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## Report Title

Final Report: Adaptive Training and Collective Decision Support Based on Man-machine Interface

### ABSTRACT

The existence of grandmother cells, i.e. hypothetical cells that respond to specific entities with high specificity, have long been theorized. The objective of this project was to develop non-traditional techniques for assessment of cognition and training effectiveness of mixed-expertise, collaborative teams. This effort comprised of three specific aims: 1) to develop a portable wireless, real-time f-EEG system for measurement and assessment of cognitive function in response to visual stimuli; 2) to develop algorithms and strategies for detecting significant events to improve situational awareness; and 3) to combine aims 1 and 2 to propose a strategy for collective decision support for mixed expertise, collaborative teams. Through the 8-month STIR duration, the CUA team designed, developed and tested the function of a portable, real-time f-EEG system (Aim 1) and conducted preliminary trials to develop algorithms and strategies to detect significant events in response to visual stimuli and to study the existence of grandmother cells (Aim 2). Preliminary results show that strong and significant personal identification with visual stimuli exhibit unique transmission dynamics and response as compared to viewing generic images. This provides evidence to support the grandmother neuron and may have high potential for providing quantitative assessment of training effectiveness.

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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)**

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Paper

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Paper

**TOTAL:**

**Number of Papers published in non peer-reviewed journals:**

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**(c) Presentations**

Number of Presentations: 0.00

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

Received      Paper

**TOTAL:**

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

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

Received      Paper

03/02/2016    1.00    Harold H. Szu, Liyi Dai, Yufeng Zheng, Jeffrey Jenkins, Jarad Kopf, Binh Q. Tran, Christopher Frenchi, Harold Szu. Bio-mining for biomarkers with a multi-resolution block chain, SPIE Sensing Technology + Applications. , Baltimore, Maryland, United States. : ,

**TOTAL:      1**

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

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**(d) Manuscripts**

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Number of Manuscripts:

Books

Received      Book

TOTAL:

Received      Book Chapter

TOTAL:

Patents Submitted

Patents Awarded

Awards

Graduate Students

| <u>NAME</u>            | <u>PERCENT SUPPORTED</u> | Discipline |
|------------------------|--------------------------|------------|
| Quoc Huynh             | 0.50                     |            |
| Jeffrey Jenkins        | 0.50                     |            |
| <b>FTE Equivalent:</b> | <b>1.00</b>              |            |
| <b>Total Number:</b>   | <b>2</b>                 |            |

Names of Post Doctorates

| <u>NAME</u>            | <u>PERCENT SUPPORTED</u> |
|------------------------|--------------------------|
| <b>FTE Equivalent:</b> |                          |
| <b>Total Number:</b>   |                          |

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### Names of Faculty Supported

| <u>NAME</u>            | <u>PERCENT SUPPORTED</u> | National Academy Member |
|------------------------|--------------------------|-------------------------|
| Binh Q. Tran           | 0.07                     | No                      |
| <b>FTE Equivalent:</b> | <b>0.07</b>              |                         |
| <b>Total Number:</b>   | <b>1</b>                 |                         |

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### Names of Under Graduate students supported

| <u>NAME</u>            | <u>PERCENT SUPPORTED</u> |
|------------------------|--------------------------|
| <b>FTE Equivalent:</b> |                          |
| <b>Total Number:</b>   |                          |

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### 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

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### Names of Personnel receiving masters degrees

| <u>NAME</u>          |
|----------------------|
| <b>Total Number:</b> |

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### Names of personnel receiving PHDs

| <u>NAME</u>          |
|----------------------|
| <b>Total Number:</b> |

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### Names of other research staff

| <u>NAME</u>            | <u>PERCENT SUPPORTED</u> |
|------------------------|--------------------------|
| <b>FTE Equivalent:</b> |                          |
| <b>Total Number:</b>   |                          |

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Sub Contractors (DD882)

## **Inventions (DD882)**

## Scientific Progress

This section describes the scientific accomplishments for the project in relation to each of the proposed efforts of the STIR proposal. See attachment for related images.

#### A. Achievement of Aim 1: Wireless, Real-time f-EEG Experimentation System

Since the start of this STIR contract (August 2014), the focus of the effort has mainly been on development, refinement, and integration of the portable, wireless, real-time f-EEG system proposed in Aim #1. The system uses a commercial off-the-shelf (COTS) 16-node, dry electrodes EEG head mounted device (Emotiv Inc., Figure 1) for collection of EEG data. This device is wireless and transmits data via Bluetooth to a PC using a USB dongle. The advantage of the system over others is the ability to collect high resolution EEG data without complicated setup and calibration as with EEG nets and similar devices. For the end user, donning the device is similar to wearing and positioning of headphones. Further, data output and sensitivity is minimally affected by hair and other artifact.

