George Mason University

Center of Excellence in Neuroergonomics, Technology, and Cognition (CENTEC)

Year 4 Progress Report

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Executive Summary

The Center of Excellence in Neuroergonomics, Technology, and Cognition (CENTEC) is funded jointly by the Air Force Office of Scientific Research (AFOSR) and the Air Force Research Laboratory (AFRL). Program Managers are Dr. James Lawton (AFOSR) and Dr. Scott Galster (AFRL).

Research, training, and scientific collaboration continued the trend of significant acceleration in the fourth year of CENTEC at George Mason University (GMU). In research, there were 27 peer-reviewed journal articles, 6 journal articles submitted, 46 conference proceedings and presentations, and 7 books and book chapters (see section 8). There were 6 joint-authored GMU/AFRL journal articles.

The major goal of CENTEC is to conduct theory-based research in neuroergonomics to support the US Air Force mission of enhanced human effectiveness in air, space, and cyberspace operations. This progress report describes the major CENTEC research efforts over the past year in support of that mission. It also describes graduate student and postdoctoral fellow training as well as scientific collaborative activities with AFRL. This report covers the period of Year 4 of CENTEC, July 15, 2013 through July 14, 2014. Financial reports have been sent separately.

The CENTEC Project areas and GMU Project Leads are as follows:

1. Molecular Genetic and Neuroimaging Studies of Complex Cognition (Parasuraman).
2. Computational Analysis of Neural Mechanisms of Learning and Memory (Ascoli).
3. Interruptions and Multi-Tasking (Boehm-Davis).
4. Multimodal Cognition (Baldwin).
5. Neuroadaptive Systems (Shaw).
6. Training the Brain (Greenwood, Parasuraman).
7. Computational Modeling of Vigilance (Trafton).

Note that Project 7, Computational Modeling of Vigilance was added to the CENTEC Project areas, following the last review of CENTEC at AFRL in February 2014. Research activities within and across each of these 7 Project areas progressed at an accelerated pace during Year 3. Several studies have been completed and published in each Project Area, including experiments jointly designed, executed, and published by GMU and AFRL scientists, as described in sections 1-7. Training of graduate students and postdoctoral fellows associated with each Project area is also described. Publications and paper presentations are listed in section 9. Project Leads in each Project area have also met with AFRL personnel and conducted joint studies and made plans for future collaborative research. Such collaborative activities include all 7 Project areas. In addition to these 7

Descriptions of the progress made in each of the project areas are given below. Note that considerable cross-fertilization has also taken place between these areas, so that some studies span more than one project area. In addition, training of graduate students and postdoctoral fellows, as well as collaborative activities with AFRL scientists, has also taken place both within and across Project areas.

Notable Scientific Breakthroughs 2013-2014

1. Variable-priority training was found to accelerate learning in supervisory control of multiple unmanned vehicles in individuals with the Met/Met variant of the COMT gene, compared to those with Val/Met and Val/Val (Raja Parasuraman, Project 1 Lead).
2. A much-upgraded version of Hippocampome.org was publicly released in May 2014 with additional functionality and content (Giorgio Ascoli, Project 2 Lead).
3. Previously it was thought that people completing procedural tasks could overcome the deleterious effects of interruptions given sufficient time. This research is the first to show that this is not the case for creative, content production tasks. (Deborah Boehm-Davis, Project 3 Lead).
4. Provided converging behavioral and neurophysiological evidence that individual differences exist in basic auditory spatial perception as evidenced through an Auditory Spatial Stroop task and an Auditory Change Deafness paradigm—a ground breaking finding that challenges existing theories of executive control over conflict detection (Carryl Baldwin, Project 4 Lead).
5. Transcranial Doppler Sonography was found to be diagnostic of trait individual differences and level of operator experience. (Tyler Shaw, Project 5 Lead).
6. Effects of cognitive training on both functional brain connectivity and far transfer were found to be detectable within a few days of training—but only with transcranial Direct Current Stimulation (tDCS). (Pamela Greenwood, Project 6 Co-Lead).
7. Application to tDCS to dorsolateral prefrontal cortex was found to ameliorate the negative effects of interruptions on complex task performance (Raja Parasuraman, Project 6 Co-Lead).
8. A novel theory of sustained attention using dynamic learning and reward has been developed and fit to experimental data. (Greg Trafton, Project 7 Lead).

Awards and Honors

1. Giorgio Ascoli (Project 2 Lead): The 2014 Society for Neuroscience abstract on network analysis (first-authored by CENTEC student Christopher Rees and last-authored by Giorgio Ascoli) pre-selected for the annual "Hot Topic" selection.
2. Deborah Boehm-Davis (Project 3 Lead): Selected as a member of the "Offshore Oil and Gas Safety Culture Framing Study" to be conducted by the Transportation Research Board of the National Academies.
3. CENTEC student Cyrus Foroughi (Project 3): Received the CEDM Travel Award from the Cognitive Engineering and Decision-Making Technical Group of the Human Factors and Ergonomics Society.
4. CENTEC student Nicole Werner (Project 3): Selected attendee, Johns Hopkins University School of Nursing Center for Innovative Care in Aging Summer Research Institute – Developing Behavioral interventions; Selected attendee, Telluride East Patient Safety Summer Camp Roundtable; Accepted a postdoctoral fellowship at the Johns Hopkins University School of Medicine
5. CENTEC student Bridget Lewis **(**Project 4)**):** Received the 2014 International Community of Auditory Display (ICAD) Outstanding Student Paper Award. NSF funded ($10,000 maximum) travel award and honorarium for participation in the invitation only ICAD Think Tank Consortium and subsequent participation in the ICAD annual symposium.
6. Tyler Shaw (Project 5 Lead): Along with CENTEC students Kelly Satterfield and Raul Ramirez, nominated for the Liberty Mutual best paper award in the journal *Ergonomics*.

1. Project 1: Molecular Genetic and Neuroimaging Studies of Complex Cognition (Parasuraman)

1.1 Research

Four studies were carried out and completed in Year 3 in Project 1, all focusing on different aspects of executive function and working memory—its genetic and neural bases and how it can be best trained. Three were large-sample behavioral genetic studies with 99, 102, and 729 participants respectively, the fourth being an ERP study with 16 participants. In addition, a number of other studies are ongoing.

In the previous years of this project we have examined the role of different dopamine genes in the control of executive function, in particular the dopamine beta hydroxylase (DBH) gene, a functional gene affecting noradrenergic and dopaminergic activity in prefrontal cortex, and the Catechol-O-Methyltransferase (COMT) gene, which modulates dopaminergic activation of prefrontal cortex. We have focused on these genes because of the known role of the prefrontal cortex in executive function. A key issue we have examined in the past year is how these genes interact with different training methods to affect performance in complex multitasking environments, including supervisory control of multiple unmanned vehicles, dual verbal-spatial working memory, and command and control tasks.

The first study examined whether variants of the COMT gene interact with training and influence the rate of learning in supervisory control of unmanned air vehicles (UVs). One of the critical issues in UV systems is the selection and training of human operators who can effectively supervise such semi-autonomous systems in a multitasking environment. Currently two or more personnel are typically assigned to a single UV, but planned systems call for a single operator to supervise multiple UVs. Some persons are better at multitasking than others, an ability that has been linked to individual differences in executive function and working memory capacity. Extensive training can improve multitasking performance, but not all individuals show the same benefit. Moreover, it is not known whether executive function contributes to multitasking performance while supervising UVs, or whether this ability modulates training-related effects in such tasks. Accordingly, we genotyped 99 participants for the COMT Val158Met SNP and had them perform a simulated air defense task requiring supervision of multiple UVs under either low or high task load, defined as the number of incoming threats they had to defend against. All participants performed for four 12-minute blocks of trials and each task load. The Met allele of the COMT gene is associated with lower enzymatic activity and hence with greater prefrontal dopamine availability than the Val allele. We therefore predicted that individuals with one or more Met alleles would be superior to those with the Val allele in supervising multiple UVs. We expected that this advantage would accrue only after training, as indicated by a gene x practice interaction.

The results supported our hypothesis that the Val158Met variant of the COMT gene influences training effects in supervisory control of multiple UVs, as revealed in a strengthened effect of genotype on performance over the course of task acquisition. The Met allele, known to encode a low activity version of the COMT enzyme, resulting in higher levels of dopamine activity in prefrontal cortex, was associated with a greater increase in enemy targets destroyed over practice blocks (see Figure 1.1). In addition, Met/Met individuals had a greater reduction in enemy red zone incursions over blocks. The results supported the conclusion that individuals with the COMT Met/Met genotype can acquire skill in such multi-UV supervisory control tasks to a higher level and/or faster than other genotype groups. Indeed, we found that 88-94% of Met/Met individuals performed better than the median group after training. The results are highly are encouraging with respect to the development of individualized training methods for operators of multi-UV systems and selecting personnel for complex supervisory control tasks. This study, which was conducted in collaboration with Dr. Ryan Jankord of the Applied Neuroscience Branch at AFRL, was published in the journal *Human Factors* (Parasuraman, Kidwell, Olmstead, Lin, Jankord, & Greenwood, 2014).

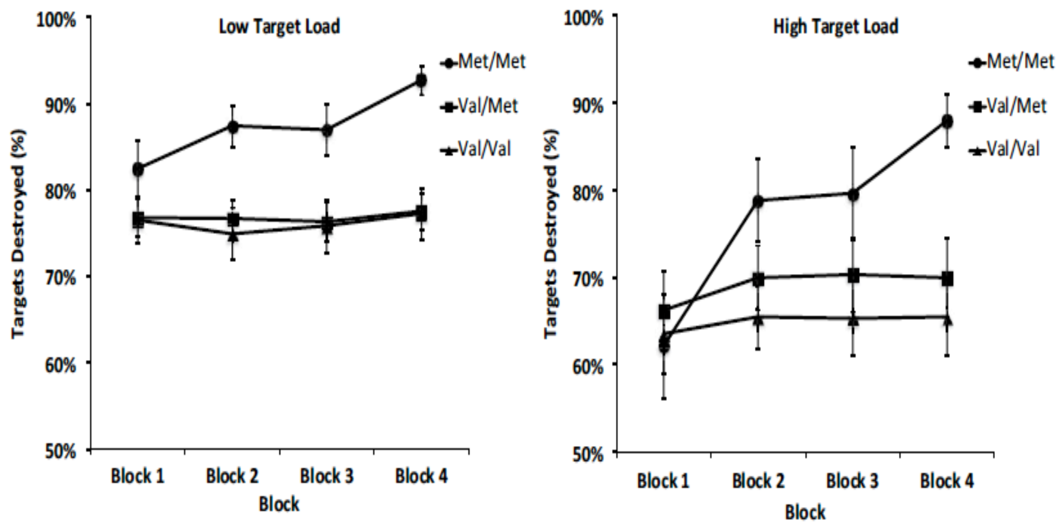

Figure 1.1 Mean percentage of enemy targets destroyed for the Met/Met, Val/Met, and Val/Val groups as a function of training blocks.

