

Technical Evaluation Report
on the
SYMPOSIUM on
APPLYING NEUROSCIENCE TO PERFORMANCE:
FROM REHABILITATION TO HUMAN COGNITIVE
AUGMENTATION

(HFM-334 RSY)
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DAY 1 – MONDAY OCTOBER 11, 2021

Each keynote speaker was introduced in presence by Giorgio Fanelli.

Keynote #1 on *Cognitive Warfare* by Dr. Francois Du Cluzel De Remaurin

Dr. Du Cluzel De Remaurin examined the construct of cognitive warfare “*neuro-weapons*” as one of tomorrow’s battlefields. A definition and historical perspective were first provided, then the basic principles of this construct were examined. The presented project had the aim to apply nanotechnology, biotechnology, computer science, and cognitics in the fields of health, security, and defense. The lecture offered insights into a future plausible scenario where cognitive threats will be more frequent, with more global consequences.

The author concluded that the NATO should give a greater consideration to the emergence of the threats that represents Cognitive Warfare.

Keynote #2 on *Brain Plasticity* by Dr. Prof. Michael Merzenich

Prof. Merzenich examined brain plasticity with a developmental perspective. The main question underlying the lecture was “*Is the brain plastic on a large scale, across the entire span of our lives?*” Innovative and exciting tools, such as the computerized BrainHQ battery, that have the potential to improve such plasticity in psychiatric and neurological samples and to reduce the risk of developing such disorders in “at risk” individuals, have been presented. The same tool may be used to increase job performance, resilience, and reduce the risk of developing psychiatric and neurological symptoms in military personnel. Overall, the use of the computerized BrainHQ battery holds potential for screening, assessment, health promotion and prevention, and treatment in the military field.

Keynote #3 on *Neuroethics* by Prof. James Giordano

Prof. Giordano attended the symposium online and gave a provocative lecture on the questions “*How far do we go?*” and “*How far should we go?*” with the growing use of brain sciences in warfare, intelligence, national security, considering that the aim is “*good*” but “*Who is good?*” The lecture pointed to the risk

associated with the use of brain sciences for purposes different than defending our societies or with its use by societies with values and objectives that are different from ours. The lecture also highlighted the different stages of progression in the use of neuroscience in different part of the world, with China being the projected leader in this. Prof. Giordano ended his lecture with an invitation to be careful in deciding what we can do and what we can't do with brain sciences because, once decided, it won't be possible to go back.

Session #1 *Enhancing Operational Performance* chaired by Candice Hatcher-Solis

Each presenter was introduced either in presence by Giorgio Fanelli or remotely by Candice Hatcher-Solis.

Paper #1 - Neuroenhancement in Military Personnel: Conceptual and Methodological Promises and Challenges by Dr. Kathryn Feltman

Dr. Kathryn Feltman attended online and presented a thorough review of the literature on the potential use of six non-invasive brain stimulation techniques (NIBS; transcranial magnetic stimulation, transcranial focused ultrasound stimulation, transcranial electrical stimulation (tES), transcutaneous peripheral nerve stimulation (tVNS), photobiomodulation, and cranial electrotherapy stimulation) and three biofeedback techniques (neurofeedback, real time fMRI feedback and functional near-infrared spectroscopy (fNIRS) feedback), with a particular focus on the feasibility of applying such techniques in the military field. The conclusion was that the reviewed techniques hold the potential to increase the mental efficiency of military personnel.

Paper #2 - Using Interpersonal Similarity in Complex Networks from Physiological Data to Assess Attentional Focus by Dr. Michael T. Tolston

Dr. Tolston attended online and focused on the role of joint attention and team situational awareness (i.e., what the other team might be doing), considering that military teams move into increasingly dynamic environments. The presenter illustrated a complex network approach to evaluate the similarities in physiological (i.e., heart rate) responses of 26 participants as a function of whether individuals were instructed to attend to a stimulus or to attend only an audiobook. Results showed that individuals instructed to attend the stimulus had physiological dynamics that were more like others in their own group, while individuals who were told to ignore the stimuli showed the opposite pattern. Dr. Tolston concluded by presenting ongoing attempts also combining EEG and electrodermal activity and illustrating the potentiality of this approach for the identification of times in which individuals may be distracted from a task.

Paper #3 - Effects of prefrontal brain stimulation by tDCS on stress regulation in healthy military personnel by Dr. Fenne Smits.

