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Effects of Physical Activity Intensity and Task Complexity on Behavioral and Hemodynamic Responses in Civilians and Military Personnel

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Abstract

Effects of Physical Activity and Task Complexity on Behavioral and Hemodynamic Responses in Civilians and Military Personnel

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Introduction: Physical activity and exercise training positively enhance cognitive performance across all age-levels. Military personnel undergo intense physical training. Currently, there is a paucity of research in this population in respect how their training may impact executive function measures. Functional near infrared spectroscopy (fNIRS) is an emerging low-cost, noninvasive neuroimaging technique sensitive enough to detect both cognitive load and state and is suitable for measuring cerebral oxygenation changes during both motor and/or cognitive behavioral tasks. The purpose of this study was to determine both behavioral and hemodynamic changes in the prefrontal cortex over varying task complexities and physical activity intensities between civilians and military personnel. **Methods:** Seventeen healthy individuals (age = 25.6 + 2.3 years, BMI = 24.2 ± 2.3; n= 12 male, n= 5 female, n= 6 military personnel) were recruited to participate in the study. Participants completed a cognitive battery (Erikson Flanker, Switcher, and Delayed-Match-to-Sample tasks) recording accuracy and reaction time both before and after physical activity conditions. Participants also completed six conditions of varying physical intensities (sit, stand, walk) and cognitive complexities (low: congruent; high: incongruent). During the congruent conditions, participants struck green objects, not red. During the incongruent conditions, participants struck red objects, not green. Independent sample t-tests were used to compare accuracy, reaction time, and HbO_2 concentration across physical activity conditions and pre- post-exercise cognitive tasks between Military and Civilians. **Results:** Physical activity conditions were validated using heart rate data. Both groups experienced significantly greater improvements in all cognitive tasks pre-post-test in reaction time, with little differences between groups. Both groups also experienced improvements in both accuracy and reaction time during the physical activity conditions as the intensity increased, with little differences between groups. Higher HbO_2 concentrations during the pre-cognitive tasks relative to the post-cognitive tasks was observed, with no significant difference between groups. **Discussion:** fNIRS modalities are a valid measure of cerebral HbO_2 concentration changes in the prefrontal cortex before, during and after physical activity in the laboratory setting using a virtual reality system. The findings of this study need to be replicated and the methods applied to different samples of the population.

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INTRODUCTION

The United States (U.S.) military personnel are among the best physically trained in the world. These individuals are put under an immense amount of stress during training and even more during combat. Individuals who are able to adapt to the situation and overcome the task at hand better suited be ready to react and handle future tasks appropriately. Additionally, military personnel are evaluated on a regular basis and must maintain a standard for body weight, mental health, and physical fitness. Understanding the effects of this training and the experiences related to active duty are largely understudied from the perspective of executive function. How humans process information and prioritize the response is largely determined by executive function (Minzenberg, Laird, Thelen, Carter, & Glahn 2009). As such, examining cognitive processing differences between and among healthy individuals in the second decade of life was both timely and warranted.

BACKGROUND

The effects of physical activity on health have been widely documented by the Centers for Disease Control and Prevention (CDC) and World Health Organization (WHO). Individuals who are physically active not only lower their risk for physical ailments such as heart disease, stroke, type 2 diabetes, some cancer but also lower their risk for mental ailments such as depression, anxiety, while improving cognitive function (CDC, 2014; WHO 2018). With respect to cognitive function, in adolescents and young adults, physical activity has been shown to improve academic achievement (CDC, 2014), while in older adults it has been shown to both improve cognitive performance (Brown et al., 2012) and lower levels of markers for Alzheimer's disease (AD; Brown et al., 2013). AD is the most common form of dementia (loss of memory and other cognitive abilities) and is the 6th leading cause of death in the U.S. (Alzheimer's Association, 2018). There is no cure and it is a progressive disease that worsens over time affecting around 5.5 million individuals, potentially reaching 16 million by 2050 (Alzheimer's Association, 2018). In 2017, AD and other forms of dementia cost the nation $259 billion and this figure could rise as high as $1.1 trillion by 2050 (Alzheimer's Association, 2018). However, physical activity has been shown to be a protective factor against Alzheimer's and vascular dementia by increasing blood and oxygen flow to the brain (Williams, Plassman, Burke, Holsinger, & Benjamin 2010; Solomon et al., 2014; Alzheimer's Association, 2018).

Of note, individuals are typically on the cognitive decline beginning in the third decade of life. However, the degree of decline can be impacted based on the notion of cognitive reserve. Cognitive reserve is defined as the differences in cognitive processes as a function of lifetime intellectual activities and other environmental factors that explain differential susceptibility to functional impairment in the presence of pathology or other neurological insult (Barulli & Stern, 2013). All experiences before the third decade of life are contributing to an individual's level of cognitive reserve. Importantly, one behavior that has a protective effect against cognitive decline and can improve cognitive reserve is physical activity (Stern, 2012). It could be expected that members of the military, depending upon age of enlistment (enlisted) or commission (officer), have a higher cognitive reserve and therefore may respond faster and more accurately.

Recently, neuroimaging modalities have become less invasive and more cost-effective, than known standard measures such as magnetic resonance imaging (MRI) and positron emission tomography (PET) scans. Functional near infrared spectroscopy (fNIRS) monitors cerebral blood flow and oxygenation related to brain function (Izzetoglu et al., 2005). Precisely, a blood-oxygen-level dependent (BOLD) signal reflects the concentration of deoxygenated hemoglobin (deoxy-Hb; Hb) and oxygenated hemoglobin (oxy-Hb; HbO_2) in the capillary beds during brain activity. In fNIRS, wavelengths of light interact with the cortical region to create an "optical window" of HbO_2 and Hb (Izzetoglu et al., 2005). Thus, the BOLD signal identifies the brain region in which HbO_2/Hb concentration changes occur when completing complex tasks (i.e., rapidly selecting an accurate answer; holding information in working memory). Such representations are an economical and mobile way to quantify how the brain responds to complex learning tasks and how the cerebral blood flow and total blood volume changes during and after physical activity at varying intensities.

The current gold standard neuroimaging modalities for cognitive neuroscience are EEGs and fMRIs. However, fNIRS pose several advantages over the current gold standards. fNIRS is an emerging low-cost, noninvasive neuroimaging technique sensitive enough to detect both cognitive load and state (Fishburn, Norr, Medvedev, & Vaidya 2014) and is suitable for measuring cerebral HbO_2 concentration changes during both motor and/or cognitive behavioral tasks (Mandrick et al., 2013). The key benefit to the current study was the ability of fNIRS to be utilized before, during, and after the physical activity conditions. This allowed the full spectrum or activity to be recorded from both the cognitive behavioral tasks to the dual task physical activity conditions.

RELEVANT fNIRS RESEARCH

fNIRS can be used to examine both behavioral responses (i.e., how quickly and accurately someone responds to a stimuli) and more recently, changes in brain blood flow while being physically active. Research has examined changes in the prefrontal cortex, most notably executive functions during incremental task demands in both single task and dual task situations (Braver et al., 1997; Jansma et al., 2000; Veltman et al., 2003; Mirelman et al., 2014). Executive function is composed of four constructs (i.e., *working memory, cognitive flexibility, inhibitory control*, and *attention*) and is defined as necessary processes that control or regulate other cognitive processes in the pursuit of goal-directed behavior (Minzenberg, Laird, Thelen, Carter, & Glahn 2009). *Working memory*, is a temporary buffer or repository for manipulation of goal-relevant information that critically depends upon the integrity of the prefrontal cortex (Miller & Cohen, 2001). Working memory is the executive function resulting from the active short-term memory system that guides and controls human's behavior. It allows the temporary storage and the further recollecting of information (McAfoose & Baune 2009). Importantly, it is a limited-capacity resource, which thus can easily saturate under extremely stressful conditions with excessively rapid streams of information (Molteni et al., 2012). Thus, working memory has been an optimal candidate for studying prefrontal cortex activation as measured by fNIRS.

Another single task executive function that has been measured by changes in oxy-Hb in the prefrontal cortex is *cognitive flexibility* (Shibuya-Tayoshi et al., 2007). *Cognitive flexibility* is the ability to shift attention between stimuli or different cognitive categories (Lezak et al., 2004; Olivera-Souza et al., 2000), and it is commonly referred to as multitasking. Although humans do not multitask, they are capable of quickly shifting their attention from one task to another. Studies have consistently shown that increasing the task demand of either a *working memory* or *cognitive flexibility* task leads to an increase in oxy-HB changes and increases in total blood volume as measured by fNIRS (Hoshi et al., 2003; Li et al., 2010; Ayaz et al., 2012; Molteni et al., 2012).

Inhibitory control is another executive function measure and relates to one's ability to resist a behavioral response, as expected (Phillips, Hannon, & Castelli, 2014). It is a critical cognitive ability that relates to how an individual efficiently deals with expectancy violation, seen in incongruent cognitive tasks (e.g., Stroop test, Switcher task). fNIRS studies have found an increase in cerebral blood flow changes and blood volume in the incongruent condition when compared to the congruent condition in the right and left frontal lobes (Ehlis et al., 2005; León-Carriona et al., 2008; Schroeter et al., 2002).