The genetic study described above shows that individual differences in the effects of practice on supervisory control performance vary with COMT genotype. Neuroimaging studies have shown that simple practice typically results in reduced cortical activation (Poldrack et al., 2001) and increased functional connectivity between different brain regions (Klingberg, 2010). However, the neural mechanisms associated with the effects of more complex training methods aimed at boosting executive function and their interactions with genes are not well understood. Various training methods have been proposed to accelerate skill acquisition so that individuals can reach higher levels of performance at an earlier stage than through practice alone (Wickens et al., 2012). Variable priority training (VPT) represents one such method that has been shown to be highly effective in the development of complex skills, particularly multitasking (Gopher et al., 1989; Gopher et al., 1994). VPT requires a trainee to perform a multi-component task in its entirety, while differentially allocating attention (priority) to sub-components of the task during different training blocks. However, it is not known whether the method is equally effective for all individuals, or whether those with specific variants of dopaminergic genes may benefit to a greater extent than those with other variants. Furthermore, as Figure 1.1 shows, practice alone was not sufficient in accelerating skill acquisition in Val/Met and Val/Val individuals, compared to those with the Met/Met variant of the COMT gene. Accordingly, in the second study we examined whether VPT would boost learning in individuals with the Val allele to a greater extent than simple practice, and whether those with the Met allele would show greater training-related gains in multitasking performance.

We used the same multi-UV supervisory control task as in the first study by Parasuraman et al. (2014). A total of 110 participants were genotypes for the Met/Val variants of the COMT gene, as in the first study. After genotyping, participants were grouped according to genotype, namely Met/Met (N=21), Val/Met (N=59), and Val/Val (N=30). All groups received a form of VPT in which they alternated emphasis on the two sub-tasks of the multi-UV supervisory control task over 6 training blocks. Data analysis for this study is ongoing, but preliminary results for the percentage of enemy targets destroyed are shown in Figure 1.2. The results showed that VPT was effective in all three genotype groups, but that the greatest benefit was observed for the Met/Met group.

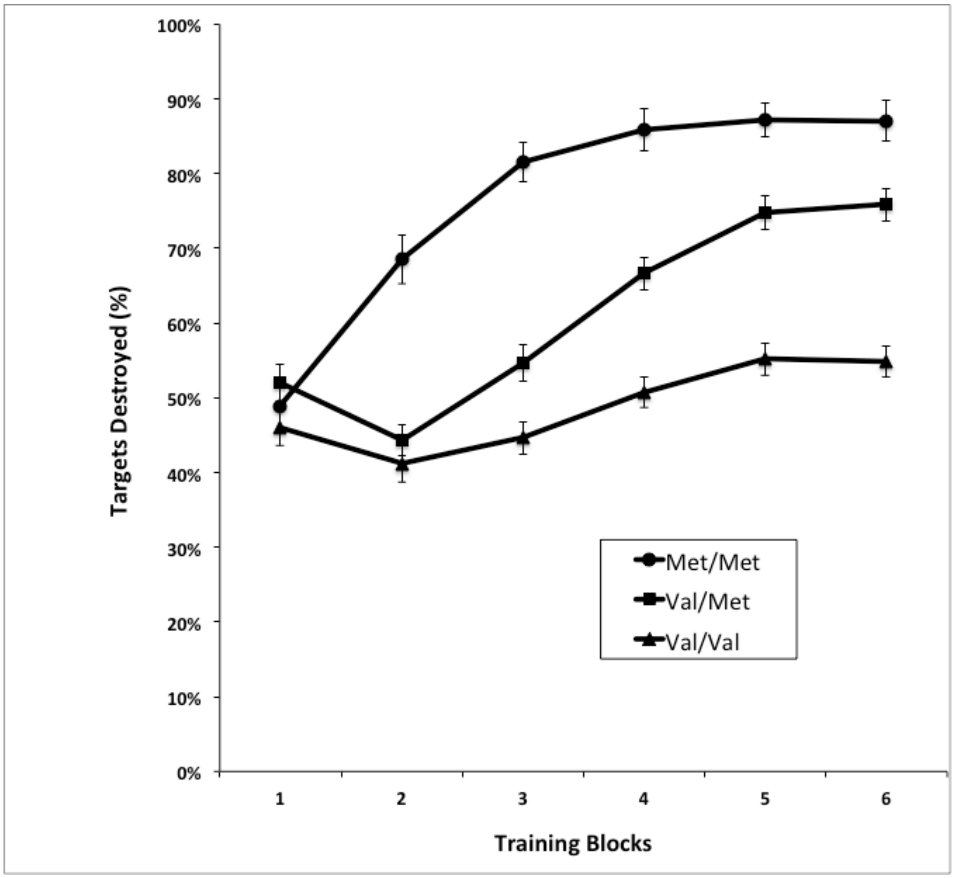

Figure 1.2 Effects of variable priority training in Met/Met, Val/Met, and Val/Val groups.

The third study was a genetic investigation involving close collaboration between AFRL (Jankord) and GMU investigators (Parasuraman, Greenwood, Schmitt). This was a large-sample study—an unbiased approach with the goal of identifying novel genetic variants related to inter-individual differences in memory and executive function. AFRL conducted attention, working memory, and stress paradigms with BXD recombinant inbred strains of mice. Using a quantitative trait locus mapping, this method revealed numerous genetic targets associated with enhanced cognition. One of the genes found to be involved in spatial memory formation in mice was formimidoyltransferase cyclodeaminase (FTCD). The FTCD gene encodes an enzyme with two functions, one of which is the breakdown of histamine that leads to the synthesis of the amino acid glutamate. Thus FTCD is important in production of the primary excitatory neurotransmitter in the brain. Information from the Allen Brain Atlas describes robust expression of FTCD mRNA in the human caudate, putamen, and globus pallidus, which are areas implicated with planning and executing movements and executive function. Additionally, this gene is strongly expressed in the human dentate gyrus, which is important in memory formation and spatial navigation. Based on this, we hypothesized that FTCD variants also modulate working memory performance in humans.

The CENTEC team researched FTCD single nucleotide polymorphisms (SNPs) using a hierarchical approach with gene variants possessing sufficient minor allele frequency for human studies. After determining SNPs with clinical significance in the literature, priority was then given to variants in the enhancer and promoter regions of the gene that could affect protein structure or microRNA binding sites. FTCD SNP rs914246 was chosen as an initial target for human trials because it is in the promoter region and linked to mental retardation. Our secondary target was rs914245 given that it is 30 base pairs away from our primary target and also in the promoter region**.** We are currently in the process of examining the effects of these SNPs in our large sample of stored DNA from people who underwent a battery of cognitive testing. As rs914246 was identified from Morris Water Maze performance in BxD mice, we tested it in working memory performance in humans (N=729). Participants were required to remember 1, 2, or 3 target locations over a 3 s delay. When test and target were hard to discriminate but working memory load was low, T/T homozygotes showed an accuracy benefit. However, when working memory load was high but discrimination difficulty was low, G/G homozygotes showed an accuracy benefit. These preliminary results from one SNP and one task show the feasibility of this unbiased approach to identifying novel SNPs important in human cognitive performance.

The fourth study in Project 1 used event-related potentials to examine the interaction between executive function and discrimination processing. Theoretical models of executive function suggest that difficult tasks require top-down control, which influences accurate sensory processing. The mechanism of top-down control has been previously shown to enhance activation in specific cortical regions that process task-relevant stimulus features. Lavie's (2005) theory of perceptual load suggests that the level of attentional modulation employed depends strongly on task demands, with more difficult tasks requiring greater top-down control. Recent work has demonstrated that the occipital–temporal N1 component of the ERP is sensitive to the difficulty of visual discrimination, in a manner that cannot be explained by simple differences in low-level visual features, arousal, or time on task. These observations provide evidence that the occipital– temporal N1 component is modulated by the application of top–down control. However, the timing of this control process remains unclear. Previous work has demonstrated proactive, top–down modulation of cortical excitability for cued spatial attention or feature selection tasks. Accordingly in this study the possibility that a similar top–down process facilitates performance of a difficult stimulus discrimination task was explored.

A total of 16 participants performed an oddball task at two levels of discrimination difficulty, with difficulty manipulated by modulating the similarity between target and nontarget stimuli. Discrimination processes and cortical excitability were assessed via the amplitude of the occipital–temporal N1 component and prestimulus alpha oscillation of the EEG, respectively. For correct discriminations, prestimulus alpha power was reduced, and the occipital–temporal N1 was enhanced in the hard relative to the easy condition. Further- more, within the hard condition, prestimulus alpha power was reduced, and the occipital–temporal N1 was enhanced for correct relative to incorrect discriminations. The generation of ERPs contingent on relative prestimulus alpha power additionally suggests that diminished alpha power preceding stimulus onset is related to enhancement of the occipital–temporal N1. As in spatial attention, proactive control appears to enhance cortical excitability and facilitate discrimination performance in tasks requiring nonspatial, feature-based attention, even in the absence of competing stimulus features.

Plans for Year 5 in Project Area 1 include the following: (1) Design and execution of a study examining the interaction between the COMT gene and other cognitive training methods on performance of multi-UV tasks. (2) Continued use of the unbiased approach of identifying mouse gene variants that can be linked to executive function and working memory in humans. (3) Design and execution of a study using functional near infrared spectroscopy (fNIRS) as a low cost neuroimaging method to track day to day changes in brain activation as individuals learn to perform a complex multi-UV supervisory control task.

1.2 Training

Two postdoctoral fellows continued to work on studies in Project 1, Maren Strenziok (MRI), and Ming-Kuan Lin (molecular genetics). In addition, two graduate students, Brian Falcone and Ryan McKendrick, who were recruited as “Air Force scholars” in Year 1 of CENTEC, and Brian Kidwell, who was recruited in Year 3, continued to work under the supervision of Raja Parasuraman. A fourth graduate student, Kevin Schmidt, is a SMART scholar and is working on the collaborative genetics project with Ryan Jankord at AFRL.

1.3 Collaborative Activities

There was substantially increased collaboration on molecular genetic research between GMU and AFRL scientists in Year 4. In particular, Raja Parasuraman and Pamela Greenwood had several meetings with Ryan Jankord on genetic research on attention, working memory, and stress in humans and rodents. Dr. Jankord participated in data analysis on the COMT-training study described previously under Project 1 Research, and is a co-author for the published journal article in *Human Factors.* As described above in the section on research, he provided Drs. Parasuraman and Greenwood with a list of potential gene “targets” gleaned from an analysis of his work at AFRL on BXD mice for examination of potential novel genes related to attention and working memory in humans at GMU. Kevin Schmidt, a graduate student at GMU, who spent the summer of 2013 at AFRL working on mouse genomics under the supervision of Ryan Jankord, has continued the collaboration when he returned to GMU in August 2013.