The EEG headset integrates with a custom designed EEG experimental management, data collection and analysis platform comprised of both hardware and software components. At the heart of the system is the EEG Experiment Runtime Service (eERS) which supports experimental set-up, experimental design and configuration, set-up for incorporation of visual stimuli, management of incoming data, and data analytics. eERS is developed with an open source strategy and future deployment is expected to be cloud-based to allow for scalability, portability and versatility. Figure 2 shows the EEG experimental platform architecture.

The eERS system allows for single or multi-user EEG analyses. For multi-user analyses, each user focuses on his/her own screen (i.e. viewpoint) and data is collected using the personalized headset. This EEG data is managed and synchronized with other users, as appropriate, through the collection proxy and is also synchronized with events in visual stimuli. Care in development has been taken to address issues of data latency resulting from incoming transmission from remote users. Additionally, missing packets resulting are also handled by the collection proxy. Once data arrives, it is processed by the data analytics engine which integrates open-source analytics engine by Octave. Algorithms are developed for key EEG feature extraction. EEG data from each of the 16 headset nodes is combined to provide 3D mapping of activated brain regions responding to stimuli. Figure 3 provides a sample of raw EEG collected from the wireless, EEG headset system along with a fused mapping in 3D of activated regions responding to stimuli.

An important aspect of the development of the eERS system includes the development of the experimental set-up engine (Figure 4). This portion of the software development allows for customized experimental set-up by trained as well as minimally trained users. It utilizes an icon-driven, drag-n-drop experimental setup schema where key components required for the experiment (i.e. single vs. multi user, visual stimuli, data outputs, etc) can be easily designed and implemented. Various stimuli (i.e. images, video, audio) as well as input devices (i.e. keyboard, mouseclicks) can be integrated and collected by the eERS system.

#### B. Achievement of Aim 2: Algorithms for Detection of Significant Events

After the completion of the system in Aim 1, the research team designed and developed and conducted preliminary perception tests using the f-EEG system to collect data for understanding cognition and expertise in order to identify significant events. For this effort, preliminary tests were conducted on laboratory personnel to assess the function, accuracy and performance, and usability of the system in Aim 1 as well as develop a protocol for deployment of the system for experimental studies including software set-up, head-gear calibration, image integration in the eERS system, and finally, data collection, visualization, and analyses.

Once tested, the wireless f-EEG experimentation system was used to examine the existence of grandmother cells. For these tests, 2 laboratory test subjects provided personalized images in each of 4 categories, 1-who (i.e. relative), 2-what (i.e. previous car owned), 3-where (i.e. prior vacation location or significant place visited previously), and 4-significant life event (i.e. graduation, wedding, etc). These images were then combined with a generic database containing similar images of people, things, places, and events. Each test subject was then 10 images in each of the 4 categories with their own image randomly inserted into the dataset and the asked to click a mouse upon seeing their own image. Three trials were repeated for each subject and category. A third laboratory person (control) was also shown the database of images but was not asked to provide any personal information.

For this preliminary test, data was analyzed by comparing the control to the two test subjects to see if EEG response to personalized images produced appreciable changes as compared to generic images. As the f-EEG system consisted of 16 spatially distributed EEG nodes (see Fig. 6; 14 EEG nodes plus 2 ground nodes, not shown), the research team was able to examine spatio-temporal changes resulting from the tests. Data for each of the 16 EEG nodes were grouped according to head location regions. These include frontal regions (nodes: AF3, AF4, F3, F4, F7, F8, FC5, FC6), back regions (nodes: O1, O2, P7, P8, T7, T8), and sides (front left: AF3, F3, F7, FC5; front right: AF4, F4, F8, FC6; back left: T7, P7, O1; back right: T8, P8, O2). Thus, taking into account spatio-temporal changes, tracking EEG activity by region over time we created spatial distribution

maps of activity in response to generic vs. personalized images. These results are shown in Figure 7. From Fig. 7, one can see the redistribution of primary brain activity spatially over time. Initially, when viewing generic images, brain activity center in the mid-brain regions and moves to the frontal lobe when viewing personalized images, and returns to baseline position after these images are removed.

In comparison of responses between each of the different categories (who, what, where, and when), analyses from the preliminary trials using Kolmogorov-Smirnov (KS) plots reveal significant differences between personalized vs. generic image data sets (Figure 8a) and also distinctly different responses by category, with the strongest association to recognition of people over things, places, and events (Figure 8b).

From the sample data collected, algorithms used to determine recognition of significant events include spatio-temporal transmission metrics related to brain activity, ratios of front-to-back activity and front-to-side activity levels, as well as “strength” (i.e. magnitude) of regional brain activity.

