EFFECTS OF PARTICIPATION IN A SIMULATED LIVE-FIRE MANEUVER ON COGNITIVE PERFORMANCE OF FIREFIGHTERS: AN EXAMINATION OF INDIVIDUAL DIFFERENCES

BY

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DISSERTATION

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ABSTRACT

Firefighting involves numerous physical, mental, and environmental stressors that could potentially impact cognition and, ultimately, safety. **PURPOSE**: Examine the effects of participation in a live-fire maneuver on executive control of new-recruit firefighters immediately following supervised fireground operations and determine which select physiological variables [heart rate (HR)], psychological states (e.g., state anxiety), or perceptual responses (e.g., thermal sensation) relate to cognitive performance. Individual differences (e.g., aerobic fitness, personality) related to differing levels of cognitive performance in firefighters were also identified. **METHODS**: New-recruit, male firefighters (N = 85; 25.76 ± 4.06 yrs) participated in a live-fire night-burn drill as part of a 6-wk academy training program. This involved emergency response, fire attack, and sear-and-rescue (54:44 ± 4:56 mins). Computerized tests of cognitive inhibition (modified flanker task), attention (0-back task), and working memory (n-back task: 1-back, 2-back) were completed pre and post firefighting. Throughout the evening, HR was continuously recorded and affective and perceptual states of each firefighter (thermal sensation, RPE, respiratory distress, feelings, felt arousal, fatigue, anxiety) were recorded pre and post (Post-0, End) firefighting. On separate days, participants completed questionnaires assessing personality and other individual characteristics, and aerobic fitness was estimated from a 1.5-mile run time. **RESULTS**: RT was significantly shorter Post Drill than Pre Drill for both Congruent (M_{diff} = -33.61±4.15 ms, p <.001, 95% CI: -41.92,-25.31) and Incongruent (M_{diff} = -43.39±4.06 ms, p <.001, 95% CI: -51.51,-35.27) trials of the modified flanker task. Shorter RT was also demonstrated Post compared to Pre Drill for target (M_{diff} = -84.43±22.68 ms, p < .001, 95% CI:-129.83,-39.03) and non-target (M_{diff} = -145.61±23.49 ms, p < .001, 95% CI:-192.63,-98.60) trials on the 2-back task. On the other hand, RT on the 1-back task (to both non-targets and targets) did not significantly change pre to post drill (p_s >.05) and 0-back RT to non-target trials became longer (M_{diff} = 20.46±8.11 ms, p = .014, 95% CI: 4.22,36.70). Flanker accuracy significantly decreased for both congruent (M_{diff} = -1.12±0.35%, p =.002, 95% CI: -1.82,-0.42) and incongruent (M_{diff} = -3.00±0.80%, p <.001, 95% CI: -4.60,-1.40) trials from pre to post drill, with selectively greater decrement to incongruent trial accuracy accompanied by a diminished interference effect for RT (M_{diff} = 9.77±2.23 ms, p <.001, 95% CI: 5.31,14.24) and an increase in interference accuracy (M_{diff} = 1.88±0.67%, p = .007, 95% CI: 0.54,3.23). 0-back accuracy on target trials (M_{diff} = -2.05±0.90%, p = .027, 95% CI:-3.85,-0.24) and d' (M_{diff} = -0.11±0.04, p = .020, 95% CI:-0.19,-0.02) were significantly lower Post Drill than Pre Drill, with no significant change in accuracy on non-target trials. For the 1-back task, target trial accuracy (M_{diff} = -5.00±1.38%, p = .001, 95% CI:-7.77,-2.23) and d' (M_{diff} = -0.33±0.10, p = .001, 95% CI:-0.52,-0.14) were significantly lower Post Drill than Pre Drill, with no significant change in non-target trial accuracy (p < .05). However, the nominal decrease in 2-back accuracy on target trials only approached significance, with no significant change in non-target trial accuracy or d'. A preliminary examination of individual-level factors, including physiological and perceptual responses to firefighting and personality, indicated potential ability to predict cognitive performance, but require future investigation. HR and dispositional resilience revealed the most steadfast relationships to performance. **CONCLUSIONS**: Current findings suggest a selective effect of firefighting performance on executive control processes, such that aspects of cognition requiring more control (such as incongruent trials on the flanker task and target trials on the n-back task) are more detrimentally affected by firefighting than less challenging counterparts (i.e., congruent trials and non-target trials). This provokes future investigation of the timing of cognitive changes, the extent to which scores on computerized assessments might reflect real-life firefighting performance, the possible manipulation of predictive factors to enhance performance through training, and the ability to recognize the need for rehabilitation and recovery in terms of cognitive function beyond physical needs.

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CHAPTER 1

INTRODUCTION

Intact cognition is necessary for successful fire suppression and search and rescue activities. Acute heat, exercise, psychological, occupational, and environmental stress have all been associated with altered cognitive performance, sometimes improved, other times impaired (Aisbett, Wolkow, Sprajcer, & Ferguson, 2012; Bourne & Yaroush, 2003; Chang, Labban, Gapin, & Etnier, 2012; Hancock & Vasmatzidis, 2003; McMorris & Hale, 2012; Verburgh, Königs, Scherder, & Oosterlaan, 2014). An appropriate advance of knowledge was needed regarding the combined effects that these stressors, all present in firefighting scenarios, place on aspects of cognitive function. It was particularly important to determine which variables might be influencing cognitive performance, and the extent of their influence. This dissertation examined the effects of participation in a live-fire maneuver on executive control performance of new-recruit firefighters immediately following supervised fireground operations. Additionally, it provided a preliminary examination of whether or not any select physiological variables [heart rate (HR)], psychological states (e.g., state anxiety), or perceptual responses (e.g., thermal sensation) could account for any of the variance in cognitive performance capabilities of firefighters immediately following a stressful live-fire maneuver. Individual differences (e.g., aerobic fitness, personality) related to differing levels of cognitive performance in firefighters were identified, as well.

These exploratory results yield a preliminary understanding of how combined heat stress and physical exertion experienced by firefighters is related to cognitive performance, specifically on cognitive control processes. The goal was to create a foundation of research from which future studies can be developed to further examine more complex cognitive functioning of this population in live-fire environments. Ultimately, such an understanding can provide the basis for developing recommendations for firefighters to ensure the highest levels of cognitive functioning possible to minimize unnecessary risks or mistakes that could result in injuries or fatalities, both in training and in the line of duty.

As part of their job, firefighters are expected to work through dangerous levels of environmental heat to complete necessary tasks; their equipment and training prepares and allows them to do so. It is a very physically demanding occupation, as researchers have shown significant decreases in stroke volume, increases in core temperature and blood lactate levels, and workloads eliciting close to maximal heart rates (Smith, Manning, & Petruzzello, 2001; Smith, Petruzzello, Kramer, & Misner, 1997; Perroni, Guidetti, Cignitti, & Baldari, 2014). Increased heart rates have been linked to disadvantageous human behavior, likely arising from fear or hormone fluctuations (Grossman, 2008, p. 31, as cited in Hartin, 2010).

Fatigue, heat stress, and extreme physical exertion have all been linked to impaired cognitive ability, unsafe worker behavior, and near fatal consequences (Armentrout, Holland, O'Toole, & Ercoline, 2006; Gaoua, 2010; Hancock & Vasmatzidis, 2003). Additionally, time constraints on task performance are not uncommon in firefighting as fire is unpredictable and conditions can worsen instantaneously. Time pressure has also been associated with poor working memory performance, especially when participants are required to make unfamiliar responses (Bourne & Yaroush, 2003). Making quick and accurate decisions could result in more efficient job performance and less time spent in an unstable environment. Therefore, it is important to determine whether cognitive deficits occur in the firefighting setting, which aspects of cognitive function are most affected (e.g., speeded processing, executive function), and the nature of such deficits (e.g., slowing of response time, greater variability in responding, changes in response accuracy). Once these factors are better delineated, strategies can be developed to attenuate such declines, prevent their occurrence, or enhance better performance. A necessary step towards such a determination would be the assessment of cognitive responses of firefighters in conjunction with real or simulated live-fire activities.

Statement of the Problem

Training programs and day-to-day career protocols for firefighters are all developed with safety in mind. However, one key piece of information has heretofore been missing: Is cognitive function impacted in firefighters during and immediately following fireground operations? It was unknown: (a) how cognitive performance is influenced by the act of firefighting; and (b) which factors influence cognitive performance in this group. Because minimal research on cognitive performance is available from the firefighting population, research from related fields of heat stress, military operations, and extreme exercise were used as starting points (National Fallen Firefighters Foundation, 2005). This project determined the extent to which cognitive performance of firefighters changed as a function of their participation in a live-fire maneuver. The project also determined whether certain individual difference factors (e.g., trait anxiety, dispositional resilience, preference and tolerance for intensity of exercise, coping strategies, personality, and aerobic fitness) related to enhanced or impaired cognitive performance in response to participation in a live-fire maneuver.

If executive control processes become impaired over time, or in response to environmental factors or workload, firefighters may have a reduced capacity to protect life and property. In theory, the combination of physical exertion and heat stress that structural firefighters encounter during fire suppression and search-and-rescue activities may be more mentally and physically tolerable to those firefighters who are more physically fit, heat acclimated, and/or experienced. Examination of the cognitive effects of firefighting and of variables that may moderate cognitive performance in firefighters (e.g., physical fitness, experience, heat acclimation, trait characteristics, etc.) can be used to inform future firefighter training that could serve to minimize injuries and fatalities, and enhance execution of live-fire maneuvers. Results from this research provide information about the variables that influence cognitive function and help form suggestions for how to maintain optimal cognitive performance on the job. This could translate not only to other firefighters, but also to Fire Service Instructors (FSIs) and shift commanders at local fire departments who are also responsible for the safety of the individuals they are supervising.

Background and Setting

Historically, research with firefighters has been aimed at assessing risk factors for cardiovascular events and developing strategies for prevention of such events. These studies have primarily focused on physiological responses to heat stress and firefighting-related physical exertion. Primary outcomes in pre-post, experimental studies involving completion of firefighting simulations include decreases in stroke volume, increases in core temperature and blood lactate levels, and workloads eliciting near maximal heart rates (Smith, Manning, & Petruzzello, 2001; Smith, Petruzzello, Kramer, & Misner, 1997). This area of research is absolutely essential for firefighter safety and well-being. Unintentionally, there has been less focus on other critically important realms of firefighter health, psychology and cognition, to which the physical demands of firefighting are undoubtedly intertwined.

Significance. Safety is of primary concern for individuals combating structural fires. Annually, US firefighters endure about 63,350-100,000 injuries (Haynes & Molis, 2014; Karter & Molis, 2014; Smith, 2011; National Fallen Firefighters Foundation, 2005), almost half occur during fireground operations (Karter & Molis, 2008, 2014), and these range from minor scrapes and bruises to fatalities. Second only to cardiovascular Line of Duty Deaths (LODDs; 48.1%), traumatic injuries accounted for 29.6% of fatalities in 2012 (United States Fire Administration [USFA], 2013). Strain/overexertion accounts for one quarter (more than any other reason) of fire-related firefighter injuries (USFA, 2011). A substantial number of injuries still occur annually, though a downward trend is visible from 1981 to 2014 (Haynes & Molis, 2014, p. 4).

Forty-nine percent of firefighter fatalities also occur on the fireground, averaging 35 deaths per year from 2001-2010 (Fahy, LeBlanc, Molis, 2013). In 2012, structure fires were the most common fire incidents to result in LODDs (“Firefighter Line-of-Duty…”, 2012). Fatal injuries consisted of sudden cardiac deaths (i.e. heart attacks), trauma exterior to the structure, and trauma occurring within the burning building.

The National Fallen Firefighters Foundation, created by Congress in 1992, put forth 16 Firefighter Life Safety Initiatives in 2004 (National Fallen Firefighters Foundation, 2005, p. 48). At this time, the Everyone Goes Home® program was initiated as a nationwide initiative to reduce LODDs. This proposed research project specifically addresses two of these Life Safety Initiatives: (#4) “All firefighters must be empowered to stop unsafe practices”; (#6) “Develop and implement national medical and physical fitness standards that are equally applicable to all firefighters, based on the duties they are expected to perform” (National Fallen Firefighters Foundation, 2005, p. 48). If it were determined that physical fitness could not only reduce the risk of cardiovascular disease, but was also important for job-related cognitive performance and safety of firefighters and the public they serve, it could provide the needed motivation for the adoption of fitness training programs and healthier lifestyles in the Fire Service.

Team members, victims, and individual firefighter lives are on the line every day, emphasizing the necessity of clear thinking of individuals working on emergency response crews. In some occupations, tolerance limits have been set to mandate that employees stop working because of the potential danger from heat stress. Safety managers attempt to match this tolerance limit with the point at which cognitive abilities are compromised (Hancock & Vasmatzidis, 2003). In firefighting, oxygen-related limits are present such that self-contained breathing apparatus (SCBA) regulators have warning bells that ring when the individual is running low on air, and at risk of hypoxia. SCBA limits duration in heat to about 20 minutes, when bottle change is necessary (Perroni, Guidetti, Cignitti, & Baldari, 2014). In normoxic conditions, it is more common practice that the firefighter exits burning buildings for reasons other than sensing detriments in their own cognitive performance (e.g., imminent danger). In some instances, individuals have chosen to ignore emergency exit signaling entirely, in order to continue their search for victims (Dunn, 2010, p. 267). If cognitive faculty were questioned to the point at which an individual should stop firefighting activities, it would likely be made as a judgment call by a superior at the scene.

Rationale. Firefighting is a physically demanding occupation associated with high mental and physical stress (Richardson & Capra, 2001). Within the context of their job, firefighters encounter extremely hot and humid environments, sustained, intense physical workloads, fatigue from exertion and/or sleep disturbance, and emotional and cognitive stressors, all while wearing heavy (~11-23 kilograms in weight; Perroni et al., 2009) personal protective equipment (PPE; Barr, Gregson, & Reilly, 2010; Cian et al., 2000; Smith, 2011). Unfortunately, it has also been reported that anywhere from 77% to 90% of career firefighters in the United States are overweight or obese (Smith et al., 2012). This places additional physical stress on the firefighter when performing high-workload activities (e.g., stair climbing while carrying equipment or gear) and has potential implications for their psychological well-being (Barr et al.). Such stressors appear to result in changes in both endocrine and neurobiological functioning with probable influences on cognition, increasing vulnerability to injury (Weeks, McAuliffe, DuRussel, & Pasquina, 2010).

Fitness for duty goes beyond performing physical tasks and tolerating high temperatures. As emergency responders, firefighters need to be healthy and able to perform their duties of protecting life and property. Both civilian and firefighter lives are on the line, emphasizing the necessity of good physical fitness, mental health, and clear thinking of emergency response team members (Wagner, McFee, & Martin, 2010). To an even greater extent, some have even suggested that the onset of cognitive impairments might occur before physiological issues do, and could thus serve as warning signals for imminent health emergencies (Hancock, 1986; Acevedo & Ekkekakis, 2001). Aerobic fitness merits investigation as a contributor to cognitive prowess, as it has been positively associated with executive control performance (Colcombe & Kramer, 2003; Hillman, Kamijo, & Pontifex, 2012). In a stratified random sample (response rate 54.9%) of 3,000 fire departments in the US in 2006, 7% required a physical fitness training program for firefighters (Peterson et al., 2008, p. 5). This underlines the necessity to investigate cognitive changes in response to firefighting and whether or not physical fitness has the potential to enhance safety. Knowing this information, training programs can developed to proactively minimize impairment of cognitive functioning in these individuals or develop an action plan for cycling firefighters out of burning buildings once a threshold has been reached for acutely diminished cognitive capacity.

The emotional stress of protecting life and property places another strain on this population. Firefighters encounter a complex array of stress-provoking factors when attacking fires and performing overhaul at fire scenes (Cian, Barraud, Melin, & Raphel, 2001). As emotional responses to stressful situations have been noted for their automatic, or unconscious, development, they may be occurring without the individual fully recognizing them (Dolcos, Iordan, & Dolcos, 2011). In some cases, emotional strain can also become detrimental to cognitive performance (Aupperle, Melrose, Stein, & Paulus, 2012). In general, reaction times of higher anxious individuals decrease (speed up) in response to participation in acute exercise activity (Barnes, Coombes, Armstrong, Higgins, & Janelle, 2010; Smith & Petruzzello, 1998). Such speeding up could result following acute firefighting activity (as it holds many of the same properties that acute exercise bouts do), and could potentially result in less accurate responding (Smith, Manning, & Petruzzello, 2001). However, our research has previously demonstrated that on simple tasks of sustained attention, though reaction times decrease immediately after firefighting, accuracy remains unaffected (Greenlee et al., 2014).

Anxiety also seems to interfere with proper working memory performance (Bourne & Yaroush, 2003; Fales et al., 2008), and there is evidence, namely in patients with PTSD, of emotional disruption of cognitive inhibition (Aupperle, Melrose, Stein, & Paulus, 2012). Working memory tends to be affected in a bottom-up manner, with emotions triggering increases in activation of evolutionarily older brain regions susceptible to emotion processing, which could interfere with cognitive performance on the job (Denkova et al., 2010). Emotions can be generated in both bottom-up (in response to sensing environmental stimuli, conscious or not) and top-down manners (in response to conscious cognitive appraisal, usually of linguistic nature) (McRae, Misra, Prasad, Pereira, & Gross, 2012, p. 253). The extent to which someone is participating in cognitive reappraisal in order to regulate his or her emotions, requires some amount of executive control (Ochsner & Gross, 2008). This implies that emotion regulation may influence one's capacity to perform concurrent processes that also demand executive function. Some firefighters (e. g., those with diminished capacities to regulate their emotions) may be susceptible to cognitive distraction by emotion, and may not even be aware that their cognitive abilities have been compromised. So, state changes affect and anxiety, as well as personality factors such as anxiety, resilience, and coping ability should be examined.

The relative lack of research on cognitive performance in firefighting conditions (Barr, Gregson, & Reilly, 2010) leaves many unanswered questions as to the demands of cognitive function in such situations, the extent to which cognitive function may differ from a neutral baseline (no heat stress or exertion), and how intimately cognitive function is related to the immediate safety of firefighters. Cognitive measures of simple or choice reaction time may not be challenging enough tasks to detect impairments following firefighting (Smith & Petruzzello, 1998), so more complex tasks should be implemented. There do appear to be deficits in concentration and working memory in response to physical exertion under heat stress, but these have usually been shown in the context of dehydration conditions (Barr et al.). Evidence from exercise, heat stress, fatigue, and military research, as well as subjective firefighter accounts, suggests that cognitive function could be compromised during firefighting activity.

Purpose

The purpose of this project was to examine the effects of participation in live-fire firefighting maneuvers on working memory and cognitive inhibitory performance. Scores on measures of cognitive performance (accuracy, RT, variability) for working memory and cognitive inhibition tasks (n-back and modified flanker tasks, respectively) measured pre-firefighting and immediately post-firefighting were compared. Each of these measures was examined with respect to individual differences of physical fitness and personality characteristics (trait anxiety; coping ability; dispositional resilience; preference and tolerance for intensity of exercise; extraversion, emotional stability, conscientiousness, agreeableness, intellect/imagination). An attempt was made to determine whether or not select physiological variables (heart rate), psychological measures (state anxiety; fatigue; energy; tiredness; tension; calmness; nervousness), or perceptual responses (thermal sensation; respiratory distress; felt arousal; affect; rating of perceived exertion) could account for any of the variance in cognitive performance capabilities of firefighters immediately following live-fire maneuvers.

Specific Aims & Hypotheses

AIM 1: Describe the participants on various individual difference parameters: physical fitness, BMI, trait anxiety, coping ability, dispositional resilience, preference and tolerance for intensity of exercise, and personality (extraversion, emotional stability, conscientiousness, agreeableness, and intellect/openness).

AIM 2: Examine participants' changes in heart rate, state anxiety, fatigue, perceived exertion, thermal sensation, respiratory distress, felt arousal, affect, and perceived energy levels before, immediately after, and ~30 minutes post-firefighting.

H_1: It was hypothesized that heart rate would be higher immediately after firefighting than pre-firefighting, and would remain elevated significantly above pre-firefighting heart rate, for the duration of post-firefighting cognitive tests.

H_2: It was hypothesized that state anxiety following firefighting would be significantly greater immediately after firefighting than state anxiety assessed pre-firefighting and 30-minutes post-firefighting.

H_3: It was hypothesized that fatigue would be significantly greater at both 0 and 30 minutes post-firefighting than pre-firefighting.

H_4: It was hypothesized that perceived exertion, thermal sensation, respiratory distress, and felt arousal would be significantly elevated post-firefighting relative to pre-firefighting.

H_5: It was hypothesized that perceived energy would decrease immediately post-firefighting from pre-firefighting levels, and then decrease further 30 minutes post-firefighting.

H_6: It was hypothesized that affect [i.e., pleasure-displeasure, as assessed by the Feeling Scale (FS)] would be more negative immediately post-firefighting relative to pre- and 30-minutes post-firefighting.

AIM 3: Determine cognitive behavioral performance of firefighters immediately post-firefighting in terms of working memory, cognitive inhibition, and cognitive flexibility relative to pre-firefighting conditions.

H_7: It was hypothesized that, in general, RT would be shorter, accuracy would not change significantly for easier tasks (flanker, 0-back) but would decrease for more difficult tasks (1-back, 2-back), and response variability would be greater post-firefighting as compared to pre-firefighting.

AIM 4: Determine the relationship between physical fitness level (particularly aerobic fitness) and cognitive performance immediately following, live-fire maneuvers.

H_8: It was hypothesized that those individuals with higher estimated aerobic fitness levels would have better accuracy and less variability in RT as measured by working memory and inhibition assessments pre-firefighting than lesser-fit individuals. It was further hypothesized that those with higher fitness would perform better on 1-back and 2-back tasks post-firefighting than less fit individuals, because they would recover more quickly.

H_9: It was hypothesized that, regardless of fitness, those who exerted themselves more during firefighting drills (indicated by higher relative HR and perceived exertion) would make more commission errors on working memory and inhibition assessments.

AIM 5: Determine the individual difference variables that best account for variance in cognitive performance immediately following live-fire maneuvers.

H_{10}: It was hypothesized that higher state anxiety would be correlated with shorter reaction time in a linear fashion, and accuracy would reflect a curvilinear relation to state anxiety. Specifically, lower and higher levels of SA would be associated with greater errors (lower accuracy) while moderate levels of state anxiety would be associated with fewer errors (higher accuracy).

H_{11}: It was hypothesized that individuals who had quicker cardiac recovery following activity would perform as well or better than their pre-firefighting scores on the cognitive tasks compared to those whose HRs remain elevated above 80% of their age-predicted HR maximum throughout cognitive testing (reflecting physiological stress).

H_{12}: It was hypothesized that perceived exertion, thermal sensation, and respiratory distress would be inversely associated with accuracy and that higher fatigue would be related to slower reaction time and lower accuracy on the flanker and n-back tasks.

H_{13}: It was hypothesized that individuals with greater tolerance for intensity of exercise would have higher accuracy than those with lower tolerance, once exertion (perceived and HR) was accounted for.

H_{14}: It was hypothesized that felt arousal and perceived energy would be inversely associated with reaction time.

H_{15}: It was hypothesized that there would be an inverse association between negative affect (lower resilience, or higher trait anxiety or lower coping ability) and cognitive performance scores (lower accuracy, greater variability) at any time point.

H_{16}: It was hypothesized that cognitive performance would be impacted (more errors of commission/lower accuracy and greater variability in reaction time) post-firefighting activity compared to pre-firefighting due to distraction from emotional (stress, anxiety), physiological (arousal, fatigue), and environmental sources (heat, smoke, fire, danger, etc.).

CHAPTER 2

LITERATURE REVIEW

Introduction

Firefighting is an occupation involving varying degrees of stress, both physical and mental, which is often compounded by having to perform physical and psychological tasks in extreme conditions. Firefighters are expected to tolerate the physical exertion of firefighting activities, extreme heat stress, and psychological stress. Injuries and falls, ranging from minor scrapes and bruises to fatal incidents, can occur on the job (Smith, 2011). A substantial number of injuries (~100,000) are incurred by firefighters while on-duty each year in the United States (National Fallen Firefighters Foundation, 2005) and almost half of these occur during fireground operations (Karter & Molis, 2008; Haynes & Molis, 2014).

The National Institute for Occupational Safety and Health (NIOSH) has publicly expressed the importance of minimizing hazards and risks during live-fire maneuvers, such as structural collapse and failure to recognize impending collapse, for firefighters both at the personal and departmental level (http://www.cdc.gov/niosh/fire/). NIOSH addressed the importance of training firefighters to identify signs of weakened floor systems, as all floors have a chance of failing, especially if there is a fire burning beneath them (Department of Health and Human Services [DHHS] Publication No. 2009-114]. Likewise, firefighters encounter scenarios in which rooms they enter could end up “flashing over” or instantly engulfing the room in flame once items in the room reach a certain temperature. Situational awareness and ability to react appropriately are essential to safety and job performance. Situational awareness is defined as “how well the individual discriminates true (signal) from false (noise) information“ (Catherwood, Edgar, Sallis, Medley, & Brookes, 2012, p. 139). Emergency situations such as fire response scenarios have the potential to elicit stimulus overload. Heightened alertness predisposes individuals to attend to a multitude of information in the environment (visual, audio, thermal sensations, perceivable physiological reactions, activity of others). Cognitive demands and the basic and skilled motor behaviors essential to moving in and manipulating the environment create extra challenge. Performance becomes hindered when the impact of the physical environment, the cognitive tasks demands, and the individual's attempts to first attend to and then ignore or react to all of these stimuli near simultaneously are compounded.

In a multiple experimental study, one group of 50 fire and rescue personnel and another group of 16 firefighters were shown a slide presentation containing images of the drive to, views of, and information about a simulated fire emergency, along with video clips related to the scenario (Catherwood, Edgar, Sallis, Medley, & Brookes, 2012). The group of 50 was tested by means of answering 26 true or false questions (13 of each) about the scenario at three intervals throughout the presentation. Fire and rescue personnel in this group were a mix of full-time and part-time firefighters, fire and rescue managers, and non-firefighter student volunteers. Situational awareness scores (number of correct responses to the true/false questions, corrected for chance responding) were significantly higher for firefighter groups than the non-firefighter student volunteers; however, years of firefighting experience were not significantly correlated with situation awareness (Catherwood et al., 2012). All participants, regardless of firefighting experience, were biased towards accepting available information as true and making false alarm errors. Neither situation awareness nor years of experience were significantly correlated to bias type. When all firefighters responses were examined, 6 had no bias, 15 had positive bias (so they rejected some information and said it was false), and 29 had negative bias. This study was repeated by Catherwood et al. (reported in the same article), with a separate group of 16 fire and rescue firefighters, crew and watch managers, to determine whether the same biases would present themselves in a more "real-life" situation. Firefighters completed a search and rescue training task in a furniture-filled, 2-story, smoky building (Catherwood et al., 2012). This time, there were 19 true/false questions. Nine individuals presented with a positive bias, and seven with a negative bias. These biases again were not linked to situation awareness.

Firefighters are at risk of encountering environmental dangers on the job, which have the potential to be further impacted by poor cognitive performance. To the extent that psychological stability is compromised, safety becomes a major concern. Yet, the extent to which cognition and subsequent safety are affected is unknown. This is due, in part, because assessment in these environments can be challenging (Maruff, Snyder, McStephen, Collie, & Darby, 2006) and replication of the “real-life” environment is often done to create a “testing” environment, which may or may not reflect what would have occurred in “real-life”. Measuring decision making and cognitive performance during real-life emergencies may also be considered unethical, for good reason, and thus people have attempted to simulate such scenarios (LeBlanc, 2009). Laboratory and simulated scenarios do not normally involve the full stress that may be present in a real-life scenario where lives are at stake (Perroni et al., 2009). In real-life settings and field simulations, there is constant flux in the environment, time is a factor, and information is ambiguous. A choice is often made between controlled laboratory settings with lower external validity and complex field scenarios that allow for data collection in a dynamic, real-time environment, though some have considered sophisticated computerized simulation research (Omodei & Wearing, 1995).

A literature review of naturalistic decision making (Zsambok, Beach, & Klein, 1992) argued that in laboratories, it has been common to look at decision making as a process of making a choice amongst known options; when in fact, decisions made in natural settings seem to involve a process by which experiential memory helps mold a plan which is then modified to meet the individual’s needs or to create a new option for task completion (Zsambok et al.; Klein, 1989, 1993). Interviews have also discovered that, when a scenario is very unfamiliar to a fireground commander, they use mental simulations to play out options in their heads before acting, and make the quickest decisions by satisficing (not waiting for the most optimal course of action, but using the first that works) (Klein, 1989, 1993). Satisficing was originally an economics concept termed by Herbert Simon (Simon, 1955, 1956), which suggested that decision makers have some minimal requirement in mind for the outcome of an action and mentally search for the first option to come to mind that is “good enough” to meet this threshold (Simon, 1978). This is especially useful in situations with daunting numbers of options and restrictive time demands.

Many times, decision making during firefighting maneuvers follows very defined “if..., then...” stimulus-response type actions (e.g., protocols) which have been learned through extensive training. In these situations, decision making in the context of front line firefighting could be looked at from the perspective of schema theory (Bartlett, 1932; Head, 1920). Schemas represent mental models created in response to an individual’s interactions with a specific item, place, or situation that can be accessed by the brain when that person encounters similar items, places or situations to help guide their behavior (Wagoner, 2013). They shift subtly in response to an individual’s subsequent interactions with different and similar environments and scenarios, over time (Bartlett, 1932; Derry, 1996). When schemas are recalled from memory, they often come with scripts or actions that should be taken in response to a recalled schema matching the current situation (Wagoner). More experience builds a larger, more defined reservoir of schemas, as well as scripts. In response to stress, individuals will either improve or have diminished performance on executive control tasks. Well-learned tasks seem to be enhanced by physical activity-induced arousal (McMorris & Hale, 2012). Having experience and more fine-tuned schemas could free up working memory capacity (Endsley, 1995). As such, it is most likely that the need for higher level executive control will occur when situation awareness is either poorly assessed or communications fail and the individual needs to quickly adapt to make a decision. However, unpredictable events in the firefighting scenario may force the individual to arrive at (somehow) and execute an action, based on previous experience or inexperience with a similar situation.

General Stress and Cognitive Function

Stress has been described as "...conditions where an environmental demand exceeds the natural regulatory capacity of an organism, in particular situations that include unpredictability and uncontrollability" (Koolhaas et al., 2011, p. 1291). Johnson, Kamilaris, Chrousos, and Gold (1992) defined a stressor as anything that disrupts homeostasis. General stress and cognitive function have been reviewed in terms of the stress response, stressful stimuli, and stress hormones on both human and animal cognitive function and performance (Bourne & Yaroush, 2003; LeBlanc, 2009; Mendl, 1999; Staal, 2004; Starcke & Brand, 2012). Multiple reviews discuss the physiological, cognitive, and behavioral responses to stress and how these can be both advantageous and disadvantageous to an individual. However, many of the impairments in attention, vigilance, reaction time (i.e. slowed), and long-term memory disruption have been noted for stressors that result in dehydrated or fatigued individuals (Cian, Barraud, Melin, & Raphel, 2001; Weeks, McAuliffe, DuRussel, & Pasquina, 2010).

A number of stressors are present in a firefighting scenario. In order to discuss the effects of firefighting on cognition, the nature of firefighting must be defined. One way to describe it would be to decompose it into component, collective stressors: occupational (e.g., job demands), heat, physiological/exertional, and psychological (e.g., anxiety), and cognitive (e.g., mental processing, being attentive to surroundings) stress. In a review of stress measurement, Baum, Grunberg, and Singer (1982) discuss stress as a complex psychophysiological process rather than a simple stimulus-response reaction, as many internal and external factors are at play. The purpose of this literature review is to cover the available literature demonstrating the effects of firefighting-related stressors on cognitive performance.

Hancock and Warm (1989) have proposed the Maximal Adaptability Model (MAM) of stress and performance in which they attempt to describe the mechanisms underlying changes in vigilance and attention tasks; Hancock and Vasmatzidis (2003) later applied it to describing safety behavior. The MAM (see Figure 2.1) underscores the importance of multiple, cumulative levels of stress influencing an individual's attentional resource capacity. Limited attentional capacity could result in errors to recognize safety hazards in time to prevent injury. The unstable environment experienced in firefighting (e.g., fire behavior, unknown extent of fire damage prior to arrival on the scene, uncertainty about who and what they will find inside, etc.) requires a large portion of the firefighters' attentional capacity, theoretically leaving them with only a limited amount to dedicate to their own risk prevention behaviors (Larsen, 2001; Prasanna, Yang, & King, 2011; Rahman, Balakrishnan, & Bergin, 2012). Firefighters are also pushed towards their physiological limits: core temperatures can rise above 39°C and maximal or near maximal heart rates are often achieved (Patterson, Taylor, & Amos, 1998; Perroni et al., 2009). Thus, following from the MAM, firefighters are often trying to perform effectively under hyperstress, reaching their maximal adaptational capacities in this stressful environment.

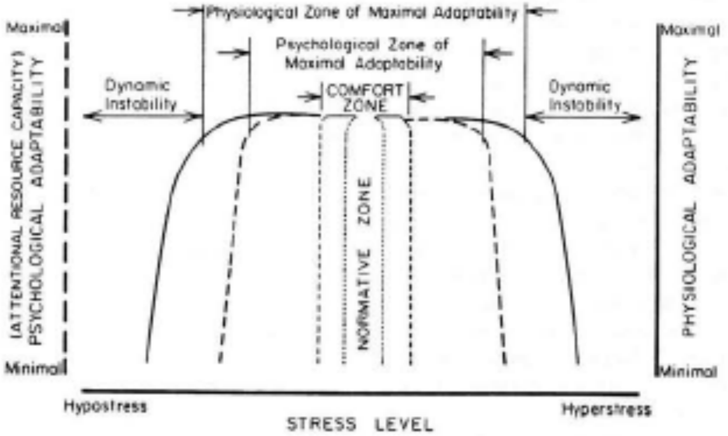


Figure 2.1. Maximal adaptability model. (*Reused with permission from SAGE Publications. © 2016 Copyright Clearance Center, Inc. Originally published in Hancock and Warm, 1989, p. 528).

A multitude of variables contribute to the task that is deemed "decision-making". Arousal, anxiety, cognitive inhibition, emotional regulation, dispositional resilience, coping ability, and experiential long-term memories fall under this umbrella, among other factors. Attention and working memory seem to be particularly important underlying processes required for decision making (Aupperle, Melrose, Stein, & Paulus, 2012). Decision making in a fire scenario “requires the appropriate selection from the range of information on offer, either from the external environment or the internal knowledge base of the decision maker” (Catherwood et al., 2011; Gasaway, 2008; Klein et al., 2010; Omedei et al., 2005 as cited in Catherwood, Edgar, Sallis, Medley, & Brookes, 2012, p. 135). Being able to sort through the sensory information they are receiving, ignore irrelevant inputs, process and use that information to appropriately execute their job (which requires switching from task to task), demands optimal functioning of executive control processes.

Executive control is similar to the brain’s management system by regulating, planning and controlling other cognitive functions (Lezak, 2007). Executive control is “a sub-set of goal-directed, self-regulatory operations encompassing the core processes of inhibition, working memory, and cognitive flexibility” (Diamond, 2013, as cited in Scudder et al., 2015, p. 244). Inhibition, for the purposes of this study, refers to cognitive inhibition, a subset of interference control (along with selective attention), not response inhibition (simply holding back impulsive action; Diamond, 2013). Cognitive inhibition is the successful act of blocking out distracters in the stimulus field from selective attention, in order to direct attentional resources to a subset of available stimuli in the environment and complete a required task. For a table of cognitive tasks commonly used to measure the different interpretations of “inhibition” see Aron (2007, p. 217).

“Working memory (WM) refers to the structures and processes used for temporarily storing and manipulating information in the face of ongoing processing and distraction” (Jaeggi, Buschkuehl, Perrig, & Meier, 2010, p.394). It is essential for performance of higher level cognitive tasks such as comprehension and reasoning (Baddeley, 2010), and has been considered necessary for effective performance in complex environments (Garavan, Ross, Li, &

Stein, 2000). Working memory in and of itself requires inhibition, and the two processes are highly intertwined (e.g., individuals need to be able to attend to and discriminate between a familiar stimulus and one that follows the matching rule for which they are currently responding) (Diamond, 2013; Oberauer, 2005). Working memory has been indicated as a predictor of fluid intelligence (Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Engle, Tuholski, Laughlin, & Conway, 1999; Jaeggi, Buschkuehl, Jonides, & Perrig, 2008; Jaeggi et al., 2010). Working memory, as measured by n-back performance, also appears to account for some variance in fluid intelligence (Jaeggi et al., 2008); however, it is not strongly correlated to other common measures used to assess this construct (Jaeggi et al., 2010). Researchers note similarities between the two constructs of working memory and fluid intelligence, in that good performance requires the individual to "maintain activation to goal-relevant information in the face of concurrent processing and/or distraction" (Conway et al., p. 179).

The third component process under the umbrella of executive control is cognitive flexibility is "the essential ability to assess and adapt ongoing psychological operations and to coordinate the allocation of cognitive processes appropriately in dynamic decision making environments" (Glass, Maddox, & Love, 2013, p. 2) or "changing perspectives or approaches to a problem, flexibly adjusting to new demands, rules, or priorities (as in switching between tasks)" (Diamond, 2013, p. 136). Cognitive flexibility requires inhibition and working memory for successful task switching, in that the prior task goals and thought must be inhibited, while the necessary information about the new task and its goals must be brought into working memory (Diamond, 2013). Tasks such as the Wisconsin Card-Sorting Task (Heaton, Chelune, Talley, Kay, & Curtiss, 1993) and other set-switching tasks and measures of cognitive flexibility have been used to measure performance of this domain of cognitive control in acute exercise settings (Del Giorno, Hall, O'Leary, Bixby, & Miller, 2010; Gondola, 1987; Netz et al., 2009; Pesce & Audiffren, 2011, Wang, Chu, Chu, Chan, & Chang, 2013).

Cognitive control, as a whole, allows the individual to ignore distracters in their environment but to also hone in on pertinent details and use those details to inform their actions and switch efficiently between tasks. Inhibitory control of attention seems to be difficult for young children, peaks in young adulthood, and then gradually declines with age (Diamond, 2013). As young adulthood is usually the start of a firefighting career and over 24% of US firefighters were 50 years old or older in 2012 (Karter & Stein, 2013, p. 13-14), it is important to note any significant effects that firefighting may have on inhibition during young adulthood that could potentially become problematic in the line of duty, or recognize characteristics of good performers that contribute to better cognitive inhibition, in order to maintain function over time.

The importance of these constructs is underscored by enhancements in technology and human-computer interfaces over the last several years, which provide necessary information for firefighters in a way that will not overload working memory capacity and still aid in improving situational awareness for appropriate decision making (Prasanna, Yang, & King, 2011; Rahman, Balakrishnan, & Bergin, 2012). Researchers in the UK have acknowledged that there is room for improvement for how well fire responders fully understand a situation (situation awareness) encountered at an emergency scene (Prasanna et al.). Software was developed (Yang, Prasanna, & King, 2009) which allows firefighters to view relevant information about the environment (temperatures separated by story in the structure, presence of hazards, information about personnel and equipment on site and in route, water supply, traffic, weather, and rescues to be made). These prototypes were tested and qualitative assessments determined that even with the use of highly tuned human-computer interfaces, information overload is an issue, the physical and psychological stressors they are encountering may still inhibit their ability to properly use the software, and use of the software may actually distract their attention from other necessary things; thus, automated alarms and intensive training may enhance the way in which firefighters interact with such tools and help diminish the working memory burden

(Prasanna et al.).

Impact of Stress on Cognitive Control

Broadly, the examinations of the effects of stress on cognition provide mixed findings. Some evidence is available to suggest that stress enhances attention and cognitive performance (Chrousos & Gold, 1992). Conversely, a more recent review demonstrates that stress (such as that evoked from an emergency situation) hinders one's ability to ignore irrelevant stimuli in their environment; heightened state anxiety and high trait anxiety seem to have this influence, as well (Bourne & Yaroush, 2003). Here, Bourne and Yaroush were referring to the general public's reaction to an emergency situation, and not necessarily that of a first responder. First responders with training and experience in emergency situations would likely have relatively blunted responses to such a stressor, or would at least be more capable of regulating their responses to this stress to respond more efficiently.

Psychological stress has specifically been associated with decreased cognitive inhibition (i.e., ability to ignore distracting stimuli). For example, Skosnik, Chatterton, Swisher, and Park (2000) examined decreased cognitive inhibition, by means of decreased scores on a negative priming task (calculated by taking the difference between reaction times on an experimental probe trial from a control probe trial) in which participants had to ignore a "+" distracter to locate a "0" on a computer screen. Stress has also been shown to elicit impairment in working memory in animals. For example, rodent spatial working memory was assessed using a T-maze paradigm; impairment was present when white noise stress was used (Devilbiss, Jenison, & Berridge, 2012). Working memory may be more useful in making decisions where risks are known than when there is too much uncertainty (Starcke & Brand, 2012).

Acute Exercise & Cognition

Since more extreme firefighting activity can be defined as a form of acute physical activity (wearing and carrying heavy PPE while participating in occupational physical activity), it makes sense to investigate the known effects of acute exercise on cognitive performance, specifically working memory and cognitive inhibition, as they may certainly come to light in a firefighting scenario. Beneficial and detrimental effects of acute exercise have been seen both during and following activity (see reviews by Brisswalter, Collardeau, & René, 2002; Kashihara, Maruyama, Murota, & Nakahara, 2009; Tomporowski, 2003). The Brisswalter et al. review of acute exercise and cognition calculated beneficial effects of moderate and high intensity exercise on complex cognitive performance tasks, and negative effects of low, moderate, and high intensity exercise on simple tasks; all included studies involved cycling or stepping exercise from 1993-2002. This review also noted 40-80% of $VO_{2\ max}$ as the optimal range for decisional tasks and improvement on cognitive performance when acute exercise lasted 20 minutes or more, even if fatigue levels rose (Brisswalter et al., 2002).

It has also been repeatedly shown that reaction time is shorter following exercise as opposed to following seated rest, especially on tasks requiring more cognitive inhibition, while simple tasks appear less affected (Hillman et al., 2009; Kamijo et al., 2007; Themanson & Hillman, 2006). Research by Chang et al. (2015) suggests that moderate intensity exercise for 20-min duration is best for reducing response time and increasing accuracy for a cognitive inhibition task (i.e., Stroop), compared to 10 or 45 minutes. An inverted-U relationship between exercise intensity and performance has been proposed (Kashihara et al., 2009).

The Eriksen Flanker task, or modified versions of it, has been used time and again as a measure of cognitive inhibition (Eriksen & Eriksen, 1974). It has been used to measure RT, accuracy, and response variability during (McMorris et al., 2009; Pontifex & Hillman, 2007) and following acute exercise (Gothe et al., 2013; Hillman, Snook, & Jerome, 2003; Hillman et al., 2009; O'Leary et al., 2011; Sandroff et al., 2016; Soga, Shishido, & Nagatomi, 2015; Stroth et al., 2009; Themanson & Hillman, 2006). This task presents an array of symbols or letters (typically 5) in the center of the computer screen. The center symbol is considered the target, while the symbols to the right or left of it are considered the flanking stimuli. For example, one modified flanker task uses five arrows (i.e., >>>>>) presented in the center of a screen. The participant is instructed to attend to the central arrow of the five arrow array (target stimulus) and make a button press based on the directionality of that central arrow. If it is pointing to the right, they are instructed to make a right button press, and if it is pointing left, they are instructed to make a left button press. Once data have been collected, the researcher can examine the implicit effect that the flanking stimuli had on the participant's performance of the task (i.e., accuracy, response time, interference effect). In this scenario, the central stimulus is considered to be either congruent (pointing the same way as the flanking arrows) or incongruent (i.e., <<><<; pointing the opposite way from the other flanking arrows). The interference effect is the difference in response time to incongruent versus congruent trials (calculated Incongruent RT - Congruent RT). This assesses the individual's ability to ignore the distracter stimuli while attempting to respond both as quickly, but as accurately as possible.

Research with young adults has examined reaction time and accuracy on a task commonly used to measure cognitive inhibition following acute exercise (Hillman, Snook, & Jerome, 2003). Performance on the modified "Letters" flanker task using incongruent and neutral trials (Eriksen & Eriksen, 1974) following 30 minutes of treadmill exercise at a mean of 83.5% of HR_{max} was compared to performance at baseline (Hillman et al.). Results indicated no significant difference in performance following exercise participation. However, the task was not completed until about 48 minutes post-exercise (once HR had returned to within 10% of pre-exercise levels) (Hillman et al.), so the immediate effects of the exercise are not necessarily known in this case.

Themanson and Hillman (2006) also compared young adults' responses to the "Letters" flanker task after 30 minutes of treadmill exercise at a mean of 82.8% of their measured maximal HR versus following 30 minutes of rest. The flanker task was initiated about 40 min post-exercise (± SD of 13.9 min), when individuals' HRs had returned to within 10% of pre-exercise HR (Themanson & Hillman). No significant differences in reaction time or accuracy were evident for fitness or condition. However, results did indicate a main effect of fitness on reaction time following a committed error: there was a greater increase in post-error slowing of reaction time in higher fit individuals than lower fit individuals, indicating that higher aerobic fitness may aid in action monitoring following errors of commission, which was supported by neuroelectrical measures of reduced error-related negativity (ERN) and increased error positivity (P_e) in higher fit individuals (Themanson & Hillman).