Meetings were also held with AFRL scientists Drs. Joel Warm, Ben Knott, Scott Galster, Andy McKinley, and Greg Funke to discuss ongoing and planned research collaboration at the following conferences: Human Factors and Ergonomics Society Conference (October 2013); the Society for Neuroscience (November 2013), and the Cognitive Neuroscience Society Conference (April 2013). Discussions were continued with scientific meetings at AFRL Dayton in August 2013. In addition, the CENTEC review at GMU in February 2013 afforded a number of opportunities for discussions between GMU scientists and AFRL scientists present.

2. Project 2: Computational Analysis of Neural Mechanisms of Memory (Ascoli)

2.1 Research

In the past 12 months, the Hippocampome.org team has continued to mine the ever-expanding body of literature for information pertaining to neuron types in the rodent hippocampus. The knowledge we have accumulated is a set of more than 120 neuron types with information about morphology, molecular marker expression, electrophysiological parameters and firing patterns, plus known and potential connectivity. In each of these project facets, the bioinformatics PhD student directly supported by CENTEC (Christopher Rees) played a direct role in mining, vetting, and/or graphically representing the data. In all, the Hippocampome.org knowledge base currently contains information from ~500 peer-reviewed articles and book chapters; thousands more sources have been examined and found to be outside the current scope of the project.

The gathered data is organized in a database that is browsable via a freely accessible web portal at www.hippocampome.org. In May of 2014, we have released a major new public version of the website. CENTEC graduate student Christopher Rees was highly involved in the programming of the portal, personally writing PHP code to implement numerous design and performance improvements.

Amassing this information into a centralized resource facilitates analyses that can lead to new discoveries. In the past year, CENTEC integrally supported three particular analysis avenues, which are discussed at length below.

First, we explored pairwise correlations between 148 properties of neuronal types, including the major neurotransmitter, the axonal, dendritic, and somatic locations in the 26 partitions and the 6 subregions of the hippocampal formation, clear positive or negative expression of 36 molecular biomarkers, and having extremely high or low preferred values for 10 electrophysiological properties. We tested for correlations between these categorical properties by utilizing contingency tables and Barnard's exact test to unveil new, statistically significant relationships and confirm previously held understandings.

Secondly, Hippocampome.org contains comprehensive knowledge of hippocampal type-based circuitry. We have compiled information on network connectivity in two stages: by (1) literature mining for experimentally verified data on synapses (or lack thereof) between neuron types; and (2) determining the binary (and later, weighted) potential for synapsing that arises from a spatial overlap of axons and dendrites of any two types. We then analyzed the resulting network by employing graph theory metrics (e.g. degree distribution, betweenness centrality, rich club coefficient, and motif composition, among others) to uncover the fundamental architectural principles of the network.

The motif composition analysis, in particular, was computationally intensive, and we took advantage of our CENTEC-fostered partnership with the military to utilize DoD High-Performance Computing (HPC) resources. Specifically, porting our network motif analysis code to the Navy's Kilrain supercomputer drastically reduced the computation time for the generation of a statistically significant set of random "control" networks for comparison of their motif composition to the Hippocampome.org network. Furthermore, using new measures like absorption and driftness, we began investigating the relationship between network topology and the dynamic behaviors of information flow, with the hopes of furthering intuition on hippocampal operation.

Third, in certain cases where molecular marker expression information from the literature cannot be directly ascribed to one of our neuron types, we still may be able to use inferential logic to match the expression data to a set of applicable types. This may be the case when the authors did not fully describe or provide references that describe the morphology. For instance, data on the co-expression or lack of co-expression (i.e. mutual exclusivity) of one marker with a second in a certain parcel (or parcels) can be used to infer information without the need of a direct assay of marker expression by a particular neuron type. In such a circumstance, as long as the first marker is known to be positively expressed for any neuron type, the second marker can be reasonably inferred to be expressed (in the case of co-expression) or not expressed (in the case of mutual exclusivity). Such inferences can also be applied in their contrapositive form, and multiple inferences can even be chained together. With CENTEC support, we gathered these inferences and built the system that applies their logic. Currently, inferences such as those described here increase the molecular marker information in the knowledge base by approximately 33%.

The data gathered for Hippocampome.org and the analyses described herein are in the process of being prepared for submission to peer reviewed journals for publication in multiple manuscripts. In the meantime, Christopher Rees presented a poster of the graph theory research at the national Society for Neuroscience conference in San Diego last year. This year, he submitted an abstract to the same conference that was accepted and pre-selected as a Neuroscience 2014 *Hot Topic*. If the abstract makes the final cut of this prestigious selection, SfN will share a lay language summary of the work with the media as part of Neuroscience 2014's *Hot Topics* book.

CENTEC also provides partial support (one research credit of tuition per semester) for a second PhD student in the Psychology program studying human memory, Robert (Bob) Gardner. His manuscript characterizing the spontaneous recall of autobiographic and prospective memory is currently under review in the flagship journal *Psychological Science*.

2.2 Training

This project supports one full time PhD student in Bioinformatics, Christopher Rees, with partial tuition support for a second PhD student in biopsychology, Robert (Bob) Gardner. Both doctoral students supported by this project are approaching graduation: Christopher Rees (Bioinformatics) on graph theory & network analysis, and Robert (Bob) Gardner (Psychology) on human memory and rat behavior. Several other graduate students are also indirectly involved in the project (although not funded by CENTEC): Ben Holmes (Wright State Univ.) on hippocampome applications, David Hamilton (Neuroscience) for the neuroinformatics portal, Siva Venkadesh (Neuroscience, Presidential fellow) on firing dynamics, Sean Mackesey (MS in Bioinformatics, now at Berkeley) on neuron counts. Postdoctoral trainees include Dr. Diek Wheeler (team lead), Dr. Alexander Komendantov (electrophysiology), Dr. Charise White (biomarkers), and Dr. Alexei Samsonovich (functional modeling).

2.3 Collaborative Activities

The 3-yr Laboratory Research Initiation grant "Computational Modeling in the Biological Band: Integrating Computational Cognitive Neuroscience into the Human Effectiveness Directorate" started at AFRL, with Dr. Tim Halverson as Task Manager, and Dr. Ascoli committing a 1.5 months/year effort. Dr. Ascoli fielded weekly calls with Dr. Halverson and Mr. Ben Holmes (a PhD student at Wright State Univ. and research intern at ARFL) and hosted Mr. Holmes at GMU for a 9-day visit in Fall 2013 for a Hippocampome crash-course, presentation seminar, and sharing database/server access. Mr. Holmes also attended weekly "pow-wow" technical meetings by teleconference with 3 postdocs and 3 PhD students ("Hippocampome team") in Ascoli's lab. A senior postdoc from Ascoli's Lab, Dr. Charise White, visited AFRL in Dayton for 3 days in Spring 2013. Dr. Ascoli paid a 1-day visit to AFRL in Spring 2014 to discuss Hippocampome applications of potential interest to WPAFB, and Dr. Halverson visited Ascoli's lab in Fairfax 2 weeks later. The two labs regularly exchanged reports, technical documents (e.g. release specifications, SfN posters, manuscript drafts), and email feedback. In the course of these interactions, several collaborative threads were identified, including (1) use of hippocampal modeling in spatial navigation & memory processing, (2) browsing/searching of hippocampus neuron type data and knowledge, (3) specific application of chemical biomarkers (e.g. NPY / stress), (4) upload of hippocampus parameters into knowledge base, (5) shared use and development of web portal and database, and (6) pursuit of joint funding opportunities.

The collaboration with ARFL DoD Supercomputing Resource Center (POC: W. Larkin) is still ongoing for remote usage of Spirit at WPAFB (73,440 CPUs/1.5 petaflops – the 14th fastest computer in the world and fastest machine for unclassified work. In addition to the collaboration with WPAFP, Dr. Ascoli has a continuing Cooperative Research And Development Agreement with Dr. David Marchette from the Dahlgren NSWC. Lastly, a "Robust Intelligence" 3-year collaborative grant with Dr. Ken DeJong (former CENTEC sub-project) was funded this year by NSF for network fine-tuning.

3. Project 3: Interruptions and Multi-tasking (Boehm-Davis)

3.1 Research

Imagine that you need to finish writing a report for a presentation tomorrow morning. You sit down and begin typing. Your phone chimes indicating you have received a new email. You read it and respond. You attempt to collect your thoughts and begin working on your report when your supervisor comes in and asks you a question. Once again, you've been interrupted and before you know it, 30 minutes have passed and you have gained no ground on completing your report. Research shows that in office environments, employees are interrupted up to six times per hour and may shift tasks every three minutes.

With such an impact on daily life, it is not surprising that there is an abundance of research focusing on interruptions. Interruptions have been well documented in office environments, in aviation, driving, and in the health care industry. A majority of this research uses time and errors as measures of disruption as they are often the most appropriate metrics for determining the effects that interruptions have on task performance. Research focusing on time has shown that interruptions increase completion time on tasks. In some cases, the delay or time lost as the result of an interruption can lead to negative consequences. Research focusing on errors has shown interruptions reduce overall accuracy in task performance and increase post-completion errors.

However, time and errors may not be appropriate measures of disruption for all domains. For example, qualitative domains such as reading comprehension and writing may be better served by analyzing the quality of the final work product as the primary measure of disruption. If an interruption only causes a loss of time when writing an essay and time is not essential, then the interruption has not negatively affected the quality of the work. However, if an interruption has resulted in the lessening of the quality of the essay, then the interruption has had a real impact on the work product.

Our early work on Project 3 focused on understanding how different features of the interrupting task (e.g., similarity to the primary task or complexity of the interrupting task) affect performance. However, over the past two years, we have turned our attention to understanding the impact of interruptions on the quality of the work that is produced. Further, we have tried to focus on tasks beyond the procedural tasks used in most interruptions research. Real-world tasks often require significant integration of information over time and the important characteristic is not how quickly someone makes a decision, but whether the decision is the correct one. For example, in a military setting, it is likely more important that an operator make the correct decision about whether observed threats in an environment signal an attack than about whether that decision is made in 5 versus 8 seconds (although timing can also be important). In business settings, the quality of a report is likely more important than whether it took the individual writing it 2 hours, or 2 hours and 10 minutes. A similar case can be made in academia; the quality of the final paper is more important than the amount of time it took the student to write it.