In addition to studying oxy-Hb changes in the prefrontal cortex while carrying out a single task, many studies have looked at oxy-Hb changes in the prefrontal cortex while carrying out a dual task. As argued by Baddeley (1986), the ability to perform tasks simultaneously is one of the most critical roles of the central executive functions concerning the dorsolateral region (Funahashi, 2006). The prefrontal cortex is an area well-known to be involved in some tasks ranging from mental (e.g., computation) to physical (e.g., handgrip task, gait balance) demands (Holtzer et al., 2011; Ward and Frackowiak, 2003).

It is well known that humans are cognitively bounded, insofar as human mental resources are fundamentally limited (Kahneman, 1973; Koechlin et al., 2003). Consequently, allocating more resources to a task inevitably limits the number of resources available for other tasks. Such limitations have been evidenced in studies measuring oxy-Hb changes in the prefrontal cortex while carrying out a dual task that involves both a cognitive task while simultaneously involving gait movement (Beurskens et al., 2013). Executive function and attention, cognitive domains that reflect frontal lobe function, are associated with gait performance (Hausdorff et al., 2008; Hausdorff & Buchman, 2013; Holtzer et al., 2014; Verlinden et al., 2013). Because this study examined the differences in aspects of cognitive function (working memory, cognitive flexibility, and inhibitory control) and cerebral blood flow changes between civilians and military personnel over varying task complexities and physical activity intensities , it is important to understand how varying cognitive and physical demands on executive function have already been investigated. In general, as the demand of the task increases, the amount of reliance on executive function to accomplish the cognitive task also increases in a linear fashion (Lavie et al., 2004; Isingrini et al., 2015; Kim, Wittenburg, & Nam 2017).

With respect to physical activity intensity, Brown and colleagues demonstrated that individuals in the highest intensity group performed significantly better on post-test cognitive tasks (Brown et al., 2012). Additionally, a positive association has been shown between aerobic fitness and brain function and volume in the prefrontal cortex (Weinstein et al., 2012), which is responsible for executive functioning, specifically *working memory*. These findings suggest that high levels of physical activity, leading to increased fitness, can improve both cognitive performance and brain structure. One mechanism proposed by which exercise improves cognitive function is through increased cerebral blood flow . Ivey and colleagues demonstrated that aerobic fitness is associated with changes in positive cerebral blood flow (Ivey, Ryan, Hafer-Macho, & Macko, 2011).

MILITARY TRAINING AND EXPERIENCES

Research over the past 25 years has demonstrated that the U.S. military is a critical social institution that disregards prior educational, occupational, income, marital/family, health, and other life course trajectories and outcomes (MacLean & Elder, 2007; MacLean, 2013; Modell & Haggerty, 1991; Settersten, 2006). Importantly, the extent to which cognitive abilities can be reshaped by military training is dependent upon individual characteristics, the timing of military service, service experiences, and historical periods (Angrist, 1990; Angrist, & Krueger, 1994; Teachman, 2004; Teachman & Call, 1996). The timing of military service varies by the individual and can include the length of active duty and time since active duty. Service experiences also vary extensively between individuals and can encompass specialization/occupation and war zone service.

Military personnel may see long-term benefits from the exercise and lifestyle patterns that carry over from the active duty period into later life in ways that are beneficial for overall health, well-being, and cognition. Most of the research in this population assesses groups with posttraumatic stress disorder or blast exposure (Roca, Hart, Kimbrell, & Freeman, 2006; Wray et al., 2012; Yehuda, Golier, Tischler, Stavitsky, & Harvey, 2005). There is a paucity of literature among this population about how differing veteran status may impact cognition. It is well-known that active duty experiences are highly variable and can influence mental health and cognition. The magnitude of the effect on mental health and cognition depends on how long an individual has been on active duty, their specialization, and whether they served in a war zone (Brailey et al., 2018). The present study did not focus on mental health but instead on how military service influences cognitive performance.

Research has consistently found that increasing the task demand during a single and dual task that involves gait movement increases brain oxygenation and total blood volume. We examined brain oxygenation changes in the prefrontal cortex while participants complete a cognitive task that was displayed on a 3D virtual reality screen while they completed either a sitting/standing/ or walking condition.

The proposed study introduced novel protocols that elicited change in cerebral blood flow in young adults while the cognitive task was displayed on a 3D virtual reality screen during which time, the intensity and task complexity are controlled. fNIRS technology was used to assess cerebral blood flow before, during, and after physical activity and lead to the development of a set of ecologically valid conditions that could be reproduced to make comparisons across multiple target populations. Introducing fNIRS technology to assess cerebral blood flow expands the exploratory nature of this research further, especially among the veteran population.

PURPOSE

The purpose of this study was to use fNIRS to determine HbO_2 concentration changes in the prefrontal cortex during varying task complexities and physical activity intensities between civilians and military personnel. Cerebral blood flow changes were measured as participants performed executive function tasks relating to working memory, cognitive flexibility, and inhibitory control.

RESEARCH QUESTIONS

1. How does physical activity intensity and task complexity influence behavioral and hemodynamic responses of healthy young adults?

As approved in IRB study# 2017-09-0020, each participant sat/stood/walked on a V-Gait treadmill and experienced different movement tasks imaged through 180º virtual reality (VR) projection screen. A within-subjects design was used, by which participants engaged in six conditions involving movement tasks (e.g., moving hands to strike objects that are green, not the red objects), which vary by physical activity intensity and task demand (see Figure 1). The conditions focused primarily focus on inhibitory control and cognitive flexibility as executive functions. Each condition remained constant, but the order in which the subject experiences the conditions was counterbalanced.

Hypothesis 1-1: Participants would exhibit higher accuracy and lower reaction time in a low physical activity intensity condition over a moderate physical activity intensity and task complexity because the higher physical and cognitive demands would inhibit reaction time and accuracy over less complex and intense conditions.

Hypothesis 1-2: Because the fNIRS technologies can monitor localized brain oxygenation changes in real life environments, we hypothesize that participants in the higher physical activity intensity and task complexity would have higher HbO_2 concentration as compensation for the more significant physical and cognitive demands.

2. How does the total volume of an acute bout of physical activity influence the behavioral and hemodynamic responses of healthy young adults?

Using a pre/post design, each participant would complete three executive function assessments using a laptop, complete the six different conditions on the V-Gait treadmill and then would repeat the cognitive assessment after completing the last condition.

Hypothesis 2-1: We hypothesize that the cognitive test scores would be improved immediately after an acute bout of physical activity compared to the baseline test scores, given the increase in HbO_2 concentration. Specifically, the participants would be able to recall more stimuli, would exhibit higher inhibitory control, and demonstrate improved cognitive flexibility during post-test over the pre-test performance on the same tasks.

3. How do healthy civilians and military personnel differ both behaviorally and hemodynamically by physical activity intensity and task complexity as well as by pre- post-exercise?

Young, healthy adults were compared to military status in all conditions as well as by pre/post testing on cognitive assessments.

Hypothesis 3-1: Across the conditions, military personnel would navigate the conditions more accurately than civilians, particularly at during the walking condition, because they have been trained to modulate competing task goals.

Hypothesis 3-2: Between groups, we hypothesize that military personnel would respond more accurately in the cognitive tasks than civilians after both high/low intensities and high task complexities, particularly those tasks that present incongruence with what the participant expects.

METHODS

STUDY DESIGN

Using a repeated measure, within- and between-subjects design, this study explored how different task complexities and physical activity intensities influenced behavioral and hemodynamic responses. Participants completed pre – and post-cognitive assessments as well as complete six different conditions (3 minutes each) with different high order thinking involving movement tasks such as striking objects that are green while avoiding the red objects (congruent) and then performed the reverse by striking the red and not the green objects (incongruent).

FUNCTIONAL NEAR INFRARED SPECTROSCOPY PROCEDURES.

fNIRS experiments were conducted with a NIRScoutTM fNIRS device located at the University of Texas at Austin. The NIRScoutTM fNIRS system is non-invasive and does not require an invasive sampling procedure. Participants were seated in a chair, and a fabric-cap with an array of plastic optodes were placed on the head of the participant. Participants were fitted with an elastic fNIRS recording cap that had places for the plastic optodes. Caps range in size from 50-62 cm. Measurements of cerebral hemodynamics were performed through LED-based optical emitters ('sources') and receivers ('detectors'). The detectors are formed by fiber optic cables whose input ends make contact with the scalp of the subject. The cable output leads to a fiber port connector and an optical sensor placed inside the fNIRS device. LED-based optics hung loosely from the array without contact to the body. This means that along with positions on the cap for plastic optodes, the cap additionally has positions for electrodes. fNIRS is an active area of research in the imaging community (Pellegrino et al., 2016). It is non-invasive and poses no increased risk to the subject. Once set-up was complete, participants were asked to sit passively while spontaneous brain activity is acquired.