Beneficial changes in neuroelectric indices of cognitive performance have also been indicated following acute exercise participation. Research in children has demonstrated greater accuracy on incongruent conditions of flanker tasks following 20 minutes of moderate-intensity treadmill exercise relative to following a 20-minute rest condition, with no significant changes in reaction time (Hillman et al., 2009). However, Hillman et al. also saw increases in P3 amplitude following acute exercise, with even larger effects showing up when children were completing the incongruent trials, suggesting greater allocation of attentional resources. These benefits appeared about 25 minutes post-exercise (Hillman et al.).

In another study, positive changes in neuroelectrical indices were paralleled by behavioral improvements; yet, these effects were selective to certain individuals, at least in children (Drollette et al., 2014). Cognitive inhibitory performance was measured via accuracy on a modified flanker task following 20 minutes of moderate intensity treadmill walking or seated rest (Drollette et al., 2014). Condition order was assigned randomly and counterbalanced. Researchers anticipated differences in performance following exercise between children who seemed to do relatively worse on flanker at baseline than children who seemed to do relatively better at baseline. Specifically, it was thought that children demonstrating less inhibition to begin with would see greater benefits of exercise participation on that aspect of cognition, relative to those who already had better cognitive function. A median split was used after the data were collected to separate 40 children (8-10 years old) into two groups based on their accuracy scores on incongruent trials following the rest condition: lower cognitive control performers and higher cognitive control performers. Incongruent trial accuracy was used, because these trials elicit the greatest challenge for cognitive inhibitory control (Drollette et al., 2014). Increased P3 amplitude, signifying greater allocation of attentional resources in the brain, was coupled with better cognitive behavioral performance following acute exercise (Drollette et al., 2014). This significant positive effect of exercise was driven by performance changes in children who were lower performers. It appears that exercise provokes larger improvements in cognitive inhibition for those children who are relatively less accurate performers following rest than those who were better performers following rest. Those considered higher performers did not show any significant change in performance following exercise, possibly due to a ceiling effect; however, shorter P3 latency, reflective of faster cognitive processing speed, was seen for both higher and lower performers following acute exercise (Drollette et al., 2014). Thus, individual differences between participants, particularly the relative cognitive challenge they need to overcome, seem to dictate how benefits of acute exercise will manifest. Whether this applies to an adult population has yet to be seen.

Another test used to assess constructs of cognitive inhibition is the Stroop task (Jaensch, 1929; Stroop, 1935). This task times an individual as they are presented with visual stimuli of varying levels of difficulty: match, neutral (used sometimes), and no match. In each condition, the participant is presented with an image of text spelling the name of a color (i.e., red, blue, green). In the “match” condition, the word is written in the same colored ink (“Red” written in red ink). In the “no match” condition, the word is written in colored ink that does not match the word (e.g., “Blue” written in red ink). “Neutral” conditions simply present a color name (e.g., red, blue, green) in black ink “Match” conditions are considered to be congruent trials, and “no match” conditions are considered to be incongruent trials. One goal requires the participant to attend to and name the color of the ink that the word is written in (ignoring the word) and another goal requires the participant to attend to and state the written color-word. In either case, when the ink and the word name do not match, more inhibition is required in order to respond correctly. Performance is gauged by reaction time and errors made.

Hogervorst, Riedel, Jeukendrup, and Jolles (1996) examined reaction time on the short-form of the color-word interference Stroop task following acute strenuous exercise in 15 endurance-trained, male athletes. Athletes (18-42 yrs, *M* = 24.9±7.9) exercised at 75% maximal work capacity on a cycle ergometer at ~100 rpm for a time trial to complete an amount of work similar to what would be completed in 1 hour (Hogervorst et al.). Reaction time was shorter post-exercise than pre-exercise, with no change in accuracy (Hogervorst et al.).

Kamijo et al. (2007) also compared cognitive inhibition performance, measured with the flanker “letter” task, in young adults on a baseline day, and following 20 minutes of low, moderate, and high intensity cycle ergometry exercise (on separate days). Reaction time was shorter following exercise than baseline, but there were no significant differences amongst the different exercise intensities and no effect of exercise on accuracy (Kamijo et al.).

Yanagisawa et al. (2010) examined the effect of moderate cycling (50% VO_{2peak}) on young adults’ cognitive performance as measured by the Stroop test compared to a rest condition. Measures were taken before and 15 min post-condition; reaction time was shorter faster following exercise and longer following rest. Accuracy was relatively high in both cases. In older adults (median age = 67.8 yrs), positive effects have been demonstrated for cognitive inhibitory performance on a Stroop task following 40 minutes of moderate intensity Pilates (*n* = 9) or strength and flexibility (*n* = 21) training (Pennington & Hanna, 2013).

Table 2.1 Summary of selected articles: Acute effects of exercise on cognitive inhibition in young adults

Author(s)	n	Mode	Duration (mins)	Intensity	Measure	Time of Post-exercise Assessment	General Effect	RT	ACC
Gothe et al. (2013)	30 f	yoga	20	low	flanker	< 5 post	+	No effect	↑higher
		treadmill exercise	20	moderate	flanker	< 5 post	neutral	No effect	No effect
Hillman, Snook, & Jerome (2003)	20 (10 f)	treadmill exercise	30	high	flanker	post-48 (mean)	+	No effect	No effect
Hogervorst et al. (1996)	15 m	cycling	time trial	high	CW Stroop	post-0	+	↓shorter	No Δ
Kamijo et al. (2007)	12 m	cycling	20	low	flanker	< 3 post	+	↓shorter after exercise relative to baseline	No effect
		cycling	20	moderate	flanker	< 3 post	+		
		cycling	20	high	flanker	< 3 post	+ or neutral		
McMorris et al. (2009)	24 m	cycling	15 or VE	moderately high	flanker	during	neutral	No effect	No effect
		cycling	15 or VE	high	flanker	during	-	No effect, trend for longer	↓lower
O'Leary et al. (2011)	36 (18 f)	treadmill walking	20	moderate	flanker	post-22 (mean)	+	No effect, less interference	No effect
		exergaming	20	moderate	flanker	post-22 (mean)	neutral	No effect	No effect
Pontifex & Hillman (2007)	41 (26 f)	cycling	6.5 min steady-state	moderate	flanker	during	-	No effect	↓lower (incongruents only)
Themanson & Hillman (2006)	28 (14 f)	treadmill exercise	30	high	flanker	post-40 (mean)	neutral	No effect	No effect
Weng et al. (2015)	26 (14 f)	active cycling	30	moderate	flanker	post-6	neutral	No effect	No effect
Yanagisawa et al. (2010)	20 (3 f)	cycling	10	moderate	Stroop	post-15	+	↓shorter; less interference	NR

Note: Δ = change; NR = not reported; VE = volitional exhaustion

In relation to the acute effects of exercise on working memory, McMorris, Sproule, Turner, and Hale (2011) performed a meta-analysis and calculated a low-to-moderate detrimental effect of acute moderate intensity exercise on accuracy (g = 0.40; p<0.01), but a strong beneficial effect on reaction time (g = - 1.41; p<0.001; negative effect size indicates shorter reaction time). Tasks were included in the meta-analysis if they had been associated with activation of short-term memory or central executive function, or activation of any areas of the brain that contribute to working memory. Surprisingly, no evidence was found to suggest that the speed-accuracy trade-off was the culprit of this discrepancy between speed becoming faster and accuracy being detrimentally affected (McMorris et al.). This negative effect of moderate exercise was also revealed through research in a female-only sample: exercise at 50% VO_{2max} resulted in worse working memory performance than 25%, 75%, or maximal exercise (Lo Bue-Estes et al., 2008).

Working memory, often assessed with the n-back task (Kane & Engle, 2002; Kirchner, 1958; Mackworth, 1959; Nystrom et al., 2000) requires participants to discriminate between a current stimulus and a reference stimulus. Depending on the task goal, the reference stimulus has been revealed some number “n” back in the sequence of stimuli being presented to the individual, and they are required to then make a button press signifying the relationship between the current stimulus and the reference. The task becomes increasingly more difficult as the number of stimuli between the reference stimulus and the current stimulus increases (sub-tests include 0-back, 1-back, 2-back, 3-back, etc.). Presentation of the stimuli has been done spatially (Drollette, Shishido, Pontifex, & Hillman, 2012; Scudder et al., 2014) as well as serially (Gothe et al., 2013; Hogan, Mata, & Carstensen, 2013). In the sequential n-back, participants are asked to compare the stimulus they previously saw, 0, 1, 2, or more stimuli back in the series, to that which appears on the screen. The 0-back requires participants to only pay attention to whether or not the stimulus that appears is, in fact, the reference stimulus, or if it is not. The participant makes a right hand response if the current stimulus is the reference, or makes a left hand response if the current stimulus is any other stimulus. The 1-back requires participants to remember the stimulus presented immediately before the current stimulus. The participant makes either a right or left hand response depending on whether the current stimulus is the same as the previous, or not, respectively. The 2-back requires the participant to remember the stimulus presented two back in the series and decide if the current stimuli is the same or not as the stimuli seen two before it.

Hogan, Mata, and Carstensen (2013) used a numeric (0-9) n-back task to assess working memory after 144 participants (ages 19-93 yrs) spent 15 minutes cycling on a stationary bike at 50 rpm (plus warm-up and cool-down). Two-back reaction time was shorter after exercise than rest, with no difference in accuracy (Hogan et al.). Others have reported enhanced accuracy on another version of the n-back task following moderate exercise (Weng, Pierce, Darling, & Voss, 2015). Robinson et al. (2013) have reported better accuracy on a different working memory task assessed immediately following firefighting drills compared to another group who was assessed 20 minutes post.

Table 2.2: Summary of selected articles: Acute effects of exercise on working memory

Author(s)	n	age	Mode	Duration (mins)	Intensity	Measure	Time of Assessment	General Effect	RT	ACC
Bue-Estes et al. (2008)	26 f	young adults	treadmill running	varied	discontinuous VO_{2max} test	ANAM	during	-	N/A	↓lower
					maximal	ANAM	post-3	-	N/A	↓lower
					maximal	ANAM	post-30	+	N/A	↑higher
Gothe et al. (2013)	30 f	young adults	yoga	20	low	n-back	< 5 post	+	No effect*	↑higher
			treadmill exercise	20	moderate	n-back	< 5 post	neutral	No effect	No effect
Hogan, Mata, & Carstensen (2013)	71** (50% f)	adults	cycling	15	moderate	2-back	post-0**	+	↓shorter	No effect
Robinson et al. (2013)	11 (5 f)	adults	FF drill	> 60	not defined	GR test	post-0	neutral†	N/A	N/A
	10 (6 f)	adults	FF drill	> 60	not defined	GR test	post-20	neutral	N/A	N/A
Weng et al. (2015)	26 (14 f)	young adults	active cycling	30	moderate	n-back	post-6	+	↓shorter‡	↑higher

Note: ANAM = Automated Neuropsychological Assessment Metrics; FF = firefighting; GR = grammatical reasoning; * = shorter than the treadmill exercise condition, just not baseline; **followed completion of 13-item affect assessment; † = better performance than the delayed condition, just not controls; ‡ = shorter than pre, but not relative to passive cycling

Other tasks accepted as measures of executive function requiring cognitive flexibility (e.g., Wisconsin Card Sorting, Contingent Continuous Performance, or Set Switching) have been examined in the context of acute exercise participation (Grant & Berg, 1948; Heaton, Chelune, Talley, Kay, & Curtiss, 1993). Tests of cognitive flexibility challenge executive control processing by requiring the individual to activate a currently relevant task as well as deactivate the no longer relevant information related to the task performed previously, and trials are intermixed with either repeated trials or switch trials. Working memory allows them to maintain relevant information about the current task set, recall the information about the other task set when switches occur, where cognitive inhibition is then required to block out irrelevant information from the previous task, and cognitive flexibility is the efficiency with which they are able to coordinate these efforts.

Evidence has shown accuracy of performance on the Wisconsin Card Sorting and Contingent Continuous Performance tasks to be worse both during and immediately following 30 minutes of high intensity recumbent cycling exercise (Del Giorno, Hall, O'Leary, Bixby, & Miller, 2010). Coles and Tomporowski (2008) reported no differences in performance of young adults on a set switching task completed pre and post following 30 minutes of moderate cycling, sitting on a cycle ergometer but not exercising, and resting while watching an educational documentary. The set switching was second or third in a series of tasks following either a 100-sec immediate recall task or a 100-sec recall task as well as short-term memory test that lasted a few minutes. In this study, set switching involved following one rule of response (e.g., right versus left button press) if the stimulus appeared in the top two quadrants of the screen, and a different rule of response if the stimulus pair appeared in one of the bottom two quadrants, necessitating a switch of focus and an alteration of behavior (Coles & Tomporowski). Other researchers have reported no change or improvement in cognitive flexibility during and following moderate intensity exercise (Del Giorno et al., 2010; Gapin, Labban, Bohall, Wooten, & Chang, 2015; Pesce & Audiffren, 2011), but decrements in performance during high intensity exercise (Del Giorno et al., 2010; Wang, Chu, Chu, Chan, & Chang, 2013), or following exercise in heat (Tomporowski, Beasman, Ganio, & Cureton, 2007). Younger and older adults who are more physically active have been shown to perform better, in general, on task switching than sedentary individuals (Hillman, Kramer, Belopolsky, & Smith, 2006).

Table 2.3 Summary of selected articles: Acute effects of exercise on cognitive flexibility in young adults

Author(s)	n	Mode	Duration (mins)	Intensity	Measure	Time of Assessment	General Effect
Coles & Tomporowski (2008)	18 (? f)	cycling	40	moderate	set-switching	post-0	neutral
Del Giorno et al. (2010)	30 (13 f)	cycling	30	moderate (75% VT)	WCST	during	-
			30	high (VT)	WCST	during	-
			30	moderate (75% VT)	WCST	post-0	+
			30	high (VT)	WCST	post-0	-
			30	moderate (75% VT)	WCST	post-20	unclear
			30	high (VT)	WCST	post-20	unclear
Gapin et al. (2015)	10 (3 f)	treadmill exercise	30	moderate	TMT-B	post-0 (after blood draw)	+
Pesce & Audiffren (2011)	53 (? f)	cycling	20-24	moderate	high demand attention task	during	+
Tomporowski et al. (2007)	11 m	cycling	15, 60, 120	moderate	category-switching test	< 5 post	-
Wang et al. (2013)	80 (31 f)	cycling	30	low	WCST	during	neutral
			30	moderate	WCST	during	neutral
			30	high	WCST	during	-
Wang et al. (2015)	27 (19 f)	cycling	20	moderate	WCST	post-?	neutral

Note: VT = ventilatory threshold; WCST = Wisconsin Card-Sorting Test

There has been some discussion regarding the effects of exercise intensity on cognitive performance (for a review, see Tomporowski, 2003); conclusions were that short (e.g., a few minutes) high-intensity bouts of exercise have shown both positive and negative effects on cognitive performance; there is no clear evidence of persistent decrements after exercise completion, though some negative effects have presented during and immediately following acute bouts. Reaction time appears to shorten as intensity increases, sometimes demonstrating an inverted-U shape, and other times simply being faster relative to rest or low-intensity exercise; accuracy was either slightly improved or not changed on most tasks in response to these, with an unclear connection to exercise-induced arousal (Tomporowski, 2003). This relationship is, however, sensitive to age because processing speed has been known to decrease with age after young adulthood (Salthouse, 1996), and children have been known to demonstrate high impulsivity in responding at baseline, such that their reaction times may not change in response to physical activity (Davidson, Amso, Anderson, & Diamond, 2006). Cycling and treadmill (e.g., aerobic) exercise were the most common stimuli and sample sizes were smaller than 10 individuals in many cases; individual experience with quick decision making and fitness level may also contribute to differences in performance (Tomporowski, 2003).

McMorris and Hale (2012) performed a meta-analytic study of the effects of different intensities of exercise on both speed and accuracy of cognitive performance tests completed either during or after an acute bout of exercise. Findings suggested that moderate intensity exercise had a moderate positive effect on speed of processing (i.e., shorter RT), while low and high intensity had no significant effects. Accuracy did not seem to differ as a result of differing intensities; however, task difficulty did seem to contribute to differential outcomes for accuracy. Central executive tasks showed a large mean effect, while attention tasks showed a small mean effect of exercise. Of note is that these conclusions were based on the measurements of cognition when studies of both during and post exercise were combined. When the authors separated outcomes during exercise from post exercise, they found that speed was not significantly different whether measured during or after exercise. The mean effect of exercise on accuracy post exercise was very small, but was significantly larger than that seen during exercise (McMorris & Hale, 2012).

In terms of exercise duration, submaximal exercise shorter than 60 minutes is not thought to diminish cognitive performance and actually appears to benefit cognitive inhibitory control, but one research group did provide evidence that durations longer than an hour (especially those resulting in dehydration) did result in slowing of reaction time and decreased short-term memory performance (Cian et al. 2000, 2001).

Based on the review of the aforementioned studies, the general trend appears to be that immediately after acute aerobic exercise improvements are seen in cognitive performance.

However, what is unique about firefighting is the addition of heat stress, in combination with exertion. One difference is the level of physiological strain placed on the body due to the addition of heat. The “exercise” stimulus is complicated in nature, as firefighting requires cardiorespiratory endurance as well as high load resistance work (Gledhill & Jamnik, 1992). Post-firefighting, in contrast to post-exercise, heat fatigue plays a more prominent role, as well as satisfaction of job completion, and feelings of relief upon exit of the high-threat environment. Thus it is thought that firefighting activities have a prolonged influence on cognitive performance due to: 1) the perturbed psychophysiological state (as compared to other moderate exercise studies); and 2) the stress provoked during the activity itself. However, any effects seen post-firefighting are not necessarily useful in explaining how cognition may be affected during firefighting activities.

Heat Stress & Cognition

Heat stress impairs cognitive function (National Fallen Firefighters Foundation, 2005; for a review see Hancock & Vasmatzidis, 2003) and a positive correlation exists between heat stress and unsafe human behavior (Hancock & Vasmatzidis, 2003). An increase in unsafe acts at work has been seen in indoor industrial plants at temperatures from 23ºC (73.4ºF) to 35ºC (95°F) WBGT, especially when physical workloads were greater (Ramsey, Burford, Beshir, & Jensen, 1983). Depending on the materials that are burning, structural fire zone temperatures are extremely variable, reaching anywhere up to 600ºC (point of flashover); post-flashover fire temperatures can rise over 1000ºC (1832ºF) (Lawson, 1998). Flashover is a discrete occurrence during which all combustible material in an enclosed space simultaneously ignites, such that flame engulfs the space from floor to ceiling and wall-to-wall (Gorbett & Hopkins, 2007; Peacock, Reneke, Bukowski, & Babrauskas, 1999).

Mental performance generally starts to degrade after 29ºC (84.2ºF) WBGT if working on a task for more than 2 hours, based on performance in hot environments; however, if the individual is going to work for less than 1 hour on the task they can usually perform proficiently at environmental temperatures up to 43ºC (109.4ºF) WBGT (Johnson & Kobrick, 2001). The greatest measured effect of heat on cognitive performance seems to be on tasks that are highly repetitive and minimally arousing (Johnson & Kobrick). It has been suggested that these psychological and cognitive perturbations are the body's natural way of getting an individual to retreat from the situation, as these tend to occur before severe physiological damage (Acevedo & Ekkekakis, 2001). People with more skill on a given task appear less affected by heat stress (Hancock & Vasmatzidis, 2003; for a list of studies on heat stress effects on cognitive performance prior to the 1990s, see Patterson, Taylor, & Amos, 1998).

Heated environments have been associated with changes in working memory performance. A study of 16 men and women in their 30s examined cognitive performance in hot versus control environments across attention tasks (Gaoua, Racinais, Grantham, & El Massioui, 2011). An environmental chamber was set to 50ºC (122ºF) and 50% relative humidity, compared to a control condition of 20ºC (68ºF) and 40% relative humidity. A pattern recognition task was used to examine short-term visual memory, and a spatial span task was used to examine working memory. The spatial span task required participants to remember a pattern of illuminated squares on a computer screen and then replicate that pattern within three attempts, otherwise the test ended (Gaoua et al., 2011). No change was seen in performance of two basic attention tests (choice reaction time, visual search). However, a task meant to assess attention and working memory, rapid visual information processing, resulted in more false alarms in the hot versus the control environment (Gaoua et al., 2011). As dehydration was ruled out as a possible explanation for the results, the authors attributed this behavior to impulsivity (Gaoua et al., 2011).

Heat stress does not seem to negatively impact performance on simple cognitive tasks (Hancock & Vasmatzidis, 2003). Reviews of heat stress and human performance have determined that as the complexity of cognitive function increases, heat has a greater negative impact than when simple cognitive functions are examined (Enander & Hygge, 1990; Hancock & Vasmatzidis, 2003; Wetsel, 2011). However, when measures of cognitive performance are done by means of complex motor function, the deleterious effect of heat on complex motor responses must also be considered (Wetsel). Barr, Gregson, and Reilly (2010) argue for the need to examine more sophisticated measures of decision making in the firefighting setting.

Physical Exertion, Heat Stress & Cognition

When stressors are compounded (e.g., athletes or military members exercising under heat stress conditions), findings have been slightly different than those done on exercise in the absence of heat. Work in extreme environments where individuals are exposed to multiple stressors has been associated with detrimental effects on cognitive performance (Lieberman, Tharion, Shukitt-Hale, Speckman, & Tulley, 2002; Paulus et al., 2009). Yet, the combinative effects of multiple stressors that firefighters encounter (i.e. sleep deprivation, heat, carbon monoxide, physical exertion, emotional stress) have received little attention in the literature as far their impact on cognitive performance (Aisbett, Wolkow, Sprajcer, & Ferguson, 2012).

As firefighters comprise an elite population of individuals trained to attend to dangerous, emergency situations, it is useful to examine research evidence from related occupations such as the military. Members of the military experience physically and mentally demanding environments, not unlike firefighters (Nindl et al., 2006; Weeks, McAuliffe, DuRussel, & Pasquina, 2010). An important difference between military practices and firefighting practices is that many military positions require continued physical training, and currently, most firefighters undergo entry-level fitness testing, but there is not always a compulsory motive to continue training after initial hire. This status quo makes novel implementation and adherence to a career-long exercise regimen challenging. Although there are some programs at local levels, physical fitness programs are scarce (Fahy, 2005). As of 2011, 70% of fire departments (impacting ~682,000 firefighters) in the U. S. still had no programs for maintaining basic firefighter fitness and (or) health, only a 6% decrease since 2005 (National Fire Protection Association [NFPA], 2011). In 2005, the National Fallen Firefighters Foundation put forth firefighter safety initiatives: one underscored the need for creating and implementing national fitness standards (p. 48). Three years after that, "...only 7% of the fire departments have a required physical fitness training program…" (Peterson et al., 2008, p. 5). Wellness initiatives have been instigated, but some organizational interference has been encountered in terms of adopting mandatory, national fitness programs (Pessemier, 2008). The majority of the 30% of departments that do provide fitness or wellness programs are ones that serve larger populations (NFPA, 2011). In terms of dollars coming into the fire service, fitness and wellness programs have only received about 4-6% of grants and funding, with PPE and other firefighting equipment receiving the majority (NFPA, 2011).

In military research, many individual stressors have been claimed to influence cognitive function: lack of sleep, environmental noise, time pressures, dehydration, heat, and suddenly changing situations (Larsen, 2001; Lieberman et al., 2005). Much is known about separate responses to stressors; little is known about combined stressors or the effects of combined stressors being repeatedly experienced over a short time period. Little is also known about the influence of experience (e.g., experienced firefighters versus new recruits). Beyond simple choice reaction time (Smith, Manning, & Petruzzello, 2001), few investigators have studied these effects in firefighters, and only group one (Robinson, Leach, Owen-Lynch, & Sünram-Lea, 2013) has attempted to measure changes in working memory during or following firefighting activity.

McMorris et al. (2006) examined heat stress and working memory performance on in eight young adult males. Cognitive tasks and mood state measures were completed prior to entering an environmental chamber in a 24.94± 1.28ºC lab in shorts and a shirt. Participants sat in a polyvinyl chloride suit in the chamber (36ºC, 75% RH) for 2 hours. During this period, they cycled for 20 min at 100W, sat 10 min, cycled 20 min, and sat 70 min. After this, they left the heat chamber and returned to sitting in their shorts and shirt for 15 mins before completing the random movement generation, verbal short-term memory, spatial short-term memory, choice reaction time and mood state measures. On a control day, the same was completed using a 20ºC 40% RH environmental chamber. Working memory performance was significantly poorer following heat stress as compared to control. There was no significant difference for choice reaction time, or verbal/spatial short-term memory, even though there was a significantly greater increase in fatigue with heat stress than with control. McMorris et al. (2006) acknowledged that dehydration could be related and a very influential extraneous variable in heat stress studies; however, they also argued that dehydration is an inevitable part of heat stress.

O'Neal and Bishop (2010) examined combinative effects of physical exertion and heat on cognitive performance. Ten males walked for 12 minutes at 3.0 $m \cdot h^{-1}$ at variable grades (aiming for a workload of ~450 $kcal \cdot ph^{-1}$ energy expenditure) and then completed 3 minutes of biceps curls in an environmental chamber, once in a cooling vest, and once without. Participants continued to repeat these two activities until they reached 90% HR_{max}, a rectal temperature of 38.7ºC, or they chose to stop (O'Neal & Bishop, 2010). This took on average 27-40 minutes, depending on whether or not a cooling vest was worn. Measures of short-term memory, math, and reaction time tracking with a mouse were undertaken 5 minutes before heat exposure and after, just outside of the environmental chamber. Overall, the group showed no significant pre-post differences; however, it appeared that individuals had different responses to the heat: some improved, some performed worse, some did not change (O'Neal & Bishop, 2010). This provides evidence to suggest that examination of individual differences may be able to help us better predict better cognitive performance following exercise under heat stress.

One group looked at the effects of heat acclimation on cognitive performance of physically active males who had never undergone heat acclimation before. Over a period of 22 days, eight young adult males experienced 19 days of heat exposure in an environmental chamber (Patterson, Taylor, & Amos, 1998). Cognitive performance was measured during the final 10 minutes of a 90-minute low-intensity cycling session on Day 1 (baseline), Day 2 (novel heat exposure) and Day 20 (after acclimation) (Patterson et al.). Although core temperature was relatively high, 39.6ºC on both days 2 and 20 (±0.6 and ±0.1, respectively), there was no effect of combined exertion and heat stress upon initial exposure nor following acclimation on visual attention, temporal or spatial disorientation, or vigilance (Patterson et al.).

Amos, Hansen, Lau, and Michalski (2000) examined cognitive responses to physical activity associated with military training in the tropics. Soldiers performed transport, patrol, and reconnaissance tasks involving light, heavy, and moderate physical activity, respectively. Environmental temperature and physiological measures were recorded throughout the day. A speed-accuracy test of cognitive performance was performed pre-activity, following patrol, and following reconnaissance. These individuals were able to effectively tolerate the demands of the tropical environment while performing military training exercises. Speed and accuracy scores improved throughout the day, despite temperatures being 30 to 33ºC with 52-59% humidity, resulting in rectal temperatures reaching up to 38.4ºC (Amos et al.). Soldiers did not suffer from significant dehydration during any of the exercises. Relatively low heart rates were recorded during activities, which is suggestive of a physically fit cohort. As such, one explanation for the lack of cognitive detriment could be that these soldiers had high fitness levels. It is also possible that the task was too simple or that the conditions were not adverse enough.

In another military study, exertional heat stress (treadmill exercise in a heated chamber) was associated with poorer performance on a visual-information processing task (Radakovic et al., 2007). Forty male soldiers (20.1±0.9 yrs) were randomly assigned to one of four experimental conditions: 1) unacclimatized in a cool room (20ºC; WBGT 16ºC; 68ºF); 2) unacclimatized in a hot room (40ºC; WBGT 29ºC; 104ºF); 3) passively acclimatized in a hot room; or 4) actively acclimatized in a hot room. They each completed an exertional heat-stress test on a treadmill (90 min or until volitional fatigue), and were allowed to drink up to 1.5 L of water. Computerized tests of attention (motor screening, reaction time, rapid visual information processing) were performed immediately before and after exercise. Unacclimatized soldiers who exercised in the heated room had significantly slower movement time on the reaction time task and had lower accuracy on the rapid information processing task when compared to baseline (i.e., before exercise). These tasks were deemed by the authors as more complex cognitive tasks than the motor screening task (Radakovic et al.). Since the acclimatized groups saw no pre-post changes in cognitive performance, it was concluded that heat, more so than exercise, was responsible for the impairments seen.

Firefighting & Cognitive Performance

Cognition, in the context of this proposal, should be viewed as a means for desirable behavioral outcomes that manifest as optimal firefighting performance. A few groups have looked specifically at cognitive performance following simulated firefighting activity (Greenlee et al., 2014; Robinson, Leach, Owen-Lynch, & Sünram-Lea, 2013; Sünram-Lea, Owen-Lynch, Robinson, Jones, & Hu, 2012; Smith, Petruzzello, Kramer, & Misner, 1997). Simulated firefighting activity can be generally described as completion of firefighting tasks (e.g., climbing stairs or ladders, pulling hose, dragging mannequins, using tools for forcible entry, etc.), while wearing personal protective equipment (PPE) in smoky, hot, sometimes fire laden buildings. These simulated activities are done in a more controlled, training-type setting in which risk has been minimized.

General psychological distress during firefighting has had some interest (Smith, Petruzzello, Kramer, & Misner, 1997; Smith & Petruzzello, 1998), but measures of specific cognitive constructs have had less attention in this population. Information regarding cognitive functioning and subsequent behavioral performance of firefighters during and following fire emergency response is scarce (Barr, Gregson, & Reilly, 2010). Many times, the cognitive measure is simple reaction time, which may not be a difficult enough task to detect any impairments following firefighting (Smith & Petruzzello).

Stress reactions, as measured by increases in heart rate during a smoke-diving scenario, were inversely associated with controlled task-focused thinking (measured by having firefighters discuss their thoughts during the smoke-diving maze, out loud; Kivimäki & Lusa, 1994). Smoke-diving training involves completion of a variety of search, rescue, and air conservation tasks in real and simulated fire conditions with an emphasis on becoming an expert in the use of the self-contained breathing apparatus (SCBA), by buddy-breathing, quickly needing to fix regulator failure, and so forth ("Advanced Breathing…", 2015). Though Kivimäki and Lusa performed their study in thermoneutral conditions (without heat), this demonstrates yet another dimension of the firefighting scenario (low visibility), and the impact that it can have on cognitive performance.

An experiment by Smith, Petruzzello, Kramer, and Misner (1997) compared physiological and psychological effects of physical activity in differing temperatures. FFs performed 16 min of a ceiling overhaul task, with a 2-min break halfway through. State anxiety (SA), heart rate (HR), and tympanic temperature were assessed before, during (physiological measures only), immediately after, and 10 min after the task. Thermal sensation, perceived respiration, and rating of perceived exertion (RPE) were assessed at the midpoint (8 min) and immediately after the task. Compared to the neutral, ambient temperature condition, HR and tympanic temperature were both significantly higher during the hot condition and remained elevated 10 minutes later. Over time, RPE increased significantly in both conditions. This increase was significantly greater for the hot condition. However, subjects' HRs reached about 90% of their age-predicted maximum and their ratings of perceived exertion did not reflect a perceptual match of this intensity. SA increased significantly after the overhaul task in the hot condition, with little to no change in the neutral condition. SA did decrease after the 10-min rest, but was still significantly higher than baseline. If individuals cannot accurately perceive how hard they are actually working, it may impinge on their safety. The authors speculated that increased SA could influence cognition, potentially resulting in drastic impairments in their ability to act as stable emergency responders (Smith et al., 1997). Anxiety, like arousal can contribute to disruptions in cognitive performance if too low or too high. The inverted-U hypothesis (Humara, 1999; Yerkes & Dodson, 1908; Post, 2003) posits that there is some level of optimal arousal for an individual to perform well, and that not enough and too much arousal results in decrements in performance.

Another study, performed by the same research group, assessed information processing of firefighter recruits before, during, and after an interrupted bout of firefighting activity (Smith, Manning, & Petruzzello, 2001). A Continuous Performance Task was used; this involved determining if a single-digit number shown on the computer screen fell into the category 1-8 (left hand response) or if it was 0 or 9 (right hand response). Male recruit firefighters (*N*=7) performed three 7-min trials. The trials involved dragging a hose, carrying a 5-gallon extinguisher up stairs, hoisting a hose, and chopping a block of wood. In this case, no significant changes were revealed for speed of reaction time in regards to the different time points. However, accuracy on the cognitive test decreased as time went on.

In a review of research with wildland firefighters, Aisbett, Wolkow, Sprajcer, and Ferguson (2012) discussed the impact of heat and carbon monoxide on cognitive and physical work performed by firefighters on the job. Aisbett et al. found clear physiological impact of heat on wildland firefighters in these studies. They also presented evidence for heat affecting cognition independently of dehydration in non-firefighter workers (Sharma, Pichan, & Panwar, 1983). However, Aisbett et al. identified a serious gap in the literature when looking for interactive effects of stressors inherent to firefighting (e.g., heat, smoke, and sleep deprivation) on cognitive performance. It is true that wildland firefighting differs from structural firefighting in scale (magnitude and duration of fireground operations). Wildland firefighting usually describes containment of fire spread and then suppression in remote, natural areas, with relatively longer response times due to fires taking longer to be noticed by civilians (“Part 1: Understanding…”, 2011). Structural firefighting involves rapid response, due to stations being embedded within densely populated regions, and rapid fire suppression in individual buildings to try and prevent as much loss of life and property as possible at time of arrival (“Part 1: Understanding…”). However, they are not completely dissimilar, and sometimes emergencies require each separate group to perform crossover duties. Both involve wearing heavy personal protective equipment and making time-sensitive decisions under heat stress. Therefore, it would not be unusual to see similar issues arise in the current population of study.

Sustained attention has been measured before and after simulated live-fire activities (Greenlee et al., 2014). Firefighters completed 18 minutes of firefighting drills: stair climbing, forcible entry, search, and hose advance. Cognitive (i.e., attention assessed via a visual continuous processing task), perceptual and psychological assessments were made before and after firefighting, incident rehabilitation, and recovery. Personality was examined via the International Personality Item Pool (IPIP; Goldberg et al. 2006) questionnaire, as an individual difference variable. Incident rehabilitation, consisting of currently used rehabilitation protocols or additional active cooling and nutritional intervention (Horn et al., 2011), did not seem to have any effect on attention. Reaction time was shorter immediately post-firefighting, followed by slowing after recovery. Accuracy was not significantly different across time points. Greater conscientiousness (a personality type linked to the tendency to delay gratification, control impulses, be self-disciplined, be organized and follow rules) was associated with shorter reaction time before and 120 min following firefighting. Higher baseline energy and lower baseline tiredness were associated with shorter, less variable reaction times at baseline and post-firefighting.

To date, one group has published an examination of more complex cognitive performance in a pre-post firefighting simulation; however participants were not firefighters (Robinson, Leach, Owen-Lynch, & Sünram-Lea, 2013). After two days of a basic training course in firefighting, 21 participants with no firefighting experience completed a simulated, 60-min search and rescue task. Volunteers spent the first day training in the classroom, and learning about fire extinguisher use. Their second day involved practicing self-contained breathing apparatus (SCBA) use and physical tasks in ambient temperature for 2 hrs. On day 3, participants entered a mock ship's galley for 60 minutes to do a search and rescue exercise in 60-130ºC temperatures and black smoke. Working memory, declarative memory, and visual attention performance were measured immediately after and 20 minutes post-firefighting. Eleven volunteers were tested immediately post, and 10 after the 20-min delay (11 additional volunteers served as controls). Rehabilitation procedures such as rehydration following the drill were not reported. Results showed impairment in visual declarative memory immediately post-firefighting, but not 20-minutes post; visual attention appeared unaffected by the activity. Working memory, as measured by a grammatical reasoning test, remained similar to baseline immediately post-firefighting, but was significantly impaired at 20-min post. State anxiety was also significantly elevated immediately post-firefighting (Robinson et al.). One shortcoming of this study, however, is that a mixed subjects design was used to examine these effects.

Dehydration

Dehydration often accompanies heat stress and is another factor that has been shown to negatively impact cognitive performance (Cian et al., 2000; Lieberman, 2007). For example, significant decrements have been seen in short-term memory, recognition, and motor speed at 2, 3, and 4% dehydration (Gopinathan, Pichan, & Sharma, 1988). Dehydration has been associated with slower decision-making and decreased short-term memory 30 minutes post-exercise (Cian, Barraud, Melin, & Raphel, 2001). Many studies of the effects of heat stress on cognition focus on dehydration effects, which have been linked to working memory dysfunction (Cian et al., 2001; Cian et al., 2000; Kapoor, Singh, Bhagi, & Singh, 2014; for a review see Hancock & Vasmatzidis, 2003; Sharma, Sridharan, Pichan, & Panwar, 1986).

Conversely, Bandelow et al. (2010) saw no effect on working memory performance pre- to post-football game when college athletes were only mild-to-moderately dehydrated up to 2.5% loss in body mass. A recent review on the effects of dehydration on mood and cognitive performance could not single out detrimental effects of dehydration in young adults (anywhere from 1-4% loss of body weight), as a discrete variable without heat or fatigue also being present (Benton, 2011). Precautionary maintenance of proper hydration and rehydration has been shown to help minimize cognitive detriment that may occur in relation to heat stress and recent efforts have been made to maintain proper hydration of on-duty firefighters (Cian et al., 2000). Fluid replacement guidelines have been set forth previously in the literature (Smith & Haigh, 2006).

Role of Individual Differences in Cognition

Individual differences, such as anxiety and experience levels, may contribute to cognitive detriment, beyond physiological strain (Barr, Gregson, & Reilly, 2010). Personalities, attitudes, motivation levels, and mood states may also influence an individual's cognitive performance (Acevedo & Ekkekakis, 2001). Firefighters have been shown to have higher levels of excitement seeking personality traits when compared to individuals who do not work in emergency rescue (Salters-Pedneault, Ruef, & Orr, 2010). Anxiety levels, emotional assessments of situations based on previous experiences, and other disorders could also affect firefighter decision-making on the job, warrant attention, and could also play moderating roles on the relationship between firefighting activity and neuroendocrine responses. McMorris et al. (2006) and Vedhara, Hyde, Gilchrist, Tytherleigh, and Plummer (2000) have proposed that cognitive performance decrements elicited by heat stress may actually be a result of emotional perceptions of stress, and it is the greater brain activation in these emotional regions of the brain that have led to increases in catecholamines and cortisol (i.e., measures commonly used as physiological indicators of stress) “at the expense of the cognitive”, not the biomarkers themselves (McMorris et al., 2006, p. 213). Along this same line, self-efficacy over the encountered situation may moderate an individual’s physiological stress response (Acevedo & Ekkekakis, 2001), which could in turn influence cognition. In a recent review of individual differences and affective state, Parasuraman and Jiang (2012) reported findings from a case study of two adults, a high performer compared to a low performer on a modified n-back task, and found greater brain activation very specific to regions associated with working memory in the high performer, while the low performer presented with activation in multiple other brain regions, including a limbic region associated with emotional regulation. Parasuraman and Jiang also examined a group of 16 participants, of whom low and high performers were divided into groups (*n*=8 each), and discovered lower posterior precuneus activation in higher performers; this region is known to be activated less during cognitive task performance than while at rest. As discussed by a panel at the 2003 Annual Meeting for Human Factors and Ergonomics Society (Karwowski et al., 2003), further study of individual differences could explain many of the equivocal findings in human performance research.

Fitness and cognition. Individual differences in physical fitness have also been highlighted in the literature, due to evidence of its relation to cognitive performance. An individual’s level of physical fitness level may influence his/her rate of recovery, resulting in different psychophysiological states following exercise; thus whatever was going on during exercise may not be reflected when measured post-exercise nor will any one person likely be impacted to the same degree at any given point post-exercise (Tomporowski & Ellis, 1986). This addresses two issues: 1) the need to account for individual fitness levels; and 2) the necessity of future work to measure cognitive performance, and further cognitive function, during exercise versus post-exercise to determine differences in brain activation and possible performance. The cardiovascular fitness hypothesis posits that there is a positive relationship between fitness and cognitive function, such that enhancements in aerobic fitness appear to selectively improve executive control, more so than simple reaction time, and this is based on evidence that older inactive adults generally have poorer cognitive function (partially age-related), but are capable of improving this through aerobic exercise training (Chodzko-Zajko, 1991; Chodzko-Zajko & Moore, 1994; Colcombe & Kramer, 2003).

As firefighting requires physical strength, aerobic endurance, and anaerobic capacity, and it places high demands on the cardiovascular system that can result in sudden death on the job; exercising for fitness and cardiovascular benefits should be a fundamental health behavior practiced routinely by all firefighters (Smith, 2011). Maintenance of high physical fitness is fundamental to successful completion of the occupational demands of the firefighter (Barr, Gregson, & Reilly, 2010). A review of occupational stress has found fitness training to be necessary for all jobs requiring physical exertion, because greater physical fitness has been connected to relatively better cardiovascular and immunological reactions to stress, not to mention its ability to combat other disease risk factors, such as obesity (Huang & Acevedo, 2011). Researchers have documented a strong inverse relationship between VO_{2max} and better work performance on physically demanding simulated firefighting tasks (Elsner & Kolkhorst, 2008; von Heimburg, Rasmussen, & Medbo, 2006).

The National Fire Protection Association (NFPA; 2012) calls for fire departments to establish physical fitness requirements and physical health exam requirements, suggesting (but not enforcing) use of the Candidate Physical Ability Test (International Association of Fire Fighters [IAFF], 2007). As such, most firefighters are expected to meet some departmental standard of physical fitness when they enter the force, early in their career, but maintenance of fitness is not universally enforced. Exercise interventions in firefighters, ambulance men, and police officers (even at low frequency, e.g., 2 $d{\cdot}wk^{-1}$) have resulted in positive change in cardiovascular risk factors and provide promise for the efficacy of such programs to enhance health (Gamble, Boreham, & Stevens, 1993). Physical fitness is certainly important for cardiovascular health and aerobic fitness has been associated with lower risk of injury in firefighters (Poplin, Roe, Peate, Harris, & Burgess, 2014). Increasing fitness levels could reduce risk of CVD, improve safety of firefighters and the public they serve, boost cognitive performance, and increase quality of life outside of work (Hancock & Vasmatzidis, 2003).

The links between exercise participation, fitness, and cognitive ability have been topics of recent, rigorous examination. Aerobic fitness, at least in children, has been positively correlated with cognitive behavioral performance on both the n-back and flanker tasks (Scudder et al., 2014). Findings suggest that adaptive responses of the body to regular exercise are associated with prevention of cognitive decline (Colcombe & Kramer, 2003), some reversal of cognitive deficit, and even some acute cognitive performance enhancement (Lee et al., 2014; Tomporowski, 2003). Participation in regular aerobic exercise, at least in adolescents, has been associated with higher cognitive performance on tasks such as the Wisconsin Card Sorting task (higher accuracy scores and use of fewer trials to complete the task, measuring cognitive flexibility), and the Stroop Color-Word test (shorter reaction times, measuring cognitive inhibition), even after controlling for the exercisers' enhanced psychomotor skill (Lee et al.).

Although the overwhelming majority of research in this area has been performed in elderly populations and individuals with pathological conditions, some have also demonstrated exercise benefits in young, healthy populations. Aerobic fitness is generally, positively associated with cognitive function (Hillman, Erickson, & Kramer, 2008) and, in older adults, aerobically trained individuals seem to do better on executive function tasks than anaerobically trained individuals (Kramer, Hahn, & McAuley, 2000). However, greater aerobic fitness levels do not appear to enhance basic psychomotor measures of cognition, such as simple reaction time or well-learned vigilance tasks (although this may be due to a ceiling effect; tasks of greater difficulty may benefit more from enhanced aerobic fitness; Blaney, Sothmann, Raff, Hart, & Horn, 1990).

The effect of physical fitness as a moderator of cognitive performance in an acute exercise testing scenario has yet to be shown (Brisswalter, Collardeau, & René, 2002); indeed, the efficacy of acute exercise has been questioned. There is some evidence that an acute bout of exercise results in improved performance on the Novel Object Recognition task 2 hours following exercise, but only in trained not sedentary individuals, (Hopkins, Davis, Vantieghem, Whalen, & Bucci, 2012). Determining whether or not physical fitness levels of firefighters differentially affect decision making capabilities thus represents an important research question.

Through chronic repetition of acute exercise bouts (i.e., regular exercise), changes in physical fitness should be related to enhanced brain functioning more so than minute responses to acute physical activity participation (Stroth et al., 2009).This suggests that even if someone is currently unfit they could change over time. This is to say that physical fitness is a variable that has the capacity to change, and in turn, could allow for the capacity to change cognitive function for the better. If physical fitness levels can be shown to differentially affect decision-making capabilities, this could potentially motivate members of the fire service to become more physically fit.