This year saw the completion of a series of studies aimed at better understanding these issues. Specifically, we conducted a series of four experiments examining the impact of interruptions on the quality of essays produced under either interrupted or non-interrupted conditions. We also conducted three studies extending this work to creative tasks. In this work, we collected data on participants completing the Alternate/Unusual Use Task developed by Guilford. Here again, we found that interruptions had a significant negative effect on the quality of performance. Third, we began a series of studies investigating the impact of interruptions on reading comprehension.

Finally, we continued work begun last year aimed at understanding the role interruptions play in a naturalistic surveillance and decision-making task. This task is specifically designed to present realistic representations of decisions soldiers make, as well as test their recognition of threats. This study has, and continues to require, extensive collaboration between AFRL and GMU as we work to perfect the stimuli needed for this study and refine the experimental paradigm. This work explores the extent to which the findings we have seen in the laboratory hold up when the "quality" is defined as making a good decision in a threatening environment. This will allow us to extend our findings both to more realistic tasks, and tasks relevant to the Air Force, and to cover additional definitions of quality.

This year, we have had several papers and book chapters describing our work to date published. Boehm-Davis' book on human-systems integration is now in production and we have a number of additional manuscripts currently under review.

In the area of multitasking, there has been extensive research investigating performance-related differences in multitasking associated with age, and while there has been specific work looking at the relationship between age and psychophysical behaviors, such as eye-movements in applications like reading, very little has been done to relate these behaviors to multitasking. Our work sought to bridge this gap. We conducted studies this year building on our previous work which found that older adults exhibit a more focused pattern of fixations in a multitask environment than younger adults, who demonstrate a significantly more diffuse pattern of fixations. A paper describing these results was presented at last year's meeting of the Human Factors and Ergonomics Society. Further, a paper describing much of the work to date is being prepared for a journal publication in conjunction with staff at AFRL.

This past year also saw the successful completion of a collaborative effort between AFRL and GMU where we examined the relative usefulness of 2-D versus 3-D cueing to help guide participants and improve performance in a multitask paradigm. Analysis for this study is currently in progress, but preliminary work suggests that 3-D cuing does not improve performance above that seen for 2-D versus simulated 3-D cuing. The data suggest that simulated depth cues alone may be sufficient to improve task performance without introducing additional task load.

3.2 Training

Three doctoral students in the Ph.D. program in Human Factors and Applied Cognition, Cyrus Foroughi, William (Bill) Miller and Nicole Werner, have been working under the supervision of Deborah Boehm-Davis over the past year. Cyrus and Nicole's focus has primarily been on interruptions. Cyrus is a first-year doctoral student who worked in our lab as an undergraduate. Nicole is currently preparing her dissertation proposal, working with Dr. Boehm-Davis. Bill's primary interest is in multitasking, although he also is involved in some interruptions-related research as it pertains to CENTEC projects. As noted in previous years, Bill is currently funded through the ASEE's SMART program, which has allowed him to spend his summers at AFRL at the 711 Human Performance Wing's Human Effectiveness Directorate since 2010. During each summer, he has met with Drs. Terry Stanard and Eric Geiselman on the continued development of CENTEC-related projects exclusive to his internship duties as a SMART scholar.

3.3 Collaborative Activities

During Year 4, our research team continued our collaboration with Drs. Paul Havig and Eric Geiselman regarding use of their 3-D version of the Multi-Attribute Task Battery (MATB), where we successfully completed data collection. Data analysis (supported by Dr. Geiselman and Eric Heft) continues and drafts of papers describing this work are being prepared. Additionally, we have continued our collaboration with Drs. Gloria Calhoun and Terry Stanard. This collaboration has involved being in near-constant contact throughout the year via e-mail and teleconferences, as well as on-site visits by Bill Miller this past summer.

4. Project 4: Multimodal Cognition (Baldwin)

4.1 Research

The project was redefined in Year 2, mainly based on interactions with researchers at the Human Effectiveness Directorate at AFRL. While *auditory* cognition was an initial point of contact with the AFRL scientists, further interaction and discussions lead to a redefinition of the area as involving both auditory and other non-visual sensory modalities, and hence the Project area was renamed *Multimodal Cognition*.

During Year 3, our research team conducted 14 (2- tactile navigational cueing, 1- Auditory Change Detection, 1 – Auditory Stroop, 6 -Multimodal Cueing, 4 -Auditory Perceptual Space) studies in this Project area. The first two studies involving tactile navigational cueing were a direct extension of collaborative work began at AFRL during a previous summer when CENTEC scholar Andre Garcia was working with Vic Finomore under the Reppenger Fellowship. The next six studies were a continuation of a major theme from Year 2—that of determining equivalent saliency, urgency, and annoyance of signals within and across sensory modalities. In the current series we extended our work to include bimodal alerts, in addition to unimodal, and examined behavioral responses within a contextually appropriate task in addition to magnitude estimation and other psychophysical techniques. Additionally, we examined both perceptions and responses under conditions of varying cognitive demand.

Tactile Navigational Cueing. Two studies were completed during Year 3. These were a continuation of research initiated at AFRL. In previous years at AFRL we had examined the feasibility of using tactile navigational guidance cueing. At GMU in Year 3 we conducted two studies examining the efficacy of different strategies for providing tactile navigational guidance to drivers. Specifically, we examined three tactile formats for presenting both a near and far cue by varying combinations of pulse rate, tactor location or both to a traditional auditory guidance cue.

All three formats yielded equivalent navigational performance and route memory, relative to the auditory guidance format, but the strategy using only pulse rate was preferred by a significantly higher number of drivers.

Auditory Change Detection. Auditory Change Deafness, an auditory analog to Visual Change Blindness, is known to be highly prevalent when listeners are not directly cued to the source of the change. However, little is currently known about what types or parameters of auditory stimuli are more resistant to change deafness and therefore might serve as more robust auditory cues. During Year 3, we completed one experiment and another two are currently in the data collection stages as part of a direct collaboration with Nandini Iyer and Brian Simpson from AFRL. We refer to this series as the Auditory Change Detection Collaboration, or ADCD. This series of investigations is aimed at examining whether location or object identity information is most susceptible to auditory change deafness and further whether or not there are individual differences in auditory change detection. Programmatic lines of experiments have been planned and are being concurrently carried out at AFRL and GMU. The research team has applied for additional grant funding through AFOSR for this work and has plans for additional grant submissions to address additional constructs in this line of research. One conference proceedings related to this work has been submitted and the current completed studies (2 at AFRL and 1 at GMU) will be used as pilot data for the upcoming grant submission. Results of the first three studies conducted at GMU are also designed to inform planned ERP investigations in this area. These ERP investigations are designed to answer questions related to the time course and information processing stage where auditory change deafness is most likely to occur. Little is currently know regarding this aspect and therefore this work promises to be ground breaking.

Auditory Stroop and ERPs. In our previous work we observed that there are individual differences in auditory spatial orientation and cue conflict as a function of navigational strategy. Our work in this area indicates that the time course of these processing differences occurs early enough to consider these differences in basic auditory spatial orientation. This year we completed another study in this series using ERP metrics to examine the time course of individual differences in rapid spatial cueing. Results indicate that differences in spatial orientation strategy are associated with different neural responses as early as 200 ms following the presentation of an auditory spatial cue. Reviewers of our submitted manuscript acknowledge that these results contribute significantly to the existing literature and are of great interest.

Multimodal Cuing. Multimodal cues are increasingly being used in operational environments yet there is still insufficient knowledge or how they compare in urgency across different modalities and combinations of modalities. In this ongoing series we have been systematically examining a wide range of parameters in visual, auditory, and tactile modalities in an effort to develop equivalent scales of perceived urgency and annoyance. This year, we extended this work to both additional signal parameters (in particular, additional tactile parameters and locations) and multimodal combinations of parameters. Further we conducted a study in a complex operational setting (simulated driving while performing a concurrent working memory task) to examine how our magnitude estimation parameters related to behavioral responses under high and low cognitive demand. The two main results from this series this year are that: 1) perceptual judgments of tactile signal urgency and annoyance are remarkably comparable at different locations on the body likely to be used in operational environments (e.g., seat pan or buttocks, waist, and the wrist); and 2) cognitive load significantly decreases an operator's ability to rapidly determine the urgency of various signals, but using signal parameters connoting "high" urgency still convey some benefit in speeding responses.

Auditory Perceptual Space. We have been conducting a series of investigations in an effort to determine the auditory parameters that contribute most to assisting operators in rapidly determining the category (e.g., imminent threat warning, status update, or social communication) of auditory signals. This year we completed four additional investigations in this series. In two of these we compiled a series of auditory signals in actual operational use by major automotive manufacturers and asked listeners to classify them by sorting them in to several different categories. In another study we asked participants to use a method of adjustment procedure to change key parameters to be within and outside the perceptual space of an imminent warning. In each experiment we also asked participants to choose their favored "prototypical" sound for each category. We then ran a series of regression analysis to determine if we could predict the parameters associated with the perceptual space of different categories, with an emphasis on the "warning" category. Main results from this series support our previous findings that temporal parameters dominate perceptions, and that inclusion in the "warning" category can be predicted with nearly 90% accuracy by only three auditory parameters.

Planned research activities for Year 5 include further examination of the effectiveness of multimodal cues under divided attention and in two stage alerting paradigms as well as extending the auditory signals to include looming signals (e.g., resembling Doppler effects). Importantly, we plan to continue our collaborative investigations with AFRL personnel, specifically with Nandini Iyer and Brian Simpson examining the parameters impacting auditory change deafness and auditory spatial attention. A portion of the work is planned to be carried out at GMU and will include neurophysiological metrics (e.g., ERP) while other portions are concurrently conducted at AFRL.

4.2 Training

Six doctoral students, Andre Garcia, Christian Gonzalez, Nick Penaranda, George Buzzell, Jesse Eisert, Jane Barrow, Dan Roberts and Bridget Lewis, were actively involved in the research. Additionally, several undergraduate students also received training by assisting with this work, Bum Sin Sik (Scott) and Ederlyn Tanangco, in particular. Of these, Andre Garcia, Nick Penaranda, and George Buzzell received funding directly from CENTEC.

Though all students discussed and participated in many aspects of each of the projects, certain students have had more of a key role in specific projects. George Buzzell and Dan Roberts played lead roles in the Auditory Stroop and ACDC series, respectively. Andre Garcia primarily worked on the Tactile navigation series and Nick Penaranda primarily worked on workload classification projects related to Project 6, and to the Multimodal experiment examining Bimodal Urgency mapping under Cognitive Load. Jesse Eisert played a key role on the Auditory Perceptual Space investigations. Bridget Lewis played a key role in the Multimodal Cuing series as well as assisting with the Auditory Perceptual Space series. Jane Barrow assisted primarily with the Auditory Spatial Stroop series. Further, Nick Penaranda, George Buzzell, and Dan Roberts continue to play a major role in training other students in EEG data collection and analysis techniques.