Product functional description. The NIRScoutTM fNIRS device performs dual-wavelength continuous-wave (CW) near-infrared (NIR) diffuse tomographic measurements on large areas of cerebral tissue at high (= several Hz) sampling rates. The two wavelengths are set at 760 and 850 nm. The system facilitates near infrared illumination of multiple target locations of the cerebral cortex (e.g., auditory cortex or visual cortex) in a time-multiplexed, scanning fashion. The device uses low-power NIR LED illumination (intensity 5mW/wavelength) and is a Class I (eye safe) research device (see page 10 of NIRScoutTM User Manual). Using LED emitters at two distinct wavelengths allows discrimination of the two oxygenation states of cerebral tissue hemoglobin. Both wavelengths are emitted simultaneously and are distinguished by modulating and demodulating each at distinct frequencies in the low kHz-range. The instrument employs parallel readout of multiple optical detector channels, each of which uses adaptive gain switching to maximize the dynamic measurement range (>109). The BOLD signal reflects the HbO_2 and Hb concentration changes in the capillary beds within the brain region during brain activity when completing complex tasks.

Mode of data acquisition. The NIRScoutTM fNIRS device was operated through a graphical user interface (GUI) on a personal computer (PC), to which it was connected by a USB controller (USB 2.0). Communication to the host PC and fNIRS operation software was established through USB connection. Through the PC, NIRStar software (NIRx) was used to check incoming brain signal quality and record neural activity.

In summary, the NIRScoutTM fNIRS system is not a medical device, and in the current research study, this device was not investigated to determine safety and usage guidelines. This device is non-invasive, as it does not require an invasive sampling procedure, such as implantation. Furthermore, this device is not intended to support human life, diagnose, cure, mitigate or treat disease.

Only IRB approved researchers associated with this study who have undergone fNIRS training specific to the principal investigator's (PI) laboratory were allowed to administer fNIRS to participants. The researchers first viewed a lecture on fNIRS setup, given by the PI or a co-PI who were already fNIRS-trained. After attending the lecture, the researchers received a walk-through tour and thorough demonstration of our fNIRS setup and procedures. Next, the researchers observed a minimum of two full fNIRS sessions to further understand the fNIRS protocol. The PI and co-PIs determined if further observation sessions were needed before proceeding to the next step of training. Once the observation sessions were completed, the researcher partook in a minimum of three supervised fNIRS sessions. During these supervised sessions, the researcher administered all aspects of the fNIRS protocol. The research trainee applied the optodes to the participant and monitored the participant and fNIRS data throughout the duration of the experiment. The researcher was closely supervised by the PI or a trained co-PI and received an evaluation at the end of each supervised session. Once the researcher successfully completed the minimum three supervised sessions (further sessions determined by the PI and co-PIs), the researcher took a written test to demonstrate their understanding of the fNIRS procedures. The researcher must receive a perfect score before he/she could independently run fNIRS participants. If the researcher failed, then he/she had the option to retake the exam after attending the fNIRS lecture and demonstration a second time.

PROTOCOL

Each participant came to the Nonlinear Biodynamics Lab (NBL, BEL 530) and wore comfortable exercise clothing and shoes appropriate for walking. After securing informed consent, each participant had four distinct phases of data collection including (a) consent agreement, health questionnaires and physical health assessment, (b) baseline cognitive health assessment, (c) physical activity participation with task complexities, and (d) post-cognitive health assessment. During the **first phase** (see Figure 2), the participants were asked to complete the consent form, health screening questionnaire and physical assessment with anthropometric information. This information enabled us to estimate the health and eligibility of the participants. Through this screening process, we made a valid, reliable determination that the potential participant meets the inclusion criteria. The first phase took approximately 15 minutes to complete for each participant. During the **second phase**, the participants were fitted for the fNIRS cap completed the baseline cognitive health assessment prior to the physical activity conditions using the Erikson Flanker, Switcher Task, and Delayed-Match to Sample (DMS) and took approximately 25 minutes. This baseline cognitive assessment was administered on a desktop computer by a researcher. During the **third phase**, participants then performed the six conditions with different starting orders on the V-Gait treadmill imaged through a 180º VR project screen. The total time of this phase was approximately 35 minutes, including practice trials. During the **last phase**, participants completed the post cognitive-health assessment using the same cognitive tests as administered during the pre-cognitive health assessment and was approximately 15 minutes.

DATA COLLECTION

Participants either sat, stood, or walked on a Motek instrumented "V-Gait" treadmill integrated with a 180° virtual reality (VR) projection screen (V-Gait treadmill; Figure 3). To prevent falls, all participants wore a commercially available, full-body mountain climbing safety harness tethered to an overhead support frame. The harness did not interfere with their normal movements. The "V-Gait" treadmill was equipped with an emergency STOP button, which was within reach of the researcher. The treadmill was also equipped with handrails. The researchers used a three-person system to enact the procedures (i.e., one researcher spotting the participant and recording HR data, one person on the Motek controlling the VR and treadmill, and a third person monitoring the fNIRS data/equipment). Each participant was attached "kinematic-motion capture markers" which was integrated with VR screen. The motion of participants was directly connected with visual and auditory feedback for GNG task during the Physical Activity Conditions.

PHYSICAL ACTIVITY CONDITIONS

Participants performed the conditions of sitting, standing, and walking with different task complexities. During this stage of the study, both green ball and red ball objects were projected to the Virtual Reality screen. At the start of each condition, participants were instructed to strike green balls (80% of total object number), not the red balls (20% of total object number) or strike the red balls (20% of total object number), not the green balls (80% of total object number) (Go-No-Go task) during physical activity conditions. In total 120 objects appeared for Go-No-Go task, and each target showed up in a 1.5 second interval during a 3-minute duration for each condition. Participants were on the V-gait treadmill for 1-minute without objects in order to both assess physical demands of the condition without the cognitive task (striking or not striking objects) and to acclimate to the physical activity condition. During the two practice sessions, virtual objects were projected onto the treadmill space. The participant was instructed to stand or walk at preferred walking speed. These conditions were used to ensure preferred walking speed and marker calibration were correctly set, which was then used in conditions 1-6.

During condition 1, participants completed a lower task complexity condition, in which the participants sat in a chair on the treadmill and were to strike the green, not the red objects. During condition 2, participants completed a higher task complexity condition, in which the participants sat in a chair on the treadmill and were to strike the red, not the green objects. During condition 3, participants completed a lower task complexity condition, in which the participants stood on the treadmill and were to strike the green, not the red objects. During condition 4, participants completed a higher task complexity condition, in which the participants stood on a treadmill and were to strike the red, not the green objects. During condition 5, participants completed a lower task complexity condition with preferred walking speed. While walking on the treadmill, participants were to strike the green, not the red objects. During condition 6, participants completed a higher task complexity condition with preferred walking speed. While walking on the treadmill, participants were to strike the red, not the green objects.

Auditory feedback was given as each item was encountered. A trial score was explained and presented at the end of each trial. At each item pass, the participant either (a) earned "points" for striking on the correct targets, or (b) lost "points" for incorrectly striking or missing the target. Cognitive performance was saved automatically for the future data collection during each condition.

Instruments and Measures

Health screen questionnaire. All potential participants who sign the informed consent form were then asked to complete a brief Health History Questionnaire. All participants were screened to ensure they had no history of serious cardiovascular, respiratory, visual, vestibular, neurological, or musculoskeletal problems that might have directly interfered with their walking. Additionally, the participants were required to report receiving > 5 hours of sleep the previous night to participate. Health History Questionnaire also included a self-report scale to measure depressive symptoms.

Mini mental state exam (MMSE). This assessment is a standard and validated questionnaire (Folstein, Folstein & McHugh, 1975) that is widely used to screen for basic cognitive impairments. A copy of this questionnaire is included in the supplemental resources.

Anthropometric measurements. Height and weight were measured using a stadiometer and a physician's scale, respectively. Body mass index (BMI) was calculated by standard anthropometric techniques (weight in kilograms divided by height in meters squared).

Measurement of executive function. Core learning variables were administered on the desktop computer in the lab setting. Participant learning was measured by the Psychology Experiment Building Language cognitive battery (Mueller & Piper, 2014), which contains the cognitive assessments of which all recorded accuracy and reaction time:

Eriksen-Flanker Task. The flanker task assesses inhibition and was administered on a desktop computer. Participants were shown several arrows and instructed to focus only on the direction of the arrow in the center of the screen and reply by hitting the corresponding arrow on the keyboard. If the flanker arrows are facing the same way as the center arrow, it was called a congruent task. If the flankers are facing the opposite way as the center arrow, then it was known as an incongruent task.

Switcher Task. The switcher task assesses cognitive flexibility and was administered on a desktop computer. Participants were shown several different colors of shapes, with letters, on the screen. They then had to choose a stimulus that switches consistently between two or three rules (shape, color, and letter) or inconsistently between three rules.

Delayed-Match-to-Sample Task. The participant then took part in the DMS task, which has a short-term memory. Participants viewed a 5x5 grid of brightly colored yellow and red squares with a unique pattern. Then, that stimulus disappeared, and the screen was blank through a delay (5 seconds). Two stimuli were then presented on the screen (a "match" and "nonmatch"). The participant indicated which stimulus was the correct "match" with a keypress.

Measurement of Physical Activity. During the Physical Activity Conditions, participants wore a Polar heart-rate monitor and an Actigraph GXT3 Accelerometer to gather physiological and step count data.