### C Achievement of Aim 3: Proposed Schema for Fusion of Data for Training of Mixed Expertise Teams and Collective Decision Support

Preliminary data from Aim 2 provide evidence of grandmother cells that respond to high levels of expertise and training and are highly specific (i.e. detection of true positives). By measuring spatio-temporal dynamics of cognition in response to visual stimuli (i.e. environment, situation awareness), it is expected that a team of mixed expertise members with different levels of training and for different expertise areas will respond differently to critical situations. This cognitive response can be measured by the f-EEG system in Aim 1. Further, quantitative assessment of training efficacy (i.e. increasing expertise in subject area) may be measured as shown by preliminary evidence shown in Aim 2.

For a team of mixed expertise members wearing the developed f-EEG system (i.e. multiple headsets), assessment of training can be performed individually and objectively by examining f-EEG for each team member in response to visual stimulus (i.e. hostile scenarios, critical environments, etc). From these quantitative assessment scores, a composite team score can be derived as in (1):

$$\text{Total Score (TS)} = \left( \sum_{i=1}^n [m_i * [wf]_i] \right) / n \quad (1)$$

where  $m_i$  = member training score (0-100%)  
 $[wf]_i$  = member weight factor  
 $n$  = number of team members

A scenario similar to the test situation can be developed where images are shown to team members of situations that are safe vs. hostile/critical requiring action. Assessing accuracy of these responses (by f-EEG and mouseclick or keystroke) combined with time duration of assessment (dt) results in a derived measure of throughput rate (TR). As training level increases, it is expected that throughput rate will decrease as well increasing correctness.

Testing of Aim 3 requires human subjects and IRB approvals that are beyond the scope of this STIR and the short duration of this grant period. It is recommended that a follow-up project be initiated using the developed f-EEG system to assess collective team training of mixed expertise members.

## Technology Transfer



**ADAPTIVE TRAINING AND COLLECTIVE DECISION SUPPORT  
BASED ON *MAN-MACHINE INTERFACE***

**Project Final Report**

**Submitted to:**

**Dr. Liyi Dai**

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### **Project Summary**

The existence of *grandmother cells*, i.e. hypothetical cells that respond to specific entities with high specificity, have long been theorized. The objective of this project was to apply modern technology and know-how to develop non-traditional techniques for assessment of cognition and training effectiveness of mixed-expertise, collaborative teams. This effort comprised of three specific aims: 1) to develop a portable wireless, real-time f-EEG system for measurement and assessment of cognitive function in response to visual stimuli; 2) to develop algorithms and strategies for detecting significant events to improve situational awareness; and 3) to combine aims 1 and 2 to propose a strategy for collective decision support for mixed expertise, collaborative teams.

Through the 8 month duration of this STIR proposal, the CUA research team designed, developed and tested the function of a portable, real-time f-EEG system (Aim 1) that is able to implement and deploy cognitive experimental studies of visual stimuli in various forms using static images and/or video content. The system is also flexible to enable cognitive assessment of audio content as well. The system uses a commercially available wireless, 16-node EEG headset capable of collecting continuous spatial information of brain function in response to external stimuli. The headset hardware is combined with open source, easy-to-use, drag-and-drop software developed by the team to enable i) flexible and customized experimental design, implementation, and deployment, ii) data collection and iii) data visualization and analyses as proposed in Aim 1 of the project.

Using the system developed in Aim 1, the CUA research team conducted preliminary trials to develop algorithms and strategies to detect significant events in response to visual stimuli and to study the existence of grandmother cells (Aim 2). Preliminary data was collected to compare responses to visual stimulus resulting from personalized images (i.e. high expertise) versus generic images from a standard dataset (i.e. low expertise). Preliminary evidence reveals a strong and differentiated response to personalized images compared to data from the generic image set. This data suggests a difference in the cognition pathway for high expertise vs. low expertise scenarios. Algorithms developed to assess cognition response include analyses of temporal responses in EEG, spatial transmission dynamics from occipital (vision)-to-temporal (memory)-to-frontal (cognition) lobes, and lastly include traditional signal processing metrics such as power spectral density (PSD). Preliminary results show that strong and significant personal identification with visual stimuli exhibit unique transmission dynamics and response as compared to viewing generic images. This provides evidence to support the *grandmother neuron* proposed in the literature and may have high potential for providing quantitative assessment of training effectiveness.

Understanding the nature of the changes in cognition as a result of high association vs. low association with visual stimuli may provide useful quantitative information regarding effectiveness of training as it relates to acquisition of expertise and learning. The system in Aim 1 has the potential to provide objective measures of training effectiveness. Combining the system achieved in Aim 1 with the preliminary evidence from Aim 2, a multi-user f-EEG system as applied to a mixed expertise, collaborative team has the potential for quantitative assessment of individual and collective team training performance. This performance measure can serve as a measure of accuracy (i.e. correctness) and combined with time duration of training, can be used for measuring throughput rate for individuals as well as collectively for the team.