Firefighters tend to be viewed by the public as relatively fit individuals (Pirlott, Kisbu-Sakarya, DeFrancesco, Elliot, & MacKinnon, 2012); however, overweight condition and obesity are highly prevalent in both career and volunteer firefighters (Smith et al., 2012). In one study, 78% of volunteer firefighters had BMIs that classified them as overweight or obese and had VO_{2max} values below what is recommended by the fire service (39 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$ vs. 45 $ml{\cdot}kg^{-}$

$^{1}\cdot \text{min}^{-1}$ for males) (Hammer, Heath, & Schroder, 2009 as cited in Hammer, 2010). In an analysis of 23 separate, international studies of firefighter aerobic fitness levels from 1982-2009, mean maximal, or estimated maximal, aerobic power ranged from 39.6 to 61 $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ (Barr, Gregson, & Reilly, 2010). According to the American College of Sports Medicine (ACSM, 2006), this would place those with lower average values under the 20th percentile for male norms in the United States making it difficult to meet the physical demands of the job (Barr et al., 2010).

Cardiovascular disease (CVD) is also highly prevalent in this occupational group; however, risk factor profiles do not seem to differ significantly in obese versus non-obese firefighters (Smith et al., 2012; Soteriades, Smith, Tsismenakis, Baur, & Kales, 2011). Notably, lack of exercise is the most common cardiac risk factor for people in the US with known heart disease (Moe et al., 2002). Unfortunately, about half of on-duty firefighter deaths result from sudden cardiac events (Smith, 2011) and cerebrovascular accidents (Green & Crouse, 1991). Recent studies suggest that acute exercise training and aerobic fitness enhancement have the potential to protect individuals from cardiovascular disease and the cognitive disruption that could result from such combinative stress as has been described by Jackson and Dishman (2006). Clearly, if physical fitness and cognition are inadequate firefighters may have reduced capacity to protect life and property. This emphasizes the necessity of interventions to enhance the human psychophysiological system.

Exercise training and subsequent fitness gains have potential to diminish CVD risk (Paffenbarger et al., 1993 as cited in Moe et al., 2002). Exercise participation has also been associated with greater cognitive functioning, enhanced learning, and prevention of cognitive decline (Bherer, Erickson, & Liu-Ambrose, 2013; Cotman & Berchtold, 2002; Colcombe & Kramer, 2003). Advances in anaerobic fitness may be necessary, as well. During one 12-minute bout of simulated firefighting activity, heart rates were markedly elevated above 85% of individual max, for more than 63% of the time (Perroni et al., 2009). Thus, fitness interventions appear to present great promise in improving the cognitive and physical health of firefighters.

Another benefit of chronic physical exercise appears to be lower hypothalamic-pituitary-adrenal-axis activation, one of the major stress response axes (Luger et al., 1987, as cited in Budde, Pietrassyk-Kendziorra, Bohm, & Voelcker-Rehage, 2010). It is plausible that firefighters who have higher levels of physical fitness may recover from the physical and psychological stress more quickly than those with lower levels of fitness. Thus, the fitter firefighter would spend less time in the “stressed” psychophysiological state following exertion (i.e., they would recover more quickly), which could manifest itself in their cognitive performance. Conversely, those who either are more fit or perceive themselves as more fit may push themselves harder during fire operations and thus be more taxed upon completion of the drill. However, it would be expected that more fit individuals would recover (e.g., return towards baseline or resting state) more quickly than less fit individuals (Tomlin & Wenger, 2001).

Some evidence is available to demonstrate the effectiveness of exercise training on improved cognitive performance in firefighters. Firefighters (*n*=21) spent 16 weeks in a progressive rowing ergometer training program at one of three local fire stations, while control firefighters (*n*=20) continued with their usual activity (Throne, Bartholomew, Craig, & Farrar, 2000). This aerobic exercise training was linked to improvements in aerobic fitness that were significantly (favorably) correlated with both physical (decreased Mean Arterial Pressure) and psychological (decreased negative affect and state anxiety) responses to completing a video-based decision making task that mimicked a fire emergency (Throne et al.).

It is imperative to examine the relationship between physical fitness and cognitive performance of firefighters working at a fire scene. If cognitive performance is significantly related to physical fitness, the fire service and society as a whole would benefit from knowing how it is affected, what an adequate (i.e., minimal) level of fitness might be, and what measures should be taken, both acutely and chronically, for optimal and safe performance of job duties, particularly during emergency fire response. In order to provide firefighters with adequate training to perform at their highest potential, it is necessary to investigate whether or not changes in cognition, specifically inhibition and subsequent working memory, occur in response to performance of firefighting activity, and further, whether or not level of physical fitness could protect them from cognitive deficit.

Determining a minimal standard for a healthy body can be done using fitness measures. However, determining that the mind is prepared for optimal performance will require a foundation of knowledge about the state of flux in cognitive behavior in this population. A recent dissertation investigating firefighter fitness and cognitive performance (Roof, 2011) concluded that fitness did not predict working memory (using the Automated Operations-Span task) or decision making performance. Automated Operations-Span task involves viewing a list of letters (3-7) and then performing simple math problems in between, then needing to recall the letters seen previously (Gohar et al., 2009). Because performance is assessed by recall and also by performance on the math problems, this also seems to tap into task-switching performance. Fitness was a significant predictor of math errors and speed errors on this part of the task, suggesting that greater fitness related to more errors. The decision making task was measured by presenting firefighters with slides, simulating participation in a drill, and then asking open-ended questions about how they would assign 4 firefighters towards the attack, followed by true-false questions about what they had seen in the images of the fire scene). Roof (2011) measured firefighter cognitive performance across different time points of a 13-week fitness training intervention: at baseline (not post-exercise), and immediately following 90 minutes of acute fitness training in week 1, at midpoint, and in week 13. Only 13 individuals were assessed, and data were not collected pre-workout. So it is unknown what differences may have presented themselves if firefighters had been tested immediately prior to each workout, in addition to post. Roof suggested from trend data that learning of the task had occurred, so it would have been interesting to know what scores would have been pre-acute exercise.

Trait anxiety and cognition. The unpredictable nature of fire scenarios cannot fully compare to relatively manageable tasks that participants have been given the opportunity to practice in a calm laboratory setting. Firefighter behavior and decision-making ability is likely influenced by emotional reactions that an individual experiences “in the moment” and those emotions that he/she has experienced over the course of their career (Dolcos, Iordan, & Dolcos, 2011).

Starcke and Brand (2012) present a summary of stress research from Selye (1956), to Lazarus (1999), to Koolhaas et al. (2011); they conclude that stress does seem to influence decision making, but that it does so differently depending on the level of uncertainty in the situation and on individual personality characteristics (e.g., trait anxiety), which might influence an individual to react to the stress in a different way than others (Starcke & Brand). Trait anxiety (TA) is defined as “a characteristic of personality that endures over time and is manifest across a variety of situations” (Donner, 2009, p. 1). Trait anxiety levels seem to be related to differences in individuals’ abilities to overcome emotional distractions that could interfere with cognition, or conversely, to make it more difficult to perform necessary cognitive tasks.

Some research has demonstrated impairment in working memory with greater levels of trait anxiety (TA). Functional magnetic resonance imaging (fMRI) scanning of 18 females (18-33 yrs) revealed TA levels to be inversely correlated with performance during completion of a working memory task interrupted by task-irrelevant emotional distracters (Denkova et al., 2010). However, one must keep in mind that firefighting distractions may actually be relevant to the task at hand. Additionally, the testing population in this study included no males, who prominently comprise the firefighting population.

Other researchers have examined this effect of TA on working memory performance in a situation in which the stimuli being presented were meant to elicit an emotional response, since working memory performance in a real-life scenario many times must be performed in the midst of emotion-provoking situations; and standard 2-back paradigms do not capture this inherently in the task (Fales, Becerril, Luking, & Barch, 2010). Twenty-nine healthy adults (35.5±10.9 yrs) were separated into high and low trait anxious groups and tested for performance on 3 separate blocks of an 2-back paradigm with human faces for stimuli: neutral, a 50/50 mix of neutral and fearful, and a 50/50 mix of neutral and happy. Results showed no group differences (high versus low trait) on RT or accuracy. It is important to note that this was just a median split of people whose scores spanned 21 to 33 on the Beck Anxiety Inventory (BAI) with an average of 24.5 ± 3.8, indicating a moderate severity level of anxiety (Beck, Epstein, Brown, & Steer, 1988; Fales et al., 2010). With possible scores ranging from 0-63 on the BAI, the group was fairly homogenous. As such, group differences may have been difficult to see. General results showed significantly faster RT on the happy block than the neutral or fear blocks; overall, emotional trials were significantly slower than neutral ones (Fales et al., 2010). This suggests brain-level competition for resources for working memory task completion and recognition of the fearful stimuli.

A verbal version of the 3-back task has also been used to examine differences in brain activation patterns between high and low trait anxious individuals (Fales et al., 2008). Participants (mostly college-aged, 20 high-anxious, 20 low-anxious) watched six 10-min videos, in groups of two: two meant to elicit negative moods, two neutral ones, and two meant to elicit positive moods (i.e., amusing videos). The order of these video groups was counterbalanced across participants while they were in a fMRI scanner. After each of the six videos, a scan was done while the individual completed a 3-back task. Results showed that accuracy and RT did not differ between groups or in response to video type. However, fMRI data showed that sustained activation of cognitive control networks in the high anxious group was significantly lower than the low anxious group. There was also relatively greater transient activation of these networks, indicative of a greater effort being put forth to complete the task. This study was modeled after the attentional control theory by Eysenck, Derakshan, Santos, and Calvo (2007) which posits that those with greater levels of anxiety require greater relative activation of brain regions associated with working memory (e.g., dorsolateral prefrontal cortex [DLPFC]) if they are to perform as well as individuals with lower anxiety. This theory assumes differences in working memory performance between low and high anxious individuals, but also allows for the possibility that no differences in cognitive behavioral performance between high and low anxious groups may be seen. That is, if the high anxious individual is capable (whether consciously or not) of evoking greater activation in the appropriate brain regions thought to be involved in performance of working memory tasks, s/he would perform behaviorally at the same level.

It is presumed that firefighters might represent a different personality profile than the average person in that they may be able to regulate their emotions more effectively than the general population in order to successfully complete their job duties under such stressful conditions. Both American and Italian fire research studies have concluded that firefighters have more positive mood profiles and lower self-reported anxiety than other age-matched individuals (Farne et al., 1991 and Smith et al., 1997 as cited in Perroni et al., 2009). Soldiers also share a similar profile (Lieberman et al., 2006 as cited in Perroni et al.). It has yet to be determined fully whether firefighters have greater “hardiness” or ability to cope with stressful situations (i.e., resilience) to the point at which they can better avoid emotional distraction and, thus, negative impacts on cognitive function. Analysis of situations firefighters persevere through suggests that at some level they are good at harnessing and coping with negative emotions or natural impulses that may arise (e.g., to flee the scene). Intuitively, one might assume that those individuals seeking out career or volunteer positions within the fire service would have personalities that predispose them to handle dangerous, volatile situations better, but there are differences even within this group. A sample of 52 career and 53 volunteer firefighters found career firefighters to have lower trait anxiety and higher conscientiousness (Petruzzello et al., 2014). It was also found that career firefighters had lower resting HR prior to firefighting activity than volunteer firefighters, and demonstrated blunted decreases in pleasantness and energy, compared to volunteer firefighters. This may possibly indicate that they had less of an anticipatory stress response due to their exposure over time in these environments, making them more adept at managing the stresses of live firefighting (Petruzzello et al.)

However, having higher trait anxiety could also benefit performance. High trait anxious individuals might have higher arousal and attentiveness in anxiety-provoking situations (Knyazev, Savostyanov, & Levin, 2005). Further, their inhibitory control of attention may be greater when a positive outcome is anticipated, which could, in part, be modulated by their state anxiety levels (Knyazev et al.). Thus, this could play to a firefighter's advantage if self-efficacy for job completion is high. Higher anxiety could in fact be a viable tool and potential factor contributing to firefighters' abilities to direct their attention to important environmental stimuli.

Continued research from Savostyanov supports Eysenck's attentional control theory (Eysenck, Derakshan, Santos, & Calvo, 2007) in that individuals with higher anxiety have more sensitive control of attention and higher rates of use of processing resources as compared to individuals with lower anxiety, at least when making correct responses (Savostyanov et al., 2009). Greater attentional control was indicated by EEG measures of greater 8-25 Hz desynchronization in higher anxious individuals than low anxious individuals prior to behavioral response (e.g., button press). Greater use of processing resources was indicated by continued desynchronization of 8-20 Hz activity after behavioral response in high anxious individuals, whereas low anxious individuals showed synchronization post-response in the same frequency range. This latter effect was thought to be indicative of more efficient response inhibition in the high anxious (Savostyanov et al.). However, error-responses were not analyzed so it is not known what occurs when errors are made and whether or not that would influence subsequent trials. Still, this suggests the importance of determining individual levels of trait anxiety and how they potentially interact with cognitive ability surrounding live-fire maneuvers.

Coping/Resilience and cognition. Emotional coping with stressful situations and resilient personality traits have the potential to relate to and predict cognition in emergency situations. Coping style seems to be related to how well someone will perform in a stressful scenario; whether they approach it as a challenge or as a threat may influence how successful they are (LeBlanc, 2009). Resilience is defined as “the ability to successfully adapt to stressors, maintaining psychological well-being in the face of adversity” (Haglund, Nestadt, Cooper, Southwick, & Charney, 2007, p. 889). It has been proposed that resilient individuals are better at using active coping strategies and to be flexible thinkers (Haglund et al., 2007). Further, cognitive resilience has been described as “...the capacity to overcome the negative effects of setbacks and associated stress on cognitive function or performance.” (Staal, Bolton, Yaroush, & Bourne, 2008, p. 2). Individual differences will dictate how resilient one’s cognitive function is depending on the situation, environment, and difficulty of the cognitive task (Staal et al.). General stress effects on cognitive performance follow a well-established inverted-U model; however, resilience, particularly cognitive resilience, varies across individuals and will differentially impact the actual behavioral performance seen by humans faced with the same amount of stress (Staal et al.). This warrants investigation in the currently proposed research with firefighters.

Perceptual Variables

Perceptual responses can greatly influence physiological reactions to stress (Acevedo & Ekkekakis, 2001). These physical sensations could also interact with cognition. Marras and Hancock (2014) provide a review of an integrated approach for examining human task performance in terms of interactions between the physical body and cognitive mind. Perceptual responses of interest include constructs such as state anxiety, affect, fatigue, perceived exertion and tiredness, respiratory distress, thermal sensation, and felt arousal.

Perceived exertion and fatigue. Fatigue manifests both physically and perceptually and may affect a firefighter's ability to perform their duties. Exercise-induced muscular fatigue has been associated with lower work efficiency (slower completion time) on a physically demanding simulated firefighting task (Dennison, Mullineaux, Yates, & Abel, 2012). Firefighters who trained $2x \cdot wk^{-1}$ for 60 min performing a circuit and aerobic exercise routine for one year (*n*=12) were compared to firefighters (*n*=37) who had not been participating in any physical training. All completed a single circuit exercise session (5 exercises, 10 reps each, 2 rounds, separated by 3 min of treadmill walking), followed by a 7-event simulated fireground test (SFGT) wearing turnout gear (e.g., stair climb, hose drag, search and rescue, forcible entry, etc.). The SFGT was also completed a number of times on separate days and pre-exercise, for comparisons. Those who were exercise-trained were significantly faster in completing the task than those who did not train; when trained firefighters' completion times following exercise were compared to both the untrained firefighters' baseline and post-exercise completion times this finding held true (Dennison et al., 2012). However, exercising and then attempting to complete simulated firefighting tasks did result in slower search and rescue performance for the trained individuals when tested immediately after exercise, compared to how they had performed at baseline (Dennison et al., 2012), suggesting that timing of exercise while on-duty is important and could be detrimental to on-duty firefighter performance if done too soon before arriving on-scene. Still, those who were trained, and more physically fit, handled the challenge better than untrained individuals. Though not measured here, one might assume that higher-fit firefighters would perceive less fatigue to the same relative workload than lesser-fit firefighters, and perhaps this would allow for more concentration on cognitive tasks.

This might be particularly important for older firefighters, as they may perceive greater physical strain in completing firefighting tasks resulting in a physiological blunting of their response to cope with the stress of the job. Researchers have recognized that studying exercise within environmentally stressful conditions also provides a good model for investigating how perception of the physical stress they are experiencing contributes to the body's overall stress response (Acevedo & Ekkekakis, 2001). Firefighting settings provide a scenario that is both physically and cognitively demanding, allowing researchers to examine these psychophysiological interactions. Acevedo and Ekkekakis argue that the presence of extreme heat might exert a massive influence on perceptions of effort [often assessed with Borg's Ratings of Perceived Exertion (RPE) scale; Borg, 1998]. On the other hand, Maw, Boutcher, and Taylor (1993) have proposed that individual perception of physiological changes such as increased heart rate and respiration may contribute more to RPE than thermal sensations do. It is also possible that regardless of the perception of these stressors, certain individuals may react differently to the same internal and external cues: experienced or motivated individuals may experience facilitated performance while inexperienced or less motivated individuals may become fatigued (Acevedo & Ekkekakis).

One psychological issue that arises in conjunction with the high physical strain of the job is the resulting inability to discern how hard they themselves are working. This became evident in a study that documented firefighter ratings of perceived exertion after completing a brief firefighting task (Smith, Petruzzello, Kramer, & Misner, 1997). Firefighters were asked how hard they felt they were working in a firefighting drill; this rating was compared to their measured heart rates. Physiological measures (i.e., heart rate) reflected higher work rates than firefighters self-reported. If a firefighter cannot accurately discern how hard they are actually working, it may impinge on their safety, because failure to recognize that they are at a level of fatigue that could negatively impact their cognitive performance and then persevering in an impaired state could result in making a harmful mistake. Smith et al. (1997) noted that this phenomenon could either be due to a true deficiency in their ability to assess how hard they are straining their body or reflective of a social stigma of being firefighters that made them feel like they should not admit how difficult things seem, or because they are minimizing the sensation of fatigue out of a sense of duty to complete the task (Smith et al., 1997). This effect has also been seen in athletes (Hogervorst et al., 1996).

In working shifts of sometimes 24 or 48 hours on and 48 or 72 hours off, firefighters might be considered at risk of sleep-deprivation. Fatigue may also contribute to potential safety concerns in shift-workers, including firefighters (Barger, Lockley, Rajaratnam, & Landrigan, 2009), as it may lead to poor reaction time and diminished cognitive performance (Weeks, McAuliffe, DuRussel, & Pasquina, 2010). A review of research with mine workers suggests that a combination of heat exposure and physical exertion, among other stressors (i.e., sleep deprivation), may negatively impact cognitive performance (Legault, 2011). Legault argued that these stressors may contribute to fatigue that then influences cognitive performance, possibly to a lesser extent if acclimated (Legault). Greater feelings of physical fatigue may even intensify the hormonal and immune manifestations of the stress response (Acevedo & Ekkekakis, 2001),

Anxiety, felt arousal, respiratory distress, thermal sensation and affect. Physical and psychological responses to firefighting environments and tasks are invariably intertwined. State anxiety has been shown to increase during and remain elevated after firefighting simulations (Smith, Petruzzello, Kramer, & Misner, 1997). This elevation in anxiety could have an impact on cognitive functioning and therefore decision making processes (Kivimaki & Lusa, 1994). In a previous study of firefighters, state anxiety increased significantly more following performance of a ceiling overhaul task in the heat than in a neutral environment and remained elevated above baseline after 10 minutes of rest (Smith et al.). Smith et al. speculated that physiological and psychological demands of the job may drastically impair firefighters’ ability to act as stable emergency responders, possibly due to increased anxiety. In theory, emotionally distracted individuals will experience some level of cognitive disruption that could affect their ability to make appropriate decisions to avoid life-threatening consequences, and working memory "...may become more inefficient during a threat due to an increase in worry and anxiety, which absorbs the limited storage and processing resources, leaving fewer available to process information from the environment" (Darke, 1988 as cited in Robinson, Leach, Owen-Lynch, & Sünram-Lea, 2013, p. 592).

Further, those who are more equipped to regulate their emotions may be able to maintain adequate cognitive functioning. Recent findings suggest that greater activation of brain areas associated with negative emotion processing plays a role in increasing sensitivity to task-irrelevant distractions by competing with the lateral prefrontal cortex, making it difficult to think clearly (Melcher, Born, & Gruber, 2011). Research has also shown that the human brain has the ability to reappraise negative emotional scenarios in a manner that deactivates emotional brain regions like the amygdala and increases activation in the prefrontal cortex (Ochsner, Bunge, Gross, & Gabrieli, 2002). This seems to act as a mechanism for increasing cognitive efficiency. At the individual level, those who can get better (if possible) at doing this should be better at handling emotions and thinking clearly under stress. Increased activity in brain regions acknowledged for regulating affect appears to have reciprocal activation with executive functioning regions when emotions distract cognition (Denkova et al., 2010).

It is somewhat unknown when and how heightened state anxiety aids or hinders cognitive performance, and working memory capacity may vary in relation to trait anxiety and relative working memory capacity (Owens, Stevenson, Hadwin, & Norgate, 2014). Anxiety has sometimes been thought to be disadvantageous to cognitive performance: if attention is allocated to threat-related information it might distract one from focusing on the task at hand; yet, if the threatening information is integrally related to the task at hand, it might be advantageous to attend to it (LeBlanc, 2009).

Perceived arousal has also been linked to cognitive performance, with relationships varying based on level of arousal and task characteristics. Lambourne and Tomporowski (2010) reviewed cycling and treadmill studies to find a negative effect of exercise-induced arousal on cognitive performance within the first 20 min of exercise, driven by the running mode of exercise, and a positive effect when task performance was measured after 20 min during or at any time post. However, only 13 of 109 total effects of task type as a moderator of the impact of exercise-induced arousal on cognitive performance following exercise were representative of measures of executive function, while 87 effects came from measures of simple processing (Lambourne & Tomporowski, 2010). Thus, more research may be necessary on tasks requiring more cognitive control to gain a more complete understanding of how exercise-induced arousal impacts executive function. For working memory, although reaction times have been shown to remain relatively stable as arousal varies, accuracy has been shown to be greater under situations of neutral emotional arousal than of relaxed or tense arousal (Choi et al., 2013). Extreme levels of nervous system excitement can also negatively impact cognitive performance; however this is not surprising as the inverted-U hypothesis for arousal and performance has long been accepted (Dabrowski, Ziemba, Tomczak, & Mikluski, 2012; Humara, 1999). In heat stress, evidence suggests that although reaction time becomes generally faster and accuracy only seems to negatively impact selective attention (but not simple processing tasks) affective arousal does not appear to significantly relate to performance (O’Connor, 1994).

Cognitive Performance During & Following Firefighting Maneuvers

The framework for the current study was built on a few pre-existing conceptual frameworks. Fewer strong connections have been made between anxiety and performance in pre-existing models of cognitive performance. Further, many researchers in the field of exercise science have begun to develop models very specific to their own needs, often focusing on mechanisms behind how exercise affects cognition and emotion, but not how other variables factor in simultaneously. An attempt was made to model this exploratory analysis of factors influencing cognitive performance, based on their expected relationships to each other and to cognitive performance in a firefighting scenario.

A recent review of firefighting called for future research to explore the differential contributions physiological strain, anxiety, and personal experience may have on cognitive function (Barr, Gregson, & Reilly, 2010). The present model posited that participants' individual differences (e.g., personality, fitness), situational stressors (e.g., HR fluctuations elicited from physical and environmental demands of the situation), and perceptual responses to environmental and task demands (e.g., state anxiety, thermal sensations) would influence their cognitive performance in a given scenario (e.g., following live-fire maneuvers). It was important to gain an understanding of the extent to which each may account for variance in cognitive performance. Physical fitness is highlighted as an individual difference of particular interest, as this is where an intervention would make the most sense. It was expected that physical fitness would not only be indirectly related to cognitive performance through the other levels of the model, but also directly related.

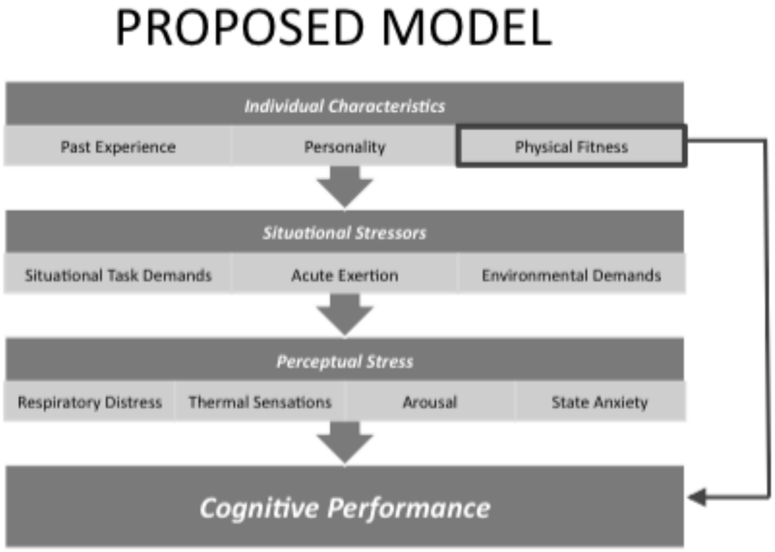


Figure 2.2. Conceptual model of variables influencing cognitive performance in firefighters.

Relationships documented in the fields of emergency response, physical activity, emotional psychology, and neuroscience were combined in order to create the hypothetical model above (Figure 2). Placement in the hierarchy followed the proposed model: perceptual variables at step 1, physiological variables at step 2, and individual difference factors at step 3. Level 1 represents perceptual stress variables measured pre and post firefighting such as arousal, thermal sensations, state anxiety, and respiratory distress. Other perceptual stress variables include: valenced affect, energy, tension, tiredness, calmness, fatigue, nervousness, and rating of perceived exertion. Level 2 represents situational stress, which is indicated by the continuously recorded heart rate data that we collected during the event. Environmental demands, though fluctuating throughout the drill, are the temperature, wind, humidity, fire behavior, noise, visibility, smoke, etc. Situational task demands encompass the duties required of the job during the drill, orders given by incident command, and guidance from instructors. Level 3 represents the individual and their innate traits, things that are known about the person before the drill even begins: BMI, aerobic fitness, personality, use of coping strategies, dispositional resilience, trait anxiety, and preference for and tolerance of intensity of exercise. Here, physical fitness is also chosen as a variable known to independently predict cognitive performance. Though Levels 2 and 3 are separated for visual purposes, it is assumed that these factors are simultaneously occurring through participation in the night-burn drill. The outcome of cognitive performance is represented by measures of reaction time and accuracy on the modified flanker task, 0-, 1-, and 2-back tasks. Pre-post change scores were also computed and used in analyses. As discussed in the literature review, it was anticipated that data would reveal significant relationships between single-level factors and cognitive performance, allowing for examination of which variables might predict executive control in firefighters relative to the night-burn scenario.

Some of the arrows could hold bidirectional properties (e.g., between acute exertion and physical fitness), but were not investigated by the hypotheses proposed for the current study. Connections between acute exertion and cognitive performance are a current topic of discussion in the literature and were examined earlier in this chapter. The relationship that personality can have with cognitive performance is best generalized as a moderate one, though the Big 5 trait of Openness seems to relate more closely to measures of cognitive performance than some other personality types (Soubelet & Salthouse, 2011). Experience, or expertise, appears to play a role in cognitive performance, but the relationship may vary when standardized tasks are used for comparison (Ericsson & Smith, 1991), in that when the sample lacks heterogeneity in experience level, this relationship is less likely to be revealed. Clearly, the more difficult a task is or the relative “demand” of the task may relate to cognitive performance differences across different tasks.

The Current Study

Research studies in firefighters have historically been aimed at assessing risk factors for cardiovascular events and developing prevention for such events (Smith, 2011). These pre- to post-activity field studies of firefighting simulations have been primarily focused on physiological responses to heat stress and firefighting-related physical exertion. Though cognitive and psychological measures were sometimes obtained in these studies, they were taken as secondary variables of interest after cardiovascular risk measures had been obtained.

To date, measurement of variables related to cognitive performance in firefighters has been done as an “add-on”, rather than as the main objective of a study. Previous scenarios have involved having an individual perform a firefighting scenario followed by spending 20-60 min having blood taken, resting, and having other physiological variables measured post-activity. When cognitive assessment was done, it was usually after other measures have been obtained. As such, results of cognitive performance that have been reported may not actually be reflective of cognitive ability immediately post-firefighting. There is no doubt that research on cardiovascular responses is absolutely essential for firefighter safety and well-being; however, psychological and cognitive issues related to participation in firefighting tasks are also critically important to successful performance as well as maintaining safety of firefighters and the victims they rescue.

One shortcoming in the field is that there is simply not much data available to describe the cognitive status of firefighters on the job. This implies a second, more salient, issue: to what extent are cognition and behavior acutely impacted by participation in firefighting activity and how might this translate to decision making that could impact injuries and fatalities? An examination of how cognitive function presents itself *during* firefighting is certainly necessary; however, clearly understanding how cognitive function presents itself *immediately post* rather than *during* firefighting activity, for now, is a necessary first step. The use of a controlled laboratory setting to measure cognitive performance had advantages, as it was a more manageable environment, and provided more flexibility to compare results across other research domains available in the literature. In these early stages it was important to examine cognitive performance immediately following the activity, because at this point, cognitive tests still need to be developed and validated for use during firefighting activity. The information gained in the current plan will be useful in designing protocols that would allow assessments of relevant cognitive parameters during firefighting activity as well. Of particular interest were cognitive impairments that might influence one's ability to successfully and safely perform desired on-duty tasks. Discoveries lend themselves to the development of training programs that promote optimal job performance.

If we can understand what effects firefighting has on cognitive performance **(Aim 3)** and which individual difference characteristics **(Aims 1, 4, & 5)** and psychological, perceptual, and physiological factors **(Aim 2)** seem to moderate this relationship, we can inform the development of training interventions to improve firefighter performance, ultimately preventing avoidable injury, death, and property loss.

Limitations

In the current study, the decisions made during computerized cognitive testing were based on following strict rules in a very controlled laboratory environment; the decisions have limited contextual value outside of the testing room. Rather, they simply provide a picture of behavior following firefighting activity. Moving from computerized cognitive testing to “live” behavior tasks could result in differences in which cognitive changes may present themselves differently or more drastically. When real emergencies occur, individuals may have a greater increase in HR than that seen in simulated scenarios (Richardson & Capra, 2001), indicating a heightened stress response. Perroni et al. (2009) also caution that cortisol and emotional responses may transpire differently in a real emergency as opposed to a simulated one. So, there is always a possibility that reliability of psychological and physiological measures thought to predict cognitive performance in a training setting could be altered in a real setting.

CHAPTER 3

METHODS

The effects of acute firefighting on the cognitive performance of firefighters are largely unknown (Hancock & Vasmatzidis, 2003). Specifically, research on working memory and cognitive inhibition of firefighters immediately following participation in live-fire maneuvers is scarce (Robinson, Leach, Lynch, & Sünram-Lea, 2013) and information about cognitive performance during live-fire maneuvers has yet to be obtained. Using a within-subjects design, pre-post activity comparisons were able to determine whether cognitive performance changed from pre to post firefighting. Correlations were also examined to see if any individual difference variables, or physiological, perceptual, or psychological variables, appeared to significantly relate to cognitive performance before and following a simulated emergency response drill ("Night-Burn"), which involved forcible entry, fire suppression, search, and rescue in the dark. This was a "two-bottle" drill, meaning that the average number of air pack bottles that a firefighter was expected to go through in order to complete the required drill was about two. This exploratory research was designed to meet the schedule and needs of an already established academy training program for structural firefighters in the state of Illinois.

Research Questions

1. What is the profile (age, fitness, trait anxiety, coping ability, dispositional resilience, preference/tolerance for intensity of exercise, and personality) of an Academy recruit firefighter?
2. How do measures of HR and state measures of anxiety, fatigue, perceived exertion, thermal sensation, respiratory distress, felt arousal, feelings, and perceived energy levels fluctuate from before, to immediately after, to ~30 minutes post-firefighting?
3. How is cognitive behavioral performance, specifically working memory and cognitive inhibition, influenced by participation in live-fire maneuvers?

4. Which individual difference and/or repeated measures variables, if any, best account for variance in cognitive performance immediately following firefighting?
    4.1. Do individual differences in age, physical fitness, trait anxiety, personality, coping ability, or dispositional resilience appear to influence cognitive performance immediately following live-fire maneuvers?
    4.2. Are perceptual variables of state anxiety, fatigue, respiratory distress, thermal sensation, feeling state, felt arousal, perceived exertion, and/or perceived energy levels associated with cognitive performance before, or immediately after, firefighting?
    4.3. Is the physiological indicator of exertion, heart rate, associated with cognitive performance before or immediately after firefighting?

Basic Assumptions

A few basic assumptions were made. It was assumed that the cognitive status of firefighters would be affected, positively or negatively, by participation in live-fire maneuvers (as compared to firefighters' presumably capable functional cognitive status outside of such situations). It was further assumed that better cognitive performance would lead to more favorable, safe outcomes for firefighters, or at the very least, would not negatively impact their on-the-job performance. The largest assumption was the definition of what constitutes good/better cognitive performance in this setting. In this case, it was operationally defined as higher accuracy on computerized cognitive tasks, or shorter response times in the absence of increased error-making.

Clearly higher accuracy on cognitive tasks is desirable, but the optimal speed at which high accuracy is achieved is not fully known and may differ from person to person. It is assumed that if firefighters trade speed (i.e., slow down) for accuracy, this is not optimal (Barr, Gregson, & Reilly, 2010; Rahman, Balakrishnan, & Bergin, 2012). Making quick decisions in a live-fire scenario is critical because it is in the nature of fire to be unpredictable. On the other hand, if they trade accuracy (i.e., make more commission errors) for faster speed, this would be even less ideal. If a decision is made so quickly that it results in injury or death, it is unacceptable. The quality and efficiency of cognitive function most certainly varies based on what is necessary for firefighters in any given situation. Ideally, effective cognitive performance will result in decisions that lead to safe exit (no or minimally injury) of people and partial or total salvage of property. In making these decisions, firefighters may sometimes need to find balance between protocol, physiological tolerance, job duties, intuition (i.e., gut feelings), and orders.

Research Design

The combination of occupational stress, heat stress, psychological stress, and physical exertion could very well impair decision making abilities, decrease firefighting efficiency/job performance, and increase risk of injury. The proposed research involved the examination of firefighting (heat exposure combined with physical exertion and psychological stress) and cognitive performance (working memory and cognitive inhibition). New, recruit firefighting academy students had their performance (accuracy, reaction time, variability) measured on two computerized cognitive tasks [n-back (Kirchner, 1958) and modified flanker (Eriksen & Eriksen, 1974)] on a resting baseline day (for practice and familiarization), and immediately pre- and post- firefighting on the evenings of Night-Burn drills. This was meant to be a descriptive, exploratory field study. Further, this research also provided cross-sectional data, as it investigated individual differences (age, FF experience, physical fitness, etc.) related to differing cognitive performance between participants. Possible state-dependent moderators of cognitive performance (state anxiety, fatigue, HR, etc.) were also examined.

Methods and Field Procedures

The Illinois Fire Service Institute (IFSI) Basic Firefighter/National Fire Protection Agency Firefighter I Academy (i.e., Academy) is a 6-week training program that is held semi-annually (in spring and fall) to train new recruit firefighters. Firefighters were observed in three different settings: (1) baseline control-in the absence of acute physical exertion and heat stress, (2) immediately pre-firefighting and (3) immediately post-firefighting. The main independent variable was "firefighting" (supervised, occupational, task-oriented physical exertion under both heat and psychological stress and physical exertion, performed during a Night-Burn drill, as a team, resulting in the use of 1.5-2 bottles of air, imposed by the Night-Burn drill). Within that framework, repeated measures of state anxiety, fatigue, energy/arousal, respiratory distress, thermal sensation, and HR were obtained pre-firefighting, immediately post-firefighting, and post-cognitive testing. Trait measures of age, anxiety, personality, preference and tolerance for exercise, emotional coping, dispositional resilience, and years of experience firefighting, were measured via self-report. Aerobic fitness was estimated using the completion time from each individual's 1.5-mile run test proctored during the 1st and 6th week of Academy training. The main dependent variables were cognitive behavioral performance scores (i.e., reaction time, variability, and accuracy) on the computerized flanker (cognitive inhibition) and 0-back (attention), and 1- and 2-back (working memory) tasks.

Firefighters received a questionnaire packet (personality, demographic, and experience questions) to complete during the first week of Academy. On a baseline day in the weeks preceding the night-burn drill participants came to the computer lab in the Learning Resource and Research Center (LRRC) building on the IFSI campus grounds, early in the morning. At this time, the cognitive tasks were described in detail and firefighters practiced the tasks and completed baseline assessments. They were also familiarized with the paper questionnaires (described in Measures and Procedures) before their use on the pre-post testing evening. There were enough computers for up to 29 participants to do this at the same time. The morning time was chosen so that firefighters would be rested and would not have performed any exercise or firefighting tasks yet that day.

On three separate evenings during week 5, each of three companies from the Academy classes (Alpha, Bravo, and Charlie) completed the Night-Burn drill. Each company was scheduled to complete the Night-Burn drill on Monday, Tuesday, or Wednesday night during both weeks 4 and 5, but was only tested on the 5th week as to not interfere with IFSI's training mission for the students during their first encounter with the Night-Burn drill. In the event of rain, Thursday or Friday night was used as an alternate date. On Night-Burn drill evenings, firefighters reported to the computer lab in the LRRC at least 30 minutes prior to drill start, at a time determined by the Academy director. They completed the computerized cognitive tasks (lasting 17-20 minutes total), serving as their pre-Night-Burn test scores. They then reported to the "dirty classroom" (simulated fire house) in their station blues (standard station uniform for a firefighter: t-shirt, pants, boots) and waited for a simulated emergency call to come in. At dusk, IFSI personnel ignited a fire in a burn structure and instructors and research staff placed the staged 9-1-1 call to the students waiting in the simulated fire house. Upon receiving the call, the assigned company responded (see Procedures below for details).

Immediately upon completion of the Night-Burn drill, ExPPL research staff escorted firefighters back to the LRRC. Research staff read and prompted responses to the perceptual state measures by pointing to the relevant measures displayed on a clipboard, as they walked together. Helmets, hoods, gloves, and air packs were removed and left outside of the LRRC building on their way to the computer lab. It was encouraged that turnout coats remain donned, but coats could be opened or removed if desired by individuals perceiving too much thermal distress. Firefighters carried their own water bottles, which were replenished constantly throughout the testing session. Once firefighters sat down in the computer lab, they completed the four paper-pen visual analogue scales and a measure of affect and anxiety. Next, computerized cognitive performance testing began, always beginning with the flanker task and then n-back tasks, followed by another round of perceptual state measures.

Participants. New, recruit firefighters (i.e., younger, inexperienced) participating in the Illinois Fire Service Institute (IFSI) Academy training from Fall 2013-Spring 2015 were recruited for this study, including males and females between the ages of 18 and 64 years. A convenient sample was taken, comprised of trainees in attendance during each semi-annual Academy at the Illinois Fire Service Institute who were willing to participate. The study was explained both verbally and in the Informed Consent document given to potential participants during the first week of Academy. All trainees participated in Academy training; however, data was only maintained for those who chose to participate in the study. The local University Institutional Review Board approved this study.

Power analysis. A minimum sample of 30 individuals was deemed necessary based on a power analysis using G*Power with the following criteria: effect size f of 0.26 based on an η^2 of 0.065 from previous research; alpha = .05; beta = .80; reliability of measures = .6; 2 conditions: normal conditions and post-firefighting; and 3 repeated measures over time (e.g., “baseline” day, pre-firefighting evening, evening after firefighting).

Measures. In line with the objectives of this research, multiple measures were collected throughout the 6-week IFSI Academy course. Demographic measures assessed general personal information such as sex, age, education, physical activity background, and fire service experience. Cognitive performance measures consisted of a working memory task and a cognitive inhibition task. Aerobic fitness and numerous individual difference measures were collected to assess any individual differences that might contribute to differential cognitive performance between subjects. Repeated perceptual (i.e., fatigue, energy, state anxiety, rating of perceived exertion, arousal, feelings, thermal sensation, respiratory distress) and physiological (i.e., heart rate) measures were collected to assess factors that might influence differential cognitive performance within or between subjects as well as for providing a physiological measure of the intensity of physical activity for the individual participants.

Demographic measures.

Health & PA history inventory. This questionnaire asks basic demographic and personal information questions (sex, age, education, previous physical activity behavior, family history, medications, etc.).

Fire service history. This self-report questionnaire asks basic questions about each individual's role in the fire service, years in the fire service, and experiences in the fire service.

Physical fitness measure.

Aerobic fitness (estimated VO_{2max}*).* The timed, 1.5-mile run test is a sub-maximal field test used to estimate an individual's aerobic fitness level (Cooper, 1968). This test is a valid, reliable way to estimate aerobic fitness (Dolgener, 1978; George, Vehrs, Allsen, Fellingham, & Fisher, 1993; Larsen et al., 2002; Weiglein, Herrick, Kirk, & Kirk, 2011). Participants completed the marked course, outdoors at the Illinois Fire Service Institute.

Cognitive measures.

Modified Eriksen flanker (flanker) task (cognitive inhibition). This task is a modified version of the Eriksen flanker task (Eriksen & Eriksen, 1974) used to assess cognitive inhibition by means of an interactive 4-5 minute computer test. Cognitive inhibition is "the stopping or overriding of a mental process, in whole or in part, with or without intention" (MacLeoud & Gorfein, 2007, p. 5). Reaction time (RT), variability of RT (SD of RT), accuracy (hits, false alarms, and percent correct), and error-types (commission, omission) on congruent and incongruent trials were assessed. The flanker task is a measure that can be compared to available literature on effects of acute exercise stress on cognitive inhibition in young adults (Hillman, Snook, & Jerome, 2003; Kamijo, Nishihira, Higashiura, & Kuroiwa, 2007; Themanson & Hillman, 2006). Participants viewed a series of 5 symbols in a horizontal row (e.g., >>>>>, >><>>, <<<<<, <<><<), and pressed a specific key on the keyboard in relation to the orientation of the central (target) symbol. The center symbol was similar (i.e., congruent) or dissimilar (i.e., incongruent) to the symbols flanking it on both the right and left sides. Participants performed 1 blocks of 200 trials (100 congruent, 100 incongruent), with a stimulus duration of 80 ms, a response window of 100-1300 ms, and an inter-trial interval of 1300 milliseconds.

N-back task (working memory). This task, created by Kirchner (1958), assessed working memory using three consecutive, and increasingly more difficult phases, called the 0-back, 1-back, and 2-back, each lasting ~4 min. A recent review by Redick and Lindsey (2013) suggests that, though the n-back does seem to validly assess a part of the generally accepted definitions of human working memory and is a widely used measure in the literature, performance on this task does not correlate well with other measures of working memory, such as simple and complex span tasks. These sentiments are similar to those of Jaeggi, Buschkuehl, Perrig, and Meier (2010). The n-back task specifically assesses the manipulation component of working memory (i.e., reorganization and updating of working memory contents), while other tasks seems to assess the maintenance component of working memory (i.e., active remembering of relevant stimuli) (Fletcher & Henson, 2001). RT, SD of RT, accuracy (hits, false alarms, and percent correct), and error-types for target and non-target were assessed. The n-back task has been used in the acute exercise literature to examine working memory in adults (Hogan, Mata, & Carstensen, 2013). Each phase required participants to discriminate between 5 different stimuli. The stimuli were five recognizable shapes (green triangles, blue circles, yellow crosses, purple stars, and red squares). Each shape was presented, one at a time, in the center of a computer screen for duration of 2900 ms with a response window of 100-2950 ms, or a 100 ms inter-stimulus interval (ISI). A total of 80 trials were presented, with equal probability of presentation of each stimulus (16 trials for each shape). Inter-trial interval (ITI) is 3000 ms. Stimuli, ISI, ITI, total trials, and probability were the same in all three phases with the exception of shape presentation order. Participants were asked to compare the shape they previously saw, either 0, 1, or 2 shapes back in the series, to that which appeared on the screen. The 0-

back, required participants to only pay attention to the presentation of the cross shape. The participant made a right hand response if the current stimulus shape was a cross, or made a left hand response if the current stimulus shape was not a cross. The 1-back required participants to remember the shape presented immediately before the current shape. The participant made a right hand response if the current stimulus shape was the same as the previous shape or a left hand response if the current stimulus shape was not the same as the previous shape. Finally, the 2-back required the participant to remember the shape presented two shapes back and make a right hand response if the current stimulus shape was the same as the second stimulus prior and a left hand response if the current stimulus shape was not the same shape as the second stimulus prior.

Individual difference measures.

Brief (COPE). This is a 28-item questionnaire with Likert scale responses ranging from 1 (I haven't been doing this at all) to 4 (I've been doing this a lot; Carver, 1997, 2007). It was derived from a full-length COPE scale (Carver, Scheier, & Weintraub, 1989) and has been shown to have acceptable reliability and validity (Carver, 1997). There are also 14 sub-scales (internal consistencies > .50, with 11 being ≥ .64), derived from two items each. The questions explored how an individual tends to cope with emotional stressors in their lives.