Dr. Smits presented a review of the effects of transcranial direct current stimulation (tDCS) on cognitive functioning and mental health in military personnel, particularly after adverse effects of stress exposure. The authors concluded that this field is not mature enough for the implementation of such technique in the military field, e.g., effect sizes are small, and heterogeneity is high. The need for the conduction of studies outside of the laboratory emerged, especially considering the unpredictability and uncontrollability of the environment for the military personnel. The presenter also highlighted the need to go beyond a single session and likely use multiple sessions in combination with cognitive training.

Paper #4 - Effects of transcranial electrical stimulation (tES) in defence and security related tasks: Meta-analysis of findings from healthy populations by Dr. Gorana Pobric.

After the break, the session started with a meta-analysis of existing studies on the use of tES techniques on several cognitive domains that are potentially relevant for Defence and Security related tasks. Dr. Gorana Pobric highlighted a crucial role of the experimental design (with larger effects for between-subjects design); the need for online stimulation at least for part of the task(s); the need to stimulate frontal areas with an

intensity ≥ 2 mA and for > 900 s as results of moderation analysis. Lastly, one session yields smaller results compared to a training paradigm. The presented concluded by highlighting a series of limitations and the need to conduct large, well-powered studies before this technique could be applied in the military field.

Paper #5 - Accelerating Image Analyst Training with Transdermal Vagal Nerve Stimulation (TVNS) by Dr. R. Andy Mc Kinley

Dr. Mc Kinley attended online, and his lecture focused on ways to develop a cost-effective training for Intelligence Surveillance and Reconnaissance (ISR) analysts, which is currently costly and time-consuming and no longer sustainable, given the increased demand of such activity. The presenter illustrated an optimized training protocol that leverages windows of increased neuroplasticity induced by non-invasive electrical stimulation of the vagus nerve, tested in active-duty Air Force participants during training on tasks involving the analysis of ISR imagery data. Preliminary results are promising and suggest that participants receiving tVNS learned at an accelerated rate, and results were retained for at least 90 days.

Session #II *Enabling Technology and Methods* chaired by Gaurav Sharma

Each presenter was introduced either in presence by Giorgio Fanelli or remotely by Gaurav Sharma.

Paper #8 - BCI Innovation at the Intersection of Restoration, Augmentation, and Intelligent Systems by Dr. Anne Marie Brouwer and Dr. Michael Wolmetz

The presenters examined the possibility to extend Brain-Computer Interfaces (BCI) from clinical populations (invasive BCI) to healthy individuals (i.e., minimally invasive surgical and high-resolution non-surgical BCI), with the aim to augment or amplify natural modes of perception, control, and mental state monitoring. This transition implies moving from passive monitoring to applications that involve intentional, conscious, often effortful involvement of the individual. The challenges associated with such a move, such as generalization across individuals and contexts, or performance under real-world conditions (e.g., the difference between anthropomorphic (i.e., control of robotic prosthetic limbs that resemble natural limbs) and non-anthropomorphic BCI (e.g., controlling an aircraft)) have been highlighted. Hybrid BCI systems that incorporate peripheral measures such as heart rate or pupil dilation could be used for restoration and augmentation in the context of spinal cord injury, severe paralysis, and amputation. Lastly, the possibility to integrate BCI with artificial intelligence has been described.

Paper #9 - Vagus Nerve Stimulation-Induced Cognitive Enhancement in Rats is Associated with Enhanced Expression of Brain-Derived Neurotrophic Factor in the Hippocampus by Dr. Candice Hatcher-Solis

Dr. Hatcher-Solis attended online and first illustrated how cognitive enhancement is needed to accelerate training for pilots and aircrew, to increase attention for cyber operators with a high workload, and to mitigate the effects of operational stressors for special operations. Then, studies conducted by Dr. McKinley's NIBS team on the use of tVNS to enhance performance in a detection task were reviewed. The goal of the presentation was however, to disentangle the exact neurobiological mechanisms underlying such effect. To do so, a preclinical study was performed in rats, in which the chosen paradigm closely mimicked the stimulation frequency and bursts commonly used in humans. Results suggested that a single session of VNS after training enhance cognitive performance, and particularly recognition memory and learning by increasing Brain-Derived Neurotrophic Factor (BDNF) expression in the hippocampus and synaptic plasticity (i.e., long term potentiation (LTP) and spontaneous spiking). The stimulation did not show clear effects on reducing anxiety-like behavior.

