George Mason University

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

Year 3 Progress Report

Submitted: July 14, 2013

Principal Investigator: Raja Parasuraman, George Mason University

Sponsored by:
Air Force Office of Scientific Research (AFOSR)
Arlington, VA 22033

Air Force Research Laboratory (AFRL)
Human Effectiveness Directorate
Wright Patterson AFB OH 45433-7801

Award No: FA9550-10-1-0385

Reporting Period: July 15, 2012 – July 14, 2013

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Executive Summary

Research, training, and scientific collaboration witnessed significant acceleration in the third year of the Center of Excellence in Neuroergonomics, Technology, and Cognition (CENTEC) at George Mason University (GMU). In particular, there was a substantial increase in the number of peer-reviewed publications featuring joint authorship between GMU and AFRL scientists. CENTEC is funded jointly by the Air Force Office of Scientific Research (AFOSR) and the Air Force Research Laboratory (AFRL). Program Managers are Dr. Jay Myung (AFOSR) and Dr. Scott Galster (AFRL). Dr. Jay Myung left AFOSR to return to his University position on May 31, 2013. The interim AFOSR Program Manager for CENTEC is Dr. Robert Bonneau.

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 3 of CENTEC, July 15, 2012 through July 14, 2013. 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. Trust in Automation and Cyberspace (Kennedy, Krueger, Parasuraman).
3. Computational Analysis of Neural Mechanisms of Learning and Memory (Ascoli).
4. Interruptions and Multi-Tasking (Boehm-Davis).
5. Multimodal Cognition (Baldwin).
7. Training the Brain (Greenwood, Parasuraman).

Note that the Project numbers differ from those in Year 2. Project 2, Trust in Automation and Cyberspace was discontinued in the middle of Year 3 and the activities within Project 4, Emerging Neuroimaging Technologies, were subsumed under Projects 1 and 7. 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 1-8. 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 Project areas, a number of other collaborative GMU-AFRL research activities are described in section 8.

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 2012-2013

1. A variant of the COMT gene was shown to interact with training in operator performance in supervisory control of multiple unmanned vehicles, such that those individuals with the highest skill acquisition following training (COMT Met allele homozygotes) could be identified. *Human Factors*, 2013, under review. (Raja Parasuraman, Project 1 Lead).

2. The Hippocampome.Org portal was released online. Quality control of the data content and functionality are actively being tested, but this resource already enables immediate access to a very large knowledge base of neuron types in the mammalian hippocampus. *Neuron*, 2013, *Nature Reviews Neuroscience*, 2013. (Giorgio Ascoli, Project 3 Lead).


5. Demonstrated the superiority of a redundant visual-auditory communications system (developed at AFRL) for mental workload management, as assessed by measures of cerebral blood flow velocity. *Ergonomics*, 2013. (Tyler Shaw, Project 6 Lead).


7. Complex auditory perception training (Brain Fitness) found to increase white matter integrity and transfer to everyday problem solving and reasoning. *NeuroImage*, 2013, under review. (Pamela Greenwood, Project 7 Co-Lead).
Awards and Honors

1. **Raja Parasuraman (Project 1 Lead)**, November 2012: Celebration of Scholarship Award for Directorship of CENTEC and Outstanding Professional Achievement and Dedication to George Mason University, College of Humanities and Social Sciences.

2. **Giorgio Ascoli (Project 3 Lead)**, January 2013: Nominated by the National Institutes of Health for the "Champions of Change" Award by the U.S. White House initiative in the "Open Science" section.

3. **Brian Falcone (Graduate Student)**, October, 2012: Received a travel grant from the Augmented Cognition Technical Group to attend the Human Factors and Ergonomics Conference, Boston, and present his paper “Comparative effects of first-person shooter video game experience and brain stimulation on threat detection learning.”

4. **Christian Gonzalez (Graduate Student)**, July 2012: International Community of Auditory Displays Outstanding Student Paper Award. Travel award and honorarium for participation in the invitation only ICAD Think Tank Consortium.
1. Project 1: Molecular Genetic and Neuroimaging Studies of Complex Cognition (Parasuraman)

1.1 Research

Three studies were carried out and completed in Year 3 in Project 1, all focusing on different aspects of executive function—its genetic and neural bases and how it can be best trained. Two studies were large-sample experiments, a behavioral genetic study with 105 participants, and a multiple session MRI study with 46 participants; the third was an ERP study with 16 participants. In addition, a number of other studies are ongoing. The three completed studies are described below.

In the previous year of this project we showed that two variants of the dopamine beta hydroxylase (DBH) gene, a functional gene affecting noradrenergic and dopaminergic activity in prefrontal cortex, are significantly associated with differences in the degree to which individuals exhibit bias in decision making with computerized aiding systems. Such aids can assist human decision makers in complex tasks but can impair performance when they provide incorrect advice that humans erroneously follow, a phenomenon known as “automation bias.” Participants were genotyped on two variants of the DBH gene, -1021 C/T (rs1611115) and 444 G/A SNP (rs1108580) and divided into groups of low and high DBH enzyme activity, where low enzyme activity is associated with greater dopamine relative to norepinephrine levels in cortex. Compared to those in the high DBH enzyme activity group, individuals in the low DBH enzyme activity group were more accurate in their decisions when incorrect advice was given and verified automation recommendations more frequently. Thus a gene that regulates relative prefrontal cortex dopamine availability, DBH, can identify those individuals who are less susceptible to bias in using computerized decision-aiding systems. This study was published in Parasuraman et al. (*PLoS One*, 2012).