## I. Project Objective:

This proposal seeks to apply modern technology and know-how to develop a non-traditional methodology of image processing of salient feature extraction to information processing and fusion in terms of human visual system (HVS) in order to train a mix of human interdisciplinary experts to increase the throughput rate of collective decision making. We define the *decision throughput rate* as the *time duration* multiplied by the *degree of correctness*. This research proposes development and refinement of a portable, wireless, real-time, and smartphone-based *functional*-electroencephalogram(*f*-EEG) system using high-density dry electrodes and compressive sensing strategies to address spatial and temporal sparseness limitations. Further, the R&D effort seeks to refine algorithms for information processing, feature extraction, and fusion algorithms for assessment of military training, assessment of situational awareness, and for collective decision support. The overall impact of the proposed work is the development of a processing algorithm interface tool for adaptive real-time feedback of knowledge acquisition correlating to long-term (i.e. hippocampus) with short-term (i.e. frontal lobe) working memory for support of complex, collective team decision-making.

Specifically, the proposed effort advances prior work by our team and will develop necessarily software to extract multiple picture (e.g. *Grandmother* image feature) in a sparse coding for pseudo-orthogonal span of the search space and model hetero-associative memory at Hippocampus to enhance *grandmother* recall in other confused SNR. This work has **three specific aims**:

- 1) conduct basic research and assessment of a portable, wireless, real-time f-EEG system for measurement of grandmother cells (i.e. selective visual neurons with high specificity for targeted visual objects) located in the human hippocampus,
- 2) development of algorithms and strategies for detection of significant events using artificial neural networks approaches to improve situational awareness, and
- 3) fusion of aim 1 (f-EEG for cognition) and aim 2 (detection of significant events) as applied to mixed expertise teams for collective decision support.

The outcome of the proposed research effort will result in an improved real-time, wireless, portable f-EEG system capable of collecting neuro-information for processing and fusion of data in order to detect significant events and to improve situational awareness and for collective team decision support in hostile and/or critical environments.

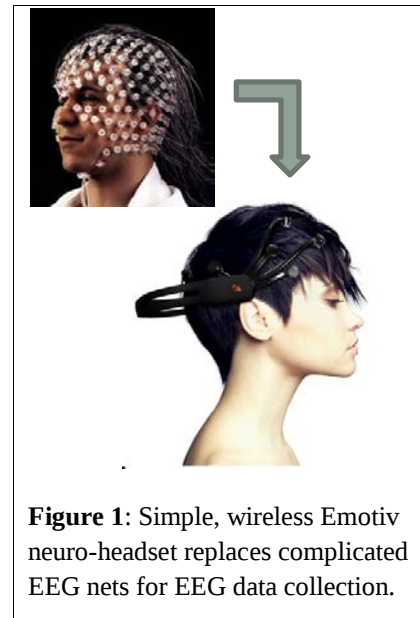
## II. Approach & Scientific Accomplishments

Section II herein describes the scientific accomplishments for the project in relation to each of the proposed efforts of the STIR proposal.

### II.A. Achievement of Aim 1: Wireless, Real-time f-EEG Experimentation System

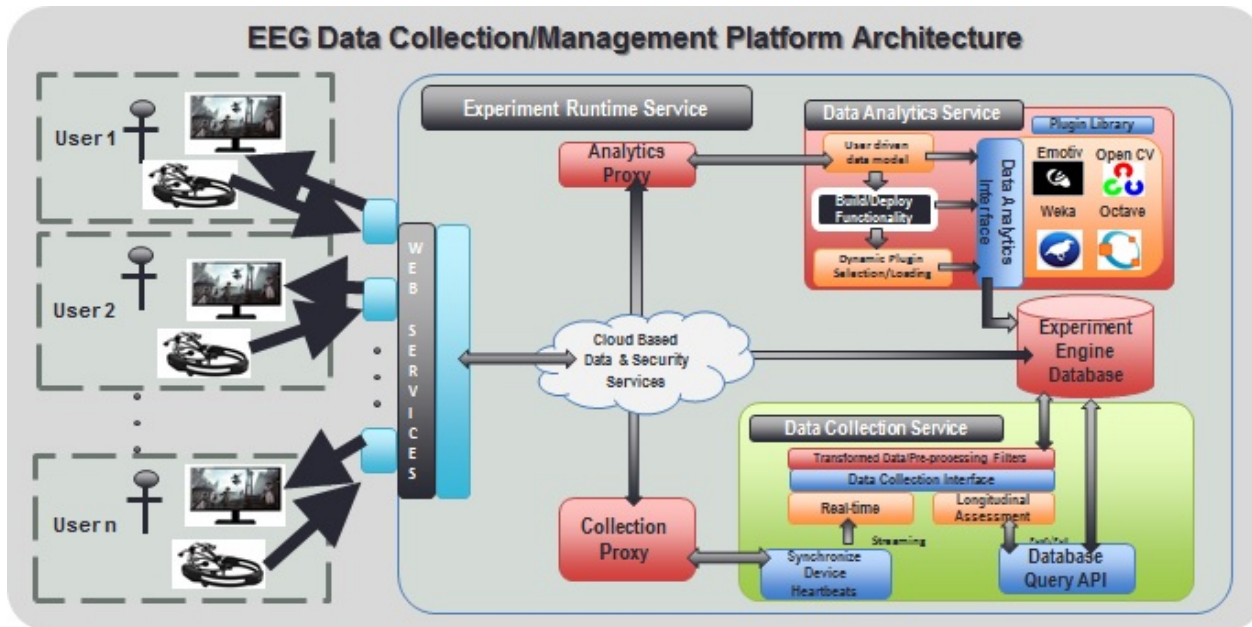
Since the start of this STIR contract (August 2014), the focus of the effort has mainly been on development, refinement, and integration of the portable, wireless, real-time f-EEG system proposed in Aim #1. The system uses a commercial off-the-shelf (COTS) 16-node, dry electrodes EEG head mounted

