ROUTING AND ACTION
MEMORANDUM

ROUTING

TO: (1) Life Sciences Division (Gregory, Frederick)

Report is available for review

(2) Proposal Files Proposal No.: 65353-LS

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CONTRACT OR GRANT NUMBER: W911NF-16-1-0507

INSTITUTION: Columbia University

PRINCIPAL INVESTIGATOR: Paul Sajda

TYPE REPORT: Interim Progress Report

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PERIOD COVERED: 01-Aug-2018 through 31-July-2019

TITLE:

ACTION TAKEN BY DIVISION

(x) Report has been reviewed for technical sufficiency and IS [x] IS NOT [ ] satisfactory.

(x) Material has been given an OPSEC review and it has been determined to be non sensitive and, except for manuscripts and progress reports, suitable for public release.

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13. SUPPLEMENTARY NOTES

The views, opinions and/or findings contained in this report are those of the author(s) and should not contrued as an official Department of the Army position, policy or decision, unless so designated by other documentation.

14. ABSTRACT

15. SUBJECT TERMS

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RPPR Interim Progress Report
as of 05-Mar-2020

Agency Code:

Proposal Number: 65353LS **Agreement Number: W911NF-16-1-0507**

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Report Date: 31-Aug-2019 Date Received: 25-Sep-2019
Interim Progress Report for Period Beginning 01-Aug-2018 and Ending 31-Jul-2019

Title: Intent Switching and Co-Adaption of Man and Machine in a Closed-Loop Brain Computer Interface

Begin Performance Period: 19-Aug-2016 **End Performance Period:** 18-Dec-2019

Report Term: 1-Annual

Submitted By: Paul Sajda Email: ps629@columbia.edu
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Distribution Statement: 1-Approved for public release; distribution is unlimited.

STEM Degrees: 0 **STEM Participants:** 2

Major Goals: Brain computer interfaces (BCI) have been an active area of research for well over a decade. Originally envisioned as communication devices for the neurologically locked-in, several BCI systems have been developed that aim to assist the otherwise neurologically healthy in human-machine interaction. For BCIs of this type, it is important to develop an understanding of man-machine co-adaption. For example, when the C3Vision BCI for image search (Sajda et al, 2010; Pohlmeyer et al. 2011) is operating in a closed loop, neural signatures are being used to train a transductive graph-based model based on “neural interest” scores. The feedback from the machine can change the prevalence and even characteristics of the images shown to the user that can, in turn, affect the user’s perceptual/cognitive state. For instance, we have observed adaptation of not only the machine, via new neural interest scores, but adaptation of the neural signatures evoked by the images, including amplitude and timing changes of said neural signatures. Most BCI systems largely ignore co-adaption and instead assume a more-or-less stationary process in terms of the stochastic nature of the man-machine interaction.

In this project our major goal is to investigate fundamental scientific questions in co-adaption of man and machine in a closed-loop brain computer interface. The following outlines the main objectives of the research project.

Objective 1. Investigate whether switches in user intent can be measured using EEG and exploited in a closed-loop BCI. Preliminary data by our group has shown how a closed-loop BCI can be used to integrate neurophysiological signatures of object recognition and attentional orienting with computer vision to enable a man-machine system for image search. However, in this preliminary work, the user was not adaptive i.e., they did not change their object of interest or intention during the search task. A basic research question is “what happens if a user changes his/her intent during the experiment?”—i.e., modifies the category of images they are interested in, as a function of the time within the experiment. Scientific literature suggests that such intent switches require a context updating (Polich, 2007) process that includes flushing of working memory and a change in the re-orienting response that may decay as a function of time. We will investigate the effect of such intent switches on the underlying neural signatures, measured via EEG, as well how to best discount the signatures of the past given their use as labels into the transductive graph-based model (Wang et al., 2009)—i.e., how to optimally fuse the neural signatures with computer vision given the intent switch. In all cases, we will use signal detection theory to construct precision/recall (P/R) and receiver operating characteristic (ROC) curves from decoded EEG and track the neural correlates of intent switches.

Objective 2. Identify additional physiological/behavioral variables that correlate with intent switching. We have preliminary data showing that pupillary measures, such as baseline pupil diameter and event related diameter changes, correlate with specific EEG components of target detection and orienting at specific post-stimulus times.

These pupillary changes also correlate with expectation/anticipation changes (Hong, Walz, & Sajda, 2012). Our hypothesis is that physiological changes in pupillary responses can be related to specific EEG components reflective of intent switching and that a combination of both physiological measures will ultimately be more informative to an exemplar-based computer vision system.

