g. 95% of trials). We found that the network adjust to the new occurrence probabilities within tens of seconds, with a precise rate that depends on the frequency of occurrence of the standard and oddball (e.g. 5/95% vs 10/90%).

In our third paradigm, we probed circuits in V1 with more sophisticated patterns. Specifically, we showed frequent or rare sequences of stimuli, allowing us to dissociate effects of stimulus probability from expectation of occurrence. That is, a stimulus could be an oddball because it occurred at an unexpected position in a sequence, rather than because it only rarely appeared. As detailed previously, some V1 neurons show evidence of learning these sequences and signaling unexpected deviations from them. Analysis in Year 2 showed that these form a smaller percentage of the population then our original analyses suggested. However, novelty effects were apparent in the LFP as well, and their behavior differed in interesting ways from parallel recordings in human subjects (see below). There are a number of reasons that could underlie this difference, including the recording method (LFP vs EEG), the animal model (monkeys vs humans) or the brain state (anesthetized vs awake). To test the role of the recording method, we performed preliminary experiments using EEGs in monkeys—an extension of our original goals. These data are currently being analyzed.

(c) Human behavioral correlates and EEG recordings: We conducted a series of EEG recordings in human subjects, using a paradigm similar to that used in the animal experiments. We adapted the paradigm described above for the visual and auditory domains, and extended the exploration to passive and active forms of deviance detection. Attention was manipulated either away from the test stimuli (passive conditions) or toward the test stimuli to press a response to indicate detection of deviant patterns (active conditions). In the passive conditions, subjects were instructed to watch a silent captioned movie while the test sounds were presented to their ears (auditory condition). Data were collected froma total of 23 participants. As detailed in our previous report, our results provide evidence that adaptation occurs for detected events in the stimulus sequence and not strictly on a stimulus-specific basis. This is interesting because it suggests that there are multiple levels of neural interaction in object event representation that includes but is not limited to SSA.

In addition to finalizing the collection and analysis of this data set, we conducted parallel experiments to determine how adaptation contributes to novelty detection. In one project, recently published, we showed that adaptation occurs on different time scales depending upon the dynamics of the listening environment, affecting the time it takes to detect new events in the input (Sussman-Fort & Sussman, 2014). We further demonstrated that attention sped up event detection, but only in more stable listening environments (Sussman-Fort & Sussman, in preparation). Additionally, our results provide evidence that adaptation occurs at different time scales based on stimulus characteristics. Thus, we provide evidence that detected events in the stimulus sequences are not processed on a strictly stimulus-specific basis (Chen et al., in preparation). This is important because it suggests that there are multiple levels of neural interactions representing object events in cortex, which includes but is not limited to the initial evaluation of stimulus features. Together, these studies provide important new knowledge of how sensory systems adapt to complex environments.

(d) Developing computational algorithms that reproduce the biological phenomena: We developed a computational model that captures regularities in the visual environment across time, and signals novel events. The approach is based on a generative account of natural movie statistics known as the Gaussian Scale Mixture model, extending our previous work for salience detection in spatial configurations (Coen-Cagli et al. 2012) to detect salient events in time (Snow and Schwartz, in preparation). The model updates its parameters—the probability of dependence between present and past inputs and the degree of dependence—as new adapting input stimuli are presented over time. The model can capture some temporal adaptation phenomena in primary visual cortex, including suppression and repulsion, as well as recent literature showing that more frequent stimuli are equalized in primary visual cortex, thus highlighting oddball stimuli that are presented less frequently (Benucci et al. 2013). We further explored the ability of this class of model to capture temporal pattern sensitivity, using the same stimulus paradigm that we ran in the cortical neurophysiology and human EEG studies, thus going beyond stimulus-specific adaptation. When the model parameters were set to capture statistical temporal dependencies in the standard pattern, the model showed larger responses to stimuli that appeared within the deviant pattern, consistent with the biological data. The computational framework we have developed provides a basis for understanding biological adaptation and novelty detection, and can be used in the future to capture salient events in more complex visual environments.

(6) Bibliography:

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Wissig SC, Patterson CA, Kohn A (2013) Adaptation improves performance on a visual search task. J Vis. 13(2):6. doi: 10.1167 /13.2.6.

(7) Appendices: N/A

Technology Transfer

Scientific Progress and Accomplishments

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(7) <u>Appendices</u>: N/A