4.3 Collaborative Activities

The following collaborative activities with AFRL scientists took place over Year 3.

a) Joint submissions between AFRL scientists and GMU CENTEC faculty Carryl Baldwin to the Human Factors conference and the HCII conference.
b) AFRL scientists Nandini Iyer and Brian Simpson and GMU CENTEC faculty Carryl Baldwin have had an ongoing collaborative series of investigations and conduct periodic telecons involving the sharing of recent results and scientific exchange. This collaboration has resulted in at least one grant and one conference submission, with many more planned activities in progress.

5. Project 5: Neuroadaptive Systems (Shaw)

5.1 Research

During year 4, a total of two studies have been completed, with one study ongoing. One focus of the research being conducted under project area 5 is on diagnostic monitoring of cognitive workload using neurophysiological measures of hemodynamic response. One such measure is Transcranial Doppler Sonography (TCD). Previous research using TCD has shown that it is an objective measure of information processing resources (i.e. cognitive workload). The consistent findings from this line of research are that the absolute level of CBFV varies directly with task difficulty, the vigilance decrement is often paralleled by a temporal decline in CBFV, and that these effects only occur when observers are task engaged. Lastly, the CBFV effects are generally lateralized to the right cerebral hemisphere, consistent with the notion that there is a right-hemispheric system involved in the functional control of vigilance. However, a very important consideration with lateralization is that much of the recent research has pointed to the fact that tasks imposing a greater demand on observers require resource recruitment from both the left and right cerebral hemispheres. Thus, bilateral increases in CBFV are also indicative of high workload. Two peer-reviewed journal articles and 4 proceedings paper have been published. It should be noted that 60% of all publications in project area 7 feature personnel from both GMU and WPAFB. Progress for year 4 is described below.

The first study was designed to examine a new individual differences measure that may be related to vigilance task performance, trait self-control. While many previous investigations have looked at individual differences in isolation and more current approaches suggest that multivariate approaches should be used to predict vigilance (c.f. Shaw et al., 2010), there was a theoretical reason for choosing trait self-control as a variable of interest. In recent years, there has been a debate about the theoretical mechanisms underlying the vigilance decrement. Currently, there are two competing theoretical accounts of the decrement function. The first is resource theory, which is an overload theory that suggests that the decrement function is due to drainage of attentional resources due to excessive task demands. The mindlessness account, which is an underload theory, suggests that the monotonous nature of the task leads to routine response as a result of lapses of attentional focus. Both sides have been able to furnish considerable evidence, with the resource theorists citing neurophysiological and self-reported workload evidence, and mindlessness theorists furnishing evidence pointing to an increase of task unrelated thoughts and boredom. Recent conjecture suggests that the two theories can be reconciled by considering a metacognitive process, trait self-control that may moderate resource allocation to task performance. More specifically, a reduction in the allocation of resources, as indexed by TCD, may be indicative of the onset of boredom and mindlessness. In the current experiment, trait level self-control was assessed using a validated measure, and resource allocation was assessed using

TCD during a 12-minute vigilance task. Participants (n=27) with higher levels of trait self-control were predicted to have better attentional resource allocation strategies than their low self-control counterparts. While results showed no performance advantage of either group, a greater decrement in CBFV for the low self-control group was observed. This suggests more efficient use of attentional resources by individuals with high self-control to maintain the same performance level. Year 5 studies will further test this theory using behavioral methods that are designed to deplete the self-control resource to determine whether self-control is indeed a potential mechanism underlying vigilance decrement

The second study, which is ongoing, is a feasibility demonstration of a new hemodynamic measure that can be used to measure cognitive load during vigilance tasks, functional Tissue Pulsatility Imaging (fTPI). While TCD is cost effective, unobtrusive, and quick to apply, it does have its limitations. Since TCD records blood flow of individual arteries during data collection, it has low spatial resolution. While the low backscatter of blood reduces spatial resolution, measuring brain tissue can circumvent this issue. fTPI overcomes the limitations of the low ultrasound backscatter of blood by using ultrasound to measure the displacement of brain tissue caused by blood flow. Since this method measures tissue, which has higher backscatter than blood, tissue from specific regions of the brain can be viewed and analyzed. Prior research has shown that fTPI can detect changes in tissue pulsatility caused by stimuli such as rotating checkerboard patterns. However, fTPI has yet to be linked to performance and utilized in human factors research, and the goal of this study was to test the feasibility of fTPI for measuring workload in behavioral tasks. In a feasibility demonstration from 8 participants, fTPI data was recorded separately for each hemisphere for both a low event rate and high event rate 10 minute vigil, totaling four 10 minute vigils during the task. Tissue velocity measured through fTPI showed significantly more tissue velocity in the right hemisphere, which is supported by previous TCD research. Further, fTPI results suggest that workload for the right hemisphere was higher for the high event rate task as compared to the low event rate task. The similarities between the tissue velocity results and previous TCD research support fTPI as a viable method for obtaining higher spatial resolution measures of mental workload. Year 5 efforts will continue along this line to further validate the feasibility of fTPI for examining cognitive load.

The final study in year 4 continues the collaborative work conducted by Victor Finomore (WPAFB) and Tyler Shaw (GMU) that has explored new display and presentation methods to enhance warfighter communication. It is well known that effective communication is critical to military operations as these missions require real-time planning, coordination, and messages transmission to a number of operators to ensure mission effectiveness. To improve our warfighter's communication effectiveness, researchers in the Air Force Research Laboratory have developed a network-centric multi-modal communication monitoring suite (MMC). Previous CENTEC work has showed an advantage of this tool compared to monaural radio and chat tools, and attenuation of workload for the MMC as indexed by TCD. Further, a previous CENTEC study has shown that workload is attenuated in well-experienced observers, though performance advantages for experienced operators were not observed. It is possible, however, that experienced observers had available resources to process other information. The goal of this investigation was to determine whether or not performance advantages could be observed with the MMC in experienced observers in multi-tasking environments, above and beyond monaural radio and chat communication performance. Eleven participants were engaged in a multi-tasking environment in which they had to monitor 8 communication channels for the presence of critical phrases while simultaneously performing a compensatory tracking task. Results indicated that the use of the

MMC display resulted in superior performance in communication monitoring, and outperformed the chat display for the tracking task. This evaluation aids in the testing and development of this newly developed multimodal communication management suite. A portion of year 5 efforts will determine the extent to which this effect is also observed with novices.

5.2 Training

This project funded one Ph.D. student, Kelly Satterfield, who has taken the lead on projects evaluating the workload of the MMC and redundant displays and has been instrumental in facilitating the collaborative efforts between Tyler Shaw, Victor Finomore, and Greg Funke. A fourth year Ph.D. student Raul Ramirez has been carrying out studies further examining the vigilance/CBFV relation, including exploring cerebral hemodynamics with other noninvasive ultrasound techniques, such as Tissue Pulsatility Indexing (mentioned above). Arielle Mandell has worked on projects examining individual differences in physiological response to vigilance tasks.

5.3 Collaborative Activities

The following collaborative activities with AFRL scientists took place over Year 4.

- A joint publication between WPAFB scientists Michael Dillard, Greg Funke, Victor Finomore and Joel Warm and GMU CENTEC faculty Tyler Shaw and Raja Parasuraman to the peer-reviewed journal *Human Factors*.
- A joint publication between GMU CENTEC faculty Tyler Shaw and WPAFB scientist Victor Finomore and Joel Warm in the peer-reviewed journal *Ergonomics.*
- Two proceedings papers between AFRL Victor Finomore and GMU CENTEC faculty Tyler Shaw on issue related to communication displays.
- Collaborations between Greg Funke (WPAFB) and Tyler Shaw (GMU) examining neurophysiological indices of shared situation awareness.
- Ongoing discussions with AFRL scientist Joel Warm, Greg Funke, and Victor Finomore.

6. Project 6: Training the Brain (Greenwood, Parasuraman)

Over the past 4 years, Project 6 has investigated the training of mind and brain in ways that support the Air Force mission of enhanced human effectiveness in air, space, and cyberspace operations. We have investigated methods to heighten cognitive functioning, but also methods to strengthen brain infrastructure, specifically white matter integrity and functional connectivity. Importantly, we have assessed cognitive training methods for effects on transfer of training to everyday functioning. In Year 4, our efforts were focused on non-invasive brain stimulation to (1) test our neurocognitive hypothesis of the role of the dorsal attention networks in transfer of cognitive training (Exp. 1); (2) examine costs in addition to the benefits of brain stimulation (Exp 2); (3) determine whether dual-task performance is heightened more effectively by part-task training or by non-invasive brain stimulation (Exp. 3); (4) determine effects of stimulation on long-term retention of multi-task learning; (5) determine immediate effects of brain stimulation during implicit and explicit learning on functional connectivity in dorsal and ventral attention networks; (6) investigate the effects of tDCS on multi-object attentional tracking (Exp. 4), and (7) examine whether tDCS can ameliorate the negative effects of interruptions on complex task performance (Exp. 5).

6.1 Research

Exp 1. Transcranial Direct Current Stimulation Alters Brain Functional Connectivity After Four Days of Cognitive Training (Cisler et al., Society for Neuroscience, 2014).

Figure 6.1. fcMRI Group x Time interaction, Connectivity between SPC seed and lateral occipital

One goal of cognitive training is to improve the neural infrastructure of the brain to support far transfer to untrained abilities. Based on our recent finding of changes in structural and functional connectivity (fcMRI) in the dorsal attention network after perception training (Strenziok et al., 2014), we hypothesized that training-related regional increases in connectivity would vary with the training task. Participants were randomly assigned to 4 days of adaptive working memory training during either 2 mA or sham tDCS to right parietal (cathode on left arm). Transfer to reasoning was stronger in the tDCS group (Wilks' lambda, $p=.048$). Whole-brain seed-based correlation analysis using a superior parietal cortex (SPC) seed showed a Group x Time interaction ($p< .05$) in lateral occipital cortex. Every person in the tDCS group showed a decrease in fcMRI from pre-to post-training while every person in the sham group showed an increase (Figure 6.1). This extends our previous finding by showing that the brain can be rapidly remodeled with training (within 4 days) in a manner that (a) involves the dorsal attention network, (b) is very specific to the training task, and (c) is related to far transfer of training.