Heart rate measurements. Before beginning the Physical Activity Conditions, the Heart rate (HR) monitor was placed on each participant's chest to determine resting HR in beats per minute (bpm) while sitting for 1-3 minutes. After the completion of each Physical Activity Condition, participants were instructed to sit quietly until HR was within 10% of resting HR.

Accelerometer measurements. Prior to beginning the Physical Activity Conditions, an Actigraph GTX3 Accelerometer was placed on the participant's right hip.

The accelerometer recorded the number of steps taken by each during each physical activity condition.

Participants

Seventeen healthy individuals (age = 25.6 + 2.3 years, BMI = 24.2 ± 2.3; n= 12 male, n= 5 female) were recruited to participate in the study. Of this, six participants were military personnel. The selected participant characteristics are displayed in Table 1.

Inclusion/Exclusion. This experiment compared the performance of Civilian Adults to that of Military Personnel Adults. The eligibility criteria were as follows: All participants were between 18-34 years of age, had a Body Mass Index (BMI) < 30, blood pressures with systolic < 140 and diastolic < 90 (Frese et al., 2011), Mini-Mental State Exam score > 23 (Folstein et al., 1975), and were able to walk unassisted for at least 5 minutes without shortness of breath, chest pain, or joint pain in the legs, neck, or back (Steffen et al., 2002; Mirelman et al., 2013).

Data Reduction and Analysis

Using a paired sample t-test, HbO_2 concentration elicited between the sitting, standing, and walking physical activity conditions was compared. Another paired samples t-test was used to compare the accuracy and reaction time between the sitting, standing, and walking physical activity conditions. An independent sample t-test was used to compare HbO_2 concentration as well as accuracy and reaction time across sitting, standing, and walking physical activity conditions between civilians and military personnel. This analysis captured the physical intensity and task complexity effect on HbO_2 concentration as well as accuracy and reaction time.

Using a paired samples t-test, HbO_2 concentration elicited during each cognitive test (Flanker, Switcher, and DMS) was compared pre- post-exercise. Another paired sample t-test was used to compare accuracy and reaction time for each cognitive test pre-post-exercise. An independent samples t-tests was used to compare HbO_2 concentration as well as accuracy and reaction time for each cognitive test between civilians and military personnel pre- post-exercise. The analysis captured the cumulative effect of the physical activity on HbO_2 concentration as well as accuracy and reaction time. All statistics are reported as mean and standard deviation followed by units (e.g. M ± SDunits).

RESULTS

In this section the results are presented by variable and by research question. First, the behavioral responses and hemodynamic responses are presented by condition and are then analyzed as pre/post repeated measures.

BEHAVIORAL & HEMODYNAMIC RESPONSES BY PHYSICAL ACTIVITY CONDITION

Physical Intensity.

Paired sample t-tests (n=17) were used to verify that the conditions increased in intensity as measured by HR. As found in Table 2, the walking condition elicited a significantly higher HR (92.07 ± 9.32bpm; 77.66 ± 10.64bpm, p<0.01) than the standing condition. Additionally, the standing condition elicited a significantly higher HR (77.66 ± 10.64bpm; 69.76 ± 9.06bpm, p<0.01) than the sitting condition. To compare HR changes before and after the start of each task, a paired sample t-tests were conducted. There was a significant increase in HR from pre-to-post in all tasks (see Table 3); sitting congruent task (73.47 ± 9.02; 68.71 ± 8.98bpm, p<0.01), sitting incongruent task (69.47 ± 10.54bpm; (67.41 ± 9.81bpm, p<0.01), standing congruent task (79.35 ± 11.58bpm; 75.35 ± 9.92bpm, p<0.01), standing incongruent task (79.06 ± 11.61bpm; 76.88 ± 11.10bpm, p<0.01), walking congruent task (95.06 ± 10.62bpm; 90.41 ± 8.43bpm, p<0.01), and walking incongruent task (92.41 ± 9.62bpm; 90.41 ± 9.37bpm, p<0.01).

Accuracy, Reaction Time, & HbO_2 Concentration.

To determine if there were differences between the physical conditions (i.e. sit, stand, and walk) among participants' (n=17) accuracy (% correct), reaction time (msec), and HbO_2 concentrations (μmol), paired sample t-tests were conducted (Table 7).

Participants in the standing conditions had a significantly higher degree of accuracy (0.954 ± 0.058%correct; 0.932 ± 0.058%correct, $p<0.01$) compared to the sitting conditions. Participants in the walking conditions had a significantly higher degree of accuracy (0.972 ± 0.033%correct; 0.932 ± 0.058%correct, $p<0.01$) compared to the sitting conditions. There was no significant difference in degree of accuracy between the walking condition and standing condition, despite the presence of a higher degree of accuracy in the walking condition. Participants in the standing conditions had a significantly lower reaction time (0.629 ± 0.040msec; 0.640 ± 0.037msec, $p<0.01$) compared to sitting conditions. Additionally, participants in the walking conditions had significantly lower reaction time compared to both the standing conditions (0.597 ± 0.037msec; 0.629 ± 0.040msec, $p<0.05$) and sitting conditions (0.597 ± 0.037msec; 0.640 ± 0.037msec, $p<0.05$). When combining all regions of the prefrontal cortex, there were no significant differences between the physical conditions among participants' HbO_2 concentrations. However, when breaking the prefrontal cortex into five regions, the walking conditions elicited a higher HbO_2 concentration only in the right ventrolateral region (-0.0002 ± 0.0003μmol; -0.0004 ± 0.0004μmol, $p<0.01$) compared to the sitting conditions.

BEHAVIORAL & HEMODYNAMIC RESPONSES BY PRE-POST EXERCISE

To determine if there were differences between pre- and post-test among participants' (n=14) accuracy (# correct; Table 4), reaction time (msec; Table 5), or HbO_2 concentrations (μmol; Table 6), paired sample t-tests were conducted.

Flanker Task.

There were no significant differences between pre- and post-test accuracy during the flanker task. Participants during the post-test demonstrated significantly lower reaction times in the both the congruent (459.12 ± 37.31msec; 465.77 ± 50.40msec, $p<0.01$) and incongruent (507.42 ± 33.47msec; 511.03 ± 57.02msec, $p<0.01$) conditions. Participants during the pre-test exhibited significantly higher HbO_2 concentrations in the orbital frontal (0.0004 ± 0.0004μmol; -0.0001 ± 0.0004μmol, $p<0.01$), medial frontal (0.0002 ± 0.0003μmol; -0.0001 ± 0.0004μmol, $p<0.05$), left ventrolateral (0.0003 ± 0.0003μmol; 0.00003 ± 0.0005μmol, $p<0.05$), and right ventrolateral (0.0003 ± 0.0003μmol; -0.00008 ± 0.0004μmol, $p<0.05$) regions, compared to post-test. There was no significant difference between pre- and post-test HbO_2 concentrations in the dorsolateral region of the prefrontal cortex during the flanker task. When combining all regions of the prefrontal cortex, participants during the pre-test demonstrated significantly higher HbO_2 concentrations (0.001 ± 0.002μmol; -0.0002 ± 0.002μmol, $p<0.05$) compared to the post-test.

Switcher Task.

There were no significant differences between pre- and post-test accuracy during the switcher task. Participants during the post-test demonstrated significantly lower reaction times in the switcher 2-rule predictable (21159.06 ± 3663.04msec; 23660.42 ± 2639.60msec, $p<0.01$), switcher 3-rule predictable (21762.90 ± 3093.51msec; 23154.44 ± 3522.84msec, $p<0.01$), and switcher 3-rule unpredictable (22569.25 ± 3558.23msec; 22961.50 ± 3581.30msec, $p<0.01$). Participants during the pre-test exhibited significantly higher HbO_2 concentrations during the switcher 2-rule predictable in the orbital frontal (0.0002 ± 0.0004μmol; -0.0002 ± 0.0003μmol; $p<0.05$) and right ventrolateral (0.0002 ± 0.0003μmol, -0.0002 ± 0.0004μmol, $p<0.05$) regions of the prefrontal cortex. Participants during the pre-test had significantly higher HbO_2 concentrations during the switcher 3-rule predictable in the orbital frontal (0.0002 ± 0.0003μmol; -0.0002 ± 0.0004μmol, $p< 0.01$), medial frontal (0.00002 ± 0.0002μmol; -0.0003 ± 0.0004μmol, $p<0.01$), left ventrolateral (0.0002 ± 0.0003μmol; 0.000009 ± 0.0005μmol, $p< 0.05$), and right ventrolateral (0.0001 ± 0.0003μmol; -0.0001 ± 0.0004μmol, $p<0.01$) regions of the prefrontal cortex. When combining all regions of the prefrontal cortex, participants during the 3-rule predictable pre-test only, exhibited significantly higher HbO_2 concentration (0.0006 ± 0.001μmol; -0.0006 ± 0.002μmol, $p<0.05$) compared to the 3-rule predictable post-test. There were no significant differences found between pre- and post-test HbO_2 concentrations in any region of the prefrontal cortex or when combining all regions during the 3-rule unpredictable.

Delayed-Match-to-Sample Task.