Dispositional resilience (DRS-15). The DRS-15 is a 15-item, shortened form self-report questionnaire (from the original DRS; Bartone, 1995; Bartone, Ursano, Wright, & Ingraham, 1989), that is meant to measure hardiness or resilience. Likert scale responses range from 0 (not true at all) to 3 (completely true). Of the 15 items, six items were reverse-scored and then all were summed up for a total score. It has a 3-week test-retest reliability of 0.78 (Bartone, 2007), as determined from undergraduates in a military academy in the United States.

Trait anxiety inventory (TAI). This 20-item questionnaire assessed how apprehensive or anxious a person felt in general, or most of the time (STAI-Form Y2; Spielberger, 1983). The

TAI uses a 4-choice Likert response format ranging from 1 (Not at all) to 4 (Very much so). For a review of reliability reports in the literature see Barnes, Harp and Jung (2002).

International personality item pool (IPIP). This is a 50-item paper-pencil questionnaire used as an individual difference measure (Goldberg et al., 2006). Each of the Big 5 personality factors (Extraversion, Emotional Stability, Conscientiousness, Agreeableness, and Intellect/Imagination) was determined based on responses to 10 of the 50 items. Items are rated on a 5-point Likert scale (1 = very inaccurate; 2 = moderately inaccurate, 3 = neither inaccurate nor accurate; 4 = moderately accurate, 5 = very accurate).

Preference and tolerance for intensity of exercise questionnaire (PRETIE-Q). The PRETIE-Q (Ekkekakis, Hall, & Petruzzello, 2005) is a 16-item questionnaire that discerns an individual's exercise habits. Responses were made on a 5-point Likert scale ranging from 1(I totally disagree) to 5 (I totally agree), in relation to a statement about their exercise habits. Half of the questions represent personal preference for and half represent perceived tolerance of exercise intensity. This scale was previously validated by Ekkekakis, Thome, Petruzzello, and Hall (2008) with a reference group of college-aged women in relation to the Godin Leisure Time Exercise Questionnaire (Godin & Shephard, 1985).

Repeated perceptual measures.

Visual analogue scale (VAS) calmness, fatigue, nervousness, and tension. These four visual analogue scales each existed as a 10 cm horizontal line with the left anchors of "Jittery", "No fatigue at all" "Nervous", or "Relaxed" and the right anchors of "Calm", "Fatigue as bad as can be", "At ease", or "Tense", respectively. Participants were asked to make a single vertical mark across the continuum to denote their current state relative to each of the anchors.

Rating of perceived exertion (RPE). This scale assessed perception of effort, that is, how hard the individual felt they were working at a given time (Borg, 1998). The scale ranges on a continuum from 6 to 20, with 6 being low exertion, and 20 being exhaustion.

Respiratory distress *(RD).* This is a single-item, self-report scale that assessed respiratory distress (Morgan & Raven, 1985). It ranges between anchors of “My breathing is okay right now” to “I can’t breathe”, on a 7-point scale.

Thermal sensation (TS). This is a single-item, self-report scale that assessed perceived thermal sensations (Young et al., 1987). It ranges between anchors of “Unbearably cold” to “Unbearably hot”, on an 8-point scale. The effective range of the scale for this study was from 4 to 8 as it was highly unlikely that any of the participants would perceive cool/cold thermal sensations.

Feeling scale (FS). Participants were asked to subjectively rate their feelings (Feeling Scale, Hardy and Rejeski, 1989). This single-item self-report scale ranges from “+5” (Very Good) through “0” (Neutral) to “-5” (Very bad).

Felt arousal scale: This single-item, self-report scale ranges from 1 (Low Arousal) to 6 (High Arousal) with numbers 2-5 placed in between, but without any category names next to them (Svebak & Murgatroyd, 1985).

Activation-deactivation adjective check list (AD ACL), state anxiety inventory (SAI). The 20 items from the AD ACL (Thayer, 1986) and 10 items from the short form of the SAI (Spielberger, 1983) were combined into a 28-item measure which assessed self-reported affect and anxiety using a 4-point Likert scale: 1 (Not at all), 2 (Somewhat), 3 (Moderately so), 4 (Very much so). Twenty of the items provided measures of perceived energy, tension, tiredness and calmness (5 items each); 10 items were used to assess state anxiety (2 of the items are used for both anxiety and tension). These 10 items were from the State Anxiety Inventory-Y1 (r=0.95 with full inventory; Spielberger, 1983). Participants chose the response that best fit how they felt at the time.

Repeated physiological measures.

Heart rate (HR). HR was monitored continuously during testing. Firefighters (FFs) wore a chest sensor that transmitted to a wrist EKG monitor (Polar Electro Oy ®, Inc., Kempele, Finland). Collected data was transferred to a computer for analysis.

Perceptual strain index (PeSI). The Perceptual Strain Index (PeSI) was calculated using the thermal sensation and rating of perceived exertion values that were collected immediately post firefighting activity (<3 minutes). The thermal sensation scale (Young et al., 1987) and the rating of perceived exertion (RPE) scale (Borg, 1998) were presented vertically. The pre-activity and end-of-study measures were assessed via paper questionnaire. Immediately post-activity, the measures were taken verbally and recorded on a clipboard carried by a laboratory staff member as the two walked up to the computer lab from the firefighter training site. RPE is meant to be a perceived representation of HR, while TS is meant to be a perceived core temperature (Petruzzello et al., 2009). Perceptual Strain Index was calculated using the following formula developed by Tikuisis et al. (2002):

$$\text{PeSI} = 5(\text{TS} - 0)*(8)^{-1} + 5(\text{RPE})*(20)^{-1}$$

This was calculated for both TSpre/RPEpre and TSpost/RPEpost. The change from pre to post in PeSI also served as a manipulation check for the firefighting activity being physically demanding. The post-firefighting PeSI and the change score were used for statistical analyses.

Radio communications. One or two undergraduate laboratory students transcribed play-by-play radio communications from each Night-Burn drill in real-time,, while another student reported the time of day for each event. These communications provided pertinent information about the time of ignition, start of the drill, arrival to the scene, a description of activities that occurred during the night-burn drill and, to an extent, who was involved. These transcriptions also reported the time at which each individual firefighter completed the drill and left for cognitive testing with the research team. Radio communication play-by-play transcriptions and researcher time recordings allowed determination of how long each individual participated in the drill, when they exited the burn building (Point of Contact, POC), arrived at the lab, and completed their post drill cognitive tests. This allowed continuous heart rate data to be averaged for the drill period, from POC to lab, from POC to end, and from lab to end. Additionally, change scores were calculated between each of these time points (to denote Post Drill HR recovery). Percent time spent in each HR zone was also calculated based on % of HR max (ACSM, 2011), with HR max estimated as 217 - 0.85*age (Miller, Wallace, & Eggert, 1993).

Procedures

All testing took place at the Firefighter Life Safety Research Center (FFLSRC) in the LRRC building and on the grounds of the Illinois Fire Service Institute (IFSI) campus in Champaign, IL. Participants completed a total of five sessions on four separate days during a 6-week firefighter training course for new recruits: Session 1—Paperwork & First Week Physical Fitness Testing; Session 2—Cognitive Performance Measures: Practice & Baseline Assessments; Session 3—Live-fire Night-Burn Training Drill, with Pre- and Post-Firefighting Cognitive Performance Assessments, Repeated Perceptual State Measures, and HR recording; Session 4—Last Week Aerobic Fitness Testing (1.5-mile run). All testing took place within the time constraints of the regular firefighter training course. The time frames chosen were modeled around the biannual 6-week Academy course provided by IFSI.

Cognitive performance was measured once in the weeks leading up to the Night-burn (Baseline) and during week 5, when the second set of live-fire Night-burn drills took place. This testing occurred pre-firefighting and immediately post-firefighting. Paper-pencil and computerized testing took place in a computer lab of standard room temperature (22°C). The live-fire firefighting condition elicited temperatures of ~47°C, based on thermocouple data recorded during Night-burn drills in previous Academy courses. Heart rate (HR) was recorded during all cognitive testing and Night-burn activities. Each evening was documented in detail, accounting for the schedule and “play-by-play” firefighting activity, based on radio communication, during the Night-burn drill. Research staff logged activities of this event in order to time-match events to HR recordings, capturing participants' physiological conditions during the testing days and providing valuable information about HR achieved during FF training.

Session 1: Paperwork. During the first week of the course, researchers provided a brief synopsis of the research study and laid out the risks and benefits of participation, provide two Informed Consent Documents (ICDs) to each person (1 for them, 1 for the research team), allowed them to read over and sign the ICD, and fielded any questions they had before providing the signed ICD to the researchers. At this time, researchers reminded participants that participation was voluntary and that at any given point during the study they had the right to withdraw without penalty. Measures of health and physical activity history, BMI, age, FF experience (Fire Experience Questionnaire), trait anxiety (TAI), dispositional resilience (DRIS-15), personality (IPIP), preference for and tolerance of intensity of exercise (PRETIE-Q), and the ability to cope with emotional stress (brief COPE) were also be obtained via questionnaires (see Measures).

Session 2: Cognitive performance measures (practice and baseline assessments). Baseline testing was performed in the morning, when firefighters had not yet been exposed to heat or the physical strain of wearing their personal protective ensemble (PPE; hood, helmet, pants, boots, coat). Cognitive performance of firefighters was assessed using tests of cognitive inhibition and working memory, using the flanker and n-back tasks, respectively (see Measures). Participants practiced each cognitive task prior to the baseline assessment. The practice tests differed from the tests used during the Night-burn testing session in that the practice tests did not utilize the entire number of trials (i.e., they were shorter). The practice and baseline cognitive performance session took place in a computer lab equipped to test 29 students at one time. Participants completed self-report measures of fatigue (VAS fatigue), energy (AD ACL), state anxiety (10-item SAI), perceived arousal (FAS), and exertion (RPE) (see Measures).

Both of the cognitive tasks were computerized (the participant interacted with a keypad, clicking with either the right or left hand, in response to a stimulus shown on the monitor). The first cognitive task was the modified flanker task in which participants' cognitive inhibition was tested. After a brief explanation, 1 practice block of 20 trials (10 incongruent, 10 congruent) was performed as an orientation to the task. Then, the full baseline assessment of 200 trials was completed. This task took ~5 mins to complete. The second cognitive task was the n-back task, which assessed participants' working memory. Next, each n-back task was explained, followed by a 10-trial practice block for each task, and then a full 80-trial baseline assessment. The total time to complete all three phases of the n-back task was ~12 mins. Practice for all of the cognitive tasks lasted around an additional 5-6 mins. Reaction time and correctness of answers (i.e., accuracy) were assessed.

Session 3: Live-fire night-burn training drill. At the beginning of the session, participants were fitted with a HR monitor (for continuous assessment). Immediately prior to completing the Night-Burn, firefighters performed pre-tests for flanker and n-back tasks in the computer lab and were asked to complete the SAI, AD ACL, TS, RD, RPE, FAS, FS, and visual analogue scales before and after these tests. They then sat in a mock station room, waited until they heard a fire alarm sound, and then attended to the situation as they would a real fire incident. The dispatcher directed them to the scene (a burning building on site), and an incident commander briefed them on their job requirements upon arrival to the structure. Each firefighter was told to complete their specified duties (squad, ladder, and engine crews), enter the building and search for an unknown number of victims, aim to complete the tasks as safely and efficiently as possible, and to follow regular protocol.

Recruit firefighters participate in this live-fire, Night-burn training drill (mimicking real fireground response operations from start to finish) during the 5th week of their 6-week course in three groups, stratified by company. Each company (Alpha, Bravo, and Charlie) of ~9 firefighters each, was observed on a separate night of the week, at the same time each night. The Night-burn drill commenced at sunset. A number of mannequins (7-10), unknown to the Academy students, were placed in a 2-story “taxpayer” building (this building mimics a mixed use property such that a business might be on the first floor while a single family home is on the second floor) on the IFSI grounds. In Fall 2013, the taxpayer was having work done, so the tower (four-story building with a bay on the first floor and burn capabilities on the second thru sixth floor) was used instead. However, those data are not included in the cognitive performance pre-post comparisons. A fire was started using wood pallets and hay in the taxpayer building. IFSI staff made a call to the station where the recruits were waiting for a call to arrive. The alarm bell sounded and recruits donned their PPE/turnout gear, loaded their fire trucks and approached the scene. An instructor accompanied each squad as they completed full fireground operations (attack, forcible entry, search-and-rescue; ~55 mins and two bottles of air) including on-scene orders from the Incident Commander (IC).

Immediately following completion of the Night-burn training drill, firefighters walked with a member of the research team to the computer lab (~5 min) in the LRRC. If a firefighter had not run out of air by the end of the drill, they were instructed to keep their respirator in as they walked to the testing building. If they were on the bell, the respirator was removed and they breathed normally through their mask. In extreme cases, (e.g., slight dizziness), the helmet and hood were also removed. During this walk, firefighters reported their feeling state, felt arousal, rating of perceived exertion, thermal sensation, and respiratory distress (viewing and responding to these on an $8^{1/2}$ x 11 sheet of paper carried by the research staff member).

Upon arrival at the computer lab, they doffed their hood, helmet, gloves, and air pack, prior to entering the building, maintaining their turnout jacket. Water was provided *ad libitum* by means of a water bottle (refilled by research staff). Affect and anxiety were measured and the computerized cognitive tasks were completed, just as they were during the pre-firefighting assessment (without any practice trials). Each firefighter sat at their own computer in the lab and began the testing session. A member of the research team stood by each computer to field questions, watch the participants for both safety and quality control reasons, and to read instructions and start and save each of the tests. After ~17-20 minutes, firefighters once again completed affect and anxiety measures. The entire session (from alarm to end of computer testing) lasted approximately 80-90 minutes.

Session 4: Aerobic fitness testing. The 1.5-mile run test took place in the morning during regular daily physical training time on the 6th week of the course. This run was completed as a post-test in conjunction with their comprehensive fitness testing done week 1 and week 6 of Academy. Testing was done in the presence of at least two research team members and one IFSI instructor in case of any adverse events. The testing protocol was as follows: participants completed a warm-up for about 5 minutes (light calisthenics and dynamic stretches). After the warm-up period, participants were instructed to run 1.5 miles as quickly as they possibly could. The participants lined up at the starting line, and one researcher will say “On your mark, get set, go!”. Two stopwatches (one back-up) were started simultaneously (on “go!”). Participants ran 5.25 laps (1.5 miles) around the marked course on the IFSI grounds, yelling out the lap number that they had completed each time they passed the researchers at the finish line. This test usually lasted no more than 20 minutes. One researcher kept track of the number of laps each participant had completed while a second researcher recorded their time as they crossed the finish line. Participants then did a cool-down by walking an extra lap at the speed of their choice.

Data Analysis and Interpretation

All statistical analyses were performed using SPSS ® 23.0.0.0 (SPSS Inc., Chicago, IL). Relationships among primary outcome variables of working memory, cognitive inhibition, and individual difference variables of emotional coping ability, dispositional resilience, preference and tolerance for exercise, trait anxiety, personality, firefighting experience, and aerobic fitness were determined. Descriptive analyses of central tendency and variability were performed to specify the sample (Aim 1). Repeated measures analysis of variance (RM ANOVA) examined influences of fireground maneuvers on physiological and perceptual variables over time (examine: HR, state anxiety, RD, TS, FAS, fatigue, affect, and perceived energy) (Aim 2). A series of one-way ANOVAs of flanker performance outcomes at each time point (Pre, Post) were performed by Congruency (Incongruent, Congruent) amongst all Task Orders/Academies (Spring 2014, Fall 2014, and Spring 2015) for RT, response accuracy, response variability and d-prime variables to determine any differences across academies or task orders. A series of one-way ANOVAs of n-back performance outcomes at each time point (Pre, Post) were also performed by Working Memory Load (0-back, 1-back, and 2-back) and Trial Type (Non-target [NT] and Target [T] trials) amongst all Task Orders/Academies (Spring 2014, Fall 2014, and Spring 2015) for RT, response accuracy, response variability and d-prime variables to determine any differences across academies or task orders. Order in these analyses refers to the N-back tests done [0-back (0), 1-back (1), or 2-back (2), all of which followed the Flanker test]. A series of separate multivariate RM ANOVAs were performed to compare cognitive behavioral performance (working memory and cognitive inhibition) across time points, to determine whether or not significant differences existed between pre and post firefighting measurements (Aim 3). Only data from individuals who performed at >70% accuracy on pre tests were included. For the modified flanker task, accuracy, RT, standard deviation of RT (SD of RT; response variability), and flanker interference were examined. For n-back tasks, RT, uncorrected accuracy, and SD of RT, for target and non-target trials, and d-prime (d’) were examined (see Scudder et al., 2014). The calculation of d’ = [z(hits) - z(false alarms)] was done for corrected accuracy scores on the n-back tasks. Pre-post change scores were also computed and used in analyses. Scores were reported in terms of measures of central tendency (mean) and variability (SD). When Mauchly’s test of sphericity was violated, the Huynh-Feldt (H-F) correction was used any time epsilon was >0.75, and if epsilon was <0.75, the Greenhouse-Geisser (G-G) correction was used. When significant interactions existed, *post-hoc* analyses were done to determine the nature of these using Bonferroni corrected *t*-tests.

Bivariate Correlations of individual characteristics that were identified *a priori* (e.g., emotional coping ability, dispositional resilience, physical fitness, etc.), physiological variables, and perceptual variables, with indicators of cognitive performance on the modified flanker task, 0-, 1-, and 2-back tasks were determined and reported as Pearson Product Moment correlations. If strong evidence was present for further analysis, hierarchical linear regressions, and hierarchical multiple linear regressions were used to determine predictive relationships between levels of the proposed model and predictors of changes in executive control, in the context of participation in firefighting activities. Placement in the hierarchy followed the proposed model: perceptual variables at step 1, physiological variables at step 2, and individual difference factors at step 3 (Aims 4 & 5). Statistical significance was set at $p = 0.05$.

Potential Problems and Alternative Strategies

The largest caveat to this study is that the measures of cognitive performance were taken immediately following firefighting, as opposed to during firefighting (when it would presumably matter most). Post-firefighting psychological measures could be capturing relief that the Night-burn scenario is over, and cognitive performance scores could potentially reflect only partial motivation to put the same effort into task completion on the computerized tests as they were presumably putting into their firefighting activities. It could also be argued that what was actually being tested is recovery performance. Yet, knowledge of cognitive performance during recovery from firefighting stress is still important to understand, because firefighting duties could continue for an undetermined amount of time (e.g., overhaul); as such, the firefighter may be able to safely continue critical tasks if they are of adequate cognitive faculties. However, the converse is also likely; that is, s/he may not be able to effectively continue. One major limitation to this study is that these tests can only explain what cognitive performance looks like immediately after firefighting (relative to before), not how it is affected during firefighting, nor what may have occurred during firefighting to have influenced their post-firefighting scores. Measurement of cognitive performance during exercise has been successful (Del Giorno, Hall, O'Leary, Bixby, & Miller, 2010; Drollette, Shishido, Pontifex, & Hillman, 2012; McMorris & Graydon, 2000); however, the extreme nature of the firefighting environment severely limits conventional measures and validated measures have not yet been created for the fire setting. This is one avenue to explore in the future.

A further complication with the measurements being taken post-firefighting was that one might have hypothesized that those exerting themselves less (e.g., lower HR and RPE) during the Night-Burn drill would perform better afterwards and those who were working harder may have become so fatigued afterwards that they performed worse post-firefighting. This was examined by recording HR during firefighting, and running analyses to determine whether or not HR was related to cognitive performance.

It was anticipated that some firefighters would be dehydrated upon completion of FF activity. Although they were allowed to drink water throughout the Night-Burn drill (and the day leading up to the drill), feasibility varies greatly because some firefighters only got to take water at air pack (bottle) change halfway through the Night-Burn drill, some got no water during the drill, and others got water even more often. As was discussed at length in Chapter 2, dehydration may influence cognitive performance beyond other independent variables. To minimize this confound, participants were provided with *ad libitum* water before, during, and after all testing sessions. Urine samples were not taken, but it is acknowledged that dehydration could impact cognitive performance. There are multiple reasons for not performing dehydration analysis. First of all, there was the desire to test cognition in a time-sensitive manner. Secondly, IFSI and the research team aimed to properly hydrate subjects as they are recommended by guidelines (Smith & Haigh, 2006) (as they would be following such a protocol in real-life emergency response scenarios). Theoretically, this should have kept them hydrated to the point that they would be in natural settings, providing us with ecologically valid data. Lastly, it was not necessary to burden subjects with another task following such an exhausting Night-burn drill.

Cognitive Assessment. The current state of the individual can affect results on cognitive performance tasks, especially during and following physical activity. Repeated state measures taken before and after testing can help account for influences on cognition. The pre-firefighting measure provided us with a non-aroused performance measure to be compared within and across subjects to see if changes in state correlated with cognitive performance and if so, whether they explain variance in cognitive scores beyond experience or aerobic fitness. However, it would have been more thorough to also examine cognition in the evening of the same baseline day. This would have better accounted for effects of practice/learning, time-of-day, and fatigue from passage of a normal day of training, in the absence of a night-burn drill.

Acclimatization. Academy training activities for new firefighter recruits in Illinois often occur more than 8 hours each day over seven weeks. When individuals are acclimated to high temperature environments, tympanic temperature and heart rate being relatively equal, cognitive performance on a series of attention tasks was unaffected (Radakovic et al., 2007). Thus, there is a chance that we may not see as large of a cognitive deficit as we might anticipate in a real emergency response situation (after not spending weeks training in burning buildings), especially on simpler tasks, such as the 0-back task.

Summary of Methods

As part of an already established Fire Academy training program, new recruits participated in a “Night-Burn” two-bottle drill during which they completed a number of firefighting tasks inside of a burning building on the Illinois Fire Service Institute campus during their 5th week of Academy Training. Cognitive performance was measured ~1 week prior (baseline), pre-, and post- (~5 minutes after drill completion). Heart rate and perceptual measures were recorded throughout the evening surrounding the Night-burn drill. Fitness was measured the week following the Night-burn drill.

The overarching aim of this dissertation was to delineate the importance of sound cognitive performance for firefighters (on-duty and in training), describe the manner in which cognitive performance is, or is not, affected during and immediately following firefighting activity, and identify individual differences that may moderate cognitive performance in firefighters. Ultimately, this provides a starting point for further examination of more sophisticated cognitive functioning and possibly the development of strategies that could positively influence safety outcomes in this population. The data presented herein demonstrate the manner in which working memory performance (the ability to hold a small amount of information in mind long enough to make information-dependent decisions) and cognitive inhibition (the ability to ignore distractions and make a quick, accurate decision) are affected immediately following firefighting activity.

Conclusions

Assessing working memory and cognitive inhibition performance immediately following live-fire maneuvers was meant to provide new information about the cognitive performance profile of firefighters and provide insight as to which environmental, physiological, psychological, or perceptual factors may enhance or impair their cognitive performance on the job. If moderators of cognitive performance can be delineated, individualized training strategies can be developed to enhance cognitive performance during and following fireground operations, to prevent job-related injuries and fatalities and potentially salvage more property. These can then be tailored to the resources of individual fire stations in the United States.

CHAPTER 4

RESULTS

The purpose of this investigation was to identify changes in firefighter cognitive performance from pre- to post-participation in a night-burn training drill, both in relation to personal traits as well as physiological and perceptual responses to the event. Average duration of the entire night-burn drill (from dispatch [or ignition in the case of Spring 2014, where no delineation was made between initial ignition and actual dispatch call to point-of-contact (POC)] across all academies was 54:44 ± 4:56 min; range of 49:00 to 64:05 min). Individual times spent from dispatch (ignition, Spring 2014) to when they personally exited the burn drill were 48:41 ± 6:07 min (range of 33:00 to 64:05; see Table A.1 in the Appendix).

Differences amongst academies and evenings were present. One-way ANOVA revealed significant differences among academies in terms of actual time spent in the night-burn drill [$F(3, 81) = 10.79$, $p < 0.001$]. Games-Howell *post hoc* comparisons indicated that Fall 2013 spent less time than both Fall 2014 (M_{diff} = 8:52, 95% CI: 4:11, 13:33, $p < 0.001$) and Spring 2015 (M_{diff} = 4:04, 95% CI: 0:14, 7:55, $p = 0.034$), and Fall 2014 spent more time than Spring 2015 (M_{diff} = 4:48, 95% CI: 1:18, 8:18, $p = 0.004$). One-way ANOVA revealed significant differences among different evenings [$F(10, 74) = 4.53$, $p < 0.001$]. Table 4.1 provides information about the date of the drill, time at the start of the drill, entire drill duration, ambient temperature, relative humidity, and wind speed and direction. Information about ambient temperature and wind speed was obtained from historical weather records for the University of Illinois-Willard airport in Savoy, Illinois, to the nearest available time (http://www.wunderground.com/history/). To provide insight to the temperatures encountered by the firefighters during these nigh burn drills, interior temperatures were recorded during one of the semesters. In fall of 2013, temperatures on October 9th for the second floor of the tower building were around 100°F at floor level, reaching a peak of around 500°F at mid level, with the majority of time spent at mid-level temperatures between 200° and 400°F throughout the drill. On October 10th, for the second floor of the tower building, temperatures at floor level again were between 100° and 200°F, reached a peak of almost 800°F at mid-level, with temperatures varying mostly between 200° and 600°F at mid-level throughout the drill.

Table 4.1 Night-Burn Drill Characteristics

Date	n	Military Start Time	Entire Drill Duration	Ambient Temp.	Relative Humidity	Wind	
			min:s (*SD* min:s)	(℉)	(%)	Speed (mph)	Direction
Fall 2013	25		52:26 (3:35)				
10/08	7	1916	51:00	62.1	58	4.6	SE
10/09	9	1908	49:00	62.1	56	5.8	ESE
10/10	9	1903	57:00	66.9	59	5.8	SE
Spring 2014	12		57:45 (6:37)				
04/08	6	1925	51:24	53.1	66	3.5	N
04/09	6	1923	64:05	52	50	12.7	S
Fall 2014	20		59:49 (3:23)				
10/06	7	1919	63:24	53.1	71	8.1	SW
10/07	6	1916	60:33	64.4	45	16.1	W
10/08	7	1914	55:36	57.2	48	3.5	NNW
Spring 2015	28		51:50 (1:10)				
04/06	10	1941	53:22	57	87	9.2	SSE
04/07	9	1943	50:55	63	93	6.9	ESE
04/08	9	1954	51:02	69.1	87	6.9	SE
TOTAL	85		54:44 (4:56)				

Figure 4.1. Timeline of events for night-burn testing.

Study Aim #1

Aim #1 was to describe the participants on various individual difference parameters: physical fitness, BMI, trait anxiety, coping ability, dispositional resilience, preference and tolerance for intensity of exercise, and personality (extraversion, emotional stability, conscientiousness, agreeableness, and intellect/Imagination). What follows addresses that Aim and its hypotheses.

Participants. Cognitive data was collected from 85 participants from Fall 2013 to Spring 2015 in conjunction with night-burn drills during IFSI Academy training. Average age was 25.76 ± 4.05 years, and only male firefighters were included in the analyses (see Table 4.2 for participant demographics; data were collected from only 1 female participant, not allowing for a large enough sub-group for meaningful study). Aerobic fitness was estimated by means of predicted VO_{2max} using each participant's completion time from a timed 1.5-mile run and the following formula: $(3.5+(483 \cdot 1.5 \text{ mi run time}^{-1}))$ (ACSM, 2013, p. 321). Mean estimated VO_{2max} post-academy (i.e., closest in time to completion of night-burn drill and cognitive testing) was 44.68 ± 4.87 $ml \cdot kg^{-1} \cdot min^{-1}$. Across academy groups, participants did not differ on age, height, weight, or BMI (all *p*-values > 0.10). *Post hoc* comparisons revealed that mean 1.5-mile run time was significantly slower for Spring 2014 compared to all other academies, but this was only a group of 12 participants. All other academies had 20 or more participants, and two individuals in Spring 2014 had 1.5-mile run times that were > 3 SDs slower than the overall mean for all 85 participants. For selected personality characteristics of participants, see Table 4.3.

Table 4.2 Participant Demographics

Measure	*n*	*M*	*SE*	*SD*	Range
Age (yrs)	85	25.76	0.44	4.05	18-35
Height (meters)	85	1.80	0.01	0.07	1.57-1.98
Weight (kg)	84	87.43	1.71	15.69	56.74-152.63
BMI (kg/ht^2)	84	27.04	0.49	4.47	17.45-46.47
1.5-Mile Run Time (min.s)	83	11.89	0.12	1.41	8.82-15.05
VO_{2max} (predicted)	83	44.68	0.53	4.87	35.59-58.26

Table 4.3 Selected Personality Characteristics of the Participants

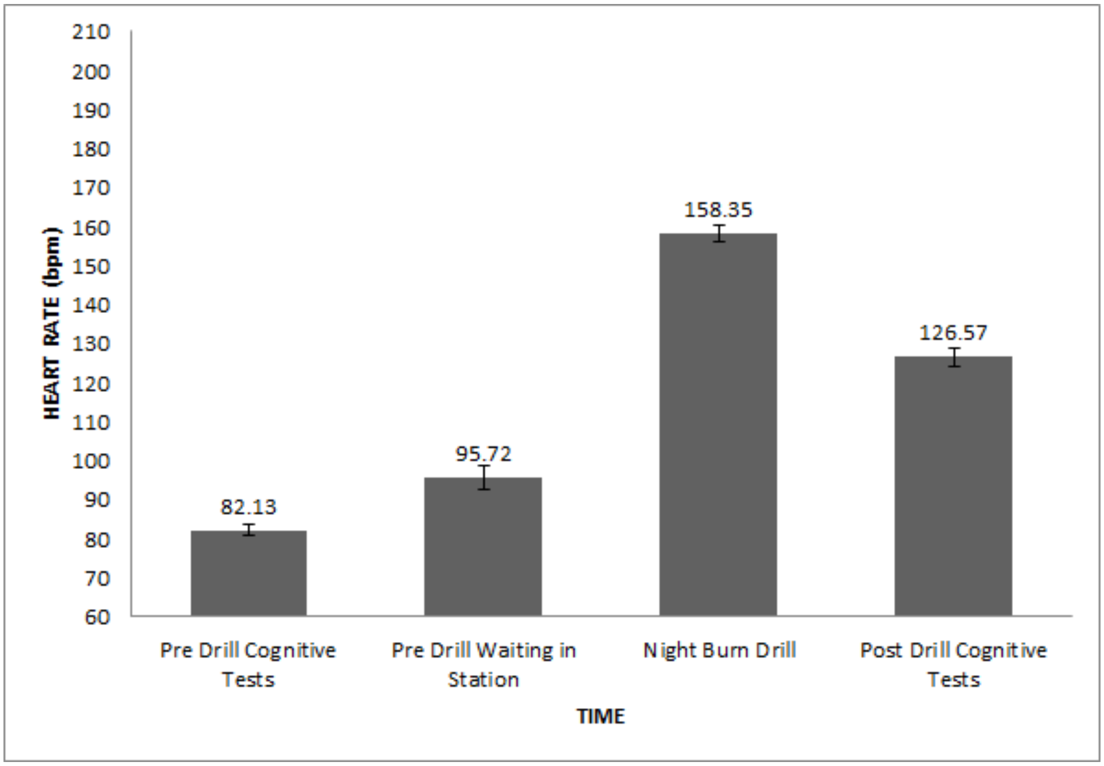
Measure	*n*	*M*	*SD*
Trait Anxiety	81	33.12	7.61
Dispositional Resilience (DR) - Total	80	48.91	4.95
DR Commitment	81	7.19	1.89
DR Control	81	10.47	1.90
DR Challenge	81	6.98	2.11
Extraversion	54	32.91	7.28
Emotional Stability	54	39.56	6.18
Conscientiousness	54	38.81	4.90
Preference for Exercise Intensity	81	26.40	5.27
Tolerance for Exercise Intensity	80	27.30	5.09

Study Aim #2

The second aim proposed to examine changes in heart rate (HR), state anxiety, fatigue, perceived exertion, thermal sensation, respiratory distress, felt arousal, affect, and perceived energy levels in the participants before (pre-drill), immediately after (post-drill), and ~30 minutes post-firefighting. What follows addresses that Aim and its various hypotheses.

H_1: It was hypothesized that HR would be higher immediately after firefighting compared to pre-firefighting, and would remain elevated significantly above pre-firefighting HR for the duration of post-firefighting cognitive tests. Measures of HR were collected only from Fall 2014 (*n*=11) and Spring 2015 (*n*=14) academies and complete data were available for 25 participants (see Table 4.4 and a graphic depiction of average HR in Figure 4.2 and continuous HR in Figure 4.3). A 4 (Time: Pre-Drill Cognitive Tests, Waiting in Station, Night-burn Drill, Post-Drill Cognitive Tests) x 2 (Academy: Fall 2014, Spring 2015) repeated-measures analysis of variance (RM ANOVA) demonstrated a significant main effect of time [$F(2.06, 47.30) = 279.40$, $p < 0.001$, partial $\eta^2 = 0.924$, GG $\varepsilon = 0.686$] with no significant time x academy interaction (p= 0.846). Pairwise comparisons indicated that mean HR was significantly different at each time point, compared to all other time points (p-values < 0.002). Average HR during the Pre Drill Cognitive Tests was significantly lower than Waiting in the Station (M_{diff} = 13.63 b·min^{-1}, 95% CI: 4.48, 22.79, p= 0.002), which was lower than the Night-burn Drill (M_{diff} = 62.68 b·min^{-1}, 95% CI: 52.85, 72.51, p< 0.001), which was higher than Post Drill Cognitive Tests (M_{diff} = 31.63 b·min^{-1}, 95% CI: 26.57, 36.69, p< 0.001).

Figure 4.2. Average HR (b·min^{-1}) at the four time points described in the text.



These data support Hypothesis 1, and further indicate the beginning of a return to Pre-Drill HR following completion of the night-burn drill.

Table 4.4 HR Before (pre-drill, waiting in station), Immediately After, and ~30 min Post-firefighting

HR Recording Period	Average Duration (min:s)	*SD* (min:s)	*M* (b·min^{-1})	*SD* (b·min^{-1})
Pre-Drill Cognitive Tests				
Fall 2014	27:51	2:43	79.81	5.14
Spring 2015	29:04	1:12	83.95	9.04
Total	28:32	2:03	82.13	7.72
Waiting in Station				
Fall 2014	29:57	1:49	93.80	8.45
Spring 2015	57:52	6:12	97.22	19.44
Total	45:35	14:55	95.72	15.41
Night-burn Drill				
Fall 2014	51:13	4:11	156.86	8.17
Spring 2015	47:45	2:14	159.51	12.24
Total	49:17	3:37	158.35	10.53
Post-Drill Cognitive Tests				
Fall 2014	23:45	1:21	126.44	7.55
Spring 2015	29:23	3:00	126.67	14.33
Total	26:54	3:43	126.57	11.62

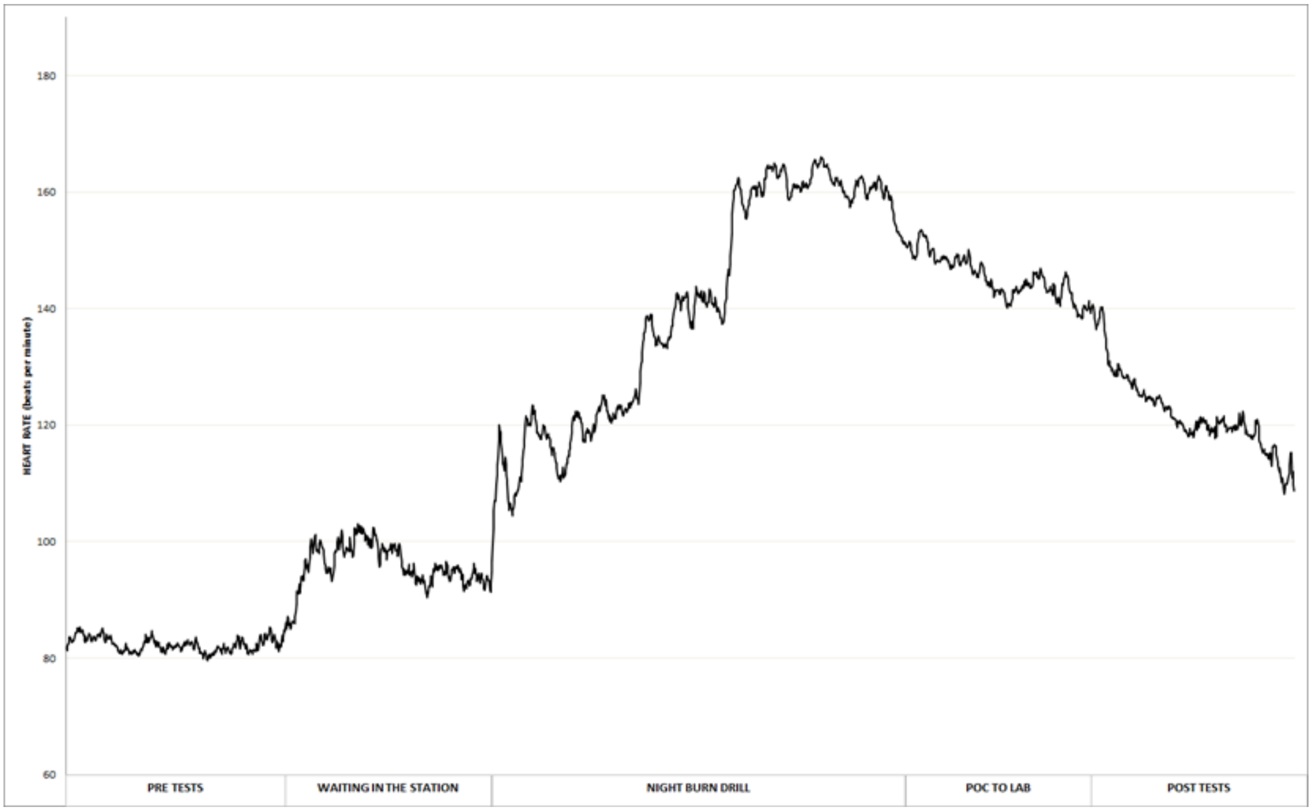


Figure 4.3. Continuous HR (b·min^{-1}) during various time points prior to, during, and after the night-burn drill and then during cognitive testing.

To examine the various hypotheses related to Aim #2, a series of 3 (Time: Pre, Post-0, End) x 3 (Academy: Spring 2014, Fall 2014, Spring 2015) repeated measures analyses of variance (RM ANOVA) were conducted for each main outcome variable. What follows are the significant findings (when present) relative to main effects for Time and Academy along with any Time X Academy interactions.

H_2: It was hypothesized that state anxiety following firefighting would be significantly greater immediately after firefighting (Post-0) than state anxiety assessed pre-firefighting (Pre) and 30-minutes post-firefighting (End). The RM ANOVA revealed a significant main effect of time for state anxiety [$F(1.72, 94.73) = 26.26$, $p < 0.001$, partial $\eta^2 = 0.323$, H-F $\varepsilon = 0.861$] with no significant time x academy interaction ($p = 0.122$). Pairwise comparisons indicated that state anxiety was significantly higher Post-0 than both Pre-Drill (M_{diff}

= 5.49, 95% CI: 3.06, 7.92, p= 0.001) and End (M_{diff} = 4.76, 95% CI: 3.21, 6.32, p< 0.001), but Pre-Drill and End did not differ (M_{diff} = 0.72, 95% CI: -1.29, 2.74, p = 1.00; see Table 4.5 and Figure 4.4). These data support Hypothesis 2.

Table 4.5 State Anxiety Inventory Scores Before (pre-drill, waiting in station), Immediately After, and ~30 min Post-firefighting

	Total (*n* = 58)		Spring 2014 (*n* = 11)		Fall 2014 (*n* = 20)		Spring 2015 (*n* = 27)	
Time	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Pre-Drill	18.60	5.76	16.91	5.72	19.30	6.81	18.78	4.97
Post-0	24.12	5.36	23.18	6.27	22.75	4.84	25.52	5.18
End	18.84	5.42	20.18	6.81	18.20	5.22	18.78	5.06

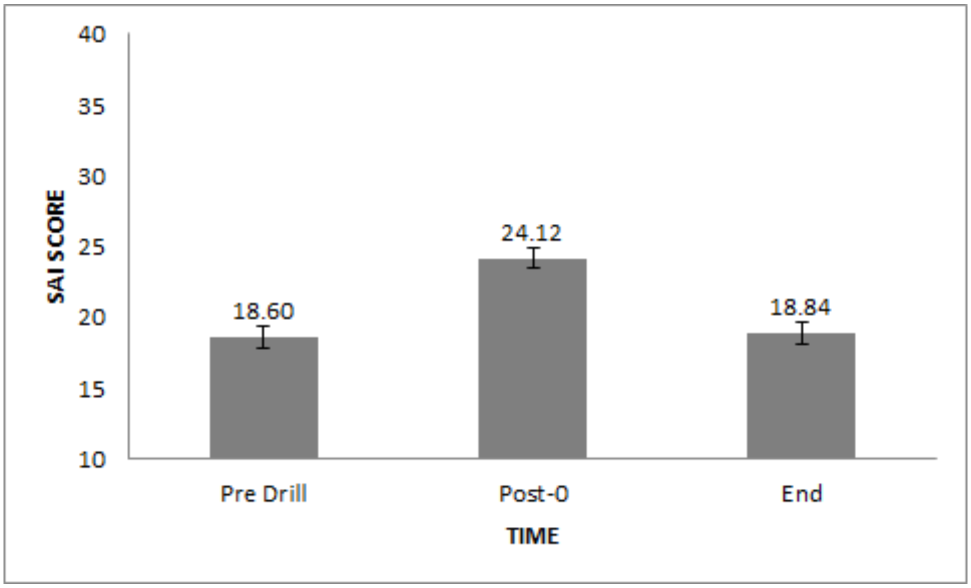


Figure 4.4. State anxiety scores before, immediately following the night-burn drill, and following cognitive testing.

H_3*: It was hypothesized that fatigue would be significantly greater at both 0 and 30 minutes post-firefighting than pre-firefighting. The RM ANOVA revealed a significant main effect of time for fatigue (assessed via the visual analogue scale, VAS) [$F(2,112) = 178.04$, $p< 0.001$, partial $\eta^2 = 0.761$] with no significant time x academy interaction ($p= 0.148$). Pairwise comparisons indicated that fatigue at each time point was significantly different from fatigue at every other time point (all *p*-values < 0.001). Fatigue Pre-Drill was significantly less than at Post-0 ($M_{diff} = 5.64$, 95% CI: 4.94, 6.35, $p< 0.001$) and End ($M_{diff} = 3.67$, 95% CI: 2.85, 4.50, $p< 0.001$) and Fatigue Post-0 was significantly higher than at End ($M_{diff} = 1.97$, 95% CI: 1.25, 2.69, $p< 0.001$; see Table 4.6 and Figure 4.5). These data support Hypothesis 3.

Table 4.6 Fatigue (VAS) Scores Before (pre-drill, waiting in station), Immediately After, and ~30 min Post-firefighting

	Total (*n* = 59)		Spring 2014 (*n* = 11)		Fall 2014 (*n* = 20)		Spring 2015 (*n* = 28)	
Time	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Pre-Drill	2.35	1.84	2.76	2.01	1.76	1.34	2.60	2.02
Post-0	8.20	1.20	7.59	1.76	7.61	0.94	8.85	0.71
End	6.11	2.23	6.38	2.01	4.89	2.20	6.88	2.01

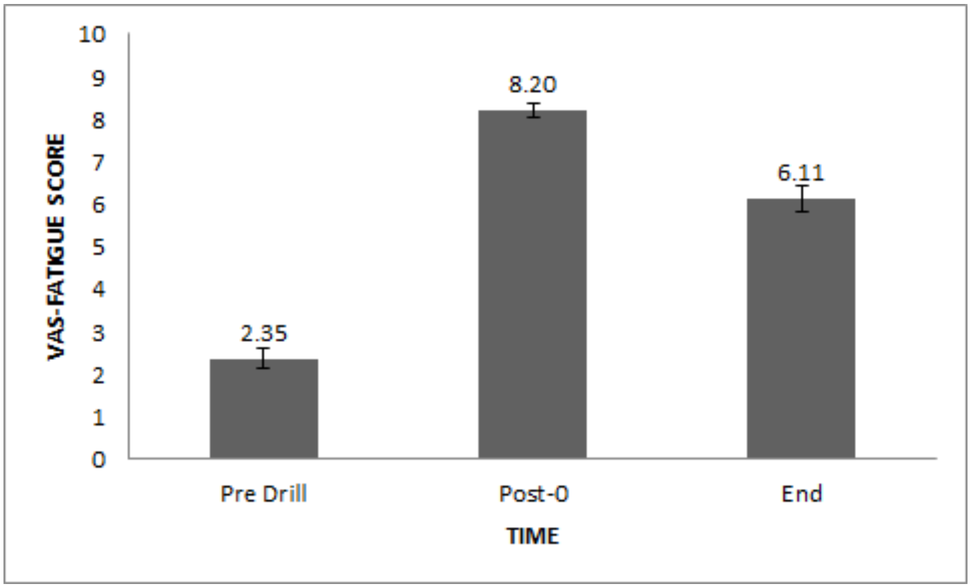


Figure 4.5. Visual analogue scale for fatigue before, immediately following the night-burn drill, and following cognitive testing.

H_4: It was hypothesized that perceived exertion, thermal sensation, respiratory distress, and felt arousal would be significantly elevated post-firefighting relative to pre-firefighting.