Figure 1.1. The COMT gene and the Val158Met SNP.
In the current year we followed up and extended this research by examining whether another gene that regulates dopaminergic activity in prefrontal cortex, the Catechol-O-Methyltransferase (COMT) gene, is associated with decision making 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 105 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 1.2). 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 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

![Figure 1.2](image-url) Mean percentage of enemy targets destroyed for the Met/Met, Val/Met, and Val/Val groups as a function of training blocks.
Jankord of the Applied Neuroscience Branch at AFRL, is currently under review in the journal Human Factors.

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, such as videogame training, are not well understood. Such training methods have been the object of much current research because of their potential for enhancing cognitive performance, but whether such training transfers to other tasks or to real-world performance has not been established. Therefore, development of training methods that transfer broadly to untrained cognitive tasks (far transfer) requires understanding of the neural bases of training and far transfer effects.

Accordingly, in the second study carried out in Project 1, we used neuroimaging methods to test the hypothesis that far transfer after six weeks of cognitive training is associated with altered attentional control demands mediated by the dorsal attention network and trained sensory cortex. (This study was carried out in collaboration with Project 7, Training the Brain, and is also described in section 7). To increase participant motivation and compliance, cognitive training was embedded into three videogames. We randomly assigned 46 participants to six weeks of training on Brain Fitness (BF-auditory perception), Space Fortress (SF-visuomotor/working memory), or Rise of Nations (RON-strategic reasoning). Before and after training, cognitive performance, diffusion-derived white matter integrity, and functional connectivity of the superior parietal cortex (SPC) were assessed. We found the strongest effects from BF training, which transferred to everyday problem solving and reasoning and selectively changed integrity of occipito-temporal white matter associated with improvement on untrained everyday problem solving (see Fig. 1.3).

These results show that cognitive gain from auditory perception training depends on heightened white matter integrity in the ventral attention network. In BF and SF (which also transferred positively), a stronger decrease in functional connectivity between SPC and inferior temporal lobe (ITL) was observed compared to RON - which did not transfer to untrained cognitive function. These findings highlight the importance of top-down control of sensory processing by the dorsal attention network.
network in cognitive training. Altered brain connectivity—observed in the two training tasks that showed far transfer effects - may be a marker for training success. This study is currently under review in the journal *NeuroImage*.

The third 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. The occipital-temporal N1 component of the ERP has previously been shown to index a stimulus discrimination process. However, the N1 has not consistently been shown to be sensitive to the difficulty of stimulus discrimination.

Accordingly, in this study 16 participants performed a discrimination task requiring judgments of the orientation of Gabor patches. We manipulated the difficulty of stimulus discrimination by modulating the similarity between serially presented targets and non-targets. The same target stimulus was employed in both easy and difficult discrimination contexts, and these physically identical target stimuli elicited a larger N1 and smaller P3b in the difficult task context. Moreover, when targets were incorrectly categorized, N1 amplitude was diminished and a P3b was not elicited. These findings provide evidence that the N1 component reflects a sensory discrimination process that is modulated by executive control, and that this component can index discrimination errors when stimulus discrimination is difficult. This study was published in the journal *Psychophysiology* (Fedota et al., 2012).

Plans for Year 4 in Project Area 1 include the following: (1) Design and execution of a study examining the interaction between the COMT gene and cognitive training on performance of multi-UV tasks. (2) Complete analysis of an fMRI study examining attention-guided working memory. (3) Design and execute 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

Three postdoctoral fellows continued to work on studies in Project 1, Maren Strenziok (MRI), Ming-Kuan Lin (molecular genetics), and John Fedota (ERPs and fMRI). Dr. Fedota left GMU in May 2013 to take a position as a research scientist at the NIH. 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 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 3. 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 a journal article currently
under review in *Human Factors*. He has recently 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, is spending the summer at AFRL working on mouse genomics under the supervision of Ryan Jankord and will continue the collaboration when he returns to GMU in August 2013.

Meetings were also held with AFRL scientists Drs. Joel Warm, Ben Knott, Scott Galster, Andy McKinley, Matt Funke, and Greg Funke to discuss ongoing and planned research collaboration at the following conferences: Human Factors and Ergonomics Society Conference (October 2012); the Cognitive Neuroscience Society Conference (April 2013); and the International Symposium on Aviation Psychology (May 2013). Discussions were continued with scientific meetings at AFRL Dayton in August 2012 and February 2013. In addition, the CENTEC review at GMU in November 2012 afforded a number of opportunities for discussions between GMU scientists and AFRL scientists present.

2. Project 2: Trust in Automation and Cyberspace (Kennedy, De Jong, Krueger, Parasuraman) (Projected Discontinued in 2013).

2.1 Research

Feedback from the review of CENTEC research in November 2011 lead to a change in direction and Dr. William G. Kennedy and Dr. Kenneth De Jong were asked to join as co-Leads of Project 2 in January 2012, with the continuing involvement of Dr. Krueger and Dr. Parasuraman in support roles. The feedback from the November 2012 review advised discontinuing the project area. Activities that were in progress have been wrapped up in an orderly fashion with the completion of two accepted publications. At the spring symposium of the Association for the Advancement of Artificial Intelligence (AAAI), Dr. Kennedy presented a talk on the preliminary results of modeling the trust data that Dr. Krueger had collected. Similarly, a poster on the topic will be presented at the International Conference on Cognitive Modeling in Ottawa. For the most part, people were found to be trusting and cooperative but also seemed to be using a “tit-for-tat” strategy as well as initiating non-trusting and uncooperative behavior under some circumstances. Future research could investigate the individual differences or external circumstance for which people are less trusting and cooperative.