There were no significant differences between pre- and post-test accuracy during the DMS task. Participants during the post-test demonstrated significantly lower reaction times in the DMS task (1719.93 ± 415.96msec; 1908.83 ± 484.46msec, $p<0.05$) compared to pre-test. Participants during the pre-test exhibited significantly higher HbO_2 concentrations in the DMS task only in the left ventrolateral region (0.0003 ± 0.0004μmol; -0.0004 ± 0.0012μmol, $p<0.05$). No other significant differences were present between pre- and post-test HbO_2 concentrations during the DMS task in any other region of the prefrontal cortex. When combining all regions of the prefrontal cortex, participants during the pre-test exhibited higher HbO_2 concentration (0.001 ± 0.002μmol; -0.001 ± 0.004μmol, $p<0.05$).

Differences in Behavioral & Hemodynamic Responses by Physical Activity Condition Between Civilians and Military Personnel

Accuracy and Reaction Time.

To determine if civilians (n=11) or military personnel (n=6) group had better accuracy (% correct) and reaction time (msec) during the six Physical Activity Conditions, paired sample t-tests were conducted (Table 7). Civilians exhibited significantly higher accuracy on the sitting congruent condition (0.925 ± 0.053%correct; 0.908 ± 0.101%correct, $p<0.05$) but had significantly lower accuracy on the sitting incongruent (0.917 ± 0.079%correct; 0.993 ± 0.017%correct, $p<0.05$) condition compared to military personnel. No significant differences were found between civilians and military personnel in accuracy or reaction time on any other condition.

HbO_2 Concentration.

To determine if civilians (n=9) or military personnel (n=4) had a higher HbO_2 concentration (μmol), paired sample t-tests were conducted (Table 7). When breaking the prefrontal cortex down into five regions, there were no significant differences found between civilians and military personnel in HbO_2 concentration in the sitting congruent condition, both standing conditions, and both walking conditions. However, in the sitting incongruent task, military personnel displayed a significantly higher HbO_2 concentration in four of the five regions of the prefrontal cortex; orbital frontal (0.0001 ± 0.0011μmol; -0.0003 ± 0.0004μmol, $p<0.01$), medial frontal (0.0001 ± 0.0009μmol; -0.0001 ± 0.0003μmol, $p<0.01$) left ventrolateral (0.0002 ± 0.0007μmol; -0.0002 ± 0.000μmol; $p<0.01$), and dorsolateral (0.00004 ± 0.0009μmol; -0.0002 ± 0.0002μmol, $p<0.01$) compared to civilians. When combining all regions of the prefrontal cortex, military personnel had a significantly higher HbO_2 concentration in only the sitting incongruent condition (0.0007 ± 0.004μmol; -0.0011 ± 0.001μmol, $p<0.05$) and walking congruent condition (-0.0001 ± 0.0003μmol; -0.001 ± 0.002μmol, $p<0.01$) compared to civilians.

DIFFERENCES IN BEHAVIORAL & HEMODYNAMIC RESPONSES BY PRE-POST EXERCISE BETWEEN CIVILIANS AND MILITARY PERSONNEL

To determine if civilians (n=10) or military personnel (n=6) had better accuracy (%correct) and reaction time (msec) during both pre- and post-cognitive tests, paired sample t-tests were conducted.

Flanker Task.

There were no significant differences between civilians and military personnel in accuracy in either the congruent or incongruent and pre- or post-tests. However, civilians had a significantly lower reaction time in the congruent portion of the flanker pre-test (460.85 ± 33.62msec; 491.49 ± 63.35msec, $p<0.05$). Military personnel exhibited a significantly higher HbO_2 concentration during the pre-flanker task in the left ventrolateral region (0.0004 ± 0.0001μmol; 0.0002 ± 0.0004μmol, $p<0.05$) of the prefrontal cortex, compared to civilians. There were no other significant differences between civilians and military personnel in HbO_2 concentration in any other region of the prefrontal cortex during either the pre- or post-tests for the flanker task. Further, there were no significant differences between civilians and military personnel in HbO_2 concentration when combining all regions of the prefrontal cortex.

Switcher Task.

Civilians had a significantly higher degree of accuracy in the switcher 2-rule predictable post-test (35.10 ± 1.45#correct; 33.17 ± 2.56#correct, $p<0.05$) compared to military personnel. There were no other significant differences between civilians and military personnel in accuracy in the switcher 2-rule predictable, 3-rule predictable, or 3-rule unpredictable. Civilians had significantly lower reaction times in the switcher 2-rule predictable post-test (20113.53 ± 2424.37msec; 22901.61 ± 4883.02msec, $p<0.05$) and 3-rule predictable pre-test (22980.24 ± 2640.58msec; 24246.22 ± 5107.31msec, $p<0.05$) compared to military personnel. Military personnel displayed a significantly higher HbO_2 concentration during the switcher 3-rule predictable pre-test in the left ventrolateral region (0.0003 ± 0.0001μmol; 0.0001 ± 0.0004μmol, $p<0.05$) and switcher 3-rule unpredictable pre-test in both the right ventrolateral (0.0003 ± 0.0001μmol; 0.0001 ± 0.0004μmol, $p<0.05$) and dorsolateral (0.0002 ± 0.0001μmol; 0.0001 ± 0.0005μmol, $p<0.05$) regions, compared to civilians. Civilians exhibited a significantly higher HbO_2 concentration during the switcher 3-rule unpredictable post-test in the right ventrolateral region (0.00005 ± 0.0005μmol; -0.00002 ± 0.0001μmol, $p<0.05$) of the prefrontal cortex compared to military personnel. There were no other significant differences in HbO_2 concentration between military personnel and civilians in any other region of the prefrontal cortex during either of the pre- or post-tests for the switcher task. Further, there were no significant differences between civilians and military personnel in HbO_2 concentration when combining all regions of the prefrontal cortex.

Delayed-Match-to-Sample Task (DMS).

There were no significant differences between civilians and military personnel in accuracy in the DMS test. Civilians had significantly lower reaction times only in the pre-DMS test (1835.07 ± 356.88msec; 2015.68 ± 655.37msec, $p<0.05$). There were no significant differences, whether combining all regions of the prefrontal cortex or separating them, between civilians and military personnel in HbO_2 concentration in either of the pre- or post-tests for the DMS task.

DISCUSSION

The purpose of this study was to determine both behavioral and cerebral HbO_2 concentration changes in the prefrontal cortex over varying task complexities and physical activity intensities between civilians and military personnel. Two secondary aims of this study were to determine both the effects of: 1) an acute bout of physical activity and 2) physical activity intensity and task complexity on behavioral and cerebral HbO_2 concentration changes, regardless of group. First, the physical activity conditions were confirmed, such that the walking condition elicited a significantly higher HR than the standing condition and the standing condition elicited a significantly higher HR than the sitting condition. Although this finding was predicted, it has never before been confirmed while simultaneously measuring HbO_2 concentration. This was a necessary validation and was important to collect evidence that the cognitive performance would not be compromised during the different physical activity conditions Research has suggested that physical activity intensity affects performance on cognitive tasks such that as intensity increases, performance increases post-test (Brown et al., 2012). The relationship can be described as an inverted-U, indicating that cognitive performance, to a point, increases as physical activity intensity increases. However, after that point, fatigue sets in and cognitive performance actually decreases (Lambourne & Tomporowski, 2010).

A surprise finding in our study was reflective of this phenomenon even though we hypothesized that cognitive performance would decrease as intensity increased during the physical activity conditions. As physical activity intensity increased (sit to stand to walk), cognitive performance (accuracy and reaction time) actually improved. Military personnel had a significantly higher HbO_2 concentration in the prefrontal cortex during both the sitting congruent and walking congruent tasks compared to Civilians. Only seeing this result in two of the six conditions indicates that this potentially does not have any clinical meaning warranting the need for a larger sample size.

For the pre- and post-test cognitive differences, assessing the cumulative effect of the single bout of acute physical activity, accuracy saw little to no improvement both between groups and when combined. Further, Civilians had significantly lower RT than military personnel in 3 of the cognitive pre-test tasks. This could be due to the small sample of both military personnel. However, both groups showed significant improvements in both reaction time in the post-test compared to the pre-test. This supports prior research indicating the physical activity can improve cognitive performance (Hwang et al., 2017; Lambourne & Tomporowski, 2010). Further, Hillman and colleagues showed that just briskly walking can improve cognitive performance (Hillman et al., 2010) just as we demonstrated in our study. In respect to HbO_2 concentration, military personnel had significantly higher concentrations only in the flanker pre-test. However, both groups together experienced higher HbO_2 concentrations during all pre-tests compared to post-tests, contrary to our hypothesis. Two possible explanations arise from these findings. One is that even though everyone experienced the same total acute bout of physical activity, not all participants concluded the physical activity conditions with the highest intensity (i.e. walking condition). For example, because the conditions were counterbalanced a participant may have started with the walking condition and ended with standing, the effects on HbO_2 concentration may have been washed out or reduced. Further study is warranted; however, if this finding can be replicated, learning during physical activity or immediately after higher intensity physical activity experiences could have the greatest cognitive performance benefits. Hwang and colleagues (2016) found that very vigorous physical activity may be necessary to elicit fastest reaction time and better accuracy among healthy young adults.