device (Emotiv Inc., Figure 1) for collection of EEG data. This device is wireless and transmits data via Bluetooth to a PC using a USB dongle. The advantage of the system over others is the ability to collect high resolution EEG data without complicated setup and calibration as with EEG nets and similar devices. For the end user, donning the device is similar to wearing and positioning of headphones. Further, data output and sensitivity is minimally affected by hair and other artefact.



The EEG headset integrates with a custom designed EEG experimental management, data collection and analysis platform comprised of both hardware and software components. At the heart of the system is the EEG Experiment Runtime Service (eERS) which supports experimental set-up, experimental design and configuration, set-up for incorporation of visual stimuli, management of incoming data, and data analytics. eERS is developed with an open source strategy and future deployment is expected to be cloud-based to allow for scalability, portability and versatility. Figure 2 shows the EEG experimental platform architecture.

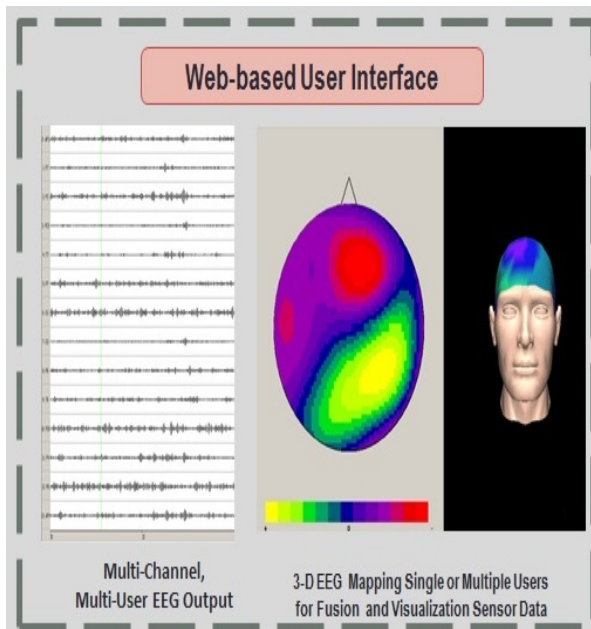
The eERS system allows for single or multi-user EEG analyses. For multi-user analyses, each user focuses on his/her own screen (i.e. viewpoint) and data is collected using the personalized headset. This EEG data is managed and synchronized with other users, as appropriate, through the collection proxy and is also synchronized with events in visual stimuli. Care in development has been taken to address issues of data latency resulting from incoming transmission from remote users. Additionally, missing packets resulting are also handled by the collection proxy. Once data



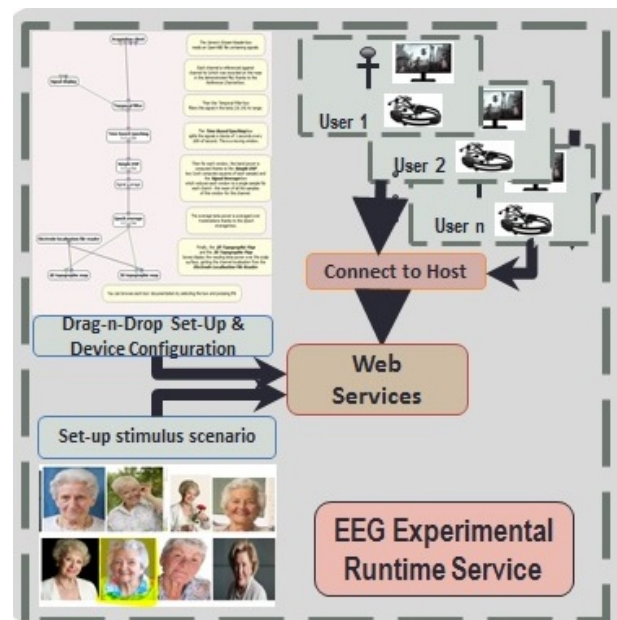
**Figure 2:** Architecture for EEG data collection and management platform. Experiment Runtime Service (ERS) module controls experimental setup and configuration, connection to webservices, data collection proxy, and data analytics. Experiments can be run with one user (i.e. individual) or with a group of users (i.e. collective). For multi-user experimentation, users can all be local or remotely connected via web-GUI interface.