While this project area is being discontinued under CENTEC, related research on the neural mechanisms of trust is ongoing under separate AFOSR funding: “Neural Signatures of Trust during Human-Automation Interactions” (PI: Frank Krueger, co-PI: Raja Parasuraman, AFOSR PM: Joseph Lyons). This project compares the similarities and differences between neural signals of human-automation trust and human-human trust. The long-term goal is to develop a cohesive model explaining how the behavioral, cognitive, and neural bases of human-automation trust influence complex human-automation interactions by bridging the gap between basic human factors and social cognitive neuroscience research. A series of experiments are being conducted that combine a behavioral automated decision-aiding task with fMRI and manipulate human-automation interaction features such as reliability, benevolence, and etiquette. If the two forms of trust are fundamentally different, then they should be associated with different underlying neural systems. If they are the same, then the neural systems should be similar or very closely overlapping. A third possibility is that the two share the same neural systems but those systems
interact differently for the two kinds of trust. Importantly, behavioral measures alone are unlikely to allow one to distinguish between these possibilities, because the same behavioral outcome (e.g. an accurate choice or a speedy response) can be associated with very different underlying neural mechanisms. Assessing both performance and brain function can therefore provide more information than either alone.

2.2 Training

Dr. Kennedy taught a computational cognitive modeling class to 14 students in the spring 2013 (PSYC-768) some of who are working on CENTEC and USAF grants. The course featured the ACT-R architecture and students developed models of different cognitive functions working through the ACT-R tutorial, additional readings, and ongoing research. The work on modeling trust and vigilance was featured.

2.3 Collaborative Activities

Dr. Ewart de Visser, a former GMU graduate student and currently a research affiliate at GMU, had conducted the experiments on human-automation trust. He has continued to work on USAF research. This year, Dr. Visser also worked with Dr. Kennedy on developing a computational cognitive model of a user working with the supervisory control system he is developing with Perceptronics Solutions, Inc. This latter work was the basis for a grant proposal that was recently selected for funding by AFRL as a Phase II SBIR project.

Discussions were also held with Scott Galster regarding AFRL work on trust in automation and cyber systems. In particular, we have discussed the possibility with Scott Galster of using an AFRL cyber simulation platform for our studies on human trust in cyberspace. The results of this research would feed thrust areas in Autonomy (Priority Steering Council) and the emerging AFRL cyber portfolio with strong support by USCYBERCOM and the 24th AF.

3. Project 3: Computational Analysis of Neural Mechanisms of Memory (Ascoli)

3.1 Research

The principal thrust of Project 3 during the third year of performance continued to be directed at advancing the “Hippocampome”, a comprehensive knowledge base of neuron types in the mammalian hippocampus. The hippocampus is the brain region responsible for the consolidation and retrieval of autobiographic, episodic, declarative (conscious), and spatial memories. This effort aims to collect sufficient quantitative information about hippocampal neurons to create a real-scale neural network simulation with realistic connectivity and neuronal dynamics, which is a central focus of this CENTEC project.

In year 3 we released the first online version of the web portal, including the morphological, biophysical and molecular characterizations of neurons. A total of 122 neuron types were phenotyped throughout areas CA3, CA2, CA1, subiculum, entorhinal cortex, and dentate gyrus. This foundation allows the establishment of potential circuit connectivity by axon-dendrite overlap as well as estimation of relative abundance of each neuron and their typical electrophysiological behavior. We have also implemented in the interactive web page advanced user functionalities such as search and browse capabilities. The knowledge base is available for
perusal at http://hippocampome.org. Although this site only went live recently, it has already received over 600 hits.

As part of the launch and testing of Hippocampome.Org, we have also co-organized an international conference on hippocampus neuron types, together with leading researchers at UCSD, Oxford University, and the Medical University of Austria and full funding by the Howard Hughes Medical Institute. The conference was held in November 2012 at the Northern Virginia Janelia Farm Research Campus near George Mason University, and included (by invitation only) 50 of the foremost experts on hippocampus neuron types as well as a senior editor of the journal Neuron.

The plans for the Hippocampome in Year 4 include completion of the quality control of the existing data and an extensive analysis of these data. In particular, we plan to carry out a multiple correlation analysis among morphological, electrophysiological, and molecular properties as well as a quantitative connectivity analysis based on graph-theoretic network and motif analyses. During this year we also plan to submit the first dedicated publication(s) on this project.

An additional component of Project 3 relates to the measurement of autobiographic memories from human subjects. Specifically, we designed two tests, named SPAM (spontaneous probability of autobiographic memory) and CRAM (cue-recalled autobiographic memory) to quantify frequency of occurrence of memories and their content in terms of the number of details remembered. The first manuscript based on results from the local college student population (submitted for publication at the time of the last yearly report) has been published in PLoS One. We are continuing to collect results from adults and elderly subjects both with in-person interactions and an on-line interface (http://cramtest.info).