DAY 2 - MONDAY OCTOBER 12, 2021

Paper #10 - Using SocialXR to measure social cognitive performance to address isolation associated with deployment and post-traumatic life events by Dr. Christopher Stapleton

The presenter attended online and reviewed the threats associated with the deterioration of sociality, also in light of the consequences of the Pandemic on mental health. Dr. Stapleton proposed the use of Social eXtended Reality (*Social XR*) to study social cohesion and group dynamics, which constitute crucial factors for the success of planned operations in the military environment. The features of Social XR have been described, e.g., its ability to track and code linguistic communication, behavioral responses, and conversational performance. The potential application on a case of aphasia, which is likely to be associated with a deep feeling of loneliness due to the inability to communicate with others with the risk of yielding a “social trauma” triggered by isolation has been briefly presented. The authors conclude with the relevant implications for missions that are associated with deep isolation, such as in the case of space astronauts. The possibility of expanding the sense of social cohesion even in extreme conditions has important future implications for the military personnel overall.

Session #III Applied Neuroscience in Health and Wellbeing chaired by Giorgio Fanelli

Each presenter was introduced in presence by Giorgio Fanelli.

Paper #6 - Perceived stress and brain network efficiency by Dr. Chiara Massullo

Dr. Massullo illustrated a study conducted in healthy individuals (i.e., university students) with the aim of investigating the associations between perceived daily life stress (by the Perceived Stress Scale; PSS) and indices of local and global brain network efficiency (assessed by resting state EEG). After controlling for age and sex, scores on the PSS resulted associated with decreased segregation in alpha frequency band. The authors concluded that this is a potentially interesting results, likely indicating impaired executive functions but also highlighted the need for replication to better understand the meaning of the resulted decreased segregation in the alpha frequency band.

Paper #7 - Cerebrum – Virtual Cognitive Rehabilitation: a modern therapy tool focused on recovering from the disorders affecting the cognitive performance of deployed soldier by Capt. Rosalba Vergini and Valerio de Lorenzo

Capt. Rosalba Vergini attended online, whereas Valerio de Lorenzo was on site. The presenters examined the consequences of exaggerated (e.g., due to acute stressors) or prolonged cortisol release (e.g., due to chronic stress) on neuronal plasticity, and how to reduce the risk of such deleterious consequences in the military personnel thanks to the implementation of *Virtual Reality* both pre- and post-deployment. The app Cerebrum was illustrated, and its potential to stimulate visual perception, auditory perception, and cognitive flexibility clearly highlighted. A still unpublished validation study conducted in 41 participants, 20 of which pathological (i.e., with psychosis, dementia, intellectual deficit, or autism spectrum disorders) has been described. Such preliminary results suggest that Cerebrum elicits the same physiological responses as real stressors with implications for its use in soldiers after appropriate customization.

Session #IV Optimizing Personnel Selection and Training chaired by Giorgio Fanelli

Each presenter was introduced in presence by Giorgio Fanelli.

Paper #11 - From genes to personalised cognitive training: mapping the genetic architectures of cognitive functioning by Dr. Liliana G. Ciobanu

The presenter attended online and illustrated a study with the ambitious goal to disentangle the genomic architecture and molecular mechanisms of cognitive functioning. The limitations of current approaches are reviewed (i.e., genome wide associations; focus on the smallest measurable components available in cognitive test data). The study aims to use genetic and cognitive assessment data from UK Biobank (i.e., over 500,000 participants), with the aim to identify the genetic variants associated with basic cognitive units and then examine how test-specific genetic variants combine to represent broader cognitive constructs and how these broader constructs are interrelated. The ultimate aim is to develop a biology-informed cognitive measurement framework, that is cognitive assessment tools tailored to the different requirements of selection, training and operational support applications. In response to my question, Dr. Ciobanu agreed on the view that epigenetics represents the future of this field.

Paper # 12 - Brains in Sync: Team coordination and interpersonal prefrontal neural synchrony during cooperative e-gaming by Mr. Mark Jesse

Mr. Mark Jesse attended online, and the presentation focused on how to increase teamwork and cooperation, considering that the ability of a team to rapidly coordinate and engage in strategic decision-making is a winning strategy, especially in high-pressure/high risk situations. FNIRS, hyper-scanning, and wearable sensors for ambulatory physiological assessment are described as non-invasive useful tools to investigate the neurophysiological mechanisms involved in interpersonal interaction and collaboration, such as during cooperative gameplay. An experimental hyperscanning protocol characterized by fNIRS and electrodermal activity monitoring, that will be performed in **teams matched** for similar task-specific skill levels and occupational background (civilian versus veterans) was illustrated.