The second potential explanation is that participants may have had higher HbO_2 concentrations during the pre-tests because the cognitive tasks were novel to them. Therefore, when taking the cognitive tasks at post-test, participants already knew the process and the strategies involved in completing them and might not have had to recruit as many resources (i.e. oxygen) to complete the tasks. Continued study, with a large number of participants may influence the findings in this study.

This study was the first of its kind to measure HbO_2 concentration differences during physical activity between civilians and military personnel. The data described within this study are pilot data for a larger study and the goal was to determine what regions of the prefrontal cortex we want to target. Visual images for oxygenation and deoxygenation of the prefrontal cortex will come with a larger sample. The goal of this study was to focus on behavioral data, while presenting hemodynamic pilot data. Further, the clinical significance of the μmol values are unknown, further warranting a larger sample.

LIMITATIONS

This study had a relatively small sample size (n=16) and even smaller for some of the analysis ran on for HbO_2 concentrations due to poor signal quality for some of the tests. First, although there was a small sample size, there was not much that could have been done to increase it. This was due to the limited time we were allotted with the fNIRS equipment (20 days total of data collection or 4 weeks for 5 days per week). The first week of data collection was not used as described below due to methodological changes, so only

15 days of total data collection (3 weeks for 5 days per week) was used. Even still, the lab was booked with participants for the 3 weeks of data collection.

Another limitation, as described above, was the even smaller sample size when analyzing fNIRS data (HbO_2 concentration). fNIRS data is very particular and it requires a strong signal to receive clean, quality data. The quality of fNIRS signal is directly influenced by the individual wearing the cap. In particular, it is mainly affected by a) hair type (i.e. thick or thin) and b) hair color, amongst others. Thicker and darker hair creates obstructions for the light from the sources to pass through causing the signal to be poor.

Delimitations

It should be noted that we excluded the first four participants from the analysis. This was because a decision was made to change the methodology after the first week of data collection. The change was to increase the number of objects which appeared from n=60 to n=120, thereby doubling the total count. This was done because the first set of conditions was too easy for the participants and by increasing the object number count, difficulty increased (i.e. objects were displayed on the screen for 1.1 seconds compared to 1.5 seconds).

Implications

The present study demonstrated that it is feasible to examine cerebral blood flow and total blood volume in the prefrontal cortex before, during and after physical activity in the laboratory setting using a virtual reality system. Now that the physical activity conditions have been validated using a within-subjects analysis, the door has been opened to utilize fNIRS modalities in an authentic, real-world setting, which have the potential to facilitate military training, learning in college coursework, and increase the cognitive reserve for later life as a means to stave off the potential effects of cognitive decline. The findings of this study need to be replicated and the methods applied to different samples of the general U.S. population.

TABLES

Table 1. Selected subject characteristics.

	Mean ± SD or n (%)	
Variable	Civilian	Military
Male/Female, n	6/5, 11	6/0, 6
Age, years	26.09 ± 3.53	24.67 ± 4.41
Race		
Caucasian	8 (72.7%)	3 (50%)
Latino	1 (9.1%)	2 (33.3%)
Asian American	2 (18.2%)	0 (0%)
Unspecified	0 (0%)	1 (16.7%)
Education		
High School	2 (18.2%)	1 (16.7%)
Bachelors	3 (27.3%)	5 (83.3%)
Masters	5 (45.5%)	0 (0%)
Doctorate	1 (9.1%)	0 (0%)
BMI	24.14 ± 2.32	24.41 ± 2.52

Table 2. Average heart rate (bpm) of participants in each PA condition.

Condition	Mean	SD
Sit	69.76	9.06
Stand	77.66	10.64
Walk	92.07	9.32

Table 3. Average heart rate (bpm) of participants after 1 and 3 minutes in each PA condition.

	Heart Rate	
Condition	Mean	SD
Sit-congruent (1min)	68.71	8.98
Sit-congruent (3min)	73.47	9.02
Sit-incongruent (1min)	67.41	9.81
Sit-incongruent (3min)	69.47	10.54
Stand-congruent (1min)	75.35	9.92
Stand-congruent (3min)	79.35	11.58
Stand-incongruent (1min)	76.88	11.1
Stand-incongruent (3min)	79.06	11.61
Walk-congruent (1min)	90.41	8.43
Walk-congruent (3min)	95.06	10.62
Walk-incongruent (1min)	90.41	9.37
Walk-incongruent (3min)	92.41	9.62

Table 4. Mean ± SD Accuracy (# correct) for both Civilians and Military Personnel during cognitive tasks, pre- and post-test.

	Civilian (n=10)		Military (n=6)	
Task	Pre-test	Post-test	Pre-test	Post-test
Flanker				
Congruent	29.90 ± 0.32	29.88 ± 0.35	30.00 ± 0.00	29.60 ± 0.55
Incongruent	28.40 ± 1.78	28.75 ± 1.28	28.67 ± 1.51	29.40 ± 0.55
Switcher				
2-rule predictable	35.18 ± 1.25	35.10 ± 1.45[a]	35.33 ± 1.21	33.17 ± 2.56
3-rule predictable	35.18 ± 1.25	35.00 ± 1.49	35.17 ± 1.60	34.50 ± 1.23
3-rule unpredictable	35.55 ± 0.82	35.30 ± 1.35	35.67 ± 0.52	34.50 ± 1.38
DMS	24.18 ± 3.55	24.90 ± 3.14	24.83 ± 2.79	23.33 ± 4.59

[a] denotes Military significantly ($p<0.05$) lower degree of accuracy than Civilians
Total # of trials: Flanker (n= 30); Switcher (n= 36); DMS (n= 30)

Table 5. Mean ± SD Reaction time (msec) for both Civilians and Military Personnel during cognitive tasks, pre- and post-test.

	Civilian (n=10)		Military (n=6)	
Task	Pre-test	Post-test	Pre-test	Post-test
Flanker				
Congruent	460.85 ± 33.62	451.84 ± 33.17	491.49 ± 63.35#	470.74 ± 44.54
Incongruent	511.23 ± 32.87	500.45 ± 26.55	525.54 ± 78.51	518.57 ± 43.31
Switcher				
2-rule predictable	24150.58 ± 4698.62	20113.53 ± 2424.37	24960.28 ± 2998.72	22901.61 ± 4883.02#
3-rule predictable	22980.24 ± 2640.58	20770.87 ± 2612.24	24246.22 ± 5107.31#	23416.28 ± 3343.35
3-rule unpredictable	22674.24 ± 3904.89	21427.10 ± 2852.55	24935.00 ± 4265.92	24472.83 ± 4047.11
DMS	1835.07 ± 356.88	1750.38 ± 291.41	2015.68 ± 655.37#	1669.19 ± 601.05

# denotes Military Personnel significantly ($p<0.05$) higher reaction time than Civilians

Table 6. Mean ± SD HbO_2 Concentration (μmol) for both Civilians and Military Personnel during cognitive tasks, pre- and post-test.

	Civilian		Military	
Task	Pre-test (n=11)	Post-test (n=9)	Pre-test (n=5)	Post-test (n=4)
Flanker	0.0009 ± 0.002	-0.0003 ± 0.002	0.0019 ± 0.001*	0.0003 ± 0.001
Switcher				
2-rule predictable	0.0003 ± 0.002	-0.0005 ± 0.002	0.0005 ± 0.002	-0.0006 ± 0.001
3-rule predictable	0.0004 ± 0.002	-0.0007 ± 0.002	0.001 ± 0.001	-0.0004 ± 0.001
3-rule unpredictable	0.0006 ± 0.002	0.0002 ± 0.002	0.0009 ± 0.001	0.0006 ± 0.001
DMS	0.0009 ± 0.002	0.002 ± 0.002	-0.0009 ± 0.004	-0.002 ± 0.003

* denotes Military significantly ($p<0.05$) higher HbO_2 concentration than Civilians

Table 7. Mean ± SD Accuracy (% correct), Reaction time (msec), and HbO_2 Concentration (μmol) for both Civilians and Military Personnel during PA Conditions.

	Civilian			Military		
Condition	Accuracy (n=11)	Reaction Time (n=11)	HbO_2 (n=9)	Accuracy (n=6)	Reaction Time (n=6)	HbO_2 (n=4)
Sit (congruent)	0.93 ± 0.05	0.64 ± 0.05	-0.0023 ± 0.002	0.91 ± 0.10#	0.63 ± 0.03	-0.001 ± 0.004
Sit (incongruent)	0.92 ± 0.08	0.65 ± 0.04	-0.0011 ± 0.001	0.99 ± 0.02*	0.64 ± 0.05	0.0007 ± 0.004*
Stand (congruent)	0.95 ± 0.07	0.61 ± 0.05	-0.0002 ± 0.002	0.97 ± 0.05	0.61 ± 0.03	-0.0001 ± 0.001
Stand (incongruent)	0.94 ± 0.66	0.64 ± 0.04	-0.0018 ± 0.003	0.97 ± 0.05	0.64 ± 0.04	-0.002 ± 0.002
Walk (congruent)	0.95 ± 0.05	0.58 ± 0.03	-0.0010 ± 0.002	0.97 ± 0.03	0.61 ± 0.03	-0.0001 ± 0.000^
Walk (incongruent)	0.98 ± 0.05	0.60 ± 0.05	-0.0013 ± 0.002	0.99 ± 0.02	0.61 ± 0.03	-0.0008 ± 0.001

# denotes Military significantly ($p<0.05$) lower degree of accuracy than Civilians
* denotes Military significantly ($p<0.05$) higher HbO_2 concentration than Civilians
^ denotes Military significantly ($p<0.01$) higher HbO_2 concentration than Civilians

FIGURES

Figure 1. Task Complexity and PA intensity conditions.