Rating of Perceived Exertion (RPE). The RM ANOVA revealed a significant main effect of time for RPE [$F(2,112) = 187.34$, $p< 0.001$, partial $\eta^2 = 0.770$] with no significant time x academy interaction ($p= 0.058$). Pairwise comparisons indicated that RPE at each time point was significantly different from RPE at every other time point (all *p*-values < 0.001). Pre-drill RPE was significantly less than Post-0 ($M_{diff} = 9.74$, 95% CI: 8.49, 10.99, $p< 0.001$) and End ($M_{diff} = 3.49$, 95% CI: 2.32, 4.65, $p < 0.001$) and RPE Post-0 was significantly higher than End ($M_{diff} = 6.25$, 95% CI: 4.90, 7.61, $p< 0.001$; see Table 4.7 and Figure 4.6).

Table 4.7 RPE Before (pre-drill, waiting in station), Immediately After, and ~30 min Post-firefighting

	Total (*n* = 59)		Spring 2014 (*n* = 11)		Fall 2014 (*n* = 20)		Spring 2015 (*n* = 28)	
Time	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Pre Drill	6.66	1.23	6.91	0.94	6.95	1.79	6.36	0.68
Post-0	16.68	3.26	16.09	4.41	15.85	3.22	17.50	2.65
End	10.12	3.28	11.27	3.64	8.80	2.07	10.61	3.61

Note: The RPE scale ranges from 6 (no exertion at all) to 20 (maximal exertion)

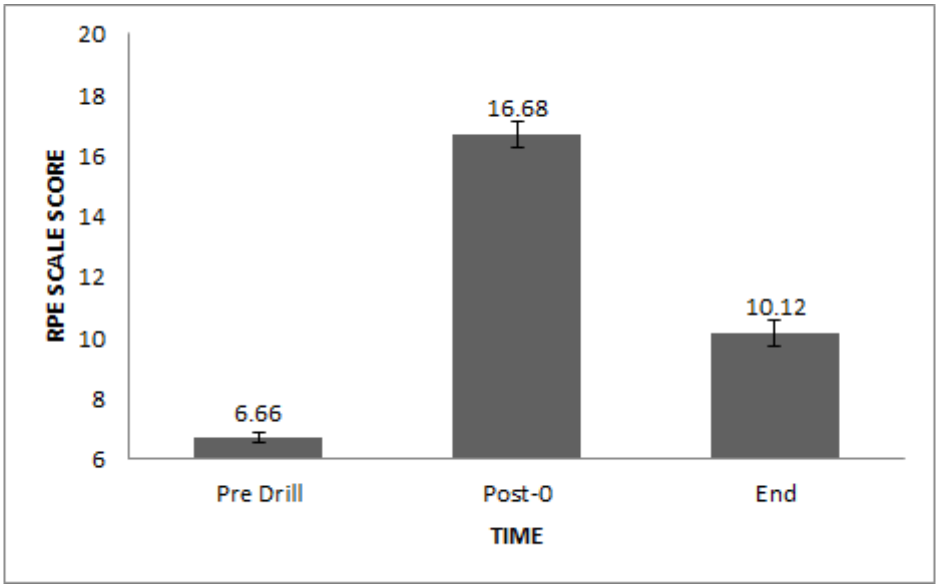


Figure 4.6. RPE before, immediately following the night-burn drill, and following cognitive testing.

Thermal Sensation (TS). The RM ANOVA revealed a significant main effect of time for TS [$F(2,112) = 151.09$, $p < 0.001$, partial $\eta^2 = 0.730$] with no significant time x academy interaction ($p = 0.923$). Pairwise comparisons indicated that TS at each time point was significantly different from TS at every other time point (all *p*-values < 0.001). Pre-drill TS was significantly less than at Post-0 (M_{diff} = 2.82, 95% CI: 2.45, 3.18, p< 0.001) and End (M_{diff} = 1.35, 95% CI: 0.94, 1.75, p< 0.001) and TS Post-0 was significantly higher than End (M_{diff} = 1.47, 95% CI: 1.05, 1.90, p< 0.001; see Table 4.8 and Figure 4.7).

Table 4.8 Thermal Sensation Before (pre-drill, waiting in station), Immediately After, and ~30 min Post-firefighting

	Total (n = 59)		Spring 2014 (n = 11)		Fall 2014 (n = 20)		Spring 2015 (n = 28)	
Time	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Pre Drill	4.04	0.78	4.23	0.52	3.78	0.82	4.16	0.81
Post-0	6.90	0.93	6.86	0.78	6.68	0.77	7.07	1.07
End	5.44	1.06	5.36	1.23	5.18	0.54	5.66	1.24

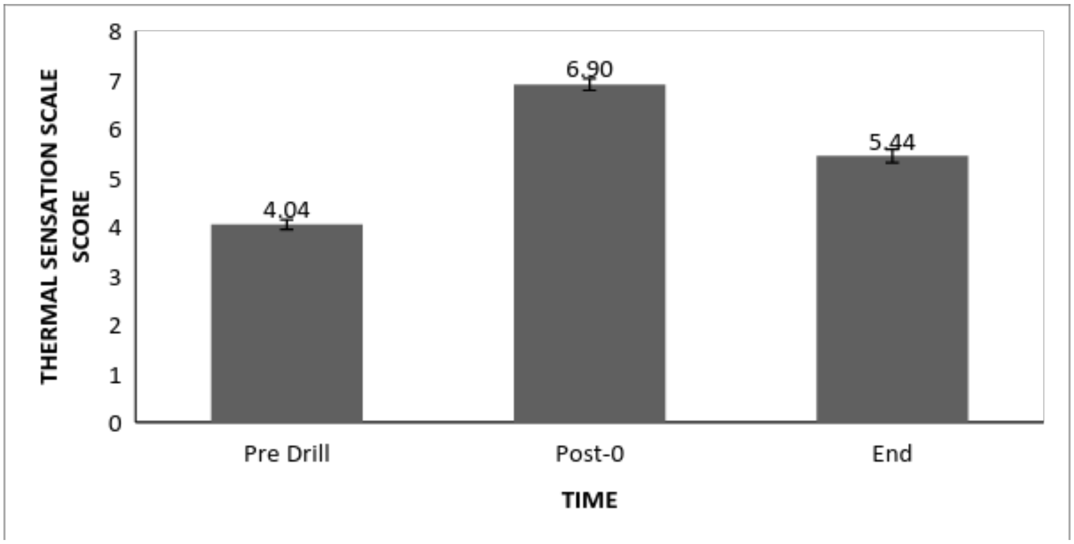


Figure 4.7. Thermal Sensation before, immediately following the night-burn drill, and following cognitive testing.

Respiratory Distress (RD). The RM ANOVA revealed a significant main effect of time for RD [$F(1.93,107.92) = 196.22$, $p< 0.001$, partial $\eta^2 = 0.778$, H-F $\varepsilon = 0.964$] with no significant time x academy interaction ($p= 0.182$). Pairwise comparisons indicated that RD at each time point was significantly different from RD at every other time point (all *p*-values < 0.001). Pre-drill RD was significantly lower than at Post-0 ($M_{diff} = 3.54$, 95% CI: 3.08, 4.01, $p< 0.001$) and End ($M_{diff} = 0.73$, 95% CI: 0.34, b1.12, $p< 0.001$) and RD Post-0 was significantly higher than End ($M_{diff} = 2.82$, 95% CI: 2.29, 3.34, $p< 0.001$; see Table 4.9 and Figure 4.8).

Table 4.9 Respiratory Distress Before (pre-drill, waiting in station), Immediately After, and ~30 min Post-firefighting

	Total (*n* = 59)		Spring 2014 (*n* = 11)		Fall 2014 (*n* = 20)		Spring 2015 (*n* = 28)	
Time	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Pre Drill	1.10	0.44	1.18	0.40	1.00	0.00	1.14	0.59
Post-0	4.76	1.26	4.45	1.51	4.25	1.16	5.25	1.08
End	1.85	1.08	1.91	1.38	1.60	0.75	2.00	1.15

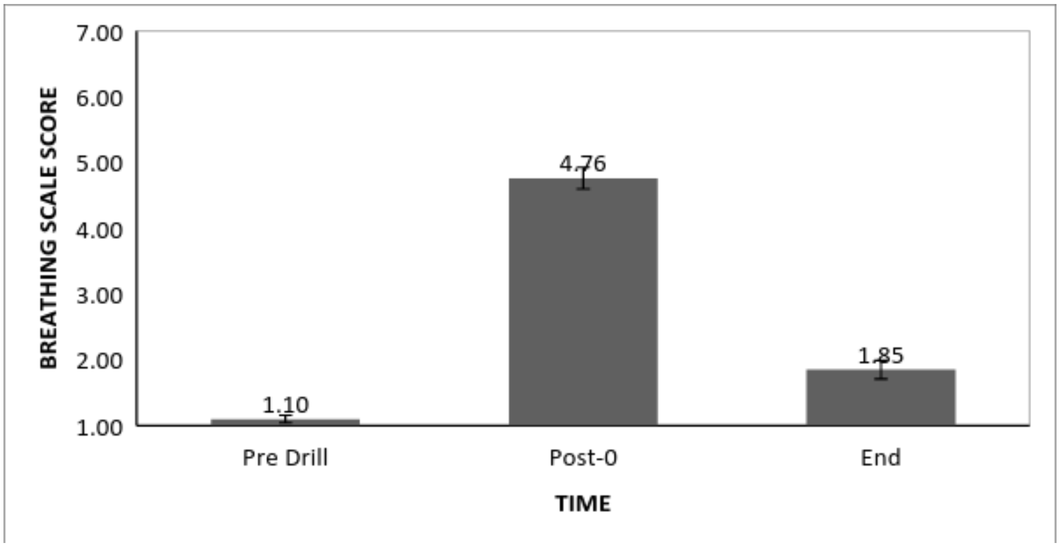


Figure 4.8. Respiratory distress (RD) before, immediately following the night-burn drill, and following cognitive testing.

Felt Arousal Scale (FAS). The RM ANOVA revealed a significant main effect of time for FAS [$F(1.79,98.39) = 23.26$, $p < 0.001$, partial $\eta^2 = 0.297$, H-F $\varepsilon = 0.894$] with no significant time x academy interaction ($p = 0.286$). Pairwise comparisons indicated that FAS Post-0 was significantly higher than both Pre-drill ($M_{diff} = 1.72$, 95% CI: 0.95, 2.50, $p < 0.001$) and End ($M_{diff} = 1.33$, 95% CI: 0.69, 1.96, $p < 0.001$), but that Pre and End did not differ ($M_{diff} = 0.40$, 95% CI: -0.13, 0.93, $p = 0.209$; see Table 4.10 and Figure 4.9).

Table 4.10 Felt Arousal Before (pre-drill, waiting in station), Immediately After, and ~30 min Post-firefighting

	Total (n = 58)		Spring 2014 (n = 11)		Fall 2014 (n = 20)		Spring 2015 (n = 27)	
Time	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Pre Drill	2.71	1.46	3.00	1.00	2.65	1.60	2.63	1.55
Post-0	4.59	1.61	4.27	1.90	4.10	1.86	5.07	1.14
End	3.16	1.30	3.36	1.03	2.70	1.30	3.41	1.34

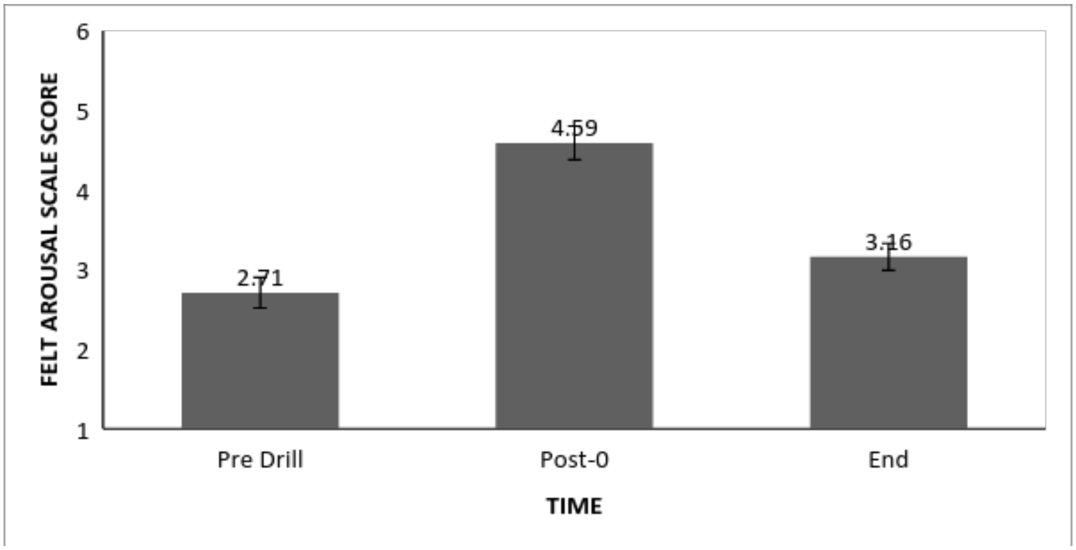


Figure 4.9. Felt Arousal before, immediately following the night-burn drill, and following cognitive testing.

These data, collectively, support Hypothesis 4 and further suggest that RPE, TS, and RD remain elevated above pre-firefighting levels following the cognitive testing period that occurred Post Drill. Felt Arousal is the only perceptual variable that appears to have fully returned to Pre Drill levels after the cognitive testing period.

H_5: It was hypothesized that perceived Energy would decrease immediately post-firefighting from pre-firefighting levels, and then decrease further 30 minutes post-firefighting. The RM ANOVA revealed a significant main effect of time for Energy [$F(1.89, 101.95) = 7.70$, $p = 0.001$, partial $\eta^2 = 0.125$, H-F $\varepsilon = 0.944$] with no significant time x academy interaction ($p = 0.183$). Pairwise comparisons indicated that Energy was significantly lower at End than Pre ($M_{diff} = 2.27$, 95% CI: 0.99, 3.55, $p < 0.001$). Energy Post-0 did not differ significantly from either Pre ($M_{diff} = 1.03$, 95% CI: -0.64, 2.70, $p = 0.404$) or End ($M_{diff} = 1.24$, 95% CI: 0.06, 2.55, $p = 0.067$; see Table 4.11 and Figure 4.10). Hypothesis 5 was only partially supported by the data. Perceived Energy did not decrease immediately post firefighting, but was the same as it was Pre Drill. However, perceptions of Energy 30-minutes post firefighting were significantly lower than both Post-0 and Pre Drill Energy levels.

Table 4.11 Perceived Energy Before (pre-drill, waiting in station), Immediately After, and ~30 min Post-firefighting

	Total ($n = 57$)		Spring 2014 ($n = 11$)		Fall 2014 ($n = 20$)		Spring 2015 ($n = 26$)	
Time	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Pre Drill	12.35	2.85	12.45	2.91	12.70	2.20	12.04	3.30
Post-0	11.63	3.77	10.55	4.06	10.95	3.03	12.62	4.05
End	10.02	3.39	10.73	3.35	9.70	2.52	9.96	4.02

Note: *AD ACL: Activation-Deactivation Adjective Checklist

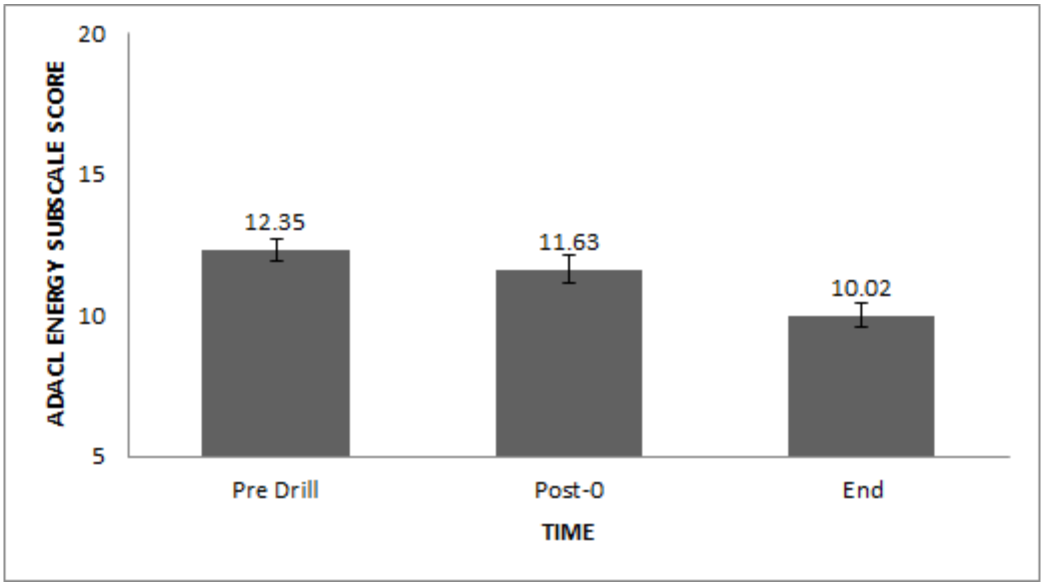


Figure 4.10. Perceived energy before, immediately following the night-burn drill, and following cognitive testing.

H_6: It was hypothesized that valenced affect [i.e., pleasure-displeasure, as assessed by the Feeling Scale (FS)] would be more negative immediately post-firefighting relative to pre- and 30-minutes post-firefighting. The RM ANOVA revealed a significant main effect of time for valenced affect [$F(1.75,97.87) = 65.09$, $p< 0.001$, partial $\eta^2 = 0.538$, H-F $\varepsilon = 0.874$] with no significant time x academy interaction ($p = 0.374$). Pairwise comparisons indicated that valenced affect at each time point was significantly different from valenced affect at every other time point (all p-values < 0.001). Valenced affect Pre was significantly higher (i.e., more positive) than Post-0 ($M_{diff} = 4.08$, 95% CI: 3.00, 5.15, $p< 0.001$) and End ($M_{diff} = 1.41$, 95% CI: 0.69, 2.13, $p< 0.001$), and Post-0 was significantly lower than End ($M_{diff} = 2.67$, 95% CI: 1.81, 3.52, $p< 0.001$; see Table 4.12 and Figure 4.11). The data supported Hypothesis 6 and further revealed that affect, despite significant improvement 30-minutes post firefighting relative to Post-0, remained significantly more negative than Pre Drill affect.

Table 4.12 Valenced Affect Before (pre-drill, waiting in station), Immediately After, and ~30 min Post-firefighting

	Total (*n* = 59)		Spring 2014 (*n* = 11)		Fall 2014 (*n* = 20)		Spring 2015 (*n* = 28)	
Time	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Pre Drill	3.19	1.47	2.73	1.62	3.35	1.50	3.25	1.40
Post-0	-1.08	2.90	-0.91	3.14	-0.25	2.73	-1.75	2.86
End	1.66	2.13	1.64	2.25	2.10	1.68	1.36	2.38

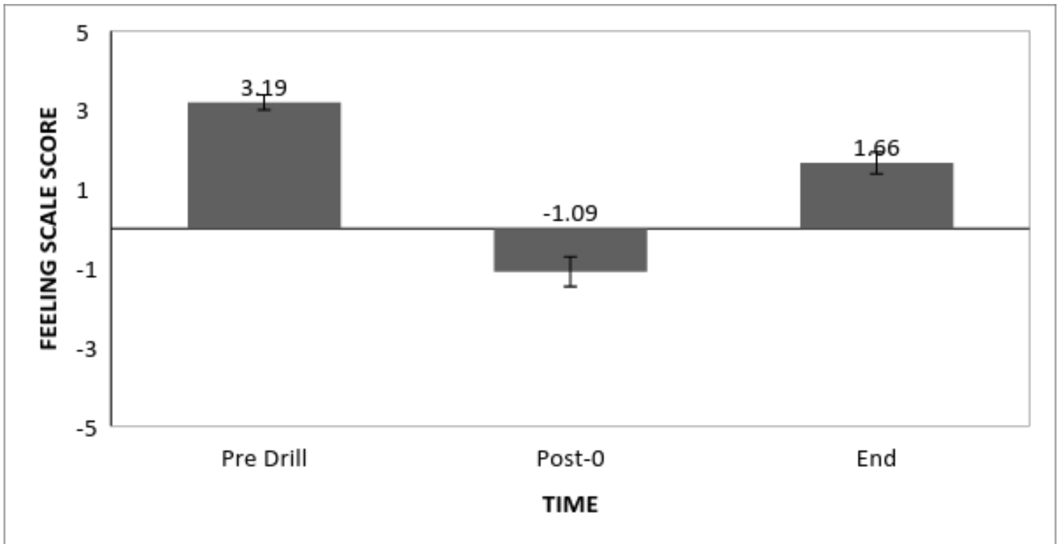


Figure 4.11. Valenced affect (as assessed by the FS) before, immediately following the night-burn drill, and following cognitive testing.

Study Aim #3

The third aim examined cognitive behavioral performance of firefighters immediately post drill relative to pre drill. What follows addresses that Aim and its various hypotheses. Due to differences in task order between Baseline and Pre Drill assessment across academies and the use of Baseline as a familiarization day, all Baseline analyses appear in the Appendix.

H_7: It was hypothesized that, in general, reaction time (RT) would be shorter, accuracy would not change significantly for easier tasks (flanker, 0-back) but would decrease for more difficult tasks (1-back, 2-back), and response variability would be greater post-firefighting compared to pre-firefighting.

Table 4.13 Order of Tests by Academy

Academy	Baseline (practice)	Pre-Drill	Post-Drill
Fall 2013	1. Flanker 2. 0-back 3. 1-back 4. 2-back	No Measures Taken	1. Flanker 2. 0-back 3. 1-back 4. 2-back
Spring 2014	1. Flanker 2. 0-back 3. 1-back 4. 2-back	1. Flanker 2. 0-back 3. 1-back 4. 2-back	1. Flanker 2. 0-back 3. 1-back 4. 2-back
Fall 2014	1. Flanker 2. 0-back 3. 1-back 4. 2-back	1. Flanker 2. 1-back 3. 2-back 4. 0-back	1. Flanker 2. 1-back 3. 2-back 4. 0-back
Spring 2015	1. Flanker 2. 2-back 3. 1-back 4. 0-back	1. Flanker 2. 2-back 3. 1-back 4. 0-back	1. Flanker 2. 2-back 3. 1-back 4. 0-back

Preliminary Analyses: Academy Differences in Modified Flanker Task Performance

A one-way ANOVA revealed a significant difference amongst academies for pretest congruent trial response accuracy [$F(2,57) = 3.94$, $p = 0.025$]. Bonferroni *post hoc* comparisons revealed that the Spring 2014 class had significantly lower accuracy than the Spring 2015 class ($M_{diff} = 1.74 \pm 0.66$, 95% CI: 0.15,3.32). Post-test congruent trial response accuracy only approached significance ($p = 0.056$). No other significant differences amongst academies were revealed for modified flanker performance. Since 10 variables were included in the ANOVA, after performing a Bonferroni adjustment to protect against type one error rate (p-value/# of outcome variables in the ANOVA), there were no significant effects for pretest congruent trial response accuracy amongst academies. Accordingly, individuals across each class were combined for analysis purposes.

Effect of Firefighting on Modified Flanker Task Performance

Separate 2 (Congruency: Congruent, Incongruent) x 2 (Time: Pre, Post) multivariate Repeated Measures (RM) Analysis of Variance (ANOVA) were performed on RT, accuracy, and response variability. There was a significant time x congruency interaction for RT [$F(1,59) = 19.18$, $p < .001$, partial $\eta^2 = .245$] and accuracy [$F(1,59) = 7.85$, $p = .007$, partial $\eta^2 = .117$], but not response variability ($p > .10$). For RT, *post hoc* comparisons revealed that the significant interaction was a function of greater change in response time (i.e., becoming shorter) from pre to post firefighting for incongruent trials ($M_{diff} = -43.39 \pm 4.06$ ms, $p < .001$, 95% CI: -51.51,-35.27) than congruent trials ($M_{diff} = -33.61 \pm 4.15$ ms, $p < .001$, 95% CI: -41.92,-25.31). The significant interaction for accuracy was a function of a larger decrease in accuracy from pre to post firefighting for the incongruent trials ($M_{diff} = -3.00 \pm 0.80\%$, $p < .001$, 95% CI: -4.60,-1.40) relative to congruent trials ($M_{diff} = -1.12 \pm 0.35\%$, $p = .002$, 95% CI: -1.82,-0.42).

RM ANOVAs by Time (Pre, Post) for Flanker Interference revealed a significant main effect of time for Interference RT (RT on correct Incongruent trials – RT on correct Congruent trials) [$F(1,59) = 19.18$, $p < .001$, partial $\eta^2 = .117$] and for Interference Accuracy (ACC on Congruent trials – ACC on Incongruent trials) [$F(1,59) = 7.85$, $p = .007$, partial $\eta^2 = .117$]. Interference RT was smaller post drill than pre drill ($M_{diff} = 9.77 \pm 2.23$ ms, $p < .001$, 95% CI: 5.31,14.24) and Interference ACC was larger post drill than pre drill ($M_{diff} = 1.88 \pm 0.67\%$, $p = .007$, 95% CI: 0.54,3.23). See Table 4.14 and Figures 4.12, 4.13, 4.14, and 4.15.

Table 4.14 Pre-Post Changes in Modified Flanker Performance (n = 60)

		Pre M (SD)	Post M (SD)	Sig. (p-value)
% ACC				
	Cong	98.88 (2.00)	97.77 (3.27)	.002
	Incong	93.00 (6.63)	90.00 (7.66)	<.001
RT on Correct Trials (ms)				
	Con	470.36 (46.60)	436.75 (40.29)	<.001
	Incong	531.78 (43.18)	488.39 (44.16)	<.001
SD on Correct Trials (ms)				
	Con	60.43(16.66)	62.80(21.92)	.384
	Incong	64.87(15.24)	63.71(18.42)	.624
Interference RT (Incong – Cong)		61.41 (20.64)	51.64 (18.23)	<.001
Interference ACC (Cong – Incong)		5.88 (6.59)	7.77 (7.00)	.007

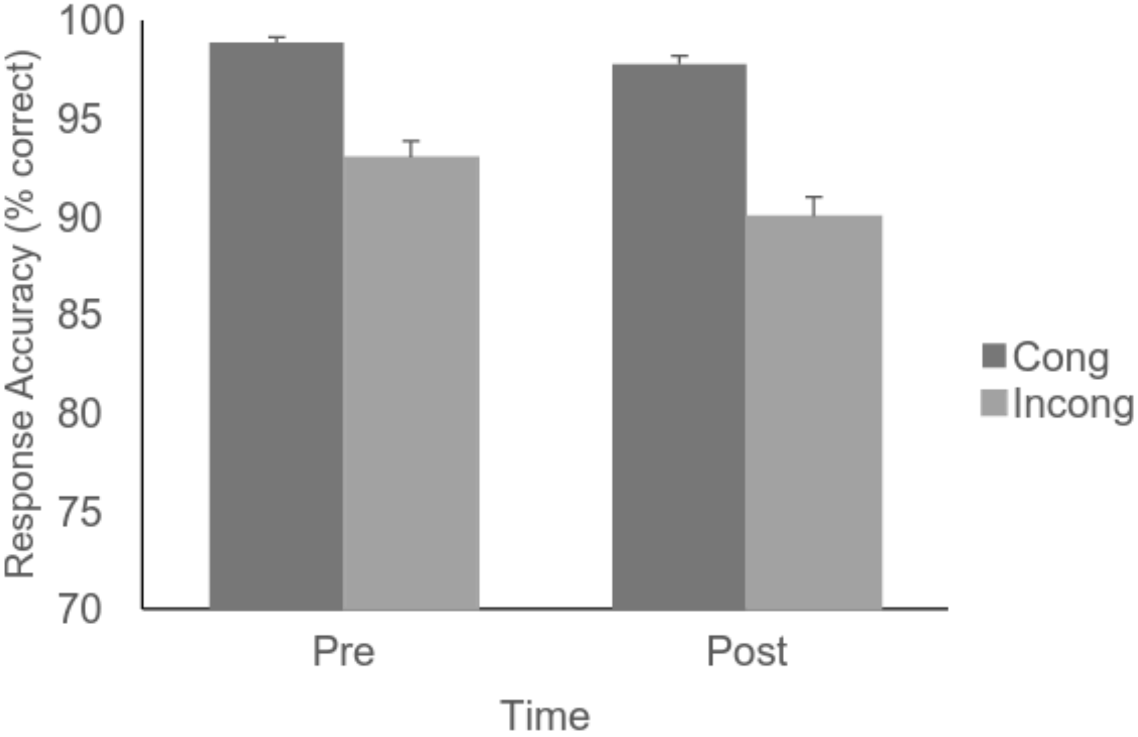


Figure 4.12: Modified Flanker Task Accuracy
Note: * = significantly different from pre drill, $p < .01$

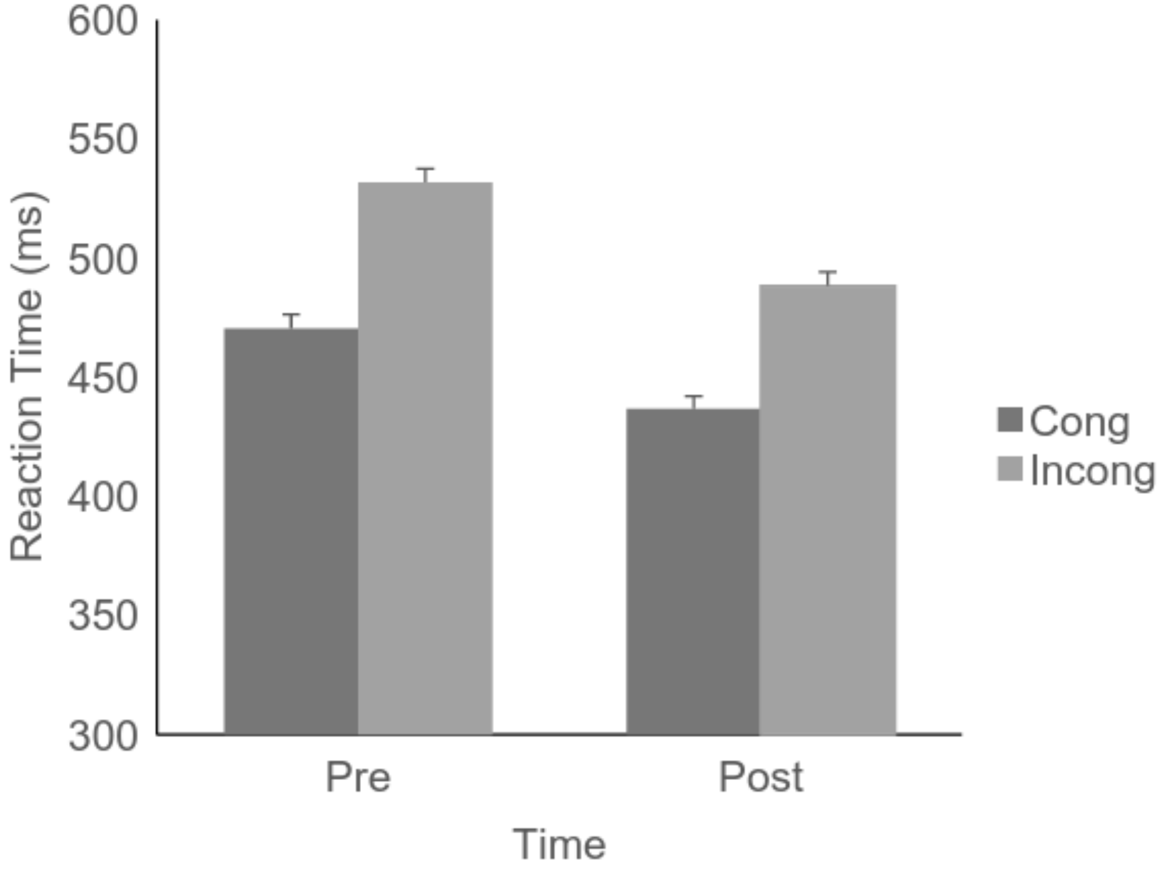


Figure 4.13: Modified Flanker Task Reaction Time on Correct Trials (ms)
Note: * = significantly different from pre drill, $p < .01$

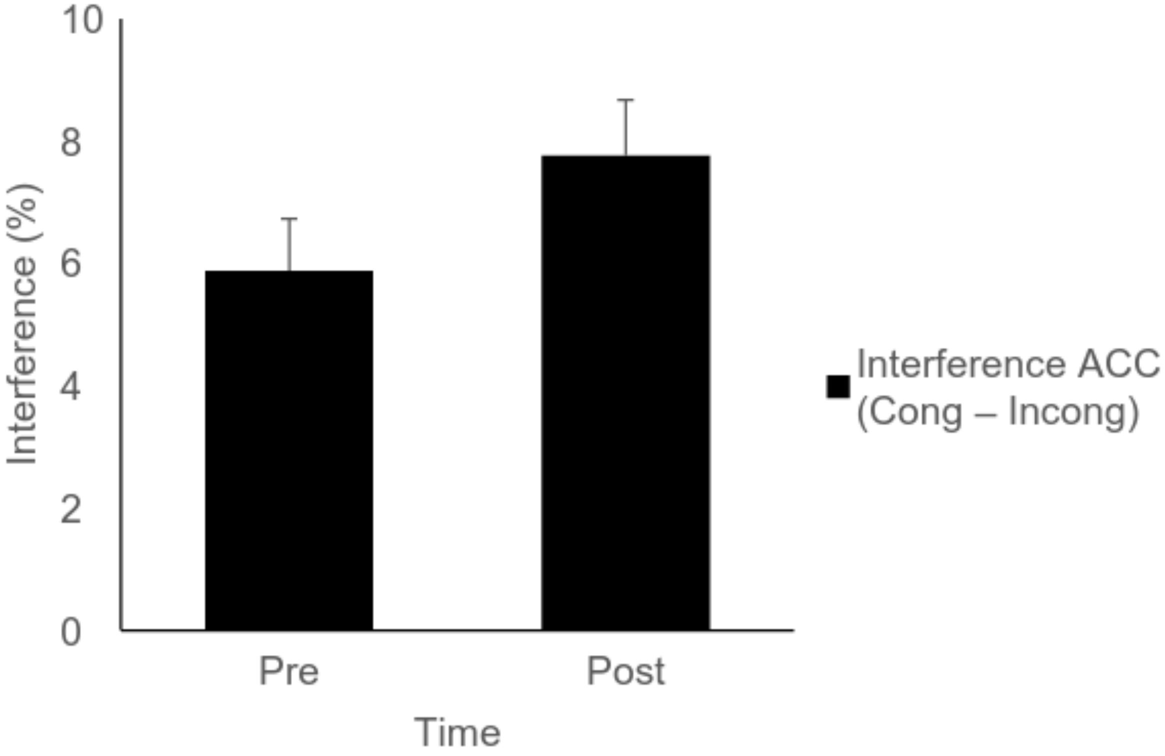


Figure 4.14: Interference Accuracy
Note: * = significantly different from pre drill, *p* <.01

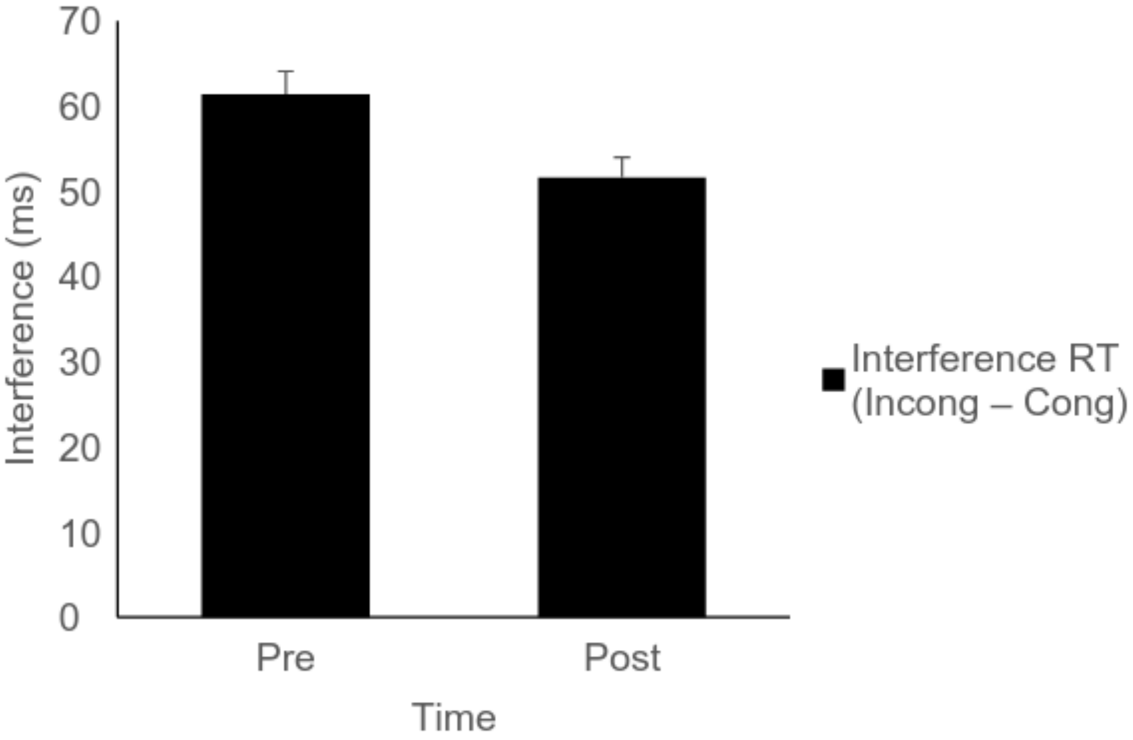


Figure 4.15: Interference Reaction Time
Note: ** = significantly different from pre drill, *p* <.01

Preliminary Analysis: N-back Task Order

A series of one-way ANOVAs of n-back performance outcomes by working memory load (0,1,2) and time (pre and post) for target (T) and non-targets (NT) trials were performed for RT, response accuracy, response variability and d-prime variables. As expected, findings revealed no significant differences in performance by task order (*p* >.05).

Working Memory Load

Omnibus analysis (Working Memory Load: 0, 1, 2) x (Time: Pre, Post) x (Trial Type: Non-target, Target) revealed significant 3-way interactions for RT [F(2,114) = 7.83, *p* = .001, partial η^2 = .121] and response variability [F(2,114) = 4.74, *p* = .011, partial η^2 = .077] but not accuracy (*p* > .05). Separate 3 (Working Memory Load: 0, 1, 2) x 2 (Trial type: Non-target, Target) RM ANOVAs revealed significant interactions for working memory load and trial type for both RT [F(2,114) = 111.02, p <.001, partial eta2 =.661] and accuracy [F(2,114) = 11.01, p

<.001, partial $\eta^2 = .162$]. As shown in Table 4.15, RT became significantly longer for non-targets as memory load increased, relative to targets. With respect to accuracy, performance on non-targets was better than target trials as load increased. No significant effects were found for response variability or d-prime ($p > 0.05$). See Figures 4.16 and 4.17 below.

Table 4.15: Working Memory Load x Trial Type (n = 58)

Outcome Measure	0-back	1-back	2-back
% ACC			
Nontarg	99.67(0.61) ^{a}	97.53(2.73) ^{b}	93.22(5.77) ^{c}
Targ	95.85(5.18) ^{a}	91.47(8.19) ^{b}	83.92(13.39) ^{c}
RT (ms)			
Nontarg	533.99(54.92) ^{a}	699.97(108.47) ^{b}	986.23(196.54) ^{c}
Targ	556.83(48.41) ^{a}	634.84(81.46) ^{b}	814.58(135.03) ^{c}

Notes: Data reported as Mean(SD); Means with different superscripts are significantly different from one another, p<.001

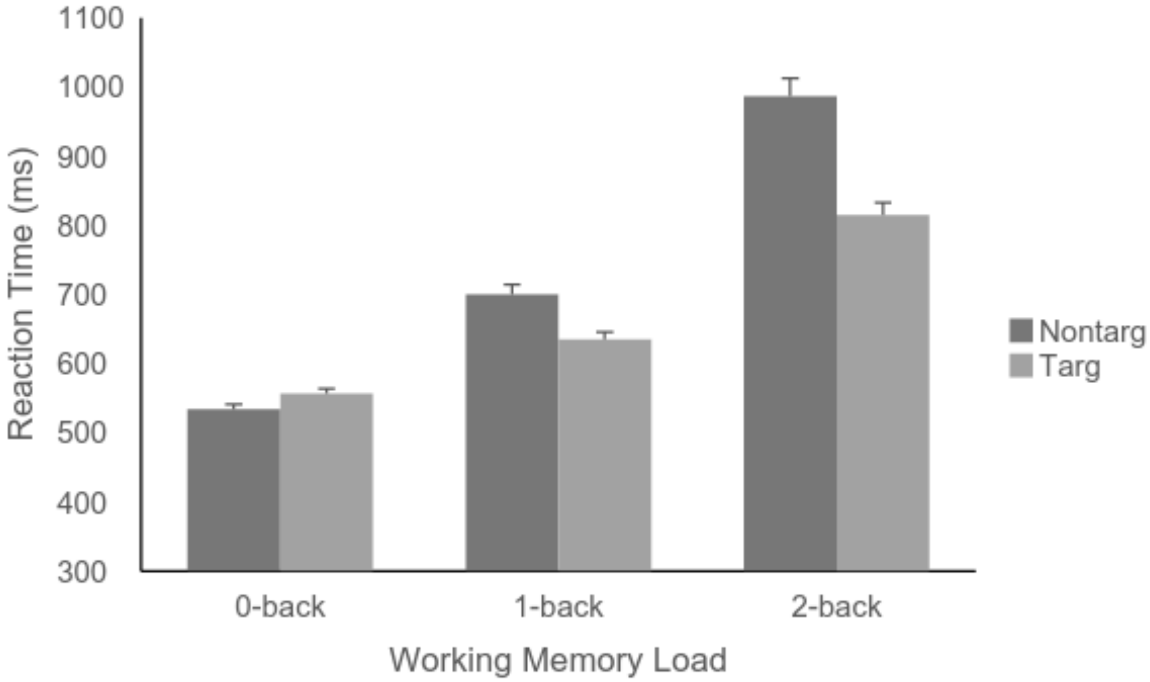


Figure 4.16: RT on Correct Trials by Working Memory Load
Note: All target and non-targets are significantly different from each other across working memory load; *p*<.001

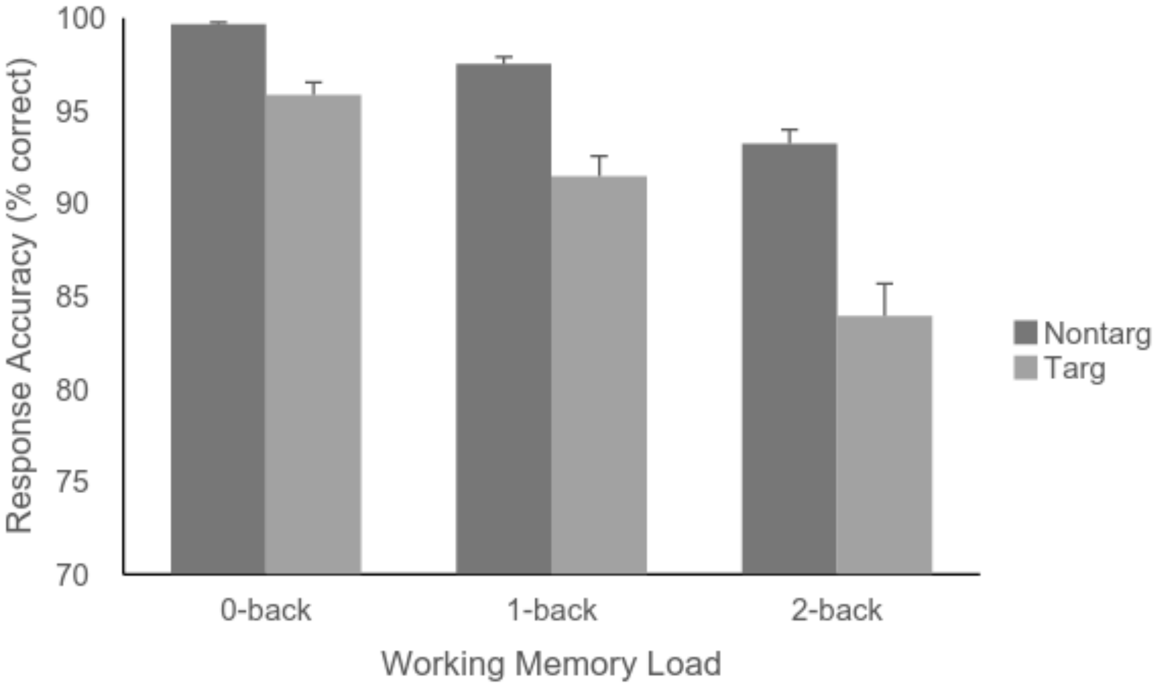


Figure 4.17: Accuracy by Working Memory Load
Note: All targets and non-targets are significantly different from each other across working memory load; *p*<.001

Effect of Firefighting on N-back Performance

Paired samples t-tests were used to compare pre-post differences for each n-back trial type (Non-targets or Targets) for RT, accuracy, response variability, and d-prime by time. For Pre-Post changes in 0-back performance, see Table 4.16, for pre-post changes in 1-back performance, see Table 4.17, and for pre-post changes in 2-back performance, see Table 4.18. See Figure 4.18 below for n-back accuracy, pre and post drill. See Figure 4.19 below for n-back reaction time on correct trials, pre and post drill. See Figure 4.20 for corrected accuracy (d') for all n-back tasks, pre and post drill.