3.2 Training

This project supports one full time PhD student in Bioinformatics, Christopher Rees, who is engaged in the Hippocampome project. Moreover, partial tuition is provided for a second PhD student in biopsychology, Robert (Bob) Gardner, who is involved with the human memory study. Two additional graduate students are training with the Hippocampome team, but are not directly supported by CENTEC: David Hamilton, a neuroscience PhD student, and Sean Mackesey, a Bioinformatics Master student. Sean is graduating this year and has been admitted to the neuroscience doctoral program at Berkeley. Furthermore, we are training a number of undergraduate interns in the “FAcility for MIning the LIterature” (FAMILI). These graduate and post-graduate trainees all work under the supervision of Dr. Ascoli

3.3 Collaborative Activities

In Year 3 we have begun to provide collaborative training to Dayton Wright Patterson Air Force Base for their starting computational cognition effort funded under the Laboratory Research Initiation Request “Computational Modeling in the Biological Band: Integrating Computational Cognitive Neuroscience into the Human Effectiveness Directorate” (Task Manager: Tim Halverson, Program Manager: Jay Myung). Dr. Ascoli’s approved effort was 1.5 months/year for 3 years, but the budget has been severely reduced due to sequestration and funding constraints.

We are also continuing an ongoing collaboration with AFOSR (POC: Dr. Willard Larkin) for remote usage of the Wright Patterson AFB’s Cray XE6 (“Raptor”), the 18th fastest supercomputer in the world (with 43,712 CPU cores). Project Area 3 also continues to be highly...
relevant to our ongoing collaboration with the Dahlgren Naval Surface Warfare Center (NSWR) currently covered by an active Cooperative Research And Development Agreement (Giorgio Ascoli, Mason PI, David Marchette, NSWR PI).

Finally, several collaborative interactions of Project 3 are emerging within the CENTEC team. Cross-species and cross-modal analysis of hippocampal navigation is pursued with Raja Parasuraman (Project Area 1) and Jim Thompson under an ONR MURI. Our recent application for a substantive instrumentation supplement under the DURIP program has been selected for funding. We have also submitted a joint NSF proposal with Ken De Jong under the “Robust Intelligence” program (still pending).

4. Project 4: Interruptions and Multi-tasking (Boehm-Davis)

4.1 Research

Few of us have the luxury of working without interruptions of one sort or another. In most workplaces, jobs arrive independent of jobs already in the queue, workers need to consult with each other to pursue parallel work streams, and jobs are suspended when parts or information needed are not readily available. In short, interruption is the norm in almost all work environments. Although interruptions have been the focus of much research, the findings regarding their impact on performance have been incongruent. A majority of research has found interruptions to be disruptive to performance on a task, leading to an increased time on task and errors. However, other studies have pointed to interruptions as facilitating performance. Clearly, there are relationships that still need to be explored as well as mediating factors that may be determining these disparate outcomes.

During Year 3 of Project 4, we continued to collect data to inform the development of a model that will allow us to capture known relationships between characteristics of interruptions and performance outcomes. This work has gone in several directions. First, we continued our work on understanding the factors that allow people to manage interruptions more effectively over time. This research led to a recently completed doctoral dissertation which will be submitted shortly to a journal.

We also continued our work on understanding how interruptions affect the overall quality of work products. Most interruptions research has been focused on the time required to resume a task and errors made at the point of resumption. Further, most of this work has used tasks that do not require significant integration of information over time. However, many decisions or products that people care about in the workplace have this characteristic. 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. Last year, we discovered that interruptions either in the planning phase or the execution phase of a task affect the quality of the final product. We also found that interruptions during planning lead to different outcomes than interruptions during execution. A paper describing a portion this work will be presented at the upcoming Human Factors and Ergonomics conference; a paper describing all of this work should be under review at a journal by the end of the summer. In the next year, we will be conducting variations of
these studies to explore the robustness of the effect and to explore more deeply the underlying causes of the differences we saw between interruptions during planning versus execution.

Third, this year saw the completion of the initial pilot phase of a multi-part study 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 to 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. Stimulus generation is nearing completion and a software framework is already in place to start data collection immediately after the stimuli generation is completed. This work will be used to explore 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.

Finally, a paper describing our past work on how complexity of the interrupting task can be defined was submitted to an archival journal for review. Unfortunately, the paper was not accepted. We have taken the reviewers’ concerns into account and are currently revising the manuscript for submission to an alternate journal.

In the area of multitasking, we completed an examination of multitasking performance and eye-movement behaviors, with a particular interest in how the two are associated with age. 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 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. These findings have been accepted for presentation at the meeting of Human Factors and Ergonomics Society this fall, with additional analyses currently being conducted as we prepare for a journal publication.

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.

4.2 Training

Three doctoral students in the Ph.D. program in Human Factors and Applied Cognition, Erik Nelson, William (Bill) Miller and Nicole Werner, have been working under the supervision of Deborah Boehm-Davis over the past year. Both Erik and Nicole’s focus has primarily been on interruptions. In the past year, Erik completed his dissertation. 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. Additionally, Dr. Boehm-Davis has signed a new graduate student, Cyrus Foroughi, who will be starting this fall.

4.3 Collaborative Activities

During Year 3, 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), plans for future collaboration, and generation of deliverables are currently in progress. 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 a number of on-site visits by Bill Miller this past summer.

5. Project 5: Multimodal Cognition (Baldwin)

5.1 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 that 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. A programmatic line of experiments has 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 into 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 4 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.

5.2 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.

5.3 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.