Objective 3. Localize and model the cortical networks underlying intent switching. The underlying cognitive substrates that give rise to and regulate intent are likely similar to those implicated in the orienting of attention, though we might expect some differences particularly with respect to endogenous vs exogenous shifts. One of our objectives is to better characterize the spatiotemporal interactions between the cortical regions underlying this orienting response: specifically, to investigate how the dynamics of these interactions are affected by switches of intent and whether these switches are a results of endogenous or exogenous factors (e.g., switching to another image of interest because one is told that it is of more value or switching because it is evokes a memory).We will use simultaneous EEG-fMRI to track intent switches . We will use dynamic causal modeling (DCM) (Friston, Harrison, & Penny, 2003; Stephan et al., 2010) to infer the interactions between regions and how the dynamics of those interactions change during a switch of intent. Our hypothesis is that the timing and localization of intent shifting will reflect the updating of processes underlying target-related attention re-orienting.

Accomplishments: In the past reporting period we have published a major paper in the Proceedings of the National Academy of Sciences (PNAS) which we shows that we can use online neurofeedback to shift an individual's arousal in a way that improves their performance in a demanding sensory-motor task. Specifically, we use a brain–computer interface (BCI) that uses information in the EEG to generate a neurofeedback signal that dynamically adjusts an individual's arousal state when they are engaged in a boundary-avoidance task (BAT).

We have also developed a linear state-space model to infer the effective connectivity in a distributed brain network based on simultaneously recorded EEG and fMRI data. Our method first identifies task-dependent and subject-dependent regions of interest (ROI) based on the analysis of fMRI data. Directed influences between the latent neural states at these ROIs are then modeled as a multivariate autoregressive (MVAR) processes driven by various exogenous inputs. The latent neural dynamics give rise to the observed scalp EEG measurements via a biophysically informed linear EEG forward model. We use a mean-field variational Bayesian approach to infer the posterior distribution of latent states and model parameters. The performance of the model was evaluated on two sets of simulations and real data. The work was accepted as a paper at the world's most prestigious machine learning conference (NeurIPS).

Training Opportunities:
Currently one Ph.D. student is being supported/mentored under this project. We also have hosted a high school summer student to assist with programming tasks related to this project.

Results Dissemination: October 2018 "Neuroengineering: A Multidisciplinary Effort to Measure, Stimulate, Model and Treat Diseases of the Brain", Keynote for UC Davis Office of Research, Neuroengineering Workshop.

October 2018 "BCIs for Labeling our Environment", Invited Plenary Speaker, IEEE SMC Brain Machine Interface Workshop, Miyazaki JAPAN.

November 2018"Fusing Simultaneously Acquired EEG and fMRI to Infer Spatiotemporal Dynamics of Cognition in the Human Brain", Plenary Speaker, IEEE Brain Initiative Workshop in Advanced Neurotechnologies, San Diego CA.

Plans Next Period: We are in the final few months of the grant/project and plan to finish writing several publications based on the experiments and data collected over the past three years.

Honors and Awards: Paul Sajda was awarded a Vannevar Bush Faculty Fellowship in 2019

Protocol Activity Status:

Technology Transfer: Patent application filed: Systems and Methods for Deep Reinforcement Learning Using a Brain-Artificial Intelligence Interface, US Patent App. 16/149,785

We continue to interact closely with ARL HRED and have transitioned some of the EEG compatible VR software and capabilities to them at APG.

RPPR Interim Progress Report
as of 05-Mar-2020

ARTICLES:

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Date Submitted: Date Published: 3/1/19 10:00AM
Publication Location:
Article Title: Regulation of arousal via online neurofeedback improves human performance in a demanding sensory-motor task
Authors: Josef Faller, Jennifer Cummings, Sameer Saproo, Paul Sajda
Keywords: neurofeedback | Yerkes and Dodson law |human performance boundary-avoidance task electroencephalography
Abstract: Our state of arousal can significantly affect our ability to make optimal decisions, judgments, and actions in real-world dynamic environments. The Yerkes–Dodson law, which posits an inverse-U relationship between arousal and task performance, suggests that there is a state of arousal that is optimal for behavioral perfor- mance in a given task. Here we show that we can use online neurofeedback to shift an individual's arousal from the right side of the Yerkes–Dodson curve to the left toward a state of improved performance. Specifically, we use a brain–computer interface (BCI) that uses information in the EEG to generate a neurofeedback signal that dynamically adjusts an individual's arousal state when they are engaged in a boundary-avoidance task (BAT).
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Conference Location: Vancouver, CANADA
Paper Title: A state-space model for inferring effective connectivity of latent neural dynamics from simultaneous EEG/fMRI
Authors: Tao Tu, Stefan Haufe, John Paisley, Paul Sajda
Acknowledged Federal Support: **Y**

Nothing additional to report