Exp 2. Transcranial Direct Current Stimulation exerts costs as well as benefits in an airspace monitoring multi-task (Scheldrup et al., Society for Neuroscience, 2014)

Cognitive multi-tasks (e.g., airspace monitoring) can be difficult to perform well. Based on evidence that tDCS-induced suppression of explicit learning benefits implicit learning (McKinley et al., 2012), we hypothesized that during a multi-task an implicit learning subtask would benefit from a tDCS cathode over right dorsolateral prefrontal cortex (dlPFC) while an explicit learning subtask would benefit from a tDCS anode over right dlPFC. Participants performed the dual-task Warship Commander (DARPA Augmented Cognition Research Group) for 20 min during random assignment to either a) F4 anode tDCS; b) F4 cathode tDCS (both 2mA); or c) sham (.1 mA) on the first, training day. Participants returned the second, retention day for a 20 min block without tDCS. Errors on Airspace Monitoring (identify incoming planes as friend or foe and take appropriate action) were reduced over games in the anode, but not the cathode, group compared to sham stimulation (Fig. 6.2, $p=.036$). Ship Status performance (remember and report on ship maintenance) was also slowed in the anode group compared to both sham and cathode groups ($p=.002$). This shows a benefit of the dlPFC anode montage for the implicit task (Airspace Monitoring), but a cost of that benefit for the explicit task (Ship Status). These findings show that tDCS can induce both costs as well as benefits on performance, but these are not easily predicted.

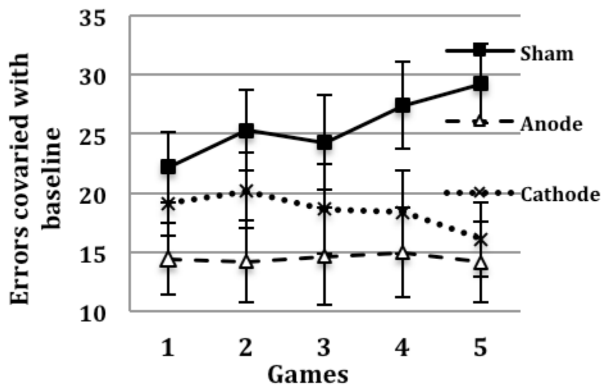

Fig. 6.2 Airspace monitoring errors.

Exp 3. Facilitating cyber defense performance: cognitive pretraining vs. direct current stimulation pretraining (Clayton et al., Society for Neuroscience, 2014).

Cyber defense operators detect anomalies in networks that were missed by automatic software -- critical for protecting military and government assets from theft and disruption. We hypothesized that part-task pretraining would have more specific effects on subsequent cyber defense performance than tDCS pretraining. We tested this with the Cyber Defense Task multi-task (CDT). Prior to CDT performance, participants were randomly assigned to 30 min of pretraining: (a) 2 mA tDCS anode over left prefrontal cortex (F3); (b) 2 mA tDCS anode over right parietal cortex (P4); (c) working memory; (d) visuospatial attention; (e) sham training/sham tDCS (.1 mA). Nonparametric signal detection metrics revealed the best CDT performance followed the prefrontal tDCS pretraining and the worst performance followed the working memory pretraining (Fig 6.3, p=.057). Contrary to our hypothesis, tDCS pretraining was superior to cognitive pretraining for improving signal detection in a simulated cyber defense task. Overall, tDCS benefited multi-task performance while part-task pretraining did not, suggesting strong and specific benefits of tDCS.

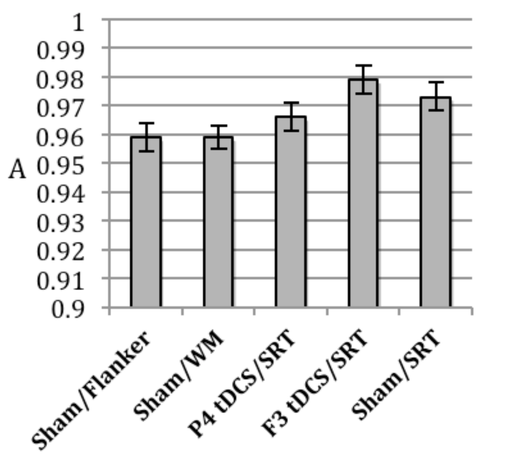

Figure 6.3. CDT signal detection performance (A) following pretraining.

Exp. 4. Effects of tDCS to anterior intraparietal sulcus on multi-object attentional tracking (Blumberg, Foroughi, Peterson, & Parasuraman, submitted to *Attention, Perception, and Psychophysics*).

Multiple object tracking (MOT) is a complex task recruiting a distributed network of brain regions. There are marked individual differences in MOT performance and specific training regimens, such as videogame practice, can enhance MOT performance, but these methods are very time consuming and require high levels of motivation.

This study focused on whether MOT training could be accelerated by non-invasive stimulation of brain areas involved in MOT performance. Active anodal stimulation was applied to the right anterior intraparietal sulcus (AIPS), an integral region in the MOT attention network and the left dorsolateral prefrontal cortex (and sham stimulation), an area associated with working memory (but not MOT) while participants completed a MOT task. Stimulation to the right AIPS significantly improved MOT accuracy more than the other two conditions. The results support the hypothesis that the AIPS has a causal relationship with MOT and that tDCS has the ability to improve MOT accuracy.

Exp. 5. Reducing the Disruptive Effects of Interruptions with Noninvasive Brain Stimulation (Blumberg, Foroughi, Scheldrup, Peterson, Boehm-Davis, & Parasuraman, submitted to *Human Factors*).

This study involved a within-CENTEC collaboration with Project 3, Interruptions and Multitasking. Interruptions are common and disruptive. Working memory capacity has been shown to predict resumption lag (i.e. time to successfully resume a task after interruption). Given that tDCS applied to brain areas associated with working memory can enhance performance, tDCS has the potential to improve resumption lag when a task is interrupted.

Participants were randomly assigned to one of four groups that received anodal (active) stimulation of 2mA tDCS to one of two target brain regions, left and right dorsolateral prefrontal cortex (DLPFC), or to one of two control areas, active stimulation of the left primary motor cortex or sham stimulation of the right DLPFC, while completing a financial management task that was intermittently interrupted with math problem solving. Anodal stimulation to the right and left DLPFC significantly reduced resumption lags compared to the control conditions (sham and left motor cortex stimulation). Additionally, there was no speed-accuracy tradeoff (i.e., the improvement in resumption time was not accompanied by an increased error rate). The results show that noninvasive brain stimulation can significantly decrease resumption lag (improve performance) after a task is interrupted.

In Year 5 of this project, we will complete the current projects, including other work not described in this report. That includes a study of long-term effects of tDCS on retention of Space Fortress training, a study of the short-term effects of tDCS on MRI-measured functional connectivity in the context of implicit and explicit task acquisition, and a study on the effects of episodic memory training on epigenetic changes in DNA methylation.

6.2 Training

Maren Strenziok continued as a post-doctoral fellow working on the MRI and cognitive training studies. Doctoral student Melissa Scheldrup has completed two studies of tDCS in complex task acquisition (currently under review) and has begun another study looking at costs and benefits of tDCS on task acquisition (Exp 2). Kevin Schmidt, a student in the Masters Program in Human Factors and Applied Cognition is working on a study of the effects of episodic memory training on dynamic changes in DNA methylation. Dean Cisler, another student in the Masters program, is conducting a study on effect of tDCS during working memory training on functional connectivity (Exp 1). Ryan McGarry has found evidence that event-related potentials

(ERPs) reflect attentional gradients around the target of visual search. We plan to use perceptual training to modulate those gradients in order to speed visual search.

6.3 Collaborative Activities

During Year 4 we met at AFRL, Dayton with Andy McKinley of the Human Effectiveness Directorate and hosted him at GMU for meetings. We have monthly phone calls to discuss research progress. We have continued our collaborative relationship with Marom Bikson of CUNY. He has modeled the electrical field for our tDCS stimulation montages and we are working with him in a new study of the immediate effects of tDCS on functional connectivity in the context of implicit and explicit learning.

Project 7: Computational Modeling of Vigilance (Trafton)

This project was formally admitted into CENTEC in 2013-2014, following previous related collaborative work on vigilance between several researchers at GMU (Trafton, Parasuraman, Shaw) and at AFRL (Gunzelmann, Warm, Greg Funke). The goal of the project is advance our knowledge of the mechanisms of human operator vigilance through computational modeling.

7.1 Research

During year 4, a series of vigilance studies have been performed. The primary novel component to these studies has been that operator's eye-movements have been tracked while performing a sustained attention task. Performance on virtually all sustained attention tasks can be captured by three rules that are repeated:

1) Attend to an unattended stimulus
2) Decide if the stimulus is a critical stimulus
3) If the stimulus is critical, respond accordingly (or ignore if non-critical)

Interestingly, operator's eye movements suggest that there is a cascade effect where the last two rules are the least impacted by sustained attention and the first rule is the most impacted. This empirical finding is predicted and explained elegantly by a new theory of sustained attention called the Reward Model.

The reward model of sustained attention has been developed using the ACT-R computational cognitive architecture. It posits that people feel a small sense of accomplishment when they find a critical stimulus, and this accomplishment rewards and strengthens previous rules that have contributed to the success of finding the stimulus. In essence, a reward is propagated backward in time via temporal-difference learning using an elaboration of the Rescorla-Wagner learning rule. This backward propagation leads to rules furthest away from the critical stimulus receiving the least amount of reward. According to the model, rules that do not receive enough reward will sometimes not fire, leading to a prediction that attending to the critical stimulus will be the first aspect of sustained attention to fail. This finding was confirmed in the empirical study in which vigilance performance was assessed for both short (400 ms) and long duration (800 ms) signals. A model match to data is included in Figure 7.1 (lines are empirical data; points are model fits).

The model provides quite a good R^2 (.96 and .64) and RMSD (.03 and.04). This finding is currently being written up for publication.

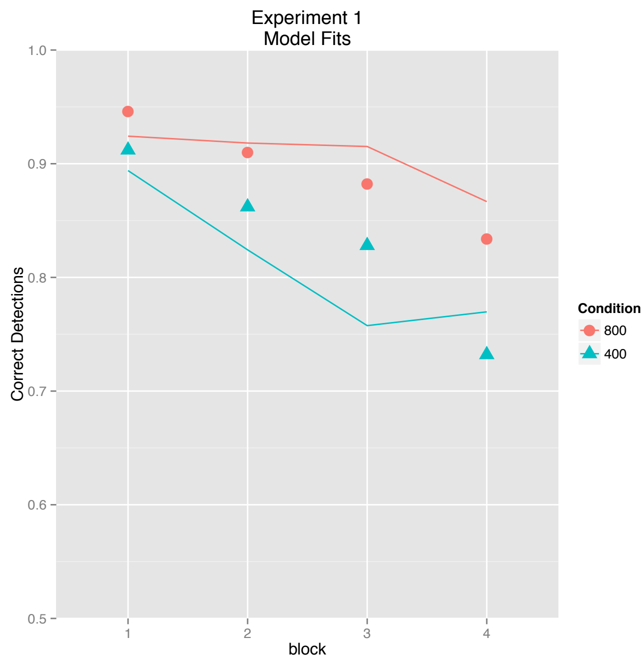

Figure 7.1 Effects of stimulus duration on vigilance performance, with Reward Model fits.