6. Neuroadaptive Systems (Shaw)

6.1 Research

During year 3, a total of three studies have been completed. The focus of the research being conducted under project area 6 is on diagnostic monitoring of cognitive workload using Transcranial Doppler Sonography (TCD) to measure, classify, and predict performance capability for use in neuroadaptive systems. Previous research has shown that TCD 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 cerebral blood flow velocity (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 (e.g. Shaw et al., 2009). 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 (Helton et al., 2010; Shaw et al., 2012). Thus, bilateral increases in CBFV are also indicative of high workload. Four peer-reviewed journal articles and 1 proceedings paper have been published, while three additional articles have been submitted during this third year effort. It should be noted that 60% of all publications and submissions in project area 6 feature personnel from both GMU and WPAFB. Progress for year 3 is described below.

The first two studies were conducted to determine the extent to which TCD can be used to identify individual differences in workload response to simple and complex tasks. The first study examined individual differences in working memory (WM) capacity. Previous CENTEC work has shown that CBFV is sensitive to unexpected variations in task load while operators perform a remotely piloted vehicle (RPV) simulation. More specifically, the results indicated that as performance decreased during periods of high load, CBFV was increased, and there was a close parallel between the CBFV and performance measures in all experimental and comparison conditions (Shaw et al., 2010; 2012). Previous work has also shown that individuals high in WM perform superiorly in this RPV simulation (de Visser et al., 2009; McKendrick et al., 2013). It is thought that this performance advantage stems from superior executive control in individuals high in WM, especially in situations in which complex decisions are required. Of particular interest in the current study was the extent to which workload, as indexed by CBFV, was attenuated in high WM operators. This finding would indicate that those individuals with high WM capacity have superior resource allocation strategies. Thirty-five participants completed a spatial working memory assessment (SSPAN) followed by a subsequent 30-min RPA simulation that featured an unexpected increase in task load towards the end of the scenario. A median split was conducted to
classify low (SSPAN = 62%) and high (SSPAN = 83%) WM operators. The findings that CBFV is sensitive to task difficulty and that performance was superior in high WM operators were successfully replicated. More importantly, results indicated that low WM operators had a significantly higher increase in CBFV during periods of task load transition. These findings indicate that the CBFV measure can successfully diagnose resource allocation strategies in high and low WM operators.

The second study examined individual differences in extraversion during a simple discrimination vigilance task. In a review of over 50 studies, Koelega (1992) found that in general, the performance of introverts generally exceeds the performance of extroverts. Shaw et al. (2010) recently replicated this finding by showing that extraversion was an independent predictor of vigilance performance in a regression model, such that extraversion was negatively correlated to detection performance in a vigilance task. What is less clear is the mechanism driving this performance difference. Eysenck and Eysenck (1985) have proposed an explanation rooted in arousal theory, in which they proposed that introverts have superior control over a cortico-reticular loop controlling arousal and alertness. Since the repetitive and monotonous features of vigilance tasks reduce the level of stimulation, it could be inferred that extroverts are more susceptible to under-stimulation in a vigilance environment, thereby leading to performance impairment. A review by Parasuraman (1984), however, has shown that in general, the arousal account is insufficient in and of itself to explain deficits in vigilance performance. For example, neurophysiological studies have shown that a decrease in cortical arousal is not always associated with a decrement in performance.

In light of these findings, a newer interpretation of the suboptimal performance of extraverts links arousal to a central attentional control mechanism (e.g. Hockey, 1988). In this system, suboptimal arousal is compensated for by an increase in effort. Adopting this model, it is a reasonable conclusion that introverts adopt a superior attentional resource allocation strategy that would yield superior performance with less effort. Twenty-five participants performed a simple discrimination vigilance task. Twelve extraverts and thirteen introverts were identified based on their score on the extraversion dimension of the big five personality questionnaire (NEO-PI-R; Costa & McCrae, 1992). Results showed that while performance did not differ between introverts and extraverts, there was a significant hemisphere x personality interaction, such that only the right hemisphere was significantly different from baseline in the introversion condition, but that both hemispheres were increased from baseline in the extraversion condition. These results are consistent with previous findings that bilateral activation is indicative of increased task difficulty— to achieve the same level of performance extraverts had to recruit cognitive resources from both the left and right hemispheres of the brain, while introverts only had an elevation in CBFV for the right hemisphere.

The third completed study focused on evaluating new displays that could increase communication effectiveness during air battle operations. Command and Control (C2) operators are responsible for the real-time management of communications from multiple distributed teammates who are all accountable for different aspects of military missions. This communication-intensive environment imposes a high degree of mental workload on C2 operators, as it is typical for operators to monitor and transmit on eight or more simultaneous channels for prolonged periods of time (Bolia, 2003). Researchers at WPAFB are exploring and developing alternative means of message transmission and have developed the Multi-Modal Communication (MMC) suite designed to help improve communication intelligibility (Finomore et al. 2010). A study completed for last year’s effort examined the potential performance benefits
of spatializing communications during a 40-minute vigilance task. Results showed that performance was enhanced in the spatialized audio condition, and CBFV was elevated to a greater extent in the more demanding monaural radio condition as compared to the spatial audio condition. However, the decrement in the spatial audio condition was still observed. Another possibility is to implement redundant visual and auditory displays, and that formed the basis for this study. Thirty participants performed a 40-minute vigilance task in which they were required to detect critical messages from 6 communication channels. In a between subjects design, 10 participants participated in either a visual (chat) only condition, an auditory (spatialized) only condition, or a redundant visual/audio condition. Results showed that performance was not only superior in the redundant visual/audio condition, but this was the only condition in which the decrement was not observed. Importantly, CBFV was not significantly increased from baseline and the typical CBFV decrement in vigilance tasks was not observed in this condition. These findings highlight the gains that result from display redundancy and have implications as to how communication can be enhanced in field settings.