Experimental Conditions

	Description of Each Condition
1	**Sit** - Low intensity/low cognitive demand, congruent task
2	**Sit** - Low intensity/high cognitive demand, incongruent task
3	**Stand** – Low-moderate intensity/low cognitive demand, congruent task
4	**Stand** – Low-moderate intensity/high cognitive demand, incongruent task
5	**Preferred walking** – Moderate intensity/moderate cognitive demand, congruent task
6	**Preferred walking** – Moderate intensity/high cognitive demand, incongruent task
7	**Accelerated walking** – Moderate-vigorous intensity/high cognitive demand, congruent task
8	**Accelerated walking** – Moderate-vigorous intensity/high cognitive demand, incongruent task

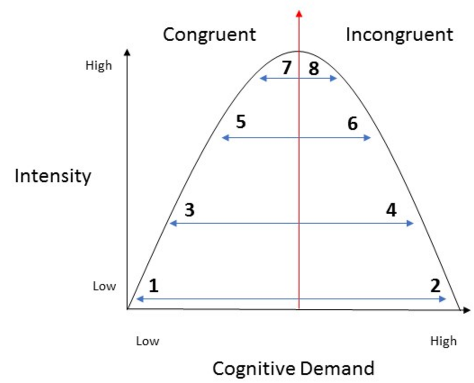
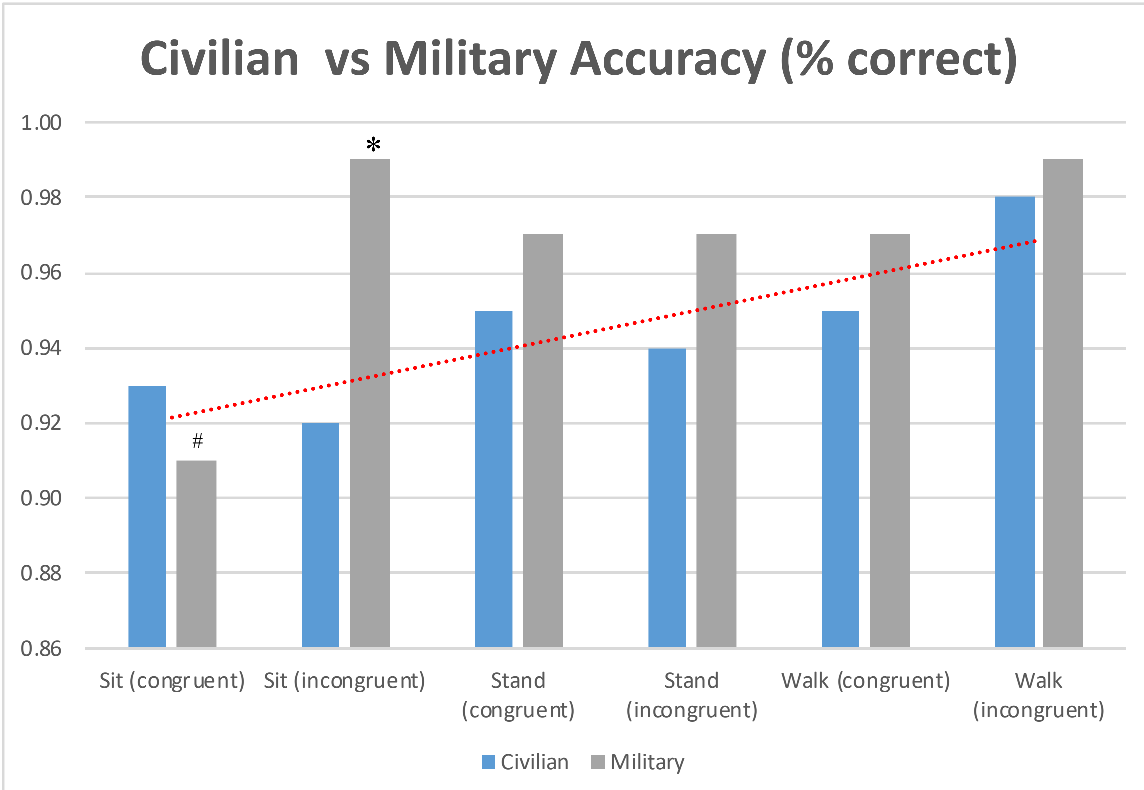


Figure 2. Study design and experimental protocol sequence.

Baseline testing (physical health)		**PRE-testing (cognitive health)**		**PA conditions**		**POST testing (cognitive health)**
- Consent form - Health Screening Questionnaire -Mini Mental State exam - Height, weight, HR, & BP - HR monitor & Accelerometer - Preferred Walking Speed	→	-Fit fNIRS cap onto participant - Flanker - Switcher - DMS	→	- Six different conditions in a row - Different starting order for each participant -Heart rate monitoring -Accelerometry	→	- Flanker - Switcher - DMS -Take fNIRS cap off participant
~ 15 min		**~ 25 min**		**~ 35 min**		**~ 15 min**

Abbreviation: HR: Heart rate, BP: Blood Pressure, DMS: Delayed-Match-to-Sample Task

Figure 3. Accuracy (% correct) between Civilian and Military Personnel during PA Conditions.



# denotes Military significantly ($p<0.05$) higher degree of accuracy than Civilians

* denotes Military significantly ($p<0.05$) higher degree of accuracy than Civilians

Figure 4. Reaction time (msec) between Civilians and Military Personnel during PA Conditions.

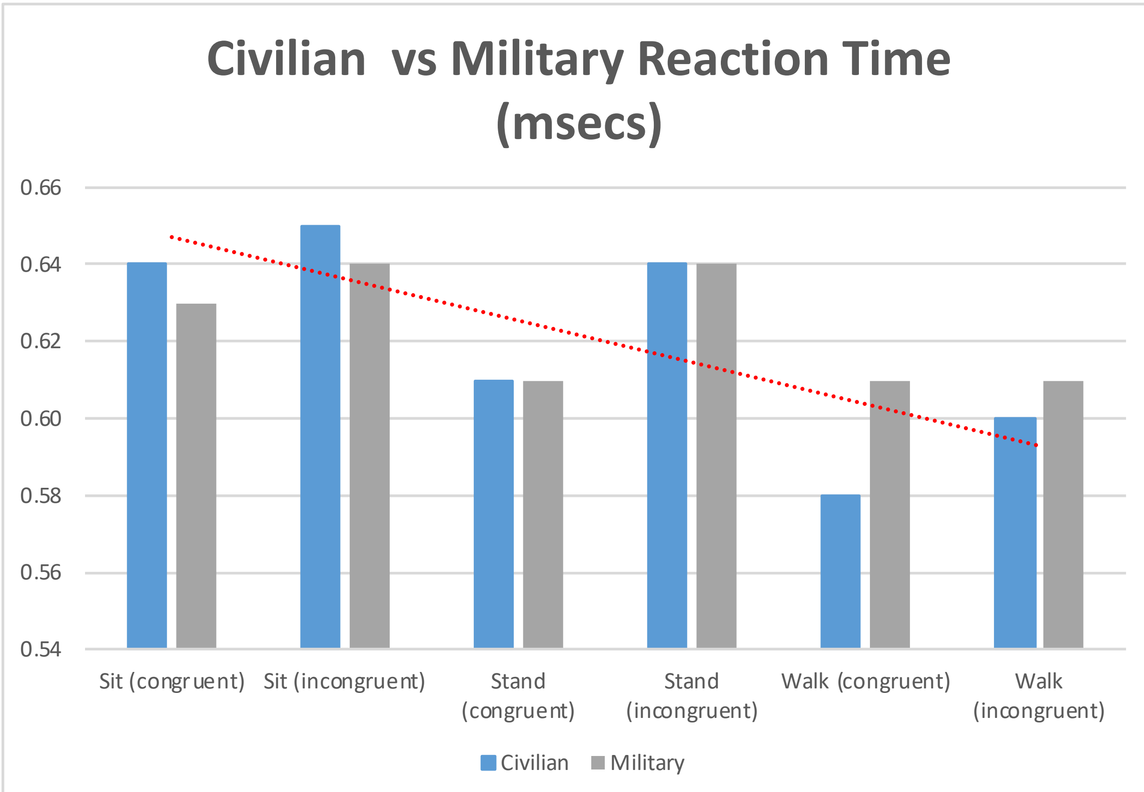
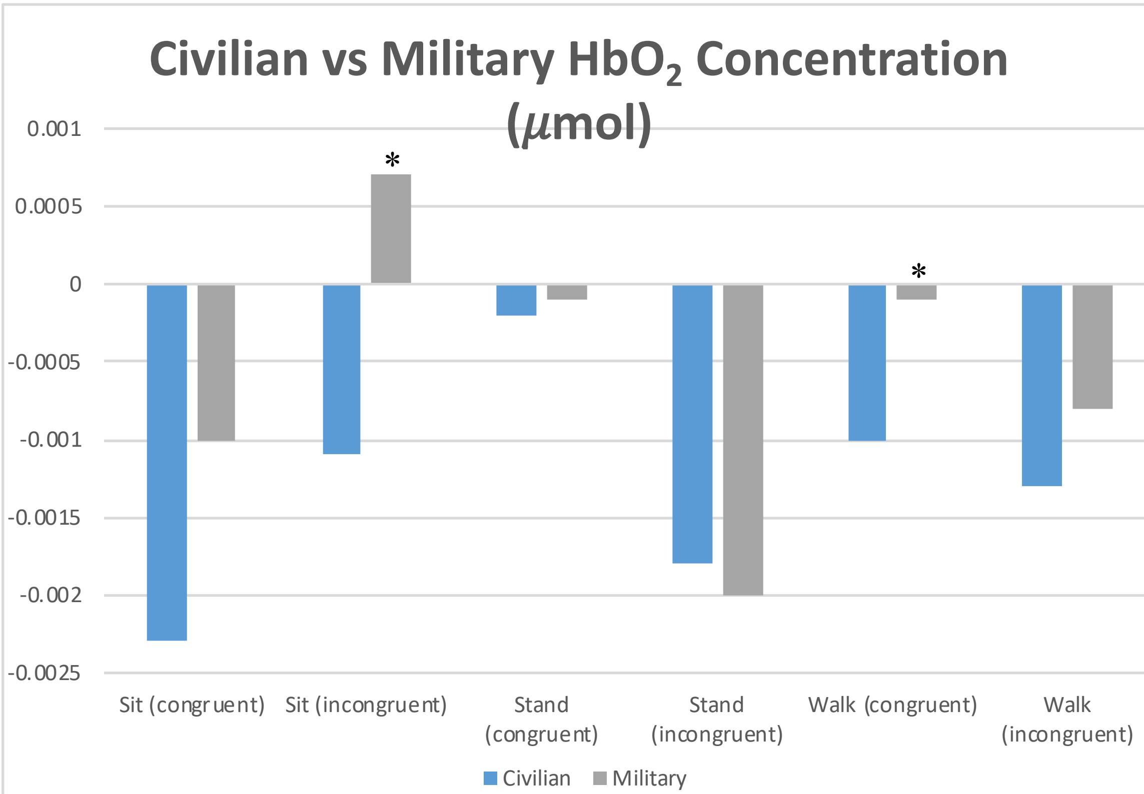