7.2 Training

Two doctoral students, one masters student, and six undergraduate students have been working with Dr. Greg Trafton during the last year, with a focus on computational modeling and sustained attention.

7.3. Collaborative Activities

This year we have had a close collaboration with AFRL, especially Dr. Glenn Gunzelmann and Dr. Kevin Gluck. We have worked with Dr. Gunzelmann to develop a model that explains the signal duration effect in sustained attention tasks (performance declines at a faster rate as signal duration decreases). This work uses Dr. Gunzelmann's theory of fatigue and was co-developed with Dan Gartenberg while he was working with Dr. Gunzelmann's group last summer during an internship program. Dr. Gunzelmann is also on Mr. Gartenberg's dissertation committee, along with CENTEC co-PIs Raja Parasuraman and Tyler Shaw.

Jorge Zuniga, a student working with Dr. Trafton also worked with Dr. Kevin Gluck last summer after he was awarded a Repperger internship fellowship.

8. **Publications and Presentations 2013-2014**

CENTEC faculty and AFRL scientists are shown in **bold**. Joint GMU/AFRL co-authored articles and presentations are shown in yellow highlight)

8.1 Summary

Peer-Reviewed Journal Articles: **27**
Journal Articles Submitted: **6**
Conference Proceedings and Presentations: **46**
Books and Book Chapters: **7**
Joint GMU/AFRL Journal Articles and Submissions: **6**

8.2 Peer-Reviewed Journal Articles

1. **Ascoli GA,** Botvinick M., Heuer R., Bhattacharyya R.(2014). Neurocognitive models of sense-making. *Biologically Inspired Cognitive Architectures, 8*:82-89.
2. Ahmed, N., de Visser, E., Shaw, T., Mohamed-Ameen, A., Campbell, M. A., & **Parasuraman, R.** (2014). Predicting human-automation performance in networked systems using statistical models: The role of working memory capacity. *Ergonomics, 53,* 295-318. http://dx.doi.org/10.1080/00140139.2013.855823.
3. Ayaz, H., **Parasuraman, R.,** McKendrick, R. A., Izzetoglu, K., Shewokis, P., & Onaral, B. (2013). Continuous monitoring of brain dynamics during cognitive skill acquisition with functional Near Infrared Spectroscopy: Empirical examples and a technological development. *Frontiers in Human Neuroscience*, 7, doi: 10.3389/fnhum.2013.00871.
4. Buzzell, G. Roberts, D. **Baldwin, C. L.,** McDonald, C. (2013). Electrophysiological Indices of Spatial/ Semantic Conflict in the Auditory Modality: Effect of Individual Differences in Navigational Strategy. *International Journal of Psychophysiology. 90(2),* 265-271.
5. **Baldwin, C. L.,** and Lewis, B. A. (2014). Equating Perceived Urgency across Modalities within a Simulated Driving Context. *Applied Ergonomics.*
6. Barrow, J. & **Baldwin, C. L.** (in press). Verbal-spatial facilitation and conflict in rapid spatial orientation tasks. Human Factors.
7. Clark, V., & **Parasuraman, R.** (2014). Enhancing brain and mind in health and in disease. *NeuroImage, 85*, 889-894.
8. Coffman, B. A., Clark, V. P., & **Parasuraman, R.** (2014). Battery powered thought: Enhancement of attention, learning, and memory in healthy adults using transcranial Direct Current Stimulation. *NeuroImage, 85*, 895-908. dx.doi.org/10.1016/j.neuroimage.2013.07.083.
9. Foroughi, C. K., Werner, N. E., Nelson, E. T., **Boehm-Davis, D. A**. (2014). Do interruptions affect quality of work? *Human Factors, 56.*
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11. Gonzalez, C. A. and **Baldwin, C. L.** (in press). Effects of Pulse rate, Fundamental Frequency, and Burst Density on Auditory Similarity. *Theoretical Issues in Ergonomic Science.*
12. **Greenwood, P. M.,** Espeseth, T., Lin, M., Reinvang, I., & **Parasuraman, R**. (2014). Longitudinal change in working memory as a function of APOE genotype in midlife and old age. *Scandinavian Journal of Psychology, 55*, 268-277.
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14. Lewis, B. L., Eisert, J. L. **Baldwin, C. L**. (in press). Effect of tactile location, pulse duration and interpulse interval on perceived urgency. *Transportation Research Record*.
15. Matthews, G., **Warm, J.S., Shaw, T.H., & Finomore, V.S**. (2014). Predicting battlefield vigilance: a multivariate approach to assessment of attentional resources. *Ergonomics, 57,* 856-875.
16. McKendrick, R., Ayaz, H., Olmstead, R., & **Parasuraman, R**. (2014). Enhancing dual-task performance with verbal and spatial working memory training: Continuous monitoring of cerebral hemodynamics with NIRS. *NeuroImage, 85,* 1014-1026. dx.doi.org/10.1016/j.neuroimage.2013.05.103.
17. McKendrick, R., Shaw, T., de Visser, E., Saqer, H., Kidwell, B., & **Parasuraman, R.** (2014). Team performance in networked supervisory control of unmanned air vehicles: Effects of automation, working memory and communication content. *Human Factors, 56*, 463-475. doi: 10.1177/0018720813496269.
18. Mehta, R., & **Parasuraman, R.** (2013). Neuroergonomics applications in physical and cognitive work: A review and discussion. *Frontiers in Human Neuroscience, 7*, doi: 10.3389/fnhum.2013.00889.
19. Mehta, R., & **Parasuraman, R.** (2014). Effects of mental fatigue on development of physical fatigue: A neuroergonomics approach. *Human Factors, 56*, 645-656.
20. Nelson, J. T., **McKinley, R. A**., Golob, E. J., **Warm, J. S., & Parasuraman, R**. (2014). Enhancing vigilance in operators with prefrontal cortex transcranial direct stimulation. *NeuroImage, 85*, 907-917. dx.doi.org/10.1016/j.neuroimage.2012.11.061.
21. **Parasuraman, R., & McKinley, A. R**. (2014). Using non-invasive brain stimulation to accelerate learning and enhance human performance. *Human Factors, 56.*
22. **Parasuraman, R.,** Kidwell, B., Olmstead, R, Lin, M-K., **Jankord, R., & Greenwood, P.** (2014). Interactive effects of the COMT gene and training on individual differences in supervisory control of unmanned vehicles. *Human Factors, 56,* 760-771.
23. Roberts, D. M. Fedota, J. R., Buzzell, G. A, **Parasuraman, R.,** & McDonald, C. G. (2014). Prestimulus oscillations in the Alpha band of the EEG are modulated by the difficulty of feature discrimination and predict activation of a sensory discrimination process. *Journal of Cognitive Neuroscience, 26*, 1615-1628.
24. **Strenziok, M., Parasuraman, R.,** Clarke, E., Cisler, D.S., **Thompson J.C.,** & **Greenwood P.M.** (2014). Neurocognitive enhancement in older adults: Comparison of three cognitive training tasks to test a hypothesis of training transfer in brain connectivity, *NeuroImage, 85,* 1027-1039. DOI: 10.1016/j.neuroimage.2013.07.069.
25. **Parasuraman, R.,** Kidwell, B., Olmstead, R., Lin, M.-K., **Jankord, R., Greenwood, P.M.** (2013). Interactive Effects of the COMT Gene and Training on Individual

differences in supervisory control of unmanned vehicles. Human Factors, DOI: 10.1177/0018720813510736.

26. Parekh R., & **Ascoli GA**. (2014). Quantitative investigations of axonal and dendritic arbors: development, structure, function and pathology. *The Neuroscientist,* In Press (2014).
27. **Strenziok, M., Greenwood, P. M., Thompson, J.C., Parasuraman, R.** (2013) Differential contributions of dorso-ventral and rostro-caudal prefrontal white matter tracts to cognitive control in healthy older adults. *PLoS ONE 8*(12):e81410. doi: 10.137

8.3 Journal Articles Submitted

1. **Baldwin, C. L.,** May, J. F., & **Parasuraman, R.** Motor Vehicle Crashes Due to Task-Induced Fatigue in Young and Older Drivers: Mitigation with Auditory Forward Collision Warnings. Submitted to *International Journal of Human Factors and Ergonomics*.
2. Blumberg, E., Peterson, M. S., & **Parasuraman, R.** Enhancing multiple object tracking performance with noninvasive brain stimulation: A causal role for the anterior intraparietal sulcus. Submitted to *Attention, Perception, and Psychophysics*.
3. Blumberg, E., Foroughi, C., Peterson, M. S., **Boehm-Davis, & Parasuraman, R**. Reducing the disruptive effects of interruptions with noninvasive brain stimulation. Submitted to *Human Factors*.
4. McKendick, R., & **Parasuraman, R.** Variable priority training combats intuitive "cognitive laziness." Submitted to *Acta Psychologica*.
5. Monge, Z., **Greenwood, P.M., Parasuraman, R., Strenziok, M**. Individual differences in reasoning and visuospatial attention are associated with prefrontal and parietal white matter tracts in healthy aging. Submitted to *Neuropsychologia*.
6. Scheldrup, M., **Greenwood, P.M.,** McKendrick, R., Strohl, J., Bikson, M., Alam, M., **McKinley,** R., **Parasuraman, R**. Transcranial direct current stimulation facilitates cognitive multi-task performance differentially depending on anode location and subtask. Submitted to *Frontiers in Human Neuroscience.*

8.4 Conference Proceedings and Presentations

1. Arbaje, A.I., Werner, N.E., Nasarwanji, M.F., Leff, B.A., Gurses, A.P. (2014). Evaluation of healthcare professionals' information management during older adults' transitions from hospital to home care. *Association for Clinical and Translational Science 2014 Meeting,* Washington, DC, April 2014.
2. Arbaje, A.I., Werner, N.E., Leff, B.A., Gurses, A.P., Tanner, E. (2014). Identifying Information Management Challenges Faced by Home Healthcare Nurses Managing Older Adults' Transitions from Hospital to Home Care. *International Home Care Nurses Organization Conference,* Singapore, September 2014.
3. **G. Ascoli.** (2013). Hippocampus: from neurons to function. Sapienza Univ. Rome, Italy, June 2013.
4. **G. Ascoli.** (2013). Much ADO about BIG learning. HRL Colloquium, Malibu, CA, July 2013.
5. **G. Ascoli.** (2013). Neuroinformatics challenges (Symp. Brain Aging). SfN13, San Diego CA, November 2013.