6.2 Training

Two doctoral students, Kelly Satterfield and Raul Ramirez, have been working on CENTEC related projects. Kelly Satterfield 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 and Victor Finomore at AFRL. Furthermore, Kelly Satterfield is interning at WPAFB this summer in the laboratories of Gregory Funke to foster a new collaboration (funded via CENTEC grant). Raul Ramirez has been carrying out studies further examining the vigilance/CBFV relation, including exploring cerebral hemodynamics with other noninvasive ultrasound techniques.

6.3 Collaborative Activities

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

- A joint publication between WPAFB scientists, Greg Funke, Victor Finomore and Joel Warm and GMU CENTEC faculty Tyler Shaw and Raja Parasuraman appeared in the peer-reviewed journal *Brain and Cognition*.
- A joint publication between GMU CENTEC faculty Tyler Shaw and WPAFB scientist Victor Finomore in the peer-reviewed journal *Ergonomics*.
- A joint publication between WPAFB scientists Victor Finomore and Joel Warm and GMU CENTEC faculty Tyler Shaw to the peer-reviewed journal *Human Factors*.
- A joint submission between WPAFB scientists Victor Finomore, Joel Warm, and Gregory Funke and GMU CENTEC faculty Tyler Shaw to the peer-reviewed journal *Human Factors*.
- A joint submission between WPAFB scientists Victor Finomore and Joel Warm and GMU CENTEC faculty Tyler Shaw to the peer-reviewed journal *Applied Psychology: Health and Wellbeing*.
- A joint project between AFRL scientist Victor Finomore and GMU CENTEC faculty Tyler Shaw examining the potential performance gains and workload attenuation that accompanies the use of redundant displays.
- Collaborations between Greg Funke (WPAFB) and Tyler Shaw (GMU) examining neurophysiological indices of shared situation awareness. Ph.D. student Kelly Satterfield is currently interning in the laboratory of Greg Funke.
- Ongoing discussions with AFRL scientist Joel Warm about new projects.

7. Project 7: Training the Brain (Greenwood, Parasuraman)

Over the past 3 years, Project 7 has investigated the training of mind and brain in ways that can support the Air Force mission of enhanced human effectiveness in air, space, and cyberspace operations. We have investigated not only ways to enhance cognitive functioning, but also methods to strengthen brain infrastructure, specifically white matter integrity and functional connectivity. In Year 3, our efforts were aimed at (a) examining the effects of working memory training on prefrontal cortex; (b) testing our neurocognitive hypothesis of the role of dorsal and ventral attention networks in successful transfer of training (Exp. 1, 2, 3); and (c) extending our finding that right hemisphere transcranial direct current stimulation (tDCS) benefits performance on a complex task (Exp. 4, 5). The tDCS studies are conducted in collaboration with Andy McKinley at Wright-Patterson AFB.

7.1 Research


The augmentation of human performance and its transfer to improved functioning at work or in everyday settings via alteration of underlying neurocognitive processes is a prime goal of neuroergonomics. Training to increase working memory capacity (WMC) represents one potential method for such neurocognitive enhancement. Individuals with high WMC have been found to exhibit superior focused visual attention (Engel, 2002) and enhanced supervisory control of unmanned aerial vehicles (de Visser et al., 2010; McKendrick et al., 2011). It is well established that repeated practice increases WMC, but whether such improvement transfers to other tasks, including higher functions required for work performance and for everyday functioning has been more difficult to show. It has been suggested that the use of complex span tasks, training on different variants of working memory, increased practice span length, and more liberal criteria for adaptive training advancement, are important factors for achieving the goals of WMC improvement and far transfer (Gibson et al., 2012).

Accordingly in this study, we had participants simultaneously perform two challenging verbal and spatial memory tasks for five sessions on separate days. Neuroimaging studies using MRI have shown that working memory training induces changes in brain function and structure, particularly in the dorsolateral prefrontal cortex. However, because of the high cost of MRI, most studies have used a pre- and post-training design, in which neurocognitive changes are assessed before and after training, so that only linear changes can be assessed. However, neural changes are likely to occur continuously and perhaps non-linearly throughout training. Therefore in this present study we examined changes in cerebral hemodynamics using near infrared spectroscopy (NIRS). Mixed effects models were used to model the changes in cerebral hemodynamic response as a result of time spent training working memory. Nonlinear increases in left dorsolateral prefrontal cortex (DLPFC) and right ventrolateral prefrontal cortex (VLPFC)
were observed with increased exposure to working memory training. Adaptive and yoked training groups also showed differential effects in rostral prefrontal cortex with increased exposure to working memory training. There was also a significant negative relationship between verbal working memory performance and bilateral VLPFC activation. These results indicate that working memory training leads to decreased proactive interference, increased neural efficiency, reduced mental workload for stimulus processing, and increased working memory capacity with training.

Experiment 2. Neurocognitive Enhancement: Comparison Of Cognitive Training Tasks To Test A Hypothesis Of Training Transfer (Strenziok et al., Neuroimage, under review).