arrives, it is processed by the data analytics engine which integrates open-source analytics engine by Octave. Algorithms are developed for key EEG feature extraction. EEG data from each of the 16 headset nodes is combined to provide 3D mapping of activated brain regions responding to stimuli. Figure 3 provides a sample of raw EEG collected from the wireless, EEG headset system along with a fused mapping in 3D of activated regions responding to stimuli.

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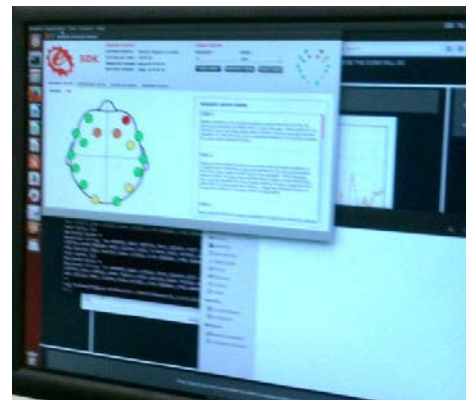
**Figure 3:** Output from eERS system showing raw 16-node EEG data (left) and fused, 3D mapping of activated brain regions responding to stimuli (right).



**Figure 4:** EEG Experimental set-up engine facilitates customization of experiments through drag-n-drop interface.

## ***II.B Achievement of Aim 2: Algorithms for Detection of Significant Events***

After the completion of the system in Aim 1, the research team designed and developed and conducted preliminary perception tests using the f-EEG system to collect data for understanding cognition and expertise in order to identify significant events. For this effort, preliminary tests were conducted on laboratory personnel to assess the function, accuracy and performance, and usability of the system in Aim 1 as well as develop a protocol for deployment of the system for

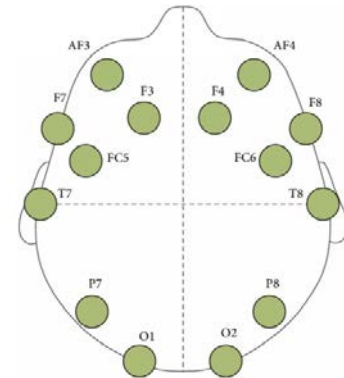


**Figure 5:** Headset set-up and calibration.

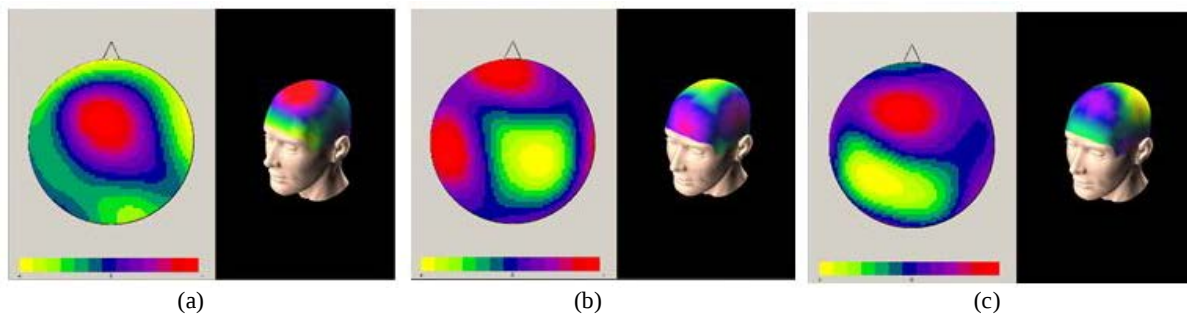
experimental studies including software set-up, head-gear calibration, image integration in the eERS system, and finally, data collection, visualization, and analyses.

Once tested, the wireless f-EEG experimentation system was used to examine the existence of grandmother cells. For these tests, 2 laboratory test subjects provided personalized images in each of 4 categories, 1-who (i.e. relative), 2-what (i.e. previous car owned), 3-where (i.e. prior vacation location or significant place visited previously), and 4-significant life event (i.e. graduation, wedding, etc). These images were then combined with a generic database containing similar images of people, things, places, and events. Each test subject was then 10 images in each of the 4 categories with their own image randomly inserted into the dataset and the asked to click a mouse upon seeing their own image. Three trials were repeated for each subject and category. A third laboratory person (control) was also shown the database of images but was not asked to provide any personal information.