Paper #13 - Wearable Brain and Body Sensing for Multimodal Assessment of Cognitive Workload and Training by Dr. Adrian Curtin

In this lecture, Dr. Curtin focused how to enhance assessment of mental workload to ultimately prevent operators' errors. Wearable brain and body imaging methods were proposed as important tools for the assessment of mental workload via neuro/physiological signals. The definition, theories, and methods of assessment on cognitive workload were first briefly reviewed, then collaborative and multimodal (i.e., combining different biosignals such as fNIRS, EEG, and ECG) studies conducted in Air Traffic Control operators and Aerial Vehicles Pilots were presented. The following step was to combine the use of wearable brain imaging (fNIRS) and peripheral physiology assessment (ECG, EOG, PPG, and eye tracking) during performance on an Inhibitory Control Task to provide a comprehensive and objective measure of the internal brain state while on task. Lastly, the limitations associated with the use of multimodal assessment (e.g., time needed) were illustrated.

Paper # 14 - A Flexible Gaming Environment for Reliably Measuring Cognitive Control by Dr. Andrew Heathcote

Dr. Heathcote attended online and described a project whose goal was to overcome the limitations of previous assessments and develop an easy to download battery of cognitive control tests enabling efficient and reliable measurement of cognitive control abilities. Abilities such as working memory, response inhibition, conflict tasks, multi-tasking, and task switching are indeed crucial for high performance under time pressure. A detailed description of each task included in such a battery was provided and reliability data were reported. The reliability test particularly stressed the importance of determining an adequate number of trials. Among the reported limitations, is the high attrition rate of participants due to low accuracy and slow responding, which has now been overcome thanks to some modifications that have already been tested in a preliminary study.

Paper # 15: Performance Based Training: Monitoring the Flow of Cognitive Load based on

Psychophysiological Measurements in a Fighter Cockpit Simulator by Mr. M.P.G. (Maykel) van Miltenburg

In line with the current move toward personalized approaches to health, Mr. van Miltenburg illustrated a type of training for fighter pilots that -instead of being based on a fixed number of hours and on a specific time schedule- is grounded on an optimal level of difficulty (i.e., personalized load model) in the learning task provided. In the presented study, upper alpha band power and theta band power derived from the EEG were used as a cognitive load metric and three sessions with multiple runs were performed by participants with a former position as F-16 pilot (age range age 37 – 50 years). Given that pilots were tasked to perform a relatively difficult exercise after the retention interval only with a short familiarization to prepare, the authors expected the workload to be graded lower after training than in the first run of the session after a retention interval. However, results were mixed, likely due to high inter- and intra-individual differences emerged. The presenter concluded with a plan on how to optimize the training, e.g., by using also heart variability data derived from the ECG.

Session #V *Enhancing Operational Performance* chaired by Anne-Marie Brouwer

Each presenter was introduced in presence by Anne-Marie Brouwer.

Paper # 16 - Assessing Cognitive-Motor Interference in Military Settings: Validity and Reliability of Two Dual-Tasking Tests by Dr. Samuele Maria Marcora

The presenter attended online and described the phenomenon of cognitive-motor interference, that is a decrease in cognitive and/or physical performance occurring when a cognitive task and a physical task are performed concurrently (dual-tasking), compared to when they are performed in isolation (single-tasking). Dr. Marcora studied this phenomenon in military settings, with soldiers, officers and cadets performing a physical task (i.e., a 10-min loaded marching), a cognitive task (i.e., a 10-min Psychomotor Vigilance Task), and combination of these tasks in two subsequent visits. A different combination of tasks was also tested (i.e., running and Word Recall). The presenter concluded that -whereas the last combination proved to be a valid and reliable dual-task test- the first combination of tasks requires further work before it can be used in the military setting to assess cognitive-motor interference.

Paper # 17 - Development of an AI pipeline for real time assessment of fighter pilots' mental state based on hybrid stream processing by Dr. Magnus Bång

Dr. Bång suggested the application of an experimental AI pipeline for investigating fighter pilot mental states in real time. The presenter illustrated how this could be done by using eye tracking, electrodermal activity and heart rate variables (e.g., heart rate variability; HRV) with a machine learning approach, enabling real time analysis and time-based inference of the different signal events. Results from ongoing empirical experiments with the system were illustrated and discussed in terms of advantages (e.g., the system allows for more advanced real time processing) and disadvantages (e.g., the sensors used must provide data with millisecond accuracy which is challenging due to internal signal processing and filtering) of the approach.