Many studies have shown that cognitive training can enhance human performance and change brain function and structure. What is not clear, however, is whether such training transfers to other cognitive tasks or to work performance or everyday functioning. That is, the cognitive and neural mechanisms that facilitate far transfer are not well understood. We hypothesized that far transfer of training to real-world functioning requires altered connectivity between the dorsal attention network (Corbetta, Patel, & Shulman, 2008) and trained cortex. Accordingly, we tested this hypothesis in a study examining the effects of six weeks of cognitive training on one of three videogames (BF-auditory perception, Space Fortress, SF-visuomotor/working memory, or Rise of Nations, RON-strategic reasoning). This study was conducted in collaboration with Project 1, Genetic and Neuroimaging Studies of Complex Cognition, as previously described in that section. Before and after training, we assessed cognitive performance, diffusion-derived white matter integrity, and functional connectivity of the superior parietal cortex (SPC). Training benefits were strongest with auditory perception (BF) training, which (a) transferred to everyday problem solving and reasoning and (b) selectively changed white matter subserving ventral attention network (see Fig. 7.1) in a manner associated with improved everyday problem solving. These results indicate that benefits from auditory perception training depend upon white matter integrity in the ventral attention network. SF also transferred positively with decreased functional connectivity between SPC and inferior temporal lobe. RON strategy training showed neither far transfer nor connectivity change. These findings point to the importance for far transfer of training of (a) perception training and (b) top-down control of sensory processing by the ventral attention network (connectivity change).
Experiment 3. Does Direct Current Stimulation during Working Memory Training Increase Brain Functional Connectivity? (in progress)

One of the goals of cognitive training is to improve the neural infrastructure of the brain to support far transfer to untrained abilities. Previous studies have found that adaptive working memory (WM) training (a) transfers to non-verbal IQ (Jaeggi, Buschkuehl, Jonides, & Perrig, 2008), (b) increases the cortical extent of fMRI activation (Olesen, Westerberg, & Klingberg, 2004), and (c) alters dopamine D1 receptor binding (McNab et al., 2009). In Exp. 2 we found that transfer of training occurred in conjunction with changed white matter and functional connectivity (correlation in activity between different brain regions). Based on this, we hypothesized that WM training would alter both functional connectivity and effective connectivity (the top-down causal relationship found to develop between prefrontal and parietal cortices during attention (Bresler et al. 2008). We also hypothesized that prefrontal tDCS would heighten training-related changes in functional connectivity in a manner related to improved WM performance. Transcranial direct current stimulation (tDCS) applies 2 mA of DC current to the scalp. This technique appears to alter the threshold for neuronal firing of cortical neurons (Bikson et al., 2004) and is considered safe in healthy people for 30 minutes of stimulation (Bikson, Datta, & Elwassif, 2009). We randomly assigned either 2mA or sham tDCS for 30 min of each training session during 4 days of adaptive WM training with pre- and post-cognitive testing and scanning (fMRI, DTI).

Experiments 4, 5. Direct Current Stimulation to Right but not Left Hemisphere Speeds Learning of the Complex Space Fortress Task (Scheldrup et al., 2013).

There is a real need to develop ways to shorten the long training period needed for many complex real-world tasks. Based on our Exp. 2 finding that cognitive training alters connectivity between trained cortex and the ventral attention networks, we hypothesized that increased activation of this network would speed complex task acquisition. In Year 1 of Project 7, we showed that tDCS to inferior frontal areas heightened perceptual sensitivity but not response bias, with effects lasting at least 24 hours after stimulation ended (Falcone, Coffman, Clark, & Parasuraman, 2012). Experiment 4. We compared anodal tDCS to right or left inferior frontal (IFG, F9,10) or parietal cortex (C3, C4) with Sham during 1 hr of SF training. Flying the space ship in a controlled manner was affected by tDCS (Figure 7.2, velocity subscore), but only when the anode was over the right hemisphere, regardless of site. Two working memory-dependent measures were not altered by tDCS. That activating the right hemisphere.
hemisphere very early in training selectively improved ship control and not working memory suggests a training role for the right hemisphere-dependent ventral attention network (Corbetta et al., 2008). That network is active when task-relevant events occur. Because Exp. 1 also found that successful training altered the ventral attention network, these results show the importance of the ventral network in successful cognitive training. **Experiment 5.** The goal of developing tDCS into a real-world training aide assumes that its effects are durable, yet this assumption has been little tested. In a follow-up study, we assess longer-term effects of tDCS on SF acquisition. Participants are randomly assigned to PFC tDCS on (a) only Day 1 of training, (b) Days 1, 2, 3 of training, or (c) only Day 3 of training. Retention testing occurs one week later. If tDCS differentially facilitates learning (through encoding), then stimulation early in training would have stronger effects than exposure to tDCS late in training. Alternatively, if tDCS differentially facilitates consolidation, then stimulation late in training would have stronger effects.

In Year 4 of this project, we will finish our ongoing study comparing working memory training with bilateral prefrontal or parietal cortex tDCS on risk aversion behavior. Second, we will use ERPs to measure effects of occipital tDCS on contrast detection threshold and the “suppressive annulus” (Hopf et al., 2006). Lowering detection thresholds with tDCS can improve detection of faint and masked stimuli. Lower thresholds can also facilitate perceptual training, shown to induce functional connectivity changes related to training (Lewis, Baldassarre, Committeri, Romani, & Corbetta, 2009) and transfer of training (Strenziok et al., submitted). We hypothesize that tDCS to extrastriate cortex would lower those thresholds. A third study we plan, in collaboration with Andy McKinley of AFRL, is to compare anodal with cathodal tDCS to prefrontal cortex in the “Warship commander” implicit task. McKinley et al. recently found that cathodal but not anodal stimulation of dorsolateral PFC during that task facilitated implicit learning. That was interpreted as suppression of PFC resulting in increased consolidation of implicit learning. However, there is recent evidence that tDCS to ventromedial and dorsolateral PFC influence subcortical striatal functioning (Chib, Yun, Takahashi, & Shimojo, 2013). As frontostriatal connections are important in implicit learning (Poldrack, Prabhakaran, Seger, & Gabrieli, 1999), we will compare anodal and cathodal tDCS to both ventromedial and dorsolateral PFC to determine the best montage for facilitating implicit learning of “Warship Commander.”