6. **G. Ascoli.** (2014). Data sharing as a foundation of reproducible science. NSF Workshop, Arlington, VA, February 2014.
7. **G. Ascoli.** (2014). Neurocognitive models of training. ONR mtg, Arlington, VA, February 2014.
8. **G. Ascoli** (2014). Minimum metadata standards for neuromorphology. AAAS Symp. Data Sharing, Washington DC, March 2014.
9. **G. Ascoli,** & M. Mainetti. (2014). Much ADO about BIG learning. *HHMI Neural Maps*, JFRC, April 2014.
10. **G. Ascoli.** (2014). Computing with a Periodic Table of the Neurons. *Joint Symp. Neur. Comp.,* Irvine, CA, May 2014.
11. **G. Ascoli** (2014). Neuroscience data sharing. *BRAIN Mtg, US Presidential Bioethics Commission*, Atlanta, GA, June 2014.
12. **G. Ascoli** (2014). Digital neuroanatomy. Symp. Adapting Brain, Keystone, CO.
13. **Baldwin, C. L.** (2013). Auditory Cognition: Individual Differences in Navigation & Auditory Spatial Perception. *Invited Colloquium presented at Benares Hindu University*. (February 2013: Varanasi, India).
14. **Baldwin, C. L**. (2013). Individual Differences in Auditory Spatial Perception. *Invited Colloquium presented at University of Pennsylvania, Computer Science Laboratory.* (March 2013: Philadelphia, PA).
15. **Baldwin, C. L.** (2014). Invited address entitled, "Individual Differences In Change Deafness: Implications For Display Design" presented at the Sonic Information Design Workshop. Held in conjunction with the *annual meeting of the International Community of Auditory Display*. (June, 2014, New York City).
16. **Baldwin, C. L**., Roberts, D. M., Buzzell, G. A., Sin, B. M.*, Jesso, M**., Simpson, B. D, &** **Iyer, N**. (2014). Individual Differences in Change Deafness: Verbal Cognitive Style Aids Detection. *Proceedings of the Cognitive Neuroscience Society.* (April, 2014: Boston, MS).
17. Cisler, D., **Strenziok, M., Parasuraman, R. Greenwood, P.M.** (2014). Intensive working memory training transfers to everyday functioning and alters connectivity between the dorsal and ventral attention networks. Society for Neuroscience.
18. Clayton, E., Cisler, D., **McKinley, R.,** Bikson, M., **Greenwood, P.M., Parasuraman, R.** (2014). Comparison of cognitive training vs transcranial Direct Current Stimulation on performance of a "Cyber Defense" multi-task. Society for Neuroscience.
19. Eisert, J., Garcia, A., Payne, J. J., & **Baldwin, C. L.** (2013). Tactile Route Guidance Performance and Preference. *Proceedings of the Human Factors and Ergonomics Society 57th Annual Meeting.* Santa Monica, CA: Human Factors and Ergonomics Society.
20. Finomore, V., Rahill, K.M., Satterfield, K., & **Shaw, T. H.** (2014). Best of Both Worlds: Evaluation of Multi-Modal Communication Management Suite. *Proceedings of the Human Factors and Ergonomic Society*, USA, 58.
21. Foroughi, C. K., Werner, N. E., Nelson, E. T., **Boehm-Davis, D. A.** (2013). Do Interruptions Affect Quality of Work? *In Proceedings of the Human Factors and Ergonomics Society Annual Meeting. 57,* 154-157.
22. Foroughi, C. K., Werner, N. E., Hatcher, M. C., Lopez, A. J., Zafar, T. W., & **Boehm-Davis, D.** A. (2014). Do Interruptions Affect Content Production? In *Proceedings of the 58th Human Factors and Ergonomics Society Annual Meeting.*

23. Garcia, A., Eisert, J., **Finomore, V.,** & **Baldwin, C. L.** (2013). Comprehension of vibrotactile route guidance cues. *Proceedings of the Human Computer Interaction International conference.* (July 2013, Las Vegas, NV).
24. Garcia, A., Eisert, J., Payne, J., **Baldwin, C. L., & Finomore, V.** (2013). Individual differences in perception of advanced navigation systems and their influence on route learning. *Proceedings of the International Symposium of Aviation Psychology*. (May, 2013: Dayton, OH).
25. R. Gardner, **G. Ascoli,** et al.: Place & response navigation in dual-solution task. *HRL Colloquium,* 2013.
26. Gartenberg, D., Veksler, B., **Gunzelmann, G**., & **Trafton, J. G**. (2014). An ACT-R process model of the signal duration phenomenon of vigilance. In *Proceedings of 58th annual meeting of the Human Factors and Ergonomics Society.*
27. Gonzalez, C. A., & **Baldwin, C. L.** (2013). Effects of Pulse rate, Fundamental Frequency, and Burst Density on Auditory Similarity. *Proceedings of the Human Factors and Ergonomics Society 57th Annual Meeting.* Santa Monica, CA: Human Factors and Ergonomics Society.
28. D. Hamilton, **G. Ascoli**, et al. (2013). Machine-readable hippocampal neuron properties. *Neuroinformatics Conf.,* Stockholm, Sweden.
29. Kidwell, B., Miller, W., & **Parasuraman, R**. (2014). Automation complacency: Using non-invasive brain stimulation to change attention allocation. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *58*, 27 October-31 October.
30. Komendantov, **G. Ascoli,** et al.: Electrophysiological phenotyping of hippocampal neurons. *Society for Neuroscience* 2013.
31. **Iyer, N.,** Thompson, E., Romigh, G., **Baldwin, C. L. & Simpson, B.** (2013). Spatial attention in an auditory dual task. *Published Abstract in the Proceedings of the Cognitive Hearing Sciences Conference.* (June, 2013: Sweden).
32. S. Larson, **G. Ascoli,** et al.: The NeuroLex Neuron curation project. *Neuroinformatics Conf.,* 2013.
33. Lewis, B. A., Penaranda, B. N., Roberts, D. M., & **Baldwin, C. L.** (2013). Max brake force as a measure of perceived urgency in a driving context. *Proceedings of the Human Factors and Ergonomics Society 57th Annual Meeting.* Santa Monica, CA: Human Factors and Ergonomics Society.
34. Lewis, B. A., Penaranda, B. N., Roberts, D. M., & **Baldwin, C. L**. (2013). Effectiveness of Bimodal Versus Unimodal Alerts for Distracted Drivers. (June 2013, Bolton Landing, NY). *Proceedings of the Driving Assessment Conference*.
35. Mandell, A., Becker, A., & **Shaw, T.H.** (2014). The effect of neuroticism on vigilance performance: A Transcranial Doppler investigation. *Proceedings of the Human Factors and Ergonomic Society*, USA, 58.
36. Miller, W. D. & Bo**ehm-Davis, D. A**. (2013). Age-Related Differences in Positional Dispersion of Fixations in a Multitask Environment**.** *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 57,* 104-108.
37. Miller, W. D. & **Boehm-Davis, D. A.,** & Stanard, T. (2014). What Happens When You Can't Press Pause? The Effect Of Interruptions On Detecting Threats In A Simulated Closed-Circuit Television Surveillance Feed. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *58*, 27 October-31 October.

38. Nadler, E., Traube, E., Lerner, N., Jenness, J., Brown, T., **Baldwin, C**., Chiang, D., Forkenbrock, G. (2013). Development of Crash Warning Interface Metrics (CWIM). *Proceedings of the 23rd Enhanced Safety in Vehicles conference.* (May 27-30, Seoul, Korea).
39. Ramirez, R., Botteicher, V., **Shaw, T. H.,** Sikdar, S, **Parasuraman, R**. (2014). Exploring the feasibility of using functional Tissue Pulsatility Imaging to measure cognitive load during an abbreviated vigilance task. *Proceedings of the Human Factors and Ergonomic Society*, USA, 58.
40. C. Rees, G. Ascoli, et al. (2013). Neuron types to parse the function of connectomes. SfN13, San Diego CA.
41. Satterfield, K., Finomore, V., & **Shaw, T.H.** (2014). Using cerebral hemovelocity to measure workload in a complex vigilance task with display redundancy. *Proceedings of the Human Factors and Ergonomic Society*, USA, 58.
42. Scheldrup, M., Strohl, J., Vance, J., Walker, D., **Greenwood, P.M., Parasuraman, R.** (2013). Transcranial direct current stimulation exerts selective benefits on executive control in a complex task whether prefrontal or motor cortex is stimulated. Cognitive Neuroscience Society Annual Meeting.
43. Scheldrup, M., Vance, J., Glazier, S., Darmini, Y., **McKinley, R.A**., Parasuraman, R., Greenwood, P.M. (2014). Transcranial direct current stimulation and acquisition of a complex task; effect of stimulation timing during training. Cognitive Neuroscience Society Annual Meeting.
44. Scheldrup, M.R., Vance, J., **McKinley, R**., Bikson, M., **Parasuraman, R., Greenwood, P.M**. (2014). Transcranial Direct Current Stimulation differentially influences implicit and explicit memory in a multi-task. Society for Neuroscience.
45. D. Wheeler, **G. Ascoli,** et al. (2013). Morphological phenotyping of hippocampal neurons. Burroughs-Wellcome Conf., Fairfax, VA.
46. D. Wheeler, **G. Ascoli**, et al. (2103). An open-access knowledge base of neuronal properties for the rodent hippocampus. Burroughs-Wellcome Conf., Fairfax, VA.

8.5 Books and Book Chapters

1. **Boehm-Davis,** D., Durso, F., & Lee, J. (Eds.) (in press). *Handbook of human-systems integration.* Washington DC: American Psychological Association.
2. **Boehm-Davis, D. A**. (in press). Using task analysis and Computational Cognitive Models to Design and Evaluate Interfaces. In J. L. Szalma, M. Scerbo, R. Parasuraman, P. A. Hancock, & R. R. Hoffman (Eds.), *The Handbook of Applied Perception Research.*
3. **Parasuraman, R.,** & Mehta, R. (in press). Neuroergonomic methods for the evaluation of cognitive and physical work. In J. Wilson & S. Sharples (Eds.). *Evaluation of Human Work.* New York: CRC Press.
4. **Parasuraman, R.** (in press). Neuroergonomic perspectives on Human-Systems Integration: Mental workload, vigilance, adaptive automation, and training. In D. Boehm-Davis, F. Durso, and J. Lee (Eds.), *Handbook of Human Systems Integration.* Washington DC: American Psychological Association.

5. Rizzo, M., & **Parasuraman, R.** (2014). Applied perception and neuroergonomics. In Hoffman, R. R., Hancock, P. A., Parasuraman, R., Szalma, J. R., & Scerbo, M., *Handbook of Applied Perception.* New York: Cambridge University Press.
6. Werner, N., Cades, D. M., & **Boehm-Davis, D. A**. (in press). Multitasking and interrupted task performance: From theory to application. In M. Carrier, N.A. Cheever & L. Rosen (Eds.) *The Wiley-Blackwell Handbook of Psychology, Technology and Society*. Newark, NJ: Wiley-Blackwell.