For this preliminary test, data was analyzed by comparing the control to the two test subjects to see if EEG response to personalized images produced appreciable changes as compared to generic images. As the f-EEG system consisted of 16 spatially distributed EEG nodes (see Fig. 6; 14 EEG nodes plus 2 ground nodes, not shown), the research team was able to examine spatio-temporal changes resulting from the tests. Data for each of the 16 EEG nodes were grouped according to head location regions. These include frontal regions (nodes: AF3, AF4, F3, F4, F7, F8, FC5, FC6), back regions (nodes: O1, O2, P7, P8, T7, T8), and sides (front left: AF3, F3, F7, FC5; front right: AF4, F4, F8, FC6; back left: T7, P7, O1; back right: T8, P8, O2). Thus, taking into account spatio-temporal changes, tracking EEG activity by region over time we created spatial distribution maps of activity in response to generic vs. personalized images. These results are shown in Figure 7. From Fig. 7, one can see the redistribution of primary brain activity spatially over time. Initially, when viewing generic images, brain activity center in the mid-brain regions and moves to the frontal lobe when viewing personalized images, and returns to baseline position after these images are removed.

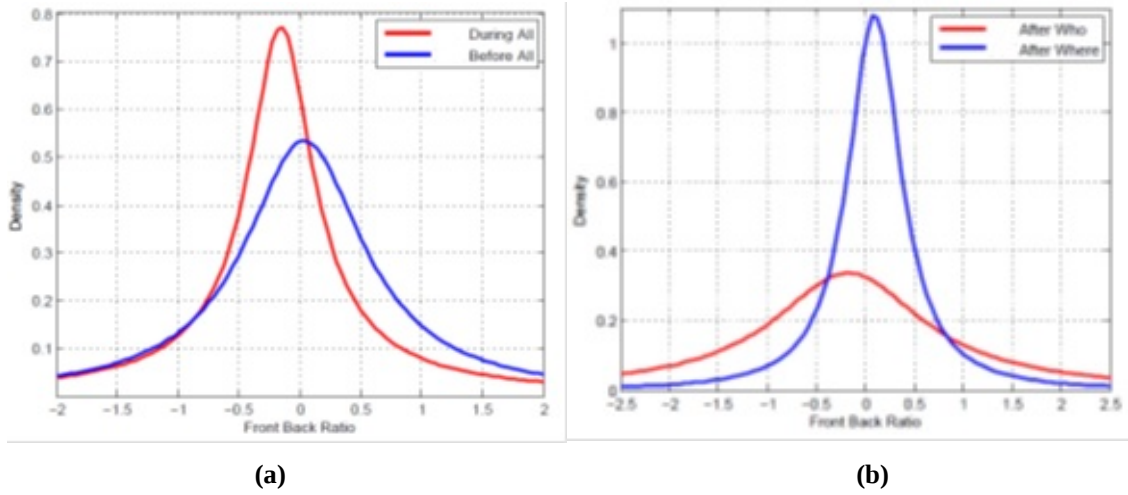


**Figure 6:** Emotiv EEG node locations.



**Figure 7:** 3-D visualization of brain activity for test subject 2 (a) before, (b) during, and (c) after being shown personalized images.

In comparison of responses between each of the different categories (who, what, where, and when), analyses from the preliminary trials using Kolmogorov-Smirnov (KS) plots reveal significant differences between personalized vs. generic image data sets (Figure 8a) and also distinctly different responses by category, with the strongest association to recognition of people over things, places, and events (Figure 8b).



**Figure 8:** KS plot comparing response (a) before (blue) and after (red) shown personalized image and (b) comparing response to “who” vs. “where” images.

From the sample data collected, algorithms used to determine recognition of significant events include spatio-temporal transmission metrics related to brain activity, ratios of front-to-back activity and front-to-side activity levels, as well as “strength” (i.e. magnitude) of regional brain activity.

### ***II.C Achievement of Aim 3: Proposed Schema for Fusion of Data for Training of Mixed Expertise Teams and Collective Decision Support***

Preliminary data from Aim 2 provide evidence of grandmother cells that respond to high levels of expertise and training and are highly specific (i.e. detection of true positives). By measuring spatio-temporal dynamics of cognition in response to visual stimuli (i.e. environment, situation awareness), it is expected that a team of mixed expertise members with different levels of training and for different expertise areas will respond differently to critical situations. This cognitive response can be measured by the f-EEG system in Aim 1. Further, quantitative assessment of training efficacy (i.e. increasing expertise in subject area) may be measured as shown by preliminary evidence shown in Aim 2.