### 8.3 Training

Maren Strenziok, continued as a post-doctoral fellow working on the MRI and cognitive training studies. We recruited Melissa Scheldrup to our doctoral program to work on tDCS training studies. She has completed one study of tDCS in complex task acquisition (presented at the Cognitive Neuroscience Society) and has begun another study looking at the longer-term effects of tDCS on task acquisition. Dean Cisler, a student in the Masters Program in Human Factors and Applied Cognition, has worked on the cognitive training studies, and has become knowledgeable in seed-based functional connectivity analyses of the fMRI data. Edward Pierce, a student in the Masters Program in Human Factors and Applied Cognition, has been working on a study using tDCS to influence risk aversion in decision-making. Ryan McGarry, a doctoral student in our program, has been involved in our cognitive training studies and is conducting a study using event-related potentials (ERPs) to measure attentional gradients around the target of search. We will use perceptual training to modulate those gradients to speed visual search.
8.3 Collaborative Activities

During Year 3 we met at AFRL, Dayton with Andy McKinley of the Human Effectiveness Directorate and have begun two collaborative studies, both using tDCS during cognitive training. We are beginning another study with event-related potential measures of effects of tDCS in visual search. We also have had several collaborative discussions with Jason Parker of Wright State Research Institute and are planning an imaging study using a cyber defense simulation developed there. We also developed a collaborative relationship with Marom Bikson of CUNY. He has modeled the electrical field for our tDCS stimulation montages and we are working with him as we use high-density tDCS electrodes in new studies to achieve more targeting stimulation.

8. Other GMU-AFRL Collaborative Research Activities

8.1 Computational Studies of Vigilance

This work involves collaboration between AFRL (Glen Gunzelmann, Joel Warm, Greg Funke), GMU (Raja Parasuraman, Daniel Gartenberg), and the Naval Research Laboratory (Greg Trafton). Operator vigilance is a critical limiting factor in the performance of many operational Air Force tasks, including unmanned air vehicle control and cyber defense. Currently there are two main theories of vigilance performance, the arousal or mindlessness theory, and the resource theory (Warm, Parasuraman, & Matthews, 2008). Computational modeling can help further our theoretical understanding of the mechanisms of vigilance, in particular the vigilance decrement over time on task. Accordingly, this study is examining the utility of models using the ACT-R architecture to account for several established findings in vigilance research: the decline in detection rate over time on task; the relative effects of simultaneous and successive discrimination on vigilance performance; and the relation between eye movements and vigilance performance. Daniel Garternberg, a graduate student at GMU working under the supervision of Raja Parasuraman, is spending part of the summer of 2013 at AFRL, Dayton, OH, working with Glen Gunzelmann and Joel Warm to further develop and test these ACT-R models.

8.2 Facilitating Cyber Defense Performance: Brain Stimulation, Working Memory, Visual Search Training

This study is being conducted in collaboration AFRL (Andy McKinley) and the University of Dayton Research Institute (Jason Parker). Military, government, and private companies need to continuously defend computers and networks against cyber attack (Lin, 2010). Although there are automated tools to protect cyber systems, those tools must be monitored by human operators lest anomalies be missed. The cognitive demands on human operators in cyber defense environments include vigilance, multi-tasking, and working memory. Jason Parker and colleagues at UDRI under an Air Force contract recently developed a simulated cyber defense task (CDT) which includes three components: working memory, visual search, and vigilance. The operator monitors “port traffic” in the upper part of a display and responds when a level is exceeded. The operator must simultaneously monitor for enemy IP addresses in lower half of display. We are investigating ways to improve performance on this task. One approach is to use cognitive training of each task component. Comparing effects of three interventions (working memory training, visual search training, tDCS to PFC) can reveal which manipulation provides the greater benefit
to overall task performance. The design uses random assignment to: (a) 30 min of adaptive working memory training followed by 20 min CDT with sham (.2 mA tDCS), or (b) 30 min visual search training (to broaden the attentional focus) followed by 20 min CDT with sham (.2 mA tDCS) or (c) 30 min of sham training (choice RT) followed by 20 min CDT plus 2.0 mA tDCS to PFC. For each group, the tDCS anode was over location F10 and the cathode was the left shoulder. We predict stronger task benefits from adaptive working memory training and PFC tDCS because the working memory component (IP addresses) is the most demanding part of the CDT task.

9. Publications and Presentations 2012-2013

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

9.1 Summary

Peer-Reviewed Journal Articles: 18
Journal Articles Submitted: 11
Conference Proceedings and Presentations: 48
Books and Book Chapters: 12
Joint GMU/AFRL Journal Articles and Submissions: 7

9.2 Peer-Reviewed Journal Articles


9.3 Journal Articles Submitted

2. Baldwin, C. L., May, J. F., and Parasuraman, R. Motor Vehicle Crashes Due to Task-Induced Fatigue in Young and Older Drivers: Mitigation with Auditory Forward Collision Warnings. Submitted to *Transportation Research: Part F*.


9.4 Conference Proceedings and Presentations


9.5 Books and Book Chapters