Paper # 19 - Interoceptive technologies. New technological solutions for stress management and human neuroenhancement by Dr. Daniele Di Lernia

The presenter attended online and focused on 'interoception', i.e., the sense of the physiological state of our inner body. Dr. Di Lernia first reviewed the most recent technological developments in terms of interoceptive stimulation (e.g., virtual reality, neurostimulation), and then illustrate the potential of newly developed interoceptive devices and non-invasive interoceptive neuromodulation (e.g., HRV enhancer). Preliminary data from different studies conducted in different samples (although of small sizes), regarding the effectiveness of these technologies in promoting wellbeing, reducing stress, fatigue, and pain, and

enhancing human performances were presented. In light of the literature linking reduced interoceptive awareness with mood dysregulation and deficit in impulse control, the proposed tools have the potential of enhancing cognitive, autonomic and stress adaptive responses in a non-invasive way. Although the military application was not directly mentioned, it clearly appears that such tools would be relevant for post-traumatic stress disorder, pain, and fatigue.

Paper # 20 - Military Pilot's Emotional Stress Analysing by Mr. Ferdinand Tesar

Mr. Tesar presented a series of studies with the overall main aim to find the appropriate indices to assess emotional stress in Air Force combat supersonic fighter pilots. The presenter illustrated the impact of emotional stress on tactical decision of these pilots, and how a tactile training could enhance resistance to high information load and be effective in simulated unexpected situations. Physiological correlates (i.e., heart rate, eye activity) of emotional stress were assessed when pilot made the incorrect tactical decision. Mr. Tesar concluded that heart rate could be effectively used to assess changes in emotional stress.

CONCLUDING TECHNICAL EVALUATION

Over the two days of the Symposium, 3 keynote lectures and 19 papers were presented. For the first time, the symposium was held in a blended modality. This decision had the cons of delaying the schedule due to occasional technical issues but had the important pros of giving the opportunity for scientific exchange beyond the time of the lectures to those who joined in presence. The chairs of the sessions were extremely successful in managing the blended modality by always asking questions to the in-site audience first and then to the online audience. Each presentation was followed by several questions by the attendees and/or by the facilitators (Q&A sessions) and all speakers were good at handling questions. Such Q&A sessions were in most cases insightful and thought-provoking and made it possible to deepen conceptual (e.g., ethical dimensions of human enhancement), methodological (e.g., specific questions on off-line versus online physiological pre-processing or analysis), and feasibility (e.g., on the applicability to the military personnel) issues. The Q&A sessions following each presentation were particularly useful for the conduction of future studies by colleagues and attendees working on the same topic, contributing to facilitate replicability and progress.

The overall impression during the closing remarks was of great satisfaction and enrichment for both the organizers and the attendees.

The topics presented in this Symposium clearly demonstrate that outstanding recent work has been conducted in the field of neuroscience, that holds a great potential for application in the military personnel. The lectures covered the possible use of neuroscientific tools such as non-invasive stimulation techniques, biofeedback techniques, physiological assessment, Brain-Computer Interface, Virtual and Extended Reality, genetics, hyper-scanning, wearables, and interoception enhancers for the screening, assessment, health promotion and prevention, and treatment in the military field.

The overall quality of the lectures was excellent, showing a specific attention not only to the promises associated with such neuroscientific advances but also to the limitations associated with the current state of the art. I particularly appreciated the frequent use of meta-analytic evidence to support assumption and data deriving from the presented research projects.

The take home message is that some of the presented tools, such as for example virtual and enhanced reality, already have enough empirical support to be used to increase job performance, resilience, and reduce the risk of developing psychiatric and neurological symptoms in military personnel. Other tools, such as non-invasive stimulation techniques, hold incommensurable potential but need further investigation before they could be used in the military personnel as the field is not mature enough. In general, the validation studies of

these neuroscientific tools need to be conducted outside the laboratory, because the environment where they will eventually be applied is extremely unpredictable and uncontrollable.

To conclude, although there is still room for improvement, the Symposium testified that outstanding neuroscientific research is being performed of potentially relevant use for improving military personnel's performance on one hand and promoting military personnel's psychological wellbeing on the other. The Symposium well aligns with the current call to reduce the gap between scientific innovation and applications, and emphasize the common goal to harness neurobiological scientific advances to select application options with the greatest likelihood of success.