For a team of mixed expertise members wearing the developed f-EEG system (i.e. multiple headsets), assessment of training can be performed individually and objectively by examining f-EEG for each team member in response to visual stimulus (i.e. hostile scenarios, critical environments, etc). From these quantitative assessment scores, a composite team score can be derived as in (1):

$$Total\ Score\ (TS) = \frac{\sum_{i=1}^n m_i * wf_i}{n} \quad (1)$$

where  $m_i$  = member training score (0 – 100%)

$wf_i$  = member weight factor

$n$  = number of team members

A scenario similar to the test situation can be developed where images are shown to team members of situations that are safe vs. hostile/critical requiring action. Assessing *accuracy* of these responses (by f-EEG and mouseclick or keystroke) combined with time duration of assessment (dt) results in a derived measure of throughput rate (TR). As training level increases, it is expected that throughput rate will decrease as well increasing correctness.

Testing of Aim 3 requires human subjects and IRB approvals that are beyond the scope of this STIR and the short duration of this grant period. It is recommended that a follow-up project be initiated using the developed f-EEG system to assess collective team training of mixed expertise members.

### **III. Scientific Barriers**

The development of the f-EEG system in Aim 1 progressed as planned. While operating wireless, the EEG headset currently requires close proximity (~10-15 feet) to the computer acquisition system due to bandwidth requirements. This constraint limits potential scenarios of ambulatory acquisition of f-EEG data (i.e. in the field training assessment). In some cases where test subjects have excessive amounts of head hair (i.e. females), the headset EEG nodes do not have good contact and acquisition may be dropped in some nodes requiring timely repositioning and adjustment.

While test data was collected on the investigators for Aim 2, there was insufficient time for the short duration of this project to obtain IRB from ARO and CUA to conduct trials in a larger sample size. This is the next step in the progression of this project. The pilot data was sufficient for the team to develop data visualization, analyses and fusion strategies to assess levels of cognition from visual stimuli.

### **IV. Scientific Significance**

The scientific significance of this research effort is first the development of a mobile, wearable, wireless f-EEG system for collection of functional EEG data. Such a system here-to-fore has not yet been realized. While the proposed application here is for studying adaptive training and mixed expertise, collective decision-making, the prototype EEG experimental runtime service platform has broader significance in brain research. It has the potential to be used to study mental health disorders and traumatic brain injury. Potential applications directly related to DOD-Army for assessment of PTSD for returning soldiers as well as dementia and Alzheimer's in older veterans. Current tools for assessing brain function have various drawbacks that make them inapplicable for the intended application.

Further, preliminary evidence from pilot data collected as part of Aim 2 shows evidence of a *grandmother cells* that are highly specific to personalized images. This response is more pronounced in facial recognition of people than in places, things, or events. This merits further study.

### **V. Collaborations and Leveraged Funding**

We are currently collaborating with Dr. Harold Szu at Army's Night Vision and Electronic Sensors Directorate (NVESD) on the current project. Further, our team has active collaborations with NIH's National Institute on Mental Health (NIMH; Drs. Lalonde and Gotay) as part of the Brain Order Disorder (BOD) Working Group.

## **VI. Technology Transfer**

In addition to the scientific merits of this work, we believe there are several opportunities for technology transfer related to the project. While currently, the project is in its nascent stage, we believe there are opportunities for the eERS system to be directly useful for brain researchers and clinicians as it provides an opportunity for quantitative assessment of brain function. The system may be useful in assessing PTSD, dementia, concussions, etc. as well as effectiveness of treatment programs. Another potential application is for the use of the system for cognitive assessment at-home individuals. We expect this system will also be useful in assessing cognition, learning, and collective decision making that may be universally useful for educators. Further, there is an opportunity for the analytics engine to be useful for analyses of laboratory collected EEGs as a service.

We will work with CUA's technology transfer office as the project progresses related to intellectual property and licensing opportunities.

## **VII. Future Research Plans**

Future research plans related to this project include human subjects studies to achieve the 3 aims of the project. Once IRB approval is obtained, we will be collecting studies using the developed eERS system to measurement of grandmother cells and refining algorithms for detection of significant events. We have submitted a research proposal to CUA's IRB to expand the efforts of Aim 2. We intend to submit for follow-up funding to ARO and to NIH for expansion of data collection related to Aim 2 (NIH for assessing cognitive function in acute and chronic mental health conditions) and Aim 3 (ARO for collective training and decision support) of this project.

Beyond the duration of the project, we intend to pursue further funding (sources include ARO, NSF, NIH) related to data fusion and 3-D visualization of complex EEG data collected. Another challenge will be to reduce the number of EEG nodes required for sensitive and high resolution EEG data. Our goal is to reduce the 16-node system to one requiring between 3-5 nodes. This effort would simplify experimental set-up and calibration, especially important as one deploys the technology out in the field and is being used by less trained individuals.

## **VIII. Anticipated Scientific Accomplishments**

The outcome of the research effort has resulted in an integrated real-time, wireless, portable f-EEG system capable of collecting neuro-information for processing and fusion of data in order to detect significant events and to improve situational awareness and for collective team decision support in hostile and/or critical environments. The system will include both hard and software components as well as an advanced analytics engine for quantitative assessment.