Figure 5. HbO_2 Concentration (μmol) between Civilians and Military Personnel during PA Conditions.



* denotes Military significantly ($p<0.05$) higher HbO_2 concentration than Civilians

REFERENCES

Alzheimer's Association (2018). 2017 Alzheimer's Disease Facts and Figures. Retrieved March 19, 2018 from https://www.alz.org/facts/overview.asp

Alzheimer's Association (2018). Prevention and Risk of Alzheimer's and Dementia. Retrieved March 19, 2018 from https://www.alz.org/facts/overview.asp

Barulli, D. & Stern, Y. (2013) Efficiency, capacity, compensation, maintenance, plasticity: emerging concepts in cognitive reserve. Trends in Cognitive Sciences, 17(10).

Brailey, K., Mills, M. A., Marx, B. P., Proctor, S. P., Seal, K. H., Spiro IIIm A., Ulloa, E. W., & Vasterling, J. J. (2018). Prospective Examination of Early Associations of Iraq War Zone Deployment, Combat Severity, and Posttraumatic Stress Disorder with New Incident Medical Diagnoses. Journal of Traumatic Stress, 31, 102-113.

Brown, B. M., Peiffer, J. J., Taddei, K., Lui, J. K., Laws, S. M., Gupta, V. B., ... & Rainey-Smith, S. R. (2013). Physical activity and amyloid-β plasma and brain levels: results from the Australian Imaging, Biomarkers and Lifestyle Study of Ageing. Molecular psychiatry, 18(8), 875-881.

Brown, B. M., Peiffer, J. J., Sohrabi, H. R., Mondal, A., Gupta, V. B., Rainey-Smith, S. R., ... & Masters, C. L. (2012). Intense physical activity is associated with cognitive performance in the elderly. Translational psychiatry, 2(11), e191.

Byun, K., Hyodo, K., Suwabe, K., Ochi, G., Sakairi, Y., Kato, M., Dan, I., & Soya, H. (2014). Positive effect of acute mild exercise on executive function via arousal-related prefrontal activations: An fNIRS study. NeuroImage, 98, 336-345.

Centers for Disease Control and Prevention (2014). Facts about Physical Activity. Retrieved March 19, 2018, from https://www.cdc.gov/physicalactivity/data/facts.htm

Gold, S. M., Schulz, K. H., Hartmann, S., Mladek, M., Lang, U. E., & Hellweg, R. (2003). Basal serum levels and reactivity of nerve growth factor and brain-derived neurotrophic factor to standardized acute exercise in multiple sclerosis and controls. *Journal of Neuroimmunology, 138*, 99-105.

Hillman, C. H., Pontifex, M. B., Raine, L., Castelli, D. M., Hall, E. E., & Kramer, A. F. (2009). The effect of acute treadmill walking on cognitive control and academic achievement in preadolescent children. *Neuroscience, 159*(3), 1044-1054.

Hwang, J., Brothers, R. M., Castelli, D.M., Glowacki, E. M., Chen, Y.T., Salinas, M.M., Kim, J., Jung, Y., & Calvert, H. (2016). Acute high-intensity exercise-induced cognitive enhancement and brain-derived neurotrophic factor in young, healthy adults. *Neuroscience Letters, 630*(6), 247-253. doi: 10.1016/j.neulet.2016.07.033

Ivey, F. M., Ryan, A.S., Hafer-Macho, C. E., Macko, R. F. (2011). Improved cerebral vasomotor reactivity after exercise training in hemiparetic stroke survivors, Stroke 42 (2011). Stroke, 42, 1994-2000.

Kim, N. Y., Wittenburg, E., & Nam, C. S. (2017). Behavioral and neural correlates of executive function: interplay between inhibition and updating processes. Frontiers in Neuroscience

Lambourne, K. & Tomporowski, P. (2010). The effect of exercise-induced arousal on cognitive task performance: a meta-regression analysis. *Brain Research, 1341*, 12-24.

Lavie, N., Hirst, A., de Fockert, J. W., and Viding, E. (2004). Load theory of selective attention and cognitive control. J. Exp. Psychol. Gen. 133, 339–354. doi: 10.1037/0096-3445.133.3.339

Minzenberg, M. J., Laird, A. R., Thelen, S., Carter, C. S., & Glahn, D. C. (2009). Meta-analysis of 41 Functional Neuroimaging Studies of Executive Function in Schizophrenia. *Archives of General Psychiatry, 66*(8), 811-822.

Solomon, A., Mangialashe, F., Richard, E., Andrieu, S., Bennett, D. A., Breteler, M., Fratiglioni, L., Hooshmand, B., Khachaturian, A. S., Schneider, L. S., Skoog, I., & Kivipelto, M. (2014). Advances in the prevention of Alzheimer's disease and dementia. J Intern Med., 275(3), 229-250.

Stern, Y. (2012). Cognitive reserve in ageing and Alzheimer's disease. Lancet Neurol, 11, 1006-1012.

Suzuki M., Miyai, I., Ono, T., Oda, I., Konishi, I., Kochiyama, T., & Kubota, K. (2004). Prefrontal and premotor cortices are involved in adapting walking and running speed on the treadmill: An optical imaging study. NeuroImage, 23, 1020-1026.

Timinkul, A., Kato, M., Omori, T., Deocaris, C. C., Ito, A., & Kizuka, T. (2008). Enhancing effect of cerebral blood volume by mild exercise in healthy young men: A near-infrared spectroscopy study. Neuroscience Research, 61, 242-248.

Weinstein, A. M., Voss, M. W., Prakash, R. S., Chaddock, L., Szabo, A., White, S. M., Wojcicki, T. R., Mailey, E., McAuley, E., Kramer, A. F., & Erickson, K. I. (2012). The association between aerobic fitness and executive function is mediated by prefrontal cortex volume. Brain, Behavior, and Immunity, 26(5)m 811-819.

Williams J. W., Plassman B. L., Burke J., Holsinger T., Benjamin S. (2010). Preventing Alzheimer's Disease and Cognitive Decline. Evidence Report/Technology Assessment No. 193. (Prepared by the Duke Evidence-based Practice Center under Contract No. HHSA 290-2007-10066-I.) Rockville, MD: Agency for Healthcare Research and Quality; 2010. AHRQ Publication No. 10-E005

Winter, B., Breitenstein, C., Mooren, F., Voelker, K., Fobker, M., Lechtermann, A., Krueger, K., Fromme, A., Korsukewitz, C., Floel, A., & Knecht S. (2007). High impact running improves learning. Neurobiology of Learning and Memory, 87(4). 597-609.

World Health Organization (2018). Physical activity. Retrieved March 19, 2018, from http://www.who.int/mediacentre/factsheets/fs385/en/