For RT, 0-back RT to non-targets only (not targets) became significantly longer (M_{diff} = 20.46±8.11 ms, p = .014, 95% CI: 4.22,36.70), 1-back RT did not change significantly (p_s > .05), and 2-back RT to both non-targets (M_{diff} = -145.61±23.49 ms, p < .001, 95% CI:-192.63,-98.60) and targets (M_{diff} = -84.43±22.68 ms, p < .001, 95% CI:-129.83,-39.03) became significantly shorter from pre to post firefighting. For response variability, 0-back SD of RT to non-targets only (not targets) increased significantly (M_{diff} = 42.61±9.50 ms, *p* < .001, 95% CI:23.58,61.64), 1-back SD of RT to targets only (not non-targets) increased significantly (M_{diff} = 32.61±11.90 ms, *p* = .008, 95% CI:8.78,56.43), and 2-back SD of RT showed no significant change (*p* < .05).

Accuracy declined significantly from pre to post for target trials only (not non-targets) in the 0-back (M_{diff} = -2.05±0.90%, *p* = .027, 95% CI:-3.85,-0.24) and 1-back (M_{diff} = -5.00±1.38%, *p* = .001, 95% CI:-7.77,-2.23) conditions, with accuracy for target trials only (not non-targets) approaching significance for the 2-back condition (M_{diff} = -3.22±1.64%, *p* = .054, 95% CI:-6.50,0.06). When accuracy was adjusted (d-prime), 0-back (M_{diff} = -0.11±0.04, *p* = .020, 95% CI:-0.19,-0.02) and 1-back (M_{diff} = -0.33±0.10, *p* = .001, 95% CI:-0.52,-0.14) d' demonstrated significant declines, while 2-back adjusted accuracy showed no significant change (*p* >.10).

Table 4.16: Pre-Post Changes in 0-back Performance

		Pre M (SD)	Post M (SD)	N	Sig. (p-value)
% ACC					
	Nontarg	99.70(0.85)	99.57(0.76)	58	.341
	Targ	96.88(4.72)	94.83(7.42)	58	.027
Correct Trial RT (ms)					
	Nontarg	523.76(52.30)	544.22(72.13)	58	.014
	Targ	551.79(52.29)	561.88(64.14)	58	.248
Correct Trial SD of RT (ms)					
	Nontarg	108.14(47.19)	150.76(63.85)	58	<.001
	Targ	97.73(86.21)	88.29(41.87)	58	.485
d-prime (d')		3.92(0.25)	3.81(0.38)	58	.020

Table 4.17: Pre-Post Changes in 1-back Performance

	Pre M (SD)	Post M (SD)	N	Sig. (p-value)
% ACC				
Nontarg	98.11(3.02)	97.04(4.32)	59	.114
Targ	94.07(6.73)	89.07(12.02)	59	.001
Correct Trial RT (ms)				
Nontarg	707.40(109.12)	691.76(131.15)	59	.276
Targ	632.03(76.23)	637.11(112.48)	59	.709
Correct Trial SD of RT (ms)				
Nontarg	204.08(82.61)	215.48(96.62)	59	.404
Targ	158.36(75.31)	190.96(113.83)	59	.008
d-prime (d’)	3.63(0.53)	3.29(0.76)	59	.001

Table 4.18: Pre-Post Changes in 2-back Performance

	Pre M (SD)	Post M (SD)	N	Sig. (p-value)
% ACC				
Nontarg	93.46(7.49)	93.16(7.10)	59	.803
Targ	85.76(13.26)	82.54(16.20)	59	.054
Correct Trial RT (ms)				
Nontarg	1057.19(220.69)	911.58(209.50)	59	<.001
Targ	859.20(165.87)	774.77(155.51)	59	<.001
Correct Trial SD of RT (ms)				
Nontarg	344.49(110.18)	324.13(103.96)	59	.187
Targ	319.78(135.43)	288.79(113.24)	59	.112
d-prime (d’)	2.87(0.89)	2.71(1.00)	59	.192

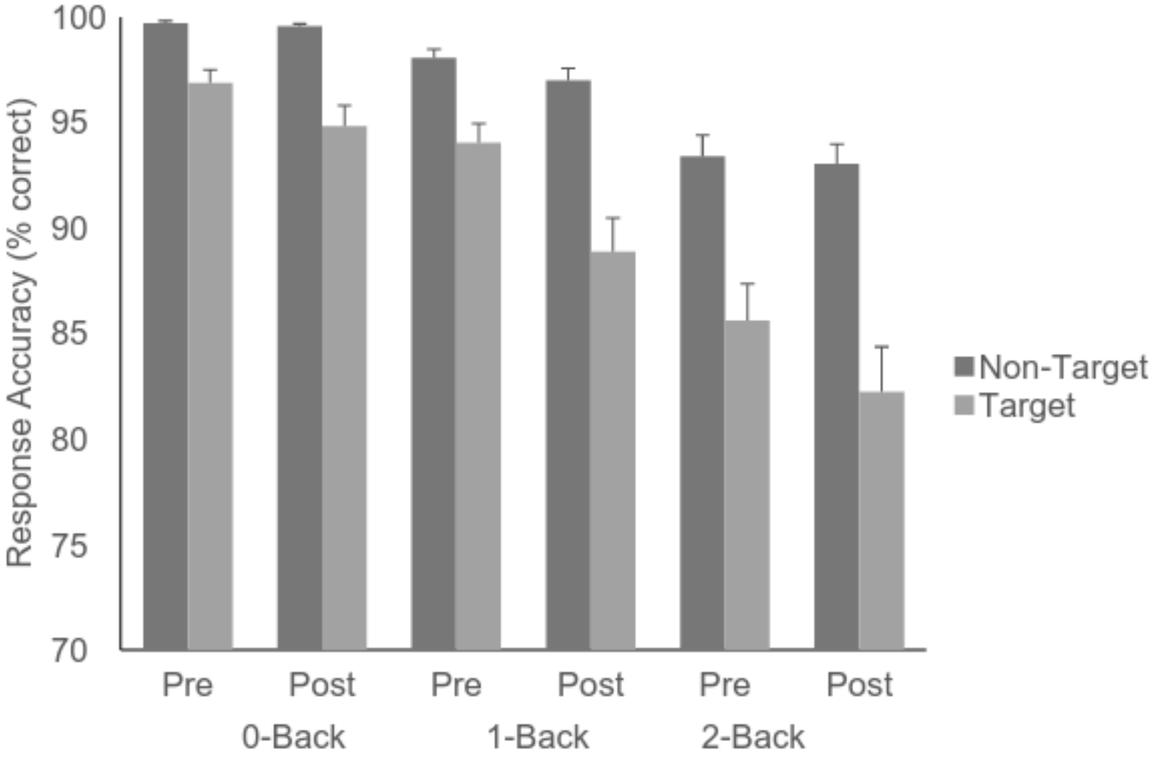


Figure 4.18: N-back Accuracy: Pre and Post Drill
Note: Post drill accuracy on target trials for 0-back and 1-back was significantly different from pre drill accuracy. Post drill accuracy on 2-back target trials was marginally significant. Post drill accuracy on non-target trials was not significantly different from pre drill accuracy for any working memory load.

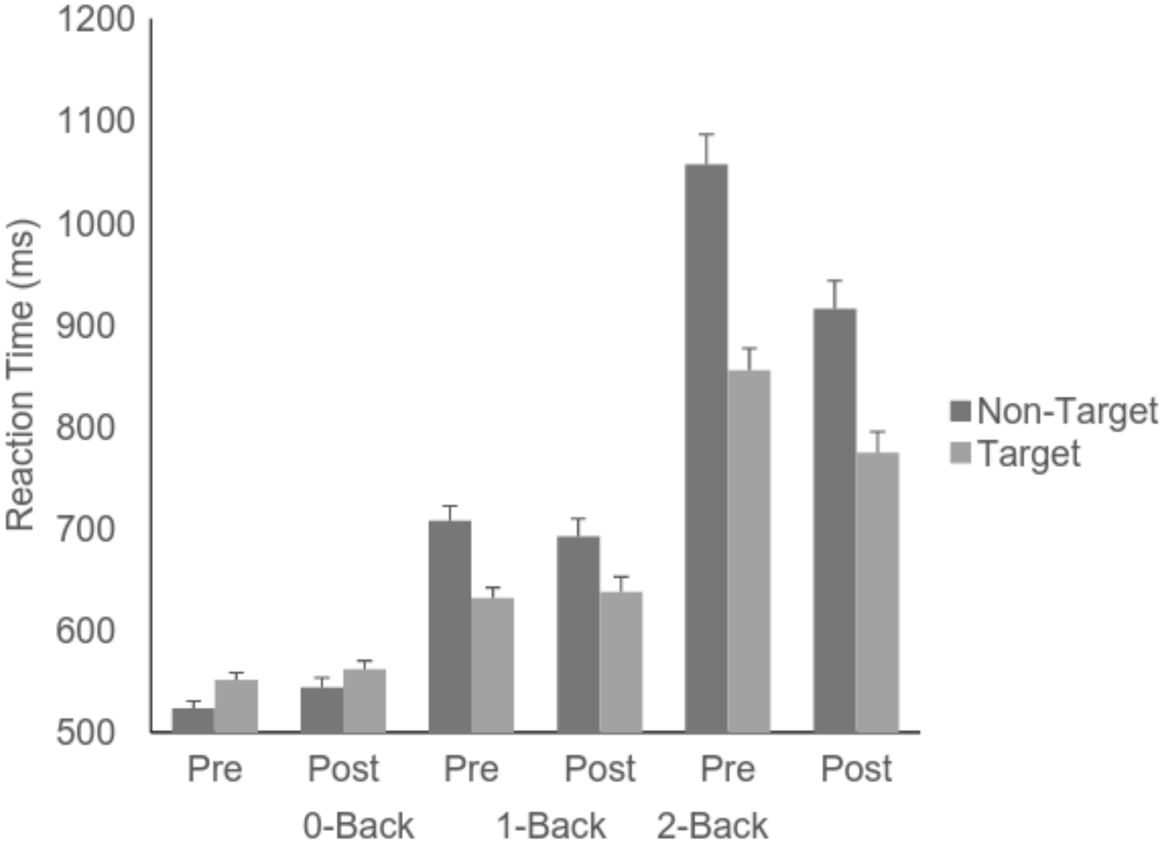


Figure 4.19: N-back Response Time (ms): Pre and Post Drill
Note: Post drill 0-back RT on non-target trials was significantly longer post drill than pre drill. Post drill 2-back RT on non-target and target trials was significantly shorter post drill than pre drill. No significant differences were present between pre and post drill for 0-back target trials or 1-back RT on non-target or target trials.

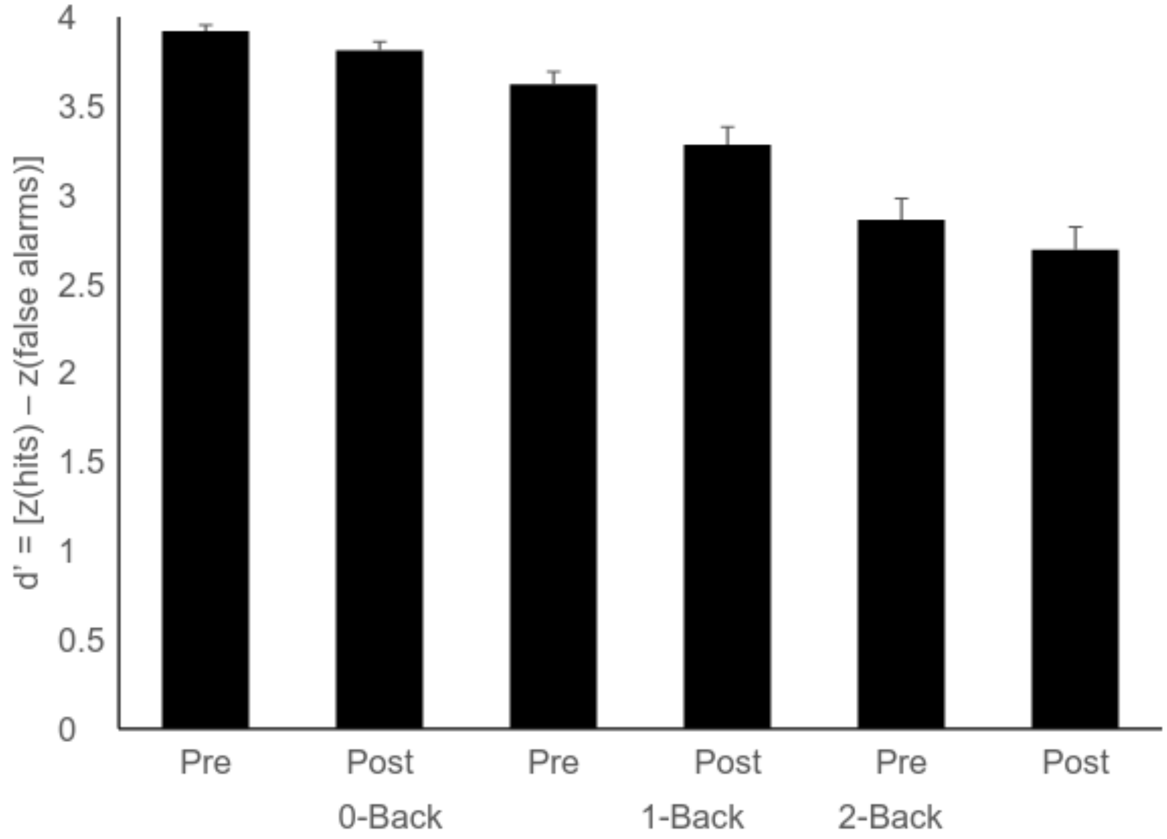


Figure 4.20: N-back Corrected Accuracy (d'): Pre and Post Drill
Note: Post drill 0-back d-prime was significantly lower than pre drill. Post drill 1-back d-prime was significantly lower post drill than pre drill. No significant difference was present between pre and post drill for 2-back d-prime.

Hypothesis 7 Summary

The data only partially support the hypothesis that, in general, reaction time (RT) would be shorter (i.e., faster) Post Drill than Pre Drill. Flanker RT was significantly shorter Post Drill than Pre Drill for both Congruent and Incongruent trials. Shorter RT was also demonstrated Post compared to Pre Drill for target and non-target trials on the 2-back task. On the other hand, the data did not support the hypothesis for 0-back or 1-back tasks. 0-back RT to non-targets actually became significantly longer and 1-back RT (to both non-targets and targets) did not significantly change pre to post drill.

The hypothesis that accuracy would not change significantly for easier tasks was not supported by the data for easier tasks (flanker, 0-back), and the hypothesis that accuracy would decrease for more difficult tasks was only partially supported by the data for the more difficult tasks (1-back, 2-back). Yet, data still reflected changes in the expected direction. The data actually revealed decrements in performance on the easier tasks, in addition to decrements seen in one of the more difficult tasks. Flanker accuracy significantly decreased for both congruent and incongruent trials from pre to post drill, with selectively greater decrement to incongruent trial accuracy. This was accompanied by a diminished interference effect for RT and an increase in interference accuracy. 0-back accuracy on target trials and d’ were significantly lower Post Drill than Pre Drill, with no significant change in accuracy on non-target trials. For the 1-back task, target trial accuracy and d’ were significantly lower Post Drill than Pre Drill, with no significant change in non-target trial accuracy. However, the nominal decrease in 2-back accuracy on target trials only approached significance, with no significant change in non-target trial accuracy or d’.

In terms of the hypothesis that response variability would be greater post firefighting, the results are somewhat inconclusive. For the 0-back task, response variability (SD or RT) significantly increased from Pre to Post Drill for non-target trials, with no significant change in SD of RT for target trials. However, for the 1-back task, response variability only significantly increased from Pre to Post Drill for target trials. Data from the Flanker and 2-back tasks fail to support the hypothesis, revealing no significant changes.

Study Aim #4

The fourth study aim proposed to determine the relationship between physical fitness level (particularly aerobic fitness) and cognitive performance immediately following, live-fire maneuvers. What follows addresses that Aim and its various hypotheses.

H_8: It was hypothesized that those individuals with higher estimated aerobic fitness levels would have better accuracy and less variability in RT as measured by working memory and inhibition assessments pre-firefighting than lower-fit individuals. It was further hypothesized that those with higher fitness would perform better on 1-back and 2-back tasks post-firefighting than less fit individuals, because they would recover more quickly.

Higher fitness was correlated with a larger negative change in HR (recovery) from Point of Contact (end of the drill) to the End of all testing (r = 0.45, p = 0.023, n = 25) and from when they sat down in the computer lab to the end of all testing (r = 0.48, p= 0.015, n = 25). A median split for aerobic fitness was made at 44.68 $mL \cdot kg^{-1} \cdot min^{-1}$, with scores inclusive of 44.68 and below being categorized as “lower fit” and scores inclusive of 45.07 $mL \cdot kg^{-1} \cdot min^{-1}$ and above being “higher fit”. All scores ranged from 35.59 to 58.26 $mL \cdot kg^{-1} \cdot min^{-1}$, with an average of 44.68 ± 4.87 $mL \cdot kg^{-1} \cdot min^{-1}$. One-way ANOVA determined no significant difference between lower and higher fit groups for average HR during the drill (p= 0.575) or 60-second averaged HR at the Point of Contact (p= 0.936). This signifies that higher fitness was related to greater recovery, and since HR averages during the drill and at point of contact did not differ between lower and higher fit individuals, higher fit individuals had quicker recovery.

Flanker task: Accuracy & Response Variability

Bivariate correlations (1-tailed p) revealed no significant relationships between aerobic fitness and Post Drill accuracy on the Flanker task (all p-values> 0.08). After performing a median split for aerobic fitness, a one-way ANOVA revealed no significant differences in Post Drill Flanker accuracy between lower and higher fit individuals for Congruent trials, Incongruent trials, nor for Flanker Interference (all $p_{s>}$ > 0.40).

There were significant correlations (1-tailed p) between aerobic fitness and Post Drill Flanker Response Variability on Correct Congruent (r= 0.21, p= 0.030, n = 83) and Correct

Incongruent (r= 0.26, p= 0.009, n = 83) trials (See Table A.10 in the Appendix). No significant differences in Post Drill Flanker Response Variability were seen, after performing a median split for aerobic fitness, between lower and higher fit individuals for all, congruent, or incongruent trials ($p_{s>}$= 0.17).

1-back Task: Accuracy & Response Variability

Bivariate correlations (1-tailed p) revealed no significant correlations between aerobic fitness and Post Drill accuracy on the 1-back task (all p-values > 0.08). A one-way ANOVA, following a median split for aerobic fitness, revealed no significant differences in Post Drill accuracy between lower and higher fit individuals for All trials, non-target trials, or target trials ($p_{s>}$= 0.28).

Bivariate correlations (1-tailed p) revealed no significant correlations between aerobic fitness and Post Drill Response Variability on the 1-back task (all p-values > 0.15). However, after performing a median split for aerobic fitness, a one-way ANOVA revealed a significant difference in response variability for non-target trials between lower fit and higher fit groups [F(1,81) = 4.31, p= 0.04], but no differences for any other measures of 1-back response variability (all p-values > 0.05). Independent samples t-tests determined that post drill response variability on non-target trials was significantly higher for the lower fit group (236.97 ± 105.31 ms) than the higher fit group (195.98 ± 71.81 ms) (t= 2.07, df = 70.40, p= 0.042, M_{diff} = 40.99, 95% CI: 1.45, 80.54).

2-back Task: Accuracy & Response Variability

Bivariate correlations (1-tailed p) revealed no significant correlations between aerobic fitness and Post Drill accuracy on the 2-back task (all p-values > 0.10). A median split on aerobic fitness did not reveal any significant differences in Post Drill accuracy between the fitness groups all p-values > 0.23).

A significant relationship was shown between aerobic fitness and Post Drill Response Variability on the 2-back task for all committed errors (Incorrect trials; $r = -0.21$, $p = 0.038$, $n = 74$), but nothing else. After a median split on aerobic fitness, a one-way ANOVA revealed significant differences in Post Drill response variability between lower and higher fit groups for All [$F(1,81) = 5.99$, $p = 0.017$], non-target [$F(1,81) = 6.39$, $p = 0.013$], Correct All [$F(1,81) = 4.48$, $p = 0.037$], Incorrect All [$F(1,81) = 8.46$, $p = 0.005$], Incorrect non-target [$F(1,81) = 9.53$, $p = 0.003$], and Correct non-target trials [$F(1,81) = 4.91$, $p = 0.030$], but not target, Incorrect target, or Correct target trials ($p_s > 0.08$). Independent samples *t*-tests revealed Post Drill response variability to be significantly greater for lower fit individuals than higher fit individuals for All ($t = 2.45$, df = 80.11, p = 0.017, $M_{diff} = 55.34$ ms, 95% CI: 10.29,100.39), non-target ($t = 2.53$, $df = 81$, $p = 0.013$, $M_{diff} == 57.68$ ms, 95% CI: 12.19, 103.17), Correct All ($t = 2.12$, $df = 81$, $p = 0.037$, $M_{diff} == 47.71$ ms, 95% CI: 2.87, 92.55), Incorrect All ($t = 2.88$, $df = 62.16$, $p = 0.005$, $M_{diff} == 110.91$ ms, 95% CI: 33.98, 187.83), Incorrect non-target ($t = 2.92$, $df = 41.34$, $p = 0.006$, $M_{diff} = 146.21$ ms, 95% CI: 44.95, 247.46), and Correct non-target trials ($t = 2.22$, $df = 81$, $p = 0.030$, $M_{diff} = 50.17$ms, 95% CI: 5.12, 95.23).

Hypothesis 8 Summary

It appears that higher fit individuals did recover more and more quickly than lower fit individuals following firefighting, because average HRs during the drill and at point of contact were not different between the lower and higher fit groups. The hypothesis that higher fit individuals would have better accuracy post drill than lower fit individuals was not supported. The data do support the hypothesis that lower fit individuals would have greater response variability on working memory tasks Post Drill than higher fit individuals, but this seemed to be specific to non-target trials. For inhibition, there appears to be some relationship between aerobic fitness and response variability, but seemingly in the opposite direction of the hypothesis. However, higher and lower fit individuals in this small, healthy, young adult sample did not appear to differ greatly.

H_9: It was hypothesized that, regardless of fitness, those who exerted themselves more during firefighting drills (indicated by higher relative HR and perceived exertion) would make more commission errors on working memory and inhibition assessments.

In terms of inhibition, there was a low positive correlation between average HR during the night-burn drill and the number of commission errors made at Post Drill assessment on All (r= 0.35, p= 0.035, n = 28) and Incongruent trials (r= 0.33, p= 0.046, n= 28), with a trend in the same direction for Congruent trials (r = +0.29, p = 0.065, n = 28). For reference, an average of 11.96 ± 9.2, 10.50 ± 8.0, and 1.46 ± 2.0 commission errors were made on All, Incongruent, and Congruent trials, respectively (for those 28 individuals). Interestingly, average HR during the night-burn drill was inversely related to accuracy on congruent trials (r = -0.48, $p<.01$, n = 28), indicating a relationship between the combination of both types of errors (commission and omission) and HR (for correlation matrices between HR and cognitive performance outcomes, see Tables A.6-A.9 in the Appendix). Those who spent longer actively participating in the drill tended to have fewer commission errors on All (r= -0.21, p= 0.028, n = 85) and Incongruent trials (r= -0.20, p= 0.033, n = 85), but not Congruent trials (r = -0.16, p = 0.070, n =85).

In terms of working memory, RPE End was significantly related to commission errors on 1-back target trials (r= 0.23, p= 0.041, n = 59); however, only 2.17 ± 2.4 of these errors were made). No measures of exertion were related to commission errors on the 2-back task Post Drill (all p = values > 0.10).

Also of note are the significant relationships between the number of errors committed on the 0-back task, signifying relationships between attention and exertion. RPE Post-0 was associated with errors committed on All 0-back trials (r= -0.26, p= 0.024, n = 58), errors committed on 0-back non-target trials (r= -0.30, p= 0.011, n = 58), average HR during the drill (*r*= 0.43, *p*= 0.011, *n* = 28), percent time spent in the moderate HR zone (*r*= -0.38, *p*= 0.024, *n* = 28), and percent time spent in the Vigorous-Extremely Hard HR zone (*r*= 0.51, *p*= 0.003, *n* = 28). Errors committed on 0-back target trials were associated with RPE End (*r*= 0.28, *p*= 0.018, *n* = 58). There was also an inverse relationship between RPE_end and 0-back target accuracy (r = -0.28, p <.05).

Though more of a proxy measure for exertion, Tiredness at the End of the drill was correlated with commission errors on All (*r*= 0.23, *p*= 0.021, *n* = 77), Congruent (*r*= 0.25, *p*= 0.015, *n* = 77), and Incongruent (*r*= 0.20, *p*= 0.045, *n* = 76) Flanker trials, All (*r*= 0.28, *p*= 0.008, *n* = 76) and target (*r*= 0.28, *p*= 0.008, *n*= 76) 0-back trials, All (*r*= 0.32, *p*= 0.002, *n* = 77), non-target (*r*= 0.29, *p*= 0.005, *n* = 77) and target (*r*= 0.24, *p*= 0.019, *n* = 77) 1-back trials, and All (*r*= 0.23, *p*= 0.025, *n* = 77) and target (*r*= 0.24, *p*= 0.019, *n* = 77) 2-back trials. These data seem to support the hypothesis, but the majority of the correlations are low in strength (for correlation matrices between perceptual responses and primary cognitive outcomes see Tables A.2-A.5 in the Appendix).

Study Aim #5

The fifth aim proposed to determine the individual difference variables that best account for variance in cognitive performance immediately following live-fire maneuvers. What follows addresses that Aim and its various hypotheses.

H_{10}: It was hypothesized that higher state anxiety would be correlated with shorter reaction time in a linear fashion, and accuracy would reflect a curvilinear relation to state anxiety. Specifically, lower and higher levels of SA would be associated with greater errors (lower accuracy) while moderate levels of state anxiety would be associated with fewer errors (higher accuracy).

There were no significant curvilinear relationships between State Anxiety (pre or end) or the change in State Anxiety (Pre to Post-0) and Flanker RT on All, Congruent, Incongruent, Correct, or Incorrect trials (all 1-tailed *p*-values > 0.05). Although not significant, there were curvilinear trends in the relationship between anxiety and accuracy (r_s= 0.31), with lower and higher anxiety associated with less accurate responding. Some low-strength bivariate correlations between anxiety and cognitive performance were present, in the anticipated directions (see Tables A.2-A.5 in the Appendix).

n-back Tasks

There was a significant inverse relationship (1-tailed) between 0-back RT on all errors of commission and State Anxiety Post-0 (*r*= -0.36, *p*= 0.022, *n* = 32). When there was a greater increase in State Anxiety from Pre to Post Drill, 0-back RT was shorter on all commission errors (*r*= -0.39, *p*= 0.014, *n* = 32) and commission errors on target trials (*r*= -0.44, *p*= 0.009, *n* = 28). For the 1-back task, there was a significant inverse relationship between State Anxiety End and RT on non-target errors of commission (i.e., Incorrect NT trials; *r*= -0.24, *p*= 0.048, *n* = 51). However, when there was an increase in State Anxiety from Pre to Post Drill, RT on all commission errors was actually longer (*r*= 0.25, *p*= 0.045, *n* = 49). Finally, for the 2-back task, there was significant inverse relationship between State Anxiety Post-0 and RT on all errors of commission (*r*= -0.24, *p*= 0.044, *n* = 54). However, when there was a greater increase in State Anxiety from Pre to Post, RT was longer for target trials (*r*= 0.22, *p*= 0.045, *n* = 58), all correct trials (*r*= 0.24, *p*= 0.036, *n* = 58), Correct targets (*r*= 0.27, *p*= 0.021, *n* = 58) and Correct non-targets (*r*= 0.22, *p*= 0.045, *n* = 58). Higher State Anxiety Pre Drill was significantly related to shorter RT on the 2-back task (see Table A.5 in the Appendix).

Hypothesis 10 Summary

The hypothesis that higher State Anxiety following the drill would be correlated with shorter RT Post Drill was only supported for RT on committed errors for 0-, 1-, and 2-back tasks, with no relationship at all to Flanker performance. Further, when the 1-back and 2-back relationships were examined in terms of change in state anxiety from pre to post, RT on both types of correct trials, and on target trials in general, was actually longer Post Drill if a greater increase in State Anxiety had occurred.

H_{11}: It was hypothesized that individuals who had quicker cardiac recovery following activity would perform as well or better than their pre-firefighting scores on the cognitive tasks compared to those whose HRs remained elevated above 80% of their age-predicted HR maximum throughout cognitive testing (reflecting physiological stress).

Nineteen of the 28 individuals with HR data had HRs that remained elevated above 80% of their age-predicted HR_{max} for any portion of Post Drill cognitive testing. Yet, mean time spent over 80% of age-predicted HR_{max} during the Post Drill cognitive tests was only 0.94 ± 1.37 min, ranging from 0 to 6.83 min. No individual had a HR that remained elevated above 80% throughout even half of post drill cognitive testing. Due to this and the small sample sizes, an alternative approach was taken to examine the relationship between Pre-Post accuracy and cardiac recovery.

Performing a median split of those whom had less and more recovery (calculated as change in $b \cdot min^{-1}$ from the end of the Night-burn Drill to the end of the Post Drill cognitive tests) allowed for one-way ANOVA of accuracy change scores for all cognitive tests. For reference, mean change in HR from POC to End was 58.02 ± 11.01 $b \cdot min^{-1}$, ranging from 35.08 to 78.85, median split at 58.08 $b \cdot min^{-1}$. Significant group differences were found for Pre-Post change in Flanker accuracy on All [$F(1,23) = 4.57$, $p= 0.043$] and Incongruent trials [$F(1,23) = 5.18$, $p= 0.033$], but not Congruent trials ($p= 0.277$), and 0-back All [$F(1,23) = 5.29$, p= 0.031] and Non-target trials [$F(1,23) = 5.70$, $p= 0.026$], but not target trials ($p= 0.104$). No significant differences were present for Pre-Post changes in 1-back or 2-back accuracy between the two recovery groups (all p-values > 0.499).

Paired samples *t*-tests revealed no significant differences in Pre-Post accuracy for Flanker or n-back tasks in the "Less Recovery" group (all *p*-values > 0.10). For the "More Recovery" group, significant differences in Pre-Post accuracy were revealed for Flanker All (*t*= 2.53, *df*=12, M_{diff}= 2.96%, 95% CI: 0.41, 5.51, *p*= 0.026) and Incongruent (*t*= 2.55, *df*= 12, M_{diff} = 4.31%, 95% CI: 0.63, 7.99, *p*= 0.025), but not congruent trials (*p*= 0.080). There were also changes in 1-back accuracy on target trials (*t*= 2.42, *df*= 12, M_{diff} = 3.46%, 95% CI: 0.34, 6.58, *p*= 0.032). Changes in 0-back accuracy on all trials were trending towards significance (*p*= 0.065). Generally, accuracy changes were in the direction of worse performance, with the exception of the 2-back task, which appeared to improve (for all, non-target, and target trials) Pre to Post Drill. Thus, the data is inconclusive about the hypothesis that those who recovered more quickly would display Post Drill accuracy on the cognitive tests that was similar or better than their own Pre Drill accuracy. Those who recovered more from POC to End appeared to perform the same or worse on Flanker, 0-back, and 1-back tasks, but better on 2-back tasks Post Drill. See Tables A.6-A.9 in the Appendix for bivariate correlations between changes in HR and cognitive performance outcomes.

H_{12}: It was hypothesized that perceived exertion, thermal sensation (TS), and respiratory distress would be inversely associated with accuracy. Higher fatigue would be related to slower reaction time and lower accuracy on the flanker and n-back tasks.

Flanker Task

For the Flanker task, only TS Post-0 was significantly correlated with accuracy on congruent trials Post Drill (*r*= -0.29, *p*= 0.027, *n* = 60) (see Table A.2 in the appendix). Upon further examination of changes in perceptual variables over time, there were significant relationships between the change in TS from pre to post-0 where greater increases were associated with greater reductions in accuracy on all (*r*= -0.41, *p*= 0.001, *n* = 60), congruent (*r*= -0.36, *p*= 0.004, *n* =60), and incongruent trials (*r*= -0.36, *p*= 0.004, *n* = 60). Looking at the data in this way, there was also a weak inverse relationship between RPE Post-0 and change in accuracy on all trials (*r*= -0.27, *p*= 0.037, *n* = 60); however, this only approached significance for congruent (*r*= -0.25, *p*= 0.055, *n* = 60) and incongruent trials (*r*= -0.24, *p*= 0.065, *n* = 60). There were no relationships between Respiratory Distress and Flanker accuracy.

The examination of fatigue indicated weak, positive relationships between RT on Flanker Correct Congruent (*r*= 0.28, *p*<.05, *n* = 84) and Correct Incongruent (*r*= 0.29, *p*<.01, *n* = 84) trials and Fatigue Post-0 (but not End), such that higher fatigue was associated with longer RT (see Table A.2 in the Appendix). Greater changes in fatigue from Pre to Post had weak, positive relationships with RT on All (*r*= 0.36, *p*= 0.002, *n* = 59), Correct (*r*= 0.36, *p*= 0.002, *n* = 59), Incorrect (commission errors) (*r*= 0.23, *p*= 0.041, *n* = 58), Congruent (*r*= 0.36, *p*= 0.003, *n* = 59), and Incongruent RT (*r*= 0.35, *p*= 0.003, *n* = 59), as well as the change in Flanker Interference (*r*= 0.23, *p*= 0.038, *n* = 59).

Change in flanker accuracy on congruent trials had a weak, inverse correlation with Fatigue Post-0 (*r*= -0.21, *p*= 0.030, *n* = 84), with higher fatigue Post-0 being related to a greater decrease in accuracy from Pre to Post. No significant relationships were present between End Fatigue and Flanker Accuracy. Greater changes in Fatigue from Pre to Post were associated with greater decrements in Accuracy on All (*r*= -0.23, *p*= 0.038, *n* = 59) and Incongruent trials (*r*= -0.22, *p*= 0.045, *n* = 59) from Pre to Post. Oddly, greater change in Fatigue from Pre to Post was also associated with higher Post Drill accuracy on incongruent trials (*r*= 0.24, *p*= 0.033, *n* = 59).

0-back Task

There were no significant relationships between 0-back accuracy (or changes in accuracy from pre to post) and RPE, TS, or RD Post-0, or changes in any of the perceptual variables from Pre to Post-0 (all *p*-values > 0.05). There also were no significant relationships between 0-back RT and Fatigue Post-0, End, or any changes in Fatigue (all 1-tailed *p*-values >

0.05). There was, however, a low, inverse relationship between Fatigue End and Post Drill 0-back Accuracy on target trials (r= -0.24, p< 0.05). Yet, greater increases in Fatigue from Pre to Post had low, positive associations with accuracy on all and non-target trials.

1-back Task

There were no significant relationships between Post Drill 1-back accuracy and RPE, TS, or RD Post-0, or changes in any of these perceptual variables from Pre to Post-0 (all 2-tailed p-values > 0.05). However, there was a weak, but significant, relationship between TS Post-0 and the Pre to Post change in 1-back accuracy on non-target trials (r= -0.28, p= 0.034, n = 59), such that greater TS Post-0 was associated with decreased accuracy on non-targets from Pre to Post Drill. This relationship approached significance for all 1-back trials (r= -0.26, p= 0.050, n = 59). These relationships were not present for RPE or RD. There were no significant relationships between 1-back RT or Accuracy and VAS Fatigue Post-0, End, or any changes in Fatigue (all 1-tailed p-values > 0.05).

2-back Task

There were no significant relationships between 2-back accuracy and RPE, TS, or RD Post-0, or changes in any of the perceptual variables from Pre to Post-0 (all p-values > 0.05), although, the relationships between TS Post-0 and 2-back accuracy on All trials (r= -0.25, p= 0.054, n = 59) and change in 2-back d' (r= -0.25, p= 0.056, n = 59) did approach significance. There was a significant relationship between TS Post-0 and the change in 2-back accuracy from Pre to Post on All (r= -0.30, p= 0.020, n = 59) and non-target trials (r= -0.27, p= 0.036, n = 59) such that when TS was relatively higher Post-0, accuracy decreased from Pre to Post Drill. This relationship trended in the same direction for RPE Post-0 and change in 2-back accuracy on non-target trials (r= -0.25, p= 0.059, n = 59), but was not present for RD.

Fatigue Post-0 had low, inverse relationships with Post Drill 2-back RT on All, Non-target, target, All Correct, Correct non-target, All Incorrect, Incorrect non-target, and incorrect target trials. Fatigue End was not significantly correlated with Post Drill 2-back RT. Yet, greater increases in Fatigue from Post-0 to End of cognitive testing were related to longer Post Drill RT on Incorrect non-targets. Greater increases in Fatigue from Pre to the very End of cognitive testing were associated with longer Post Drill 2-back RT on target trials (r_s= 0.13 – 0.26, $p_s \geq$ 0.05). Greater increases in Fatigue from Pre to Post-0 were actually associated with improvements in Pre to Post Drill 2-back Accuracy on target trials (r= 0.24, 1-tailed p= 0.034, n = 59). No other relationships were present between Post Drill 2-back Accuracy or Pre to Post changes in Accuracy and Fatigue or changes in Fatigue.

Hypothesis 12 Summary

Different relationships between RPE, TS, RD, and accuracy existed depending on the cognitive task. For the Flanker task, it seemed that higher RPE and TS at the post-0 time point were related to decrements in flanker accuracy; however, RD was unrelated. The relationships between flanker accuracy and RT with fatigue are slightly confusing because there were weak inverse associations with post-drill accuracy and RT, but greater changes in fatigue (pre to post) were actually correlated with higher accuracy on incongruent trials post drill and longer RT. So, the hypothesis seems to be supported for RPE and TS, but not RD and Fatigue, and the strength of these relationships is not as strong as anticipated. The only support for the hypothesis with the 0-back task was that higher fatigue was related to lower accuracy. For 0-back, RPE, TS, nor RD were associated with accuracy and fatigue was not related to RT. For the working memory tasks, only weak relationships were present such that greater TS Post-0 related to diminished accuracy from pre to post. RPE, RD, and Fatigue did not relate to 1-back accuracy, and Fatigue did not relate to 1-back RT. Fatigue post-0 was actually related (low strength) to faster RT on the 2-back task, thus suggesting the opposite of what was hypothesized. However, when fatigue increased from post-0 to end, it did appear to relate to a slowing of RT and better accuracy on the 2-back task.

H_{13}: It was hypothesized that individuals with greater tolerance for intensity of exercise would have higher accuracy than those with lower tolerance, once exertion (perceived and HR) was accounted for.

In the entire data set, there were significant correlations between Tolerance for Intensity of Exercise (post) and Flanker Accuracy on All (*r*= -0.29, *p*= 0.005, *n* = 82), Congruent (*r*= -0.25, *p*= 0.012, *n* = 82), and Incongruent trials (*r*= -0.27, *p*= 0.006, *n* = 82), but no measures of accuracy for any of the n-back tasks. Simple linear regression indicated that Tolerance predicted 8.1%, 6.2%, and 7.5% of variance in Post Drill Flanker Accuracy on All [*F*(1,80) = 7.07, *p*= 0.009], Congruent [*F*(1,80) = 5.30, *p*= 0.024], and Incongruent trials [*F*(1,80) = 6.48, *p*= 0.013], respectively. However, in order to account for average HR during the drill, the sample was drastically diminished (HR data was only available for 28 individuals out of the 82 with Tolerance measures). In this subset sample, there were no significant relationships between tolerance and accuracy on any of the inhibition or working memory assessments. If HR is ignored, RPE could not be accounted for on its own, because it had no bivariate relationships with any accuracy outcome variables that were also present for tolerance. Therefore, the predictive relationship cannot be reliably tested and the hypothesis is not supported.

H_{14}: It was hypothesized that felt arousal and perceived energy would be inversely associated with reaction time.

There were no significant relationships between Felt Arousal or Energy (Post-0 or End) and Flanker RT Post Drill. On the 0-back Task, there were no significant relationships between Felt Arousal and RT. There were no significant relationships between Energy Post-0 and Post Drill 0-back RT. Energy at the End of the evening had weak, inverse relationships with Post Drill 0-back RT on correct target (r=-0.25, p<.05) and correct non-target (r= -0.38, p<.01) trials, indicating shorter RT with higher energy (see Table A.3 in the Appendix). For the 1-back task, no relationships existed between Felt Arousal (Post-0 or End) or Energy (Post-0 or End) and

Post Drill RT. For the 2-back task, a weak, inverse relationship between Felt Arousal at the End and Post Drill 2-back RT on correct non-target trials (*r*= -0.32, *p* <.05; see Table A.5 in the Appendix) was the only one of significance. No other relationships existed between Felt Arousal (Post-0 or End) or Energy (Post-0 or End) and Post Drill 2-back RT. Taken together, Hypothesis 14 appears to only be supported by the data from the 0-back task. Flanker, 1-back, and 2-back data fail to support the hypothesis that Felt Arousal and Energy would be inversely associated with RT.

H_{15}: It was hypothesized that there would be an inverse association between negative affect (lower resilience, or higher trait anxiety or lower coping ability) and cognitive performance scores (lower accuracy, greater variability).

Bivariate correlations (2-tailed) revealed significant correlations between personality factors and Post Drill cognitive performance scores. Numerous low-strength correlations were uncovered. Rather than displaying every significant correlation below, general patterns related to the hypothesis (from significant relationships only) are explained. All correlation matrices with significant relationships for primary outcome variables can be found in the Appendix (See Tables A.2-A.13).

Flanker Task

There were weak, inverse relationships between Resilience [DRS-Commitment (pre)] and Post Drill Flanker Response Variability on All Commission Errors (Incorrect trials) and Incorrect Incongruent trials. There were also weak, positive relationships between DRS-Challenge (pre) and Post Drill Flanker Accuracy on All and Congruent trials, and a weak, inverse relationship with Response Variability on Congruent trials. Trait anxiety had no significant relationships with Flanker Accuracy, and a weak, positive correlation with Post Drill Flanker Response Variability on All Commission Errors (Incorrect trials).

In terms of Coping strategies, Self-Distraction, Active, Reframing, Religion, and Self Blame Coping all had inverse correlations with aspects of Flanker Response Variability, but individual relationships were all of low strength. Substance Use, Emotional Support, and Planning Coping had positive relationships with aspects of Flanker Response Variability, again of low strength. Self-Distraction and Self Blame Coping had weak inverse relationships with Flanker Accuracy, while Emotional Support Coping had a weak, positive correlation with Post Drill Flanker Accuracy on Congruent trials. Denial, Instrumental Support, Disengagement, Venting, Humor, and Acceptance Coping were not related to Post Drill Flanker Accuracy or Response Variability.

An examination of the accuracy change scores (from pre to post drill) provided a number of significant relationships between personality factors and flanker performance. Trait anxiety and Venting Coping had weak, inverse relationships with the change in accuracy on congruent trials, and Denial Coping had a weak, inverse relationship with the change in accuracy on incongruent trials. DRS_Commitment (post) had a weak, inverse relationship with the change in Flanker interference. DRS_Challenge (post) had a weak, positive relationship with the change in accuracy on congruent trials.

0-back Task

Trait anxiety and Resilience (pre) were not related to 0-back accuracy (all p's > 0.05). Only Resilience (post) (DRS_Challenge) had weak, inverse relationships with Post Drill 0-back Accuracy on All trials and d'. Trait anxiety had weak, inverse correlations with Post Drill 0-back Response Variability on target and correct target trials. Resilience (DRS_Commitment (pre and post) had moderate, positive relationships with Post Drill aspects of 0-back Response Variability.

Active Coping had a moderate, inverse relationship with Post Drill 0-back Response Variability on Incorrect target trials. Denial and Disengagement Coping had moderate, positive relationships with Post Drill 0-back Response Variability on Incorrect trials (errors of commission). Substance Use Coping had weak, positive relationships with Post Drill 0-back Response Variability on All, Correct All, non-target, and correct non-target trials. Reframing, Planning, Humor, and Acceptance Coping had weak, positive relationships with Post Drill 0-back Accuracy on either All or non-target trials, while Self Blame Coping had weak, positive relationships with Post Drill 0-back Accuracy on All, target, and non-target trials, and d'. Self-Distraction, Emotional Support, Instrumental Support, Venting, and Religion Coping were not related to Post Drill 0-back Accuracy or Response Variability.

An examination of the accuracy change scores (from pre to post drill) provided a number of significant relationships between personality factors and 0-back performance. Active, Instrumental, and Reframing Coping all had weak, inverse relationships with the change in accuracy on 0-back target trials, and the change in d'. Humor and Acceptance Coping both had weak, positive relationships with the change in 0-back accuracy on non-target trials.

1-back Task

Trait Anxiety and DRS_Commitment (pre) had weak, inverse relationships with Post Drill 1-back Response Variability. DRS_Commitment (post) had moderate, inverse relationships with Post Drill 1-back Accuracy on All, non-target, and target trials, d', and Response Variability on Incorrect target trials. DRS_Control (post) had weak, inverse relationships with Post Drill Accuracy on All trials and d', a moderate, inverse relationship with Response Variability on All Incorrect trials (errors of commission), and a strong, inverse relationship with Response Variability on Incorrect target trials.

Self-Distraction, Active, and Religion Coping had weak, inverse relationships with 1-back accuracy, while Denial Coping had weak, positive relationships with Post Drill 1-back accuracy. Self-Distraction and Substance Use Coping had weak, positive relationships with Post Drill 1-back Response Variability. Denial and Religion Coping had weak, inverse relationships with

Post Drill 1-back Response Variability on All Incorrect and Incorrect target trials. Reframing Coping had a weak, inverse relationship with Post Drill 1-back Response Variability on Incorrect target trials, but a weak, positive relationship with Response Variability on Correct target trials.

An examination of the accuracy change scores (from pre to post drill) provided a number of significant relationships between personality factors and 1-back performance. DRS_Commitment (post) had a weak, inverse relationship with the change in 1-back Accuracy on All trials and change in d'. Self-distraction and Active Coping had moderate, and Instrumental Support and Reframing Coping had weak, inverse relationships with the change in 1-back Accuracy on All trials. Self-Distraction and Active Coping had weak, inverse relationships with the change in accuracy on non-target trials. Active and Reframing Coping had moderate, and Self-Distraction, Instrumental Support, Reframing, Planning, Humor, Acceptance, and Religion Coping had weak, inverse relationships with the change in 1-back Accuracy on target trials. Active Coping had moderate, and Self-Distraction, Instrumental Support, Reframing, and Planning Coping had weak, positive relationships with the change in 1-back d'.

2-back Task

Trait Anxiety had no relationship with Post Drill 2-back accuracy, but had weak, inverse relationships with Response Variability on target and correct target trials. There were no significant relationships between Resilience (pre) measures and Post Drill 2-back Accuracy or Response Variability. DRS_Committment (post) had moderate, inverse relationships with Post Drill 2-back Accuracy on All and non-target trials, and d'. DRS_Challenge (post) had a moderate, positive relationship with Post Drill 2-back Response Variability on Incorrect non-target trials (errors on non-targets).

Active and Reframing Coping had weak, positive relationships with Post Drill 2-back Response Variability on Correct target trials. Emotional Support Disengagement, and Planning Coping had weak, positive relationships with Post Drill 2-back Accuracy, Denial, Emotional

Support, Venting, Humor, and Acceptance, and Reframing Coping all had weak, inverse relationships with aspects of 2-back Response Variability. Self-Distraction, Substance Use, Instrumental Support, Religion Coping, and Self-Blame Coping were not related to Post Drill 2-back Accuracy or Response Variability.

An examination of the accuracy change scores (from pre to post drill) provided a number of significant relationships between personality factors and 2-back performance. Trait anxiety had weak, positive relationships with the change in accuracy on all and non-target trials. DRS_Challenge (pre) had weak, inverse relationships with the change in accuracy on all and target trials, as well as d'. Resilience [DRS_Commitment (post) and DRS_Control (post)] had both weak and moderate, inverse relationships with changes in 2-back accuracy. Active and Planning Coping had weak, inverse relationships with changes in accuracy on either All and/or non-target, but not target trials. Emotional Support Coping had a weak, positive relationship with the change in accuracy on target trials.

Hypothesis 15 Summary

In all, the strongest, most steadfast relationships between personality traits and accuracy were between Resilience and accuracy on working memory tasks, such that higher resilience was related to lower accuracy. The strongest relationships between personality traits and response variability were with Resilience, where greater Commitment and Control were linked to lower response variability on 0-back and 1-back tasks, respectively, but Challenge was linked to greater variability on for 2-back task. Active, Denial, and Disengagement Coping held moderate relationships with response variability on the 0-back, and Active and were linked to accuracy on the 1-back task. Many of the associations between personality and either accuracy or response variability were quite weak, and few reached significance at the p <.01 level. The way hypothesis 15 is written is slightly confusing. It was expected that more resilient individuals would have better accuracy and lower variability in their responding. These data do not support the hypothesis surrounding resilience and accuracy, but rather suggest the opposite. These data do, however, partially support the hypothesis surrounding resilience and response variability, at least for 0 and 1-back tasks. The data does not support the hypothesis in the proposed direction for trait anxiety (more anxiety less accuracy, more anxiety more variability), but seems to indicate more anxiety, less variability, at least for n-back tasks. The description of "low coping ability" also does not make sense in the context of how coping is measured; it was initially meant to be interpreted as the use of more negative coping strategies relating to lower accuracy and greater variability. This seems to be supported for the 0-back task in that Active Coping was related to less variability in RT, while Denial and Disengagement were related to greater variability in RT. However, inverse relationships were present between Active and Reframing Coping and Accuracy on the 1-back task (failing to support the hypothesis).

H_{16}: It was hypothesized that cognitive performance would be impacted (more errors of commission/lower accuracy and greater variability in reaction time) post-firefighting activity compared to pre-firefighting due to distraction from emotional (stress, anxiety), physiological (arousal, fatigue), and environmental sources (heat, smoke, fire, danger, etc.).

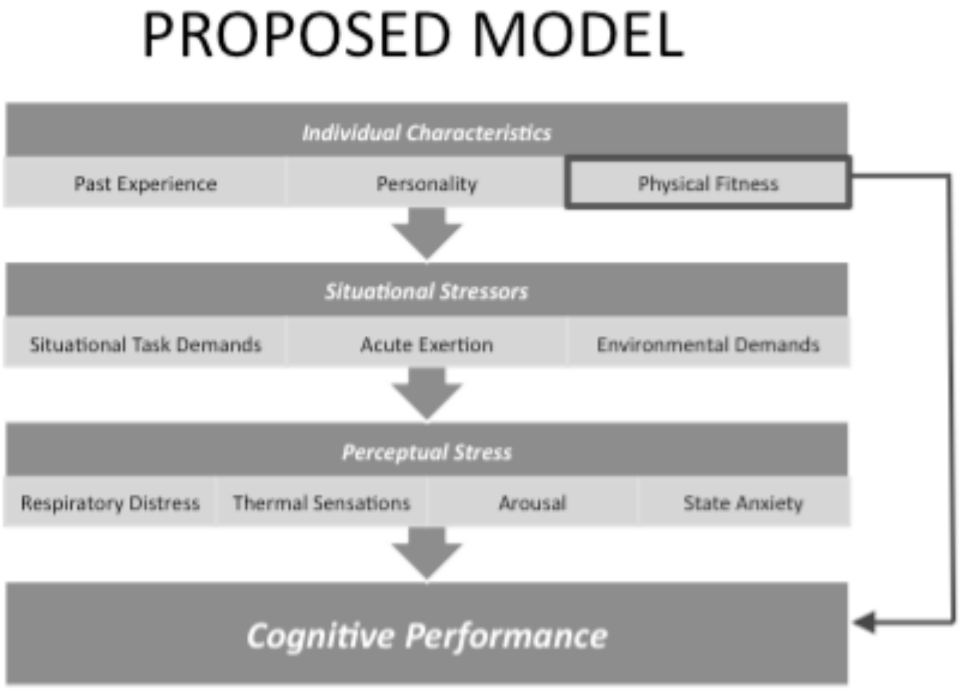


Figure 4.21. The proposed model.

To test the proposed model, hierarchical and then hierarchical multiple regressions were performed. Any dependent outcome variable (i.e., measure of cognitive performance) that had shared predictions was examined via hierarchical linear regression. Hierarchical multiple regressions were performed when multiple variables on the same level predicted the same outcome variables. For example, trait anxiety and self-distraction coping are both individual difference variables, thus they were entered on the same step (Step 3) to determine their combined impact on the dependent outcome variable, after accounting for perceptual stressors. Many inter-level interactions did not make it into final regressions, because one or both of the variables did not predict a cognitive outcome. In the case of situational stress (i.e., HR), hierarchical regressions were performed separately due to the small number of individuals who had complete HR data. Thus, Step 2 was essentially skipped in many cases.

Hierarchical Multiple Regressions: Combining Level Factors with Shared Predicted Outcomes

Flanker task.

Outcome: Post drill flanker omission errors on all trials. Self-Distraction Coping, Reframing Coping, DRS Challenge (pre-academy), AD ACL Tiredness Post-0, VAS Nervousness End, AD ACL Energy End, and AD ACL Tiredness End were all identified previously as significant independent predictors of Post Drill Flanker Omission Errors on All trials. Further, there existed at least one connection between Level 2 and Level 1 predictors. Hierarchical multiple regression determined that the individual differences factors of Self-Distraction Coping, Reframing Coping, and DRS Challenge (pre-academy) did not predict any unique variance in Post Drill Flanker Omission Errors on All trials once the perceptual variables of Tiredness (Post-0, End), Nervousness End, and Energy End were accounted for (see Table 4.19). Together, the perceptual variables explained 22.7% of variance in Post Drill Flanker Omission Errors on All trials, with VAS Nervousness End and ADACL Tiredness Post-0 carrying the largest β-weights.

Table 4.19 Prediction of Post Drill Flanker Omission Errors on All Trials by Level 2 Individual Difference Variables (Coping and Resilience) Accounting for Level 1 Perceptual Variables (Tiredness, Nervousness and Energy)

		b	SE b	β
Step 1				
	Constant	-0.82	1.63	
	AD ACL Energy End	-0.02	0.07	-0.04
	AD ACL Tiredness End	-0.12	0.08	-0.26
	VAS Nervousness End	0.26	0.11	0.35*
	AD ACL Tiredness Post-0	0.22	0.08	0.43*
Step 2				
	Constant	-1.47	2.58	
	AD ACL Energy End	-0.03	0.08	-.06
	AD ACL Tiredness End	-0.10	0.09	-.23
	VAS Nervousness End	0.27	0.11	.37*
	ADACL Tiredness Post-0	0.22	0.09	.43*
	DRS Challenge (pre-academy)	0.05	0.11	.08
	Self-Distraction Coping	-0.11	0.19	-.09
	Reframing Coping	0.05	0.22	.04

Note: R^2 = 0.227 (p = 0.006) for Step 1: ΔR^2 = 0.044 (p = 0.105) for Step 2. *p < .05, ** p < .01, ***p < .001

Outcome: Post drill flanker omission errors on incongruent trials. Level 2 predictors [Self-Distraction Coping, DRS Challenge (pre-academy)] and Level 1 predictors (AD ACL Tiredness End, AD ACL Energy End, Change in Thermal Sensation from Pre to End) were all identified previously as significant predictors of Post Drill Flanker Omission Errors on Incongruent trials. AD ACL Tiredness End and Change in Thermal Sensation from Pre to End were shared by both Level 2 factors, while AD ACL Energy End was only predicted by DRS Challenge (pre-academy). Hierarchical multiple regression determined that the individual differences factors of

Self-Distraction Coping, Reframing Coping, and DRS Challenge (pre-academy) did not predict any unique variance in Post Drill Flanker Omission Errors on Incongruent trials once the perceptual variables of Tiredness (End), Energy End, and Change in Thermal Sensation from Pre to End were accounted for (see Table 4.20). Together, the perceptual variables explained 20.4% of variance in Post Drill Flanker Omission Errors on Incongruent trials, with the change in Thermal Sensation from Pre to End carrying the largest β-weight.

Table 4.20 Prediction of Post Drill Flanker Omission Errors on Incongruent Trials by Level 2 Individual Difference Variables (Coping and Resilience) Accounting for Level 1 Perceptual Variables (Tiredness, Energy, and Change in Thermal Sensation)

		b	SE b	β
Step 1				
	Constant	0.75	0.76	
	AD ACL Energy End		0.04	-.11
	AD ACL Tiredness End		0.04	.17
	Change in Thermal Sensation (End – Pre)		0.09	-.43**
Step 2				
	Constant	0.33	1.08	
	AD ACL Energy End	-0.03	0.04	-.12
	AD ACL Tiredness End	0.04	0.04	.18
	Change in Thermal Sensation (End – Pre)	-0.29	0.11	-.42**
	DRS Challenge (pre-academy)	0.03	0.05	.07
	Self-Distraction Coping	0.01	0.10	.02

Note: R^2 = 0.204 (p = 0.016) for Step 1: ΔR^2 = 0.006 (p = 0.858) for Step 2. *p < .05, ** p < .01, ***p < .001

Outcome: Post drill flanker response variability on correct congruent trials. Level 2 predictor [DRS Challenge (pre-academy)] and Level 1 predictors (AD ACL Tiredness End, AD ACL Energy End) were identified previously as significant predictors of Post Drill Flanker

Response Variability on Correct Congruent trials. Both Level 1 predictors were shared by the Level 2 factor. Hierarchical multiple regression determined that the individual difference of DRS Challenge (pre-academy) did not predict any unique variance in Post Drill Flanker Response Variability on Correct Congruent trials once the perceptual variables of Tiredness End and Energy End were accounted for (see Table 4.21). Together, the perceptual variables explained 14.6% of variance in Post Drill Flanker Response Variability on Correct Congruent trials, with ADACL Tiredness End carrying the largest β-weight.

Table 4.21 Prediction of Post Drill Flanker Response Variability on Correct Congruent Trials by Level 2 Individual Difference Variable (Resilience) Accounting for Level 1 Perceptual Variables (Tiredness and Energy)

		b	SE b	β
Step 1				
	Constant	47.55	22.03	
	AD ACL Energy End	-0.89	1.10	-.11
	AD ACL Tiredness End	2.23	1.05	.30*
Step 2				
	Constant	54.03	31.72	
	AD ACL Energy End	-0.87	1.11	-.11
	AD ACL Tiredness End	2.15	1.09	.29 †
	DRS Challenge (pre-academy)	-0.42	1.47	-.04

Note: $R^2 = 0.146$ ($p = 0.004$) for Step 1: $\Delta R^2 = 0.001$ ($p = 0.776$) for Step 2. *$p < .05$, ** $p < .01$, ***$p < .001$, † $p = 0.053$ (approaching significance)

Outcome: Post drill flanker accuracy on congruent trials. Level 2 predictors [Emotional Stability (Big-5), Self-Distraction Coping, Tolerance (post-academy), DRS Challenge (pre-academy)] and Level 1 predictors (VAS Nervousness End, Felt Arousal End, AD ACL Tiredness End) were identified previously as significant predictors of Post Drill Flanker Accuracy on Congruent trials. VAS Nervousness End was shared by Tolerance (post-academy) and Emotional Stability, AD ACL Tiredness End was shared by Self-Distraction Coping and DRS

Challenge (pre-academy), while Self-Distraction Coping only predicted Felt Arousal End. Hierarchical multiple regression determined that the individual differences did not predict any unique variance in Post Drill Flanker Accuracy on Congruent trials once the perceptual variables were accounted for (see Table 4.22). Together, the perceptual variables explained 19.2% of variance in Post Drill Flanker Accuracy on Congruent trials, with Felt Arousal End carrying the largest β-weight.

Table 4.22 Prediction of Post Drill Flanker Accuracy on Congruent Trials by Level 2 Individual Difference Variables (Personality, Coping, Tolerance, and Resilience) Accounting for Level 1 Perceptual Variables (Nervousness, Arousal, and Tiredness)

		b	SE b	β
Step 1				
	Constant	104.53	2.93	
	AD ACL Tiredness End	-0.14	0.16	-.14
	Felt Arousal End	-1.12	0.43	-.40*
	VAS Nervousness End	-0.38	0.23	-.23
Step 2				
	Constant	99.10	6.97	
	AD ACL Tiredness End	-0.09	0.17	-.09
	Felt Arousal End	-1.06	0.46	-.38*
	VAS Nervousness End	-0.31	0.27	-.19
	DRS Challenge (pre-academy)	0.07	0.26	.05
	Self-Distraction Coping	-0.17	0.43	-.06
	Tolerance (post-academy)	-0.05	0.14	-.05
	Emotional Stability (Big-5)	0.14	0.10	.23

Note: R^2 = 0.192 (p = 0.026) for Step 1: ΔR^2 = 0.060 (p = 0.547) for Step 2. *p < .05, ** p < .01, ***p < .001

Outcome: Pre to post change in flanker accuracy on congruent trials. Level 2 predictor [Emotional Stability (Big-5)] and Level 1 predictors (VAS Nervousness End, State Anxiety Post-0, AD ACL Tension End) were all identified previously as significant predictors of the Change in Flanker Accuracy on Congruent trials from Pre to Post Drill. All Level 1 predictors were shared by the Level 2 factor. Hierarchical multiple regression determined that the individual difference of Emotional Stability (Big-5) did not predict any unique variance in the Change in Flanker Accuracy on Congruent trials from Pre to Post Drill once the perceptual variables were accounted for (see Table 4.23). Together, the perceptual variables explained 30.3% of variance in the Change in Flanker Accuracy on Congruent trials, with Felt Arousal End carrying the largest β-weight.

Table 4.23 Prediction of the Change in Flanker Accuracy on Congruent Trials from Pre to Post Drill by Level 2 Individual Difference Variable (Emotional Stability) Accounting for Level 1 Perceptual Variables (Nervousness, State Anxiety, and Tension)

		b	SE b	β
Step 1				
	Constant	5.95	1.68	
	State Anxiety Post-0	-0.19	0.09	-.36*
	AD ACL Tension End	-0.14	0.16	-.15
	VAS Nervousness End	-0.31	0.16	.24†
Step 2				
	Constant	0.72	3.48	
	State Anxiety Post-0	-0.17	0.09	-.32††
	AD ACL Tension End	-0.11	0.16	-.12
	VAS Nervousness End	-0.25	0.16	-.19
	Emotional Stability (Big-5)	0.11	0.06	.22

Note: R^2 = 0.303 (p = 0.001) for Step 1: ΔR^2 = 0.041 (p = 0.094) for Step 2. *p < .05, ** p < .01, ***p < .001, † p = 0.060, †† p = 0.053

0-back task.

Outcome: Post drill 0-back RT on target trials. Level 2 predictors [Active Coping, Agreeableness (Big-5)] and Level 1 predictors (AD ACL Calmness Post-0, Felt Arousal Post-0) were previously identified as significant predictors of Post Drill 0-back RT on target trials. AD ACL Calmness Post-0 was shared by both Level 2 factors, while Active Coping only predicted Felt Arousal Post-0. Hierarchical multiple regression determined that the individual differences did not predict any unique variance in the Post Drill 0-back RT on target trials once the perceptual variables were accounted for (see Table 4.24). Together, the perceptual variables explained 15.1% of variance in Post Drill 0-back RT on Target trials; however, no single factor carried a significant β-weight.

Table 4.24 Prediction of Post Drill 0-back RT on Target trials by Level 2 Individual Difference Variables (Active Coping and Agreeableness) Accounting for Level 1 Perceptual Variables (Calmness and Arousal)

		b	SE b	β
Step 1				
	Constant	527.76	57.87	
	Felt Arousal Post-0	-5.26	6.97	-.13
	AD ACL Calmness Post-0	5.95	3.34	.30
Step 2				
	Constant	631.91	124.70	
	Felt Arousal Post-0	-3.33	7.16	-.08
	AD ACL Calmness Post-0	5.14	3.53	.26
	Agreeableness (Big-5)	-1.02	2.53	-.06
	Active Coping	-10.50	9.25	-.18

Note: R^2 = 0.151 (p = 0.030) for Step 1: ΔR^2 = 0.036 (p = 0.415) for Step 2. *p < .05, ** p < .01, ***p < .001

1-back task.

Outcome: Pre to post change in 1-back d'. Level 2 predictors [Intellect/Openness (Big-5), Self-Distraction Coping, Active Coping] and Level 1 predictors (RPE End, Felt Arousal Post-0) were all identified previously as significant predictors of the change in 1-back d' from Pre to Post Drill. Felt Arousal Post-0 was shared by Intellect/Openness (Big-5) and Active Coping, while Self-Distraction Coping only predicted RPE End. Hierarchical multiple regression determined that the individual differences from Level 2 predicted 20.5% unique variance in the change in 1-

back d' from Pre to Post Drill once the perceptual variables were accounted for (see Table 4.25). Together, the perceptual variables explained 18.0% of variance in bringing the model fit to *R* =.621, R^2 = .386.

Table 4.25 Prediction of the Pre to Post Change in 1-back d' by Level 2 Individual Difference Variables (Intellect/Openness, Self-Distraction Coping, and Active Coping) Accounting for Level 1 Perceptual Variables (RPE and Arousal)

		b	SE b	β
Step 1				
	Constant	-1.13	0.49	
	Felt Arousal Post-0	0.17	0.07	.33*
	RPE End	0.07	0.03	.30*
Step 2				
	Constant	-3.32	0.77	
	Felt Arousal Post-0	0.11	0.07	.22
	RPE End	0.06	0.03	.27†
	Self-Distraction Coping	0.13	0.09	.21
	Intellect/Openness (Big-5)	0.02	0.02	.17
	Active Coping	0.17	0.11	.24

Note: R^2 = 0.180 (p = 0.011) for Step 1: ΔR^2 = 0.205 (p = 0.007) for Step 2. *p < .05, ** p < .01, ***p < .001, † p = 0.059

Outcome: Post Drill 1-back response variability on incorrect target trials. Level 2 predictors [DRS Commitment (pre-academy), Extraversion (Big-5)] and Level 1 predictors (Change in VAS Calmness from Pre to End, RPE End) were identified as significant predictors of Post Drill 1-back Response Variability on Incorrect target trials. RPE End was predicted by DRS Commitment (pre-academy), while Change in VAS Calmness from Pre to End was predicted by Extraversion. Hierarchical multiple regression determined that the individual differences from Level 2 did not predict any unique variance in Post Drill 1-back Response Variability on Incorrect target trials once the perceptual variables were accounted for (see Table

4.26). Together, the perceptual variables explained 24.7%; however, no single factor carried a significant β-weight.

Table 4.26 Prediction of Post Drill 1-back Response Variability on Incorrect Target Trials by Level 2 Individual Difference Variables (Resilience and Personality) Accounting for Level 1 Perceptual Variables (RPE and Calmness)

		b	SE b	β
Step 1				
	Constant	71.29	92.86	
	RPE End	12.72	8.52	.26
	Change in VAS Calmness (End – Pre)	-19.68	9.99	-.35†
Step 2				
	Constant	146.31	214.87	
	RPE End	5.72	8.56	.12
	Change in VAS Calmness (End – Pre)	-12.34	9.78	-.22
	DRS Commitment (pre-academy)	-22.71	13.20	-.35
	Extraversion (Big-5)	12.20	4.98	.51*

Note: R^2 = 0.247 (p = 0.022) for Step 1: ΔR^2 = 0.147 (p = 0.066) for Step 2. *p < .05, ** p < .01, ***p < .001, † p = 0.059

Outcome: Post drill 1-back RT on target trials. Level 2 predictors (Trait Anxiety, Self-Distraction Coping) and Level 1 predictors (Change in State Anxiety from Pre to End, AD ACL Tiredness End) were identified previously as significant predictors of Post Drill 1-back RT on target trials. Self-Distraction Coping predicted AD ACL Tiredness End, while Trait Anxiety predicted the Change in State Anxiety from Pre to End. Hierarchical multiple regression determined that the individual differences from Level 2 predicted 11.8% unique variance in Post Drill 1-back RT on target trials once the perceptual variables were accounted for (see Table 4.27). Together, the perceptual variables explained 13.0%; bringing the model fit to R=.498, R^2= .248, with Trait Anxiety carrying the only significant β-weight.

Table 4.27 Prediction of Post Drill 1-back RT on Target Trials by Level 2 Individual Difference Variables (Trait Anxiety and Coping) Accounting for Level 1 Perceptual Variables (State Anxiety and Tiredness)

		b	SE b	β
Step 1				
	Constant	609.64	59.80	
	Change in State Anxiety (End – Pre)	7.12	2.83	.35*
	ADACL Tiredness End	2.576	4.64	.08
Step 2				
	Constant	695.92	91.90	
	Change in State Anxiety (End – Pre)	4.60	2.89	.22
	ADACL Tiredness End	3.49	4.58	.10
	Trait Anxiety	-5.17	2.09	-.34*
	Self-Distraction Coping	15.92	13.20	.17

Note: $R^2 = 0.130$ ($p = 0.041$) for Step 1: $\Delta R^2 = 0.118$ ($p = 0.041$) for Step 2. *$p < .05$, ** $p < .01$, ***$p < .001$

Outcome: Post drill 1-back accuracy on target trials. Level 2 predictors [Self-Distraction Coping, Intellect/Openness (Big-5)] and Level 1 predictors (AD ACL Calmness End, AD ACL Tiredness End) were all identified previously as significant predictors of Post Drill 1-back Accuracy on target trials. Self-Distraction Coping predicted AD ACL Tiredness End, while Intellect/Openness predicted AD ACL Calmness End. Hierarchical multiple regression determined that the individual differences from Level 2 did not predict any unique variance in Post Drill 1-back Accuracy on target trials once the perceptual variables were accounted for (see Table 4.28). Together, the perceptual variables explained 16.3%, with AD ACL Calmness End carrying the only significant β-weight.

Table 4.28 Prediction of Post Drill 1-back Accuracy on Target Trials by Level 2 Individual Difference Variables (Coping and Personality) Accounting for Level 1 Perceptual Variables (Calmness and Tiredness)

	b	SE b	β
Step 1			
Constant	71.40	9.14	
ADACL Tiredness End	-0.46	0.46	-.14
ADACL Calmness End	1.98	0.68	.40**
Step 2			
Constant	97.70	16.52	
ADACL Tiredness End	-0.35	0.46	-.11
ADACL Calmness End	1.51	0.71	.31*
Self-Distraction Coping	-1.24	1.32	-.14
Intellect/Openness (Big-5)	-0.46	0.31	-.22

Note: R^2 = 0.163 (p = 0.018) for Step 1: ΔR^2 = 0.071 (p = 0.150) for Step 2. *p < .05, ** p < .01, ***p < .001

Fifteen other hierarchical regressions and nine other hierarchical multiple regressions were built based on shared relationships between levels; however, none of these reached statistical significance (p < 0.05) for predicting the shared cognitive outcome.

CHAPTER 5

DISCUSSION

The purpose of this investigation was to identify changes in firefighter cognitive performance from pre- to post- participation in a night-burn training drill, both in relation to personal traits as well as physiological and perceptual responses to the event. The first primary aim was to describe academy firefighters on various individual difference parameters. The second primary aim was to examine participants' changes in heart rate, and perceptual states before, immediately after, and ~30 minutes post-firefighting. The third primary aim was to determine the impact of firefighting on cognitive behavioral performance immediately post-firefighting in terms of working memory and cognitive inhibition. The fourth primary aim involved determining the relationships that existed specifically between aerobic fitness and cognitive performance immediately following live-fire maneuvers. The fifth, and final, aim was to determine the individual difference variables that best accounted for variance in cognitive performance immediately following live-fire maneuvers.

Participants

From Fall of 2013 to Spring of 2015, data were collected from 85 adult, male firefighters. Average BMI for the participants (27.04 ± 4.47, range= 17.45 to 46.47) classifies the overall sample as overweight (25.0-29.9), with some falling below the normal range (18.5-24.9) and some being classified as obese (≥30; World Health Organization [WHO], 2016). This is similar to ranges reported previously (Horn et al., 2015). The estimated aerobic fitness of the current sample of firefighters was 44.68 ± 4.87 $ml\cdot kg^{-1}\cdot min^{-1}$, with individual values ranging from 35.59 to 58.26 $ml\cdot kg^{-1}\cdot min^{-1}$. The aerobic fitness of our sample was within the range of average firefighter aerobic fitness (Barr, Gregson, & Reilly, 2010), where a combination of measured and estimated values ranged from 39.6 to 61 $ml\cdot kg^{-1}\cdot min^{-1}$. This level of fitness is also satisfactory for performance of firefighting activities based on minimal aerobic fitness recommendations (45 and

33.5 ml·kg^{-1}·min^{-1}), set due to wearing heavy PPE, physical exertion, and fatigue (Gledhill & Jamnik, 1992; & Sothmann et al., 1990, respectively) and the NFPA supports the recommendation of at least 42 ml·kg^{-1}·min^{-1} (NFPA, 2013). Fitness in this sample was also higher than that measured in other new-hires (Roberts, O'Dea, Boyce, & Mannix, 2002). Fitness was lower than some groups of slightly older (late 30s) male firefighters (Elsner & Kolkhorst, 2008; Garver et al., 2005), even though firefighter fitness has been shown to decrease with age (Baur, Christophi, Cook, & Kales, 2012; Saupe, Sothmann, & Jasenof, 1991).

Attention

Simple attention was assessed via the 0-back task, where participants only had to discriminate between one target stimulus and any other non-target stimulus. In the current study, RT on all 0-back non-target trials became significantly longer from pre to post, though numerically only by 20 milliseconds, with no change in target trial RT. Prior studies of the impact of firefighting on simple information processing have revealed faster reaction times (Greenlee et al., 2014) and no change (Smith, Manning, & Petruzzello, 2001). Physical exertion under heated conditions has also demonstrated no change in RT on simple tasks (McMorris et al., 2006; Zhang et al., 2014), so the present results are different. Though not statistically significant, it seemed that those who did 0-back as the final task in the n-back sequence were generally slower than those who performed the 0-back first in the sequence, and this occurred for two of the three cohorts studied. Longer RTs on these trials would suggest that more time may have been required to either determine and/or produce the appropriate response.

Accuracy, on the other hand did decrease significantly, driven by the 2.05% decrease in accuracy on target trials (non-target trials demonstrated no change). This information, in addition to the RT results, suggests that decreases in accuracy were not a result of a speed-accuracy trade-off. The slowing of RT on non-target trials and the decrease in accuracy might also represent brain regions competing for resources between attention and emotion regulation (due to heightened awareness during the stressful event, and perceptions of thermal strain, respiratory distress, perceived exertion, negative affect, and fatigue that lasted throughout the entirety of the post testing session). This may reflect difficulty in concentrating, perhaps deliberating their response, straining to maintain good performance, or simply a lapse in attention during deliberation. Response variability on the 0-back task was also greater for non-target trials following firefighting, indicating that the ability to focus was perturbed following firefighting activity. Greater response variability (reflected by SD of RT) has been interpreted to reflect cognitive dysfunction or strained function (Ode, Robinson, & Hanson, 2011; Swick, Honzel, Larsen, & Ashley, 2013). However, concussion research has provided evidence that greater response variability can be a byproduct of RT slowing (e.g., Sosnoff et al., 2007). Concussed individuals presented with lower accuracy and greater response variability on a flanker task than healthy individuals.

Response times to a relatively simple measure of attention became longer, accuracy diminished, and variability in responding increased. This was seen when attention was assessed anywhere from 10-18 minutes following firefighting. In previous studies, firefighters have presented with shorter RTs on a simple information processing task following activity (about 7-10 min post firefighting) and remained fast for two hours following firefighting; however, accuracy on these tasks was no different than pre-firefighting (Greenlee et al., 2014). A small study (n = 7) reported no change in RT or accuracy following 16 mins of firefighting, though there was a trend for increasing error rate as individuals returned for successive bouts of firefighting activity (Smith, Manning, & Petruzzello, 2001).

Other studies of heat stress have provided equivocal results. An exertional heat stress test on a treadmill, lasting 90 minutes or until volitional exhaustion, resulted in decreases in accuracy on simple attention tasks, but only in those who were not acclimated to the heat (Radakovic et al., 2007). In contrast, up to 50 minutes of treadmill exercise in PPE in a heated room (33–35ºC) (non-firefighters) did not result in any changes in simple reaction time when measured immediately post-exercise (Morley et al., 2012). A daylong reconnaissance drill of varying intensities of work, in a hot environment, resulted in faster RT as the day went on, and increasing accuracy (Amos, Hansen, Lau, & Michalski, 2000). This could have been due to a learning effect throughout the day, or the intermittent nature of the physical activity may have allowed for rest and recovery between testing periods. Nonetheless, performance was not negatively influenced by heat and exertion in that case. Thus, something about the combined stresses of the firefighting activity, not just the relatively higher intensity activity, or the heat stress, may have resulted in this significant decrease in RT and accuracy immediately following firefighting.

To a certain point, stress and arousal may benefit cognitive performance, while too low or too high levels may be detrimental or not impact performance, depending on the task (inverted-U hypothesis; Davey, 1973). It could be that more intense stress (such as that elicited from our night-burn drill) is required to induce heightened arousal that endures for a longer period of time following activity and influences cognitive performance.

Cognitive Inhibition

Cognitive inhibitory performance was assessed within ~5 minutes of completing the night-burn drill, using the modified flanker task. Reaction time was significantly shorter post drill than pre drill for both correct congruent and correct incongruent trials. This result has been shown by others when assessing RT in young adults on the modified flanker task immediately post-exercise (Kamijo et al., 2004; Kamijo, Nishihira, Higashiura, & Kuroiwa, 2007). Still, others have reported no change or only marginally significant decreases in flanker RT following acute exercise (Gothe et al., 2013; Hillman, Snook, & Jerome, 2003; Kamijo et al., 2009; Themanson & Hillman, 2006). Two of these studies provided light and moderate intensity exercise stimuli (Gothe et al. 2013, Kamijo et al., 2009), whereas the current firefighting stimulus was high intensity, based on mean HR during the drill. The other two did provide a vigorous intensity exercise stimulus of 30 minutes, but measured modified flanker performance only after HR had returned to within 10% of baseline, which averaged 40-48 minutes post exercise, after all post testing would have concluded in the current study of firefighters (Hillman, Snook, & Jerome, 2003; Themanson & Hillman, 2006). When other measures of cognitive inhibition (i.e., Stroop task) have been used to assess young adults immediately (within 10 minutes) following exercise, RT has been shorter (Chang et al., 2014; Tonoli et al., 2015). In the current study, response variability on the flanker task did not change at all from pre to post firefighting.

Accuracy on modified flanker trials dropped by larger (-3%) and smaller (-1%) decrements on incongruent and congruent trials, respectively. Incongruent trials are typically more challenging, but acute exercise research has generally demonstrated no changes in flanker accuracy following moderate intensity aerobic exercise (Davranche, Hall, & McMorris, 2009; Hillman et al., 2003; Kamijo, Nishihira, Higashiura, & Kuroiwa, 2007). Some have even reported improvements in accuracy post-exercise, with accuracy on incongruent trials improving even more than congruent trials (Pontifex, 2013; Hillman et al., 2009; Drollette et al., 2014). However, flanker accuracy has been shown to be impaired *during* moderate intensity exercise (Olson, Chang, Brush, Kwok, Gordon, & Alderman, 2015). Thus, it could be that the psychophysiological state of the firefighters following the night-burn drill in the current study was more similar to what individuals might be experiencing during exercise, rather than following exercise, at least in laboratory settings. In the context of firefighting, it is unclear what practical relevance this seemingly small change in performance might have.

Ideally, it would seem undesirable to have accuracy on a learned task diminish by 1-3% after doing firefighting activity—especially if that task required ignoring distractions in order to make a decision that avoided injury, fatality, or more time spent in a dangerous environment than is necessary. Between 2006 and 2008, fire development was listed as the top general contributing factor to firefighter injury on-scene, accounting for 30.5% of fire-related injuries (United States Department of Homeland Security [USDHS], 2011). This shows the necessity for firefighters to be able to adapt quickly and make decisions based upon how the environment is changing in order to maintain safety. For example, if it was learned that whenever a certain scenario ("x") presents itself on the fireground, you do a programmed behavior ("y"). On the first day of training the firefighter might fumble around and forget to do "y", but do "z" instead. Through academy they learn to do "y", and do "y" very well. Then, stress or other distractions in the environment may influence their ability to acknowledge the need to execute "y", and they might revert back to "z" or some other option. An example of this occurred during one of the night-burns in the current study. Recruits were told to provide water supply from the hydrant, and most performed the skill in a timely manner because they had learned this and practiced it during training. However, during one of the stressful night-burn scenarios, one individual attempted to turn the wrench in the wrong direction and struggled for a long period of time trying to provide water supply. Meanwhile, the fire was growing, any "victims" were spending longer amounts of time inside potentially inhaling smoke, and team members were forced to wait to perform their duties. Likewise, as fire develops, the scenario that originally presented itself may change, resulting in the need to inhibit their initial plan to do "y" and select an alternate strategy.

There was significantly less flanker interference post drill compared to pre drill (-Δ of 9.77 ms) indicating that although RTs for both incongruent and congruent trials decreased following firefighting, RT on incongruent trials decreased more. This reduced flanker interference is generally considered positive because it reflects a reduction of the effort required to manage the conflict that arises when targets are flanked by irrelevant distracting stimuli (O'Leary, Pontifex, Scudder, Brown, & Hillman, 2011). This change in interference is consistent with previous acute exercise research. Research with children and young adults has shown that flanker interference is reduced following 20 minutes of moderate treadmill exercise, compared to rest (Hillman et al., 2009; O'Leary et al., 2011). However, in this case it did not seem to be advantageous due to the fact that the reduced interference occurred in the presence of diminished accuracy on both types of trials (incongruent and congruent).

Accuracy of performance on the modified flanker task was relatively high at pre drill, and still relatively high at post drill (with the mean accuracy being 93%, 97%, and 90%, on all, congruent, and incongruent trials). Yet, the small amount of change that occurred could still be a cause for concern. As an integral aspect of executive control, cognitive inhibition serves to block irrelevant information in order to attend to and process relevant information. If this isn't done efficiently, even small decrements at this level could translate into a cascade of detrimental effects. These could include longer processing times, reduced ability to maintain and manipulate information in working memory, or impaired capacity to switch between tasks, ultimately resulting in performance of an action that cannot be retracted. In a firefighting scenario, failure of the executive control system to perform at its best could lead to injury or more time spent in a dangerous setting, increasing risk of injury. There is also the possibility that the translated effects of a 1-3% decrease of accuracy in cognitive inhibitory performance would not result in negative consequences on the fire ground. However, if firefighting does have this effect on inhibitory control in young, relatively healthy adults of average fitness it could potentially become problematic as they age. Further, that 1-3% was the average decrement for the group; the decrement was even greater for certain individuals.

Working Memory

Reaction Time (RT). In the current study, working memory on increasingly difficult tasks was examined through performance on serial 1-back and 2-back tasks. RT on the 1-back task did not change significantly in response to firefighting. However, when the data was examined more closely, different effects appeared to emerge depending on when the 1-back task was performed in the sequence of tasks. RT to all 1-back trials was nominally longer post drill than pre drill when it was done in the order of Flanker, 0-back, 1-back, and 2-back, and appeared to be driven by responses to target trials (also significantly longer). Yet, when the order was Flanker, 1-back, 2-back, 0-back, target trial RTs were nominally shorter post drill than pre drill, displaying the opposite effect. A likely explanation for the shorter RTs when the 1-back was performed earlier in the sequence would be heightened stimulation from the stress of the night-burn event. Heightened arousal in response to moderate intensity exercise has previously been demonstrated to result in shorter processing speeds (McMorris & Hale, 2012). RTs may have slowed over recovery as has been seen previously, accounting for the longer RTs seen when the 1-back was performed later in the sequence (Smith, Manning, & Petruzzello, 2001). Though not examined statistically, this contrasting effect of firefighting does not appear to be due to a general performance difference on the 1-back task, because pre drill RTs were similar. Further, this pattern remained for all correct target trials, indicating that it was not derived from any divergent attempts to maintain accuracy. Since the perceptual responses to the night-burn drill did not differ when different task sequences were used, it is not thought that cognitive performance differences arose from any greater or lesser psychophysiological strain elicited from the separate night-burn events. The slower RTs when the 1-back is performed longer after firefighting activity has ended would presumably be due to relative decreases in arousal and energy, and sustained feelings of fatigue and negative affect. Rather, the order of task completion and timing of assessment may have contributed to the contrasting effects and could also explain the net zero change in RT seen from our statistical tests. Non-significant changes in RT could also be due to the differential increases and decreases that occurred for different individuals (i.e., inter-individual variability), potentially indicating individual differences in responses to firefighting stress.

Recent evidence from cognitive psychology suggests that performance of a working memory task before another working memory task might activate more attention-oriented brain activity. Scharinger, Soutschek, Schubert, and Gerjets (2015) investigated use of the flanker paradigm within the n-back paradigm. They used a modified flanker letters task in 0-, 1-, and 2-back conditions to examine the interplay between inhibitory control and working memory updating. The flanker interference effect (statistically) disappeared in the 2-back paradigm, while it persisted in lower load 0-back and 1-back tasks (Scharinger et al.). These authors and Sörqvist and Rönnberg (2014) have both suggested that the more individuals need to engage in the task, such as the difficult 2-back, the less distracting stimuli may matter. Essentially, working memory updating enhances attention and improves inhibitory control, because this is requisite for accomplishing higher loads on working memory.

Thus, another explanation for the null effect of firefighting on 1-back RT could be that changes in RT on 1-back tasks are somehow impacted by the task performed immediately prior to their completion. Performance of either the 0-back (a relatively easier task) or the 2-back (a relatively more challenging task) prior to the 1-back could have somehow impacted the way in which the brain was allocating resources towards processing the tasks, influencing the level of focus that was being provided, at least initially, to performance of the 1-back task, ultimately resulting in contrasting outcomes for RT performance following firefighting. Hence, when the sequence order was 2-back, 1-back, 0-back 1-back RTs were nominally faster than when the order was 0-back, 1-back, and 2-back.

In the current study, the uninfluenced (“true”) effect of firefighting on 1-back would be best represented by the order of 1-, 2-, 0-back. The decrease in RT on target trials in this sequence only approached significance though, leaving the conclusion to be that firefighting had no effect on 1-back RT when measured within ~10-14 minutes of drill completion. Another way of putting this might be that the more time passes following completion of a drill, the more concern you might have about slowed RTs, potentially implicating diminished working memory during overhaul or salvage following a more intense fire suppression and search and rescue activity. Working memory might be particularly important during the handling of charged hose, overhaul, forcible entry, and ground ladder use, four of the most injury provoking activities that firefighters participate in (Duncan, Littau, Kurzius-Spencer, & Burgess, 2014). During handling of a charged hose and overhaul, it is especially important that firefighters are aware of their environment, monitoring things such as floor stability, proper ventilation, and uneven ground, while completing their job duties (Duncan et al., 2014). Unfortunately, we did not have a sequence where the 1-back task was completed last to be able to address this assumption. Yet, if this assumption holds, it is recognized that salvage and overhaul tasks, themselves, are extremely physically demanding (Smith, Petruzzello, Kramer, & Misner, 1997). This brings up the importance of considering implementation of a secondary relief crew that could take over this stage of the fire response scenario, as well as addressing the financial burden on departments for providing extra personnel to accommodate such a need. As of 2011, there was still no evidence that efforts have been made to increase assignment of at least 4 career firefighters to an engine or pumper, towards compliance with recommendations from NFPA 1710 (NFPA, 2011). Thus, future examination of this effect is needed.

Fortunately, 2-back data is available at all three positions in the n-back task sequence (the modified flanker was completed immediately post drill, prior to the n-back tasks): first (~10 mins post drill), second (~14 mins post drill), and third (~18 mins post drill). It is clear that 2-back RT was significantly reduced following firefighting. Shorter 2-back RTs have been demonstrated before following moderate intensity exercise (Hogan, Mata, & Carstensen, 2013). Visual inspection of 2-back RTs revealed a dose (time) response effect, such that the more time accumulated post drill, the longer RTs on target trials got. It could be that the longer time went on, and energy decreased, 2-back RT slowed. Shorter delays between the end of firefighting and the point of assessment might elicit shorter RTs (energy is up still, arousal is higher, HR is higher). The previous argument that having a working memory task precede another working memory test would facilitate performance on the subsequent task is still upheld. However, at post drill it seems as if the firefighting stimulus (whether it was arousal or something else about the firefighting activity driving performance changes) influenced 2-back RT such that when the 2-back was performed first in the task sequence for n-backs, RTs were faster than when it was performed in other locations in the sequence. Working memory processing seemed to be hastened by firefighting, possibly slowing throughout recovery.

One way to examine this working memory "priming" effect in the brain might be to examine where in the trial block errors actually occurred. If they occurred early in the trial block for individuals who had not yet completed the other working memory task, it might lend evidence to support our theory. Likewise, if there is a front-end distribution of errors in a group that had not yet completed another working memory task, and there was a more even distribution of errors throughout the entire trial block for a group that had already completed a working memory task, the theory would find further support. However, absence of a clear front-end distribution of errors in the 120 or 210 task sequence would fail to support this theory.

Reaction time on a working memory task has been shown to be shorter both immediately and 30 minutes following 30 minutes of moderate aerobic exercise (Pontifex, Hillman, Fernhall, Thompson, & Valentini, 2009). Pontifex et al. also found that this relative decrease in RT from pre to post exercise was disproportionately larger when the level of difficulty of the working memory task was higher, which may help explain why we saw significant decreases in RT for the 2-back task and not for the 1-back task.

Accuracy. For 1-back accuracy, accuracy on target trials decreased after firefighting. It is probable that some of the decreases in accuracy could be attributable to the deficit seen in inhibitory processing, as working memory depends upon efficient inhibition of irrelevant inputs. Visually, both Spring 2014 (0-1-2 completers) and Spring 2015 (2-1-0 completers) cohorts presented with decreases in accuracy. Both of these cohorts had reacted similarly in terms of

RT, leading more credibility to the idea that timing of assessment may hold some responsibility for this. Fall 2014 showed no change in 1-back accuracy. As Spring 2014 seemed to show a greater relative decrement in performance than Spring 2015, it may be that worse performance on 1-back was due to performing 0-back first and not being ready (“primed”) to do a working memory task once energy started to lose wane, whereas when performance already primed with the 2-back was better. If errors occurred earlier in the block of 80 trials, this assumption would support the claims of Scharinger, Soutschek, Schubert, and Gerjets (2015) and Sörqvist and Rönnberg (2014). If there is no general pattern for where the errors occurred within the trial block, then an explanation is unknown at this point.

The findings for 2-back accuracy make the effect of firefighting on working memory seem a little less clear. Target trials occurred infrequently, totaling 20% of all trials in the 80-trial block. Shorter RT on correct target trials of the 2-back would initially suggest facilitated performance. However, a decrease in accuracy on target trials (~3.2%) approached significance. It is possible that no significant change was seen for 2-back performance, because individuals had maxed out their n-level for this type of working memory task. As they did not receive any kind of working memory training intervention, as a group they may have not been able to perform any better than they did at pre test, making any decrements that occurred post test appear insignificant.

If there were a simple linear relationship between time of assessment and performance, then one might expect the 2-1-0 sequence to do the best and the 1-2-0 sequence to do middle, since the 0-1-2 sequence demonstrated the only significant within cohort decrements (down 7% for all trials, down 14% for targets, $-\Delta d' = -0.98$). Though not significant, accuracy improved very slightly for 0-1-2 (up 1% on all trials, up 1.3% for targets, $+\Delta d' = 0.18$) and decreased slightly for 2-1-0 (down 1% for all trials, down 2.5% for targets, $-\Delta d' = 0.11$). The result that 2-back accuracy only decreased significantly post drill when the tasks were completed in the ascending order (0-1-2) could have been due to fatigue, but since RT was slower, it was not result of a speed-accuracy trade-off.

It was predicted that 1- and 2-back tasks would show the greatest decrements in accuracy in response to firefighting, relative to the easier 0-back and flanker tasks, because research has shown that as the complexity of cognitive function increases, heat has a greater negative impact than when simple cognitive functions are examined (Enander & Hygge, 1990; Hancock & Vasmatzidis, 2003; Wetsel, 2011). However, it could be that since the firefighters had been removed from the extreme heat for at least 10 minutes by the time they began the first n-back task, heat played less of a role. Our thermal perception results did demonstrate a decline (i.e., perceptions of being less hot) from post-0 to end. Firefighters had doffed their helmets, mask, air pack, and gloves before entering the computer lab, relieving a good amount of thermal strain. We had attempted to maintain some thermal strain by asking firefighters remain in their turnout jackets (closed if possible); however, they were also given the option to unzip or remove the jackets if they felt too uncomfortable (which many ended up doing). It was originally hypothesized that the more complex working memory tasks (1- and 2-back) would show decreases in accuracy from pre to post firefighting, but it seemed to be the case that 1-back was impacted more negatively than 2-back.

It was also thought that flanker accuracy would only decrease slightly or not at all following firefighting, relative to changes seen in the n-back tasks. Instead, we actually found flanker accuracy to have the most striking decrements. McMorris et al. (2011) had previously reported a moderate detrimental effect of exercise on working memory when individuals exercised at a moderate intensity level. The negative effects of firefighting seen on 1-back task accuracy in this study may have been driven by this task being completed later into recovery, and perhaps perceptual states at that time may reflect how one might feel in response to moderate exercise, even though the firefighting drill itself was more strenuous. When it came to the 2-back task, only 1 cohort completed this at the end of their task order and showed declines in performance. Energy was lowest at this point in the evening, potentially providing some explanation.

Another group has examined both flanker and n-back following acute exertion. Weng, Pierce, Darling, and Voss (2015) demonstrated that acute moderate intensity cycling benefitted working memory performance, where 1-back and 2-back accuracy improved by 2.57% and 6.40%, respectively. N-back RT also decreased following active exercise, while flanker performance (accuracy and RT) remained unchanged by active exercise (Weng et al.). In this case, 26 individuals were randomized and counterbalanced across four groups, either completing flanker or n-back first after an active 30-min exercise bout (with 5 min warm-up and 5 min cool-down) or a control. The beginning of cognitive assessment began about 6 min post exercise, with flanker or n-back occurring at 6 or 12 min post depending on the order; this was very similar to the current firefighting study. Interestingly, the selective improvement that they saw for 2-back was also present in the 1-2-0 sequence. Contrary to the current findings where there were decreases in both RT and accuracy, they saw no change in flanker performance.

After a simulated firefighting drill (completed by civilians), Robinson et al. (2013) demonstrated better working memory performance (as measured by a grammatical reasoning task) for a sample of individuals who were assessed immediately after firefighting, compared to a sample who were assessed 20 minutes post firefighting. Thus, it very well could be that the delayed after-effects of firefighting are more detrimental to performance, whereas heightened situational awareness, and the physiological arousal that comes with it, may maintain performance when measured very close to the end of activity.

Response Variability. In terms of response variability on the 1-back task, there was a significant increase in SD of RT on target trials in response to the firefighting stimulus. Both 0-back, 1-back, 2-back and 2-back, 1-back, 0-back sequences demonstrated increased variability on 1-back correct target trials, from pre to post drill. Perhaps this indicated greater effort to perform due to diminishing working memory ability as time went on following the live-fire maneuver. However, no significant changes were present with respect to SD of RT for the 2-back task.

Additional Notes on Cognitive Performance

The impact that task order might have on cognitive performance scores measured pre to post firefighting was examined as an exploratory analysis. The initial switch from the 0-1-2 order was made in Fall of 2014 to move the assessment of working memory tasks closer in time to the end of the firefighting drill. The ascending task order of 0-back, 1-back, 2-back was originally used for its intuitive learning order when individuals encounter the task for the first time. However, in order to examine working memory effects of firefighting, the 0-back test of attention was moved to the end of the order, allowing the 1-back to be assessed 4 minutes earlier. The modified flanker task remained as the first in the sequence so that there was a constant measure of cognitive performance to compare across groups that was measured at the same time. On Baseline day, the Fall 2014 cohort still learned and practiced the tasks in the ascending order. Pre and Posttests followed the order of 120. In Spring of 2015, it was thought that since we had captured performance on 012, and 120 orders, we would also want to see if the 210 order captured any different trends in performance, particularly having the most challenging working memory task closer to the end of the firefighting drill. Since the 2-back task is so mentally challenging during the learning period, it was decided to have them practice on Baseline day in the order that they would test pre-post (i.e., 2, 1, 0).

This unfortunately introduces another confound to the between group comparisons, because the Fall 2014 group learned the test at baseline in one order, and then tested in another order, while the other two groups maintained their learning orders on test day (Spring 2014: 012; Spring 2015: 201). Thus, we included the baseline comparisons only in the appendix, because all groups maintained their pre to post-test task orders, and could be more reliably compared to each other across this time point only. Analyses included Academy as a between subjects factor. However, interactions can be interpreted in a few different ways. It could be that interactions represented differences in task order, individual-level differences of the samples, or cohort effects. Further, there is an issue of small sample size in the Spring 2014 cohort (n = 11 for pre-post comparisons), which could sometimes be driving interactions that may not actually exist with a larger sample, possibly discrediting the task order argument. Lastly, though the academies did not differ in demographics (aside from the two lesser-fit individuals in Spring 2014), these comparisons were between subjects.

A review of acute exercise effects on executive function reported a small-to-moderate positive effect of exercise on interference control, but no significant effect on working memory (Verburgh Königs, Scherder, & Oosterlaan, 2014). This, along with the inverted-U theory of optimal arousal for cognitive performance may explain why interference control in our study was more negatively impacted following exertion, while working memory seemed less influenced. If inhibitory control improves following exercise, it may be that when measured after some delay following the end of the drill (greater than the ~5 min delay assessed here), inhibitory control is enhanced. Working memory would benefit from this increased ability to inhibit information that is no longer pertinent to the assessment of a constantly changing n-back stimulus, in relation to a current stimulus. Exercise studies have demonstrated faster RT on the 2-back task when measured within 5 mins post-exercise (Gothe et al., 2013; Hogan, Mata, & Carstensen, 2013). Hogan, Mata, and Carstensen (2013) examined 15 minutes (plus warm-up and cool-down) of moderate intensity aerobic cycling and saw no changes in accuracy (Hogan et al.). Interestingly, Gothe et al. (2013) reported both decreases in RT and noticeable increases in accuracy (5 and 10%) on 1-back and 2-back tests of working memory following 20 minutes of yoga practice, but not aerobic exercise or rest in college-aged females. The Gothe et al. study provides both a mode difference and different sex sample from our firefighting study, but findings were noteworthy.

When discussing decision making in work environments like firefighting, the influence of team members present in the scenario must be considered. Presence of others may influence how stress affects an individual, and ultimately their cognitive performance (see review, Staal, Bolton, Yaroush, & Bourne, 2008). Firefighting has been described as a coordinated effort among individuals who differ in occupational rank (McLennan, Omodei, Holgate, & Wearing, 2003). The juxtaposition of an individual with lower rank needing to make decisions on the front line, while being still concerned with how the Incident Commander, Instructor, or their partner might react to it, is constantly at play, in addition to how their decision might impact all of these other individuals, themselves, and any victims they may be attempting to save. If individuals can anticipate each other's' actions and feel that they have good social support, they may perform better and even have lower stress responses than if they were performing alone (LeBlanc, 2009).

Lack of situational awareness is defined by the IAFF as "the absence of knowledge and understanding of the environment that is critical to those who need to make decisions in complex areas such as fire ground operations, air traffic control, and military command and control" (Moore-Merrell, Zhou, McDonald-Valentine, Goldstein, & Slocum, 2008, p. 15). Lack of situational awareness accounted for 37.3% of line-of-duty injuries in metropolitan firefighters, with 28.5% stemming from lack of wellness/fitness, and 10.6% from human error (Moore-Merrell et al.). Though it is true that the academy recruits will not be accomplishing complex cognitive tasks, executive control during the night-burn drill is not a "complex" decision of where to put the line in or when to approach the 3rd floor. Cognitive control has been described by Miller and Cohen (2001) as the taking in of information from environment, using of knowledge to integrate past and present information, inhibition of irrelevant information, prediction of the impact of immediate actions, and focusing on current goals, all at the same time (Coutlee & Huettel, 2012). In this way, it is the ability to attend to relevant information in the environment and from pre-existing schemas, process the information and elicit the appropriate behavioral outcome based on the current situation. Though firefighting behaviors may be largely physical and relatively well-learned, it is the subtle alterations from training and experience which are needed to perform their job at each slightly varied emergency response scenario that require optimal cognitive control (i.e., inhibition, working memory, and cognitive flexibility). Fatigue may very well alter the firefighter's ability to do this, resulting in a set way of acting (e.g., "muscle memory") that may or may not be safe for the given situation. Executive control processes never become automatic (Rogers & Monsell, 1995 as cited in Pontifex et al., 2009). So, in a fire scenario what might occur is higher level functioning is what coordinates the choosing of a certain schema and the manipulation of that schema based upon the current scenario. Working memory is a cognitive control process necessary to regulate use of schemas that already exist (Kane & Engle, 2000). It may be that schemata interfere with cognitive performance in unpredictable situations but free up working memory capacity in a situation where a trained individual is dealing with new information to process.

Potential Mechanisms

In order to fully understand the aforementioned relationships between physical exertion, heat, and cognition physiological responses to stress of firefighting should be examined. Reactions to altered levels of hormones and catecholamines during a stress response, may have the ability to influence the brain. Stress results in the activation of the Hypothalamic-Pituitary-Adrenocortical (HPA)-axis, which downstream, elicits many hormones and catecholamines (Tsigos & Chrousos, 2002). The cortisol response from the HPA-axis is certainly active in response to moderate to high intensity, acute physical activity (such as that which may occur during a firefighting maneuver; Hill, Zack, Battaglini, Viru, Viru, & Hackney, 2008). Perroni et al. (2009) demonstrated increases in salivary cortisol peaking at 108.5% 30 minutes after completing physically taxing firefighting drills (no heat), returning to baseline 90 minutes later. Sünram-Lea et al. (2012) have reported increases in cortisol immediately after a 60-min live-fire simulated search and rescue, but decreased substantially 30 minutes post, potentially due to differences in the drills and recovery. Cortisol appears to affect both cognition and emotional processes through its actions on the hippocampus and amygdala (de Kloet, Fitzsimons, Datson, Meijer, & Vreugdenhil, 2009).

A review by Kashihara et al. (2009) suggests that the inverted-U curve for cognitive performance and intensity of exercise is seen because neurotransmitter release to a certain point is good, but beyond that point too much is no longer beneficial. This could explain the positive effects seen in response to moderate exercise, in the sense that this may provide an optimal stimulus. When an individual exercises to an intensity that results in relatively greater distress and fatigue, substances released in response to those psychological states are also high in quantity while cognitive performance appears to be diminished (Kashihara et al.). It is unclear whether and how long this effect might endure following activity, but likely differs as a function of the intensity of the activity and the delay in time for cognitive assessment (Chang, Labban, Gapin, & Etnier, 2012). It is not a new idea that the products of acute and chronic stress responses (i.e., glucocorticoids, catecholamines) elicit both positive and negative changes in cognition, namely learning and memory (Bourne & Yaroush, 2003; Gold, 2005; McEwen & Sapolsky, 1995). A recent review demonstrated links between multiple hormones of the endocrine system and cognitive performance (Aleman & Torres-Alemán, 2009). Growth factors, insulin, leptin, ghrelin, and sex hormones all have supporting evidence for either positive or negative influences (Aleman & Torres-Alemán).

Specifically, McMorris and Hale (2012) reported findings that RT is shorter during, but not after, acute exercise and concluded that this was likely due to exercise induced arousal which results in the release of dopamine and norepinephrine neurotransmitters. Evidence of longer RT on the n-back task has been shown in healthy individuals taking dopamine antagonists; bilateral ventrolateral PFC activation was diminished and RTs were longer on all n-back (0, 1, 2) trials relative to a placebo and a dopamine partial agonist (Goozee et al., 2016). It is thought that dopamine activity is elevated in efforts to tolerate demands of exercise in heated conditions (Bridge, Weller, Rayson, & Jones, 2003). As there is an inverted-U relationship between optimal dopamine levels and executive control performance (Cools & D'Esposito, 2011), such that too low and too high levels are related to impaired performance, some interplay between exertion, psychological stress, and thermoregulation in the firefighting environment may very well have contributed to differing levels of pre-post change in cognitive performance.

Increased levels of epinephrine and norepinephrine have previously been associated with increased arousal and alertness thought to help maintain adequate performance under stress (Palinkas et al., 2007; Weeks, McAuliffe, DuRussel, & Pasquina, 2010). Changes in catecholamines and adrenocorticotropin hormone in response to high intensity exercise have been linked to changes in RT and errors on the flanker task (i.e., greater increases in neurobiological representations of arousal were correlated with smaller increases in RT and more errors; McMorris et al., 2009). Working memory appears to be negatively impacted by cortisol increases (Lupien, Maheu, Tu, Fiocco, & Schramek, 2007; Taverniers, Van Ruysseveldt, Smeets, & von Grumbkow, 2010).

The endocrinological stress response appears to differ with respect to training and familiarity with stressful conditions. The magnitude of the response may also matter, as individuals who have a larger cortisol response to an event have been seen to perform better 30 minutes later than those who had smaller cortisol responses to the same event (Absi, Hugdahl, & Lovallo, 2002 as cited in Bourne & Yaroush, 2003). Soldiers who have more experience with extreme situations tend to have greater release of epinephrine (associated with increased alertness) than inexperienced soldiers, presumably allowing them to perform even better in the face of stress (Weeks, McAuliffe, DuRussel, & Pasquina, 2010). Those who are more endurance trained have heightened catecholamine responses to intense exercise as well (Zouhal, Jacob, Delamarche, & Gratas-Delamarche, 2008).

Acevedo and Ekkekakis (2001) proposed a transactional psychobiological model that depicts the important contributions that individual differences (e.g., personality and past experience) have on the cognitive appraisal of perceptions that arise from participating in physical exertion in stressful environments, further contributing to the physiological stress response. This provides support for an argument that traits innate to each individual may help explain why people both react to stress differently and consequently present with differing alterations in cognition, possibly accounting for some of the divergence in cognitive performance (i.e., some get faster, some get slower, some have better accuracy, some perform worse) of different individuals in response to the same stressful event (e.g., firefighting).

On top of this, Dietrich’s Transient Hypofrontality Hypothesis suggests that when an individual is exercising the prefrontal cortex (PFC) has to compete with the motor cortex for resources. This results in diminishing allocation of resources to the PFC and diminishing capacity of this system to perform cognitive work (Dietrich, 2003; Miller & Cohen, 2001), because executive control processes depend on PFC activation (Courtney, Petit, Haxby, & Ungerleider, 1998; Wagner, Maril, Bjork, & Schacter, 2001). The theory of Reticular Hypofrontality posits that arousal from exercising (i.e., stress) is increased and prefrontal cortex activation is also increased, sometimes leading to improved performance of well-learned and habitual tasks (Dietrich & Audiffren, 2011). Acute moderate exercise elicits increased dorsolateral prefrontal activation (Yanagisawa et al., 2010). It has previously been accepted that non-executive tasks require less PFC activity and are more concerned with attention and alertness (Dietrich & Audiffren, 2011), which is why they may be less impacted by moderate levels of exertion. More strenuous exercise could overwhelm the PFC to the demise of higher-level cognitive performance on tasks requiring the PFC (Dietrich & Sparling, 2004; Dietrich, 2006; McMorris & Hale, 2012). Alternatively, Hommel et al. (2011) has suggested that greater environmental stress demands (i.e., noise) may stimulate more activation in brain regions responsible for cognitive control, possibly as a compensation mechanism. This might help explain why working memory performance dropped off as stress demands decayed over time after the end of the drill, but not why cognitive inhibitory performance decreased immediately following firefighting.

If fatigue after-effects are culprit to some of performance decrements seen later in the evening, it could be explained by compensatory control of performance under stressful conditions earlier in the evening (Hockey, 1997). For instance, cognitive control demands either during the firefighting activity itself (not assessed here) or the initial attempts to perform well on the first (flanker) and subsequent (n-back) tasks may have been fighting to maintain performance under high stress, but at some point (likely different for different people) the neural system could no longer perform at optimal levels, and performance scores suffered. Then, as people recovered (again at different rates), perhaps task stimulation or personality (increased motivation to perform well) kicked back in to help them perform well (possibly explaining why some people showed decrements and others did not). Further, when individuals attempt to suppress negative affect, amygdala activation has been shown to decline while PFC activation increases (Phan, Fitzgerald, Nathan, Moore, Uhde, & Tancer, 2005).

It is very plausible that the inverted-U hypothesis for exercise-induced arousal and cognitive performance can explain why some evidence from the acute exercise literature suggests a small positive effect of exercise on cognitive performance, with selective enhancement of tasks requiring more executive control (Tomporowski, 2003) while others have reported equivocal findings (Brisswalter et al., 2002; McMorris & Graydon, 2000). Relating their conclusions to the findings within the current study of firefighters, it seems that timing of the task assessment and psychophysiological state of the individual during that assessment may be the factors which confound the ability to discern clear effects of exertion on cognitive performance. The notion that timing of assessment was an important issue has been mentioned previously (Tomporowski, Beasman, Ganio, & Cureton, 2007).

Exercise induced arousal has reportedly been reduced following high intensity exercise, with moderate intensity exercise providing more optimal levels for simple information processing (Kamijo et al., 2004). In the current study, 0-back performance declined, which may reflect this phenomenon, since two of our groups did the 0-back last in their order when arousal from firefighting was declining. The decrements seen in attention seemed to translate to worse 1-back performance on targets, but not to any widespread effects on 2-back performance. This could be because: (a) 2-back first was aided by arousal; (b) 2-back last was hindered by fatigue or low energy; (c) performance of the 2-back benefitted from doing 1-back first; or (d) because no two cohorts were assessed at the same time point.

Firefighting activity obviously differs from most of the acute exercise reported in the literature, especially in regard to the thermal strain, extra weight that must be carried in PPE, and the nature of study in the field versus a laboratory. The present study utilized actual firefighting tasks performed under heat and psychological stress. A review by Lambourne and Tomporowski (2010) reported that regardless of the type of exercise, even if it was fatiguing, cognitive performance generally improved post exercise (*d*= 0.20). It is likely that at the time point at which the studies included in the review made their assessments, the psychophysiological state of the individuals was conducive to facilitated performance on the tasks they assessed. Given the current results, it appears that the context of the physical activity, the type of cognitive task, and the attentional state of the individual (based upon prior completion of other cognitive assessments) all contributed to the performance effects seen, and in the case of firefighting, performance effects following activity seem to be negative.

Cognitive Performance Summary

Fire is unpredictable and conditions can often worsen instantaneously, creating pressure for time-sensitive execution of tasks during fire fighting. In relation to cognitive performance, time pressure has been shown to influence decreases in RT, especially on decision making tasks that usually elicit longer RTs without any time pressure (Dror, Busemeyer & Basola, 1999). Though performance must be quick, it must also be accurate. Inaccurate judgment calls or imprecise behaviors could result in injury, or worse. In an attempt to mimic these real-life requirements, task instructions read to the firefighters prior to computerized cognitive testing emphasized the need to respond quickly, but also as accurately as possible. All of the main effects seen for the group only tell part of the story. As has been suggested by O'Neal and Bishop (2010), some individuals improve, others get worse, and some stay the same in response to a combination of cycling and arm curls in a heated environment until volitional exhaustion. Parasuraman and Jiang (2012) provide a review of evidence revealing individual differences in brain activation patterns, event-related potentials, and genetics which relate to divergent cognitive performance effects seen in research studies and discuss the importance of examining data in this way to uncover differences that would likely be masked by performing group level analyses. Strenuous firefighting activity, at least in this night-burn drill, may be detrimental to executive control performance and the psychophysiological responses that individuals have to such an event. There seemed to be a selective decrement in cognitive performance for aspects requiring more control (incongruent trials on the flanker task and target trials on the n-back task) following participation in this live-fire night-burn drill. In addition, the personal traits and cognitive skill that they bring to the table to begin with may influence the basic relationship between exertion and cognition.

Model Testing

This section provides preliminary insights on the influence of physiological and perceptual responses to firefighting, as well as individual difference traits, on cognitive performance. It must be noted that in this group, there is definitely less variability in individual difference variables than there would be in a group of firefighters coming from a wider age range, a broader range of fitness levels, differing levels of experience, different geographic locales, and one that also includes females. Thus, a larger, more diverse sample will be more appropriate for determining reliable relationships between individual difference variables and cognitive performance in firefighters. For most of the individual difference factors, weak relationships existed were found with cognitive performance variables, and likely many were by chance occurrence. However, a few stood out as being more salient, and an even more distinct few showed predictive relationships with cognitive performance in this firefighting scenario. A hierarchical model of firefighters' executive control performance in response to participation in a live-fire maneuver was initially proposed which placed individual differences at the third level, situational stressors (e.g., HR) at the second level, and perceptual stresses (e.g., thermal strain, respiratory distress, felt arousal) as having the most direct influence as predictors (see Figure 2 in Chapter 3).

In terms of perceptual variables, respiratory distress was removed from the model of working memory performance due to the failure to find significant relationships, and RPE was additionally removed for just 2-back task performance. In terms of individual difference variables, trait anxiety was removed from the cognitive inhibitory performance model. BMI, aerobic fitness, and emotional stability (Big 5 personality trait) were all removed from the model for working memory performance. The only two perceptual variables that had no relationships with any of the individual difference factors were the post-0 measures of respiratory distress and nervousness.

Factors that remained in the model were those having a relationship between the individual difference factor and a perceptual factor, and both of those were independently related to the same cognitive performance variable. An extensive list of factors remained. However, that also means that factors from the individual difference level and the perceptual level that had independent relationships with cognitive performance factors, but were unrelated to each other, were not included in the analysis. It does appear that certain individual differences, perceptual responses, and HR do provide some direct predictive capacity of executive control performance following firefighting. As these were not the focus of the model the way it was proposed, and so many relationships were present in this preliminary search, these will not be discussed in depth here. The factors that were relevant to the specific hypotheses are discussed above. Ultimately, being able to predict cognitive performance from psychophysiological states provides limited, but useful, control over an otherwise unknown situation. In terms of prevention, firefighters may be able to train to prolong the amount of time they can spend firefighting before decrements in performance occur. Certain individual difference traits may be advantageous for cognitive performance and firefighters can train towards enhancing those traits.

Physiological responses to firefighting. HR during the firefighting drill acted in a manner that was expected. HR increased slightly, but significantly, as firefighters left the pre drill cognitive testing session and began waiting for the simulated emergency call. Since this was a training exercise, they knew that a call would come at some point, so anticipation of the stress could have contributed to this rise. Further, this increase in HR included the short walk from the computer lab to the station and any bathroom breaks, talking, or moving around that occurred as the recruits sat together in the station. Previous reports of anticipatory rises in HR have been seen prior to simulated firefighting drills (e.g., smoke diving) (Kivimäki & Lusa, 1994) and in real-life emergency response situations when firefighters are on their way to the scene and the extent of physiological stimulation may depend on the information of the impending emergency scenario received during dispatch or during ingress on the way to the scene (Brown & Stickford, n.d.).

Similar anticipatory rises in anxiety (indicated by increased HR) have also been reported by studies of individuals preparing to parachute jump, with data indicating (though not significant) possible negative learning effects on a motor tracking task due to anticipatory anxiety (Hammerton & Tickner, 1969). However, physiological indicators may not always match in a time-sensitive manner with cognitive performance, suggesting that perceptual responses may be better predictors of performance. Increases in state anxiety have been reported when individuals were in anticipation of helicopter underwater evacuation training and immediately following that stress, while working memory was preserved during the anticipation of the stress but performance worsened after experiencing the stressful scenario and salivary cortisol did not increase until 25 minutes post-stressor (Robinson, Sünram-Lea, Leach, Owen-Lynch, 2008).

During drill completion, average HR rose by about 62 $b \cdot min^{-1}$ compared to the average HR while awaiting the emergency call (reaching a mean drill HR of 158.35 ± 10.53 $b \cdot min^{-1}$). Only 21 minutes of intermittent firefighting drills have been shown to elicit age-predicted maximal HR in young adult firefighters (Smith, Manning, & Petruzzello, 2001). Even performing firefighting drills outside at an airport for 18-20 minutes only resulted in a peak HR of 96.89 ± 7.35% of age predicted HR_{max} (Del Sal et al., 2009). Others have shown an increase of 75 $b \cdot min^{-1}$ at the end of 18 min of firefighting (Smith et al., 2011). This is about the same as has been reported for actual structural fires (Sothmann et al., 1992), and about 30 $b \cdot min^{-1}$ lower than reported in other live fire drills and activities, though these usually lasted <25 mins (for summary table of mean HR in firefighting see review by Eglin, 2007). Others have reported average HRs of 152.1 $b \cdot min^{-1}$, 168 $b \cdot min^{-1}$, and 167.4 (M_{peak}) $b \cdot min^{-1}$ during 12, 18, and 18 min durations of firefighting activity (Burgess et al., 2012; Horn et al., 2011, Smith et al., 2011).

From the end of the drill through the end of the cognitive tests, HR declined (~31 b·min^{-1}), but remained significantly elevated above pre- drill levels. Previous research has shown HR to remain elevated above baseline for at least 50 minutes following firefighting activity (Horn et al., 2011). As post drill cognitive testing lasted just under 30 minutes, in addition to ~5 min as firefighters made their way to the lab, it was expected that HR would remain elevated. This design was meant to assess individuals while they were still experiencing psychophysiological stress from firefighting, as the eventual concern is in addressing how cognition is affected during firefighting activity.

Al-Zaiti, Rittenberger, Reis, and Hostler (2015) reported on relatively fit (VO_2 = 46.7 ± 7.5 ml·kg^{-1}·min^{-1}) firefighters (n = 42) who completed 24 ± 5 (ranging 17-35) minutes of fire suppression and plywood chopping exercise. This shorter firefighting stimulus resulted in 52.4% of individuals exceeding age predicted HR_{max} and 71% exceeding HR_{max} measured in the maximal treadmill test. In a longer-duration study (~3 hrs) of intermittent firefighting, average HR of firefighters was recorded at 139.6 ± 14.7 b·min^{-1} during the first 31-min block of work, and 150.5 ± 14.5 b·min^{-1} during the second 18-min block of work, followed by two more blocks of work (Horn, Blevins, Fernhall, & Smith, 2013). The drill scenario was similar in that water supplies were established, fire attack occurred, and forcible entry and search and rescue were undertaken. Average age of these individuals was slightly higher than our sample (32.8 ± 9.8 yrs) and one might expect higher average HRs than the ones we reported; however, a major difference was their allowance of 20-40 minute rest cycles between each work block. In our night-burn drills, recruits were usually under time pressure to change their partners' bottles for their air packs, grab a quick drink and return to firefighting activities between work bouts. Further, peak HRs did exceed 180 b·min^{-1} for all of their work cycles.

HR in the current study appeared to influence cognitive tasks in a time-dependent manner, such that the longer the cognitive task occurred after firefighting, the less effect HR had. This makes sense in that the more time passed following the drill, the more HR recovered back towards pre drill levels (flanker was impacted more than n-back performance). Another way to look at it would be that inhibition was impacted more by HR than working memory, but this conclusion would be too presumptuous given that working memory was not measured in the same time window as cognitive inhibition. Specifically, higher average HR was moderately related to more commission errors on the flanker task and longer time spent in the drill was weakly associated with fewer errors. It is possible that individuals who physically exerted themselves more spent less time in the drill because they worked so hard that they had to leave the drill early and this high level of exertion led to subsequently diminished performance on cognitive tasks assessed immediately after they left the drill. On the other hand, those who had low or moderate HRs were possibly able to tolerate the drill for a longer amount of time, but also weren't exerting themselves as much, contributing to their better performance on the flanker task. Although HR may contribute to changes in cognitive performance, both of these relationships were low in strength, suggesting that other factors are involved, perhaps individuals' perceptions of this physiological change. As there were significant relationships between HR variables and cognitive performance post drill, it would be a clear next step to investigate whether these findings might be attributed, at least in part, to rises in core temperature.

Though only a proxy measure for exertion, Tiredness at the end of all testing in the current study was associated with more commission errors on both types of flanker trials, all and target 0-back trials, both types of 1-back trials, and all and target 2-back trials. The change in tiredness from pre to post-0 was able to predict 11.4% of variance in flanker response variability. It remains to be examined whether those who had greater changes in tiredness also showed greater changes in accuracy, but the presence of this relationship is strengthened by the presence of a relationship between both tiredness at the end and energy at the end of the evening also predicting flanker variability (which was measured immediately post firefighting). Greenlee et al. (2014) previously showed that greater Tiredness prior to participating in firefighting was associated with greater variability of RT on all post-firefighting trials, and especially for frequent stimuli, on a basic information processing task.

Kivimäki and Lusa (1994) previously demonstrated that heart rate was inversely associated with cognitive performance. They used HR as an indicator of physiological stress and correlated it with a crude assessment of task-focused thinking (where they had firefighters verbally share their thoughts in real-time) as they completed a smoke-diving course in thermoneutral conditions. Our data extends knowledge surrounding this relationship to more complex, mainstream performance measures.

BMI & aerobic fitness. Coming into this investigation it was thought that higher BMI would be related to worse cognitive performance following stressful firefighting activity because BMI has been shown to be negatively correlated with executive control performance (Gunstad et al., 2007). BMI is of further importance as it has previously been shown to be a predictor of injury in firefighters (Kuehl et al., 2012). The present sample did have a mean BMI that fell into the overweight classification, and this is not surprising. In 2009, a study of 214 firefighters reported 56% at overweight, and 19% as obese, according to their BMI (Donovan et al., 2009). BMI did have weak negative relationships with SD of RT for all, incongruent, and congruent flanker trials as well as with ACC on Congruent trials. However, BMI did not relate to RT or changes in accuracy on the flanker task from pre to post. At least in this sample of firefighters, BMI appeared to be unrelated to attention and working memory. Though it is clear that firefighters had not physiologically recovered back to pre drill levels during the post drill cognitive testing, different results may have emerged if we had measured performance on these parameters of cognition immediately after the drill (as we did for cognitive inhibition). BMI was also moderately correlated with fitness.

In terms of aerobic fitness, it was thought that higher aerobic fitness would serve as a buffer against cognitive decrement post drill. Fitness and higher physical activity levels have previously been reported to have disproportionately larger, beneficial effects on performance of executive control processes (compared to simple response discrimination) by adults (Colcombe & Kramer, 2003). More active or higher fit people have the ability to allocate greater attentional resources towards their environment, allowing them to process information more quickly (Gomez-Pinilla & Hillman, 2013). Firefighter fitness did not relate to flanker RT or accuracy, but it was related to greater variability in RT on the flanker task only, a task that elicited shorter RTs post firefighting than pre test. In the current study, higher fitness was weakly related to greater response variability on all, congruent, incongruent, and all correct trials of the flanker task (but not any of the incorrect categories). However, only a very small amount of variance in flanker response variability was predicted by fitness (see Figure A.1 in the Appendix). The lower fit group (based on a median split) also had higher variability on the 1-back and 2-back tasks (all and non-target) post drill than the higher fit group. Since post drill variability in RT was larger than pre drill, and accuracy decreased following the drill, these data suggest that increased variability in RT might reflect some level of cognitive dysfunction.

It was originally thought that more variability in RT was bad, because previous research in firefighters had revealed that greater tiredness was related to more variability and slower RT on a simple information processing task (Greenlee et al., 2014). Generally, greater variability on attention and executive control tasks has been thought to signify impairment, because individuals with dementia present with greater response variability than healthy individuals (Gamaldo, Allaire, Kitner-Triolo, & Zonderman, 2012). At least in children, individuals with higher aerobic fitness have less response variability and higher accuracy on the flanker task, even when RTs are not different (Wu et al., 2011). A different study of children only saw this fitness effect for a more difficult flanker task (incompatible stimulus-response) that required the participants to respond in the opposite direction on the keypad of the target stimulus (Moore et al., 2013). Lower variability is perhaps better at rest, and in a situation in which arousal is heightened and RTs are shorter, greater variability demonstrates an attempt (unsuccessful in the current study) of higher fit individuals to maintain executive control.

Themanson and Hillman (2006) have previously noted an effect of fitness where higher fit individuals showed greater action monitoring than lower fit individuals. Higher fit individuals showed relatively larger increases in RT (i.e., slowing down) following committed errors, compared to lower fit individuals (Themanson & Hillman, 2006; Themanson, Pontifex, & Hillman, 2008). Post-error slowing was not included as part of our analyses in the firefighting study, but the increased variability in RT in firefighters with higher fitness could be reflective of such a behavior, and should be examined in terms of the coefficient of variation (SD of RT/mean RT) in the future (Parks et al., 2015).

Fitness did not appear to have any relationship with accuracy performance on any of the other cognitive performance variables for the flanker or n-back tasks. There are a number of possible explanations for these findings. First, the academy recruit sample investigated in this study was generally young and healthy, was currently participating in daily fitness training, and presented with average fitness. A larger amount of variability in aerobic fitness is likely needed to truly examine fitness differences in relation to acute changes in cognitive performance following firefighting. Second, the measure of fitness, though reliable, was estimated from a 1.5-mile run test, rather than direct assessment from oxygen consumption during a graded exercise test to exhaustion.

It has been previously shown in young, male sailors that those who increased their VO_{2max} through aerobic training, improved their performance on the 2-back task, while sailors who detrained over the same period of time and decreased their VO_{2max} did not (Hansen et al., 2011). Further, post test RT for these sailors was faster for less fit individuals on simple tests of attention, where it did not change for more fit individuals, and RT on the tests of executive function was faster for individuals who had improved their fitness (Hansen et al., 2011). In this case, differences were seen between groups that were either trained or detrained, whereas our sample was actively participating in physical fitness training as part of the academy. The trained sailors had higher HR variability (HRV) during cognitive tests, while the detrained group had lower HRV during the same cognitive tests. As cognitive tests in the present study were performed when HR was elevated dramatically above resting levels, it may be that fitness effects were less influential at this point in time than they would have been had we assessed group differences at rest.

It was important to determine how physical fitness (tested as these individuals enter the career force) related to cognitive performance abilities in response to participation in live-fire maneuvers. In training, safety is a concern, and on duty, safety is a concern. If fitness is related to cognitive abilities, concerns about cognitive performance on the job might increase as firefighters age and/or stop training as diligently. Such knowledge could lead to determination of a course of action to influence changes in protocols for fitness requirements, break times, and potentially fit for duty. Maintaining adequate aerobic fitness is critical for firefighters to help them tolerate physical demands of the job (Dennison, Mullineaux, Yates, & Abel, 2012; Pawlak et al., 2015; Perroni, Guidetti, Cignitti, & Baldari, 2014; Williford, Duey, Olson, Howard, & Wang, 1999) and prevent cardiovascular disease. If a relationship was found between cognition and fitness it could provide an additional incentive, beyond cardiovascular disease prevention, to exercise and maintain physical fitness throughout their careers to benefit their cognitive and job performance.

It was hypothesized that greater aerobic fitness would be related to better cognitive performance following firefighting stress, and that this would be due to better tolerance of the stressors of firefighting. Aerobic fitness training has previously been shown to decrease stress reactivity in firefighters (by means of blunted increases in mean arterial pressure, HR, state anxiety, and negative affect) in response to viewing a firefighting emergency scenario and being asked to make decisions in regards to the scenario, in the presence of a fire official (Throne, Bartholomew, Craig, & Farrar, 2000). In the present data, unfortunately, fitness did not appear to be as strongly tied to cognitive performance as anticipated. However, given that the recruits were categorized as having good aerobic fitness, the fact that they still showed decrements in cognitive performance is slightly more alarming, because not all firefighters are meeting this level of fitness. When Wynn and Hawdon (2012) examined aerobic fitness requirements in the United Kingdom fire services, they compared departments that had minimal fitness requirements of at least 42 $ml\cdot kg^{-1}\cdot min^{-1}$ to those with no entry-level requirements and linked more injuries (8% increase, 95% CI 7.16, 8.84 for full-time firefighters) during initial firefighter training to the group that had no minimal fitness requirements. Optimistically, fitness training during recruit training and the first year of work has demonstrated significant reductions in injury occurrence, relative to historical cohorts (Griffin et al., 2015).

Cardiac recovery and cognitive performance. Though HR did remain elevated above 80% of age-predicted max for a few minutes into the post drill cognitive testing session (for 19 of 28 people), HR didn’t remain this high for an extended period. From the time that firefighters met with the research team members immediately after the drill, near the burn structure until the last individual’s HR dropped below 80% of their age-predicted max was a duration of ~12 minutes, just under 7 minutes into the cognitive testing period. However, the average amount of time before HR dropped below 80% was <1 minute. So, this does indicate that a few individuals had higher HRs during the flanker task, but that HRs were at least below 70% age-predicted max for the working memory tasks.

In the sub-sample of individuals with HR data (n= 25), higher fit firefighters experienced quicker recovery, reflected by a greater mean decrease in HR from the point-of-contact with the research to the end of cognitive testing. Follow-up analyses indicated that there was a significant positive relationship between HR recovery and aerobic fitness, supporting the hypothesis that greater fitness would relate to better cognitive performance following firefighting. It was anticipated that those who were in better physical condition might not experience the physiological effects of the firefighting scenario for as long post drill, compared to those who were not as fit. It was thought that if they recovered more quickly, they would find themselves in a psychophysiological state more similar to pre drill, which would then allow performance on the cognitive tests to be similar to pre drill.

No significant differences were seen in pre-post accuracy for flanker or n-back tasks in the “Less Recovery” group. Those who recovered more from point-of-contact to the end of cognitive testing appeared to perform the same or worse on Flanker, 0-back, and 1-back tasks post drill, which is the opposite of what we had hypothesized (i.e., that those who recovered more quickly would display post drill accuracy on the cognitive tests that was similar or better than their own pre drill accuracy). Specifically, the “More Recovery” group demonstrated significant decreases in accuracy pre to post drill on flanker (all and incongruent trials) and 1-back accuracy (target trials), with 0-back going in the same direction.

Even though more recovery, and quicker recovery (as appears evident by the same average HR during drill and average HR at point-of-contact between these two “recovery” groups), is believed to be a good fitness response to physiological stress, it may be that this juxtaposition of change from heightened awareness and stress to less physiological stress over a quicker period of time impacted their ability to perform well on tasks that require inhibition and working memory. The process of physiological recovery may have taken precedence over cognitive demands of the tasks, causing accuracy to suffer.

Perceptual responses to firefighting. Relationships between information processing and self-reported perceptual responses to firefighting deserve examination, as these are quick and easy ways to assess stress, which itself is a cause of concern when it comes to maintaining adequate cognitive function. The night-burn drill, in which firefighter recruits participated, elicited generally anticipated changes in the perceptual variables assessed in this study. The patterns of change across time for all of the perceptual measures (state anxiety, fatigue, RPE, thermal sensation (TS), respiratory distress (RD), and valenced affect) were almost identical, with the exceptions of perceived Energy and Felt Arousal. The majority of perceptual responses indicated a significant increase from pre to post-0 (increase in negative feelings for valenced affect), and then a significant decrease from post-0 to end, with end levels remaining significantly elevated above pre drill levels. This pattern mimicked that which was reported for HR. In relation to the literature, these changes in perceptions replicate previous findings in firefighters and heated exercise settings. TS, RPE, RD all have been shown to increase in response to the execution of firefighting tasks, with additional increases seen when tasks are performed under heat stress (Smith, Petruzzello, Kramer, & Misner, 1997).

Rating of perceived exertion (RPE). The demonstrated changes in perceived exertion (RPE) were anticipated as RPE was minimal at pre test (M = 6.7), increased dramatically by post-0 (M = 16.68) and had begun a slow decline by the end of all testing (M = 10.12). RPE has previously been shown to be higher while exercising (Maw, Boutcher, & Taylor, 1993), or performing firefighting activities (Smith, Petruzzello, Kramer, & Misner, 1997) in heated conditions, compared to the same activities in neutral or cool conditions. Tomporowski, Beasman, Ganio, and Cureton (2007) demonstrated RPE increases over time spent doing moderate exercise in warm (30°C, 40% RH) environment. RPE values of ~17 and ~16 have been reported after 60 minutes of interrupted treadmill and stepping exercise in a heated chamber (35°C; Zhang et al., 2014), and 14 mins of firefighting (Horn et al., 2015, respectively). RPE did partially reflect physiological work. Higher RPE post-0 was moderately related to higher average HR during the drill and more time spent in vigorous-extremely hard HR zone, while more time spent in moderate zone was negatively associated with RPE post-0.

Effects of firefighting on attention abilities were related to how much perceived exertion firefighters reported at post-0 (more exertion, fewer commission errors) on all and non-target trials. For working memory, a weak relationship between performance and perceived exertion occurred in the expected direction: more commission errors on 1-back target trials related to greater perceived exertion measured at the end of the drill. Yet, the 2-back task showed no such relationships. More clear relationships emerging for 0-back and 1-back might be explained by the manner in which data were collected from our cohorts. The 0-back was assessed at the end of the n-back task order in two academies and 1-back was assessed as the second n-back task in the order in two academies. So, this provided larger data sets from people being assessed at the same time points on these tasks, whereas the 2-back was assessed at all different time points following firefighting. The differing trends in the relationships between performance and exertion on the 0-back and the 1-back might be explained by the actual time point at which each was assessed more often; for the 0-back two academies were assessed at the end of testing when energy levels had dropped and psychophysiological effects of firefighting on cognitive performance may have diminished. This might explain why fewer errors were related to higher RPE at post-0. When RPE was examined at the end of all testing, higher RPE was related to more errors on the 0-back task. The 1-back, on the other hand, was assessed as the second task in the n-back task order for two of the academies, at least 4 minutes earlier than when the majority of 0-back data was collected. This was also at a point in time when individuals had not recovered as much from the firefighting drill.

Thermal sensation (TS). TS increased as expected with live-fire maneuvers, increasing from 4.04±0.78 pre drill to 6.90±0.93 immediately post drill, only declining to 5.44±1.06 at the end of all testing about 30 minutes later. Core temperature has been previously shown to rise

0.7ºC in only 18 minutes of live-fire activities (Horn et al., 2011; Smith et al., 2011). In the live-fire study discussed earlier, maximum core temperatures were recorded at 38.43ºC during the first 31 minutes of firefighting (Horn, Blevins, Fernhall, & Smith, 2013). Post-0 TS scores were previously recorded to increase significantly over 18 mins of firefighting (Greenlee et al., 2014). Longer firefighting activity from the current study produced even larger changes, and at the end of the cognitive testing period TS levels had still not returned to pre-drill levels. This indicates that the current sample of firefighters was experiencing almost the same amount of thermal strain after about 30 minutes of completing firefighting activities as has been shown immediately after 18 minutes of firefighting activity. Contributions to thermal sensations are heat radiating from fire, heavy PPE, and physical exertion (Perroni, Guidetti, Cignitti, & Baldari, 2014). Studies in the French military have found similar physiological responses to wearing protective clothing while exercising for 60 minutes at only 45% VO_{2max} in heat (Jimenez et al., 2008). However, this clothing was slightly different than firefighting PPE, as it was meant for biological, radioactive, and chemical agent protection (Jimenez et al.).

Greater increases in TS were related to greater decreases in accuracy on flanker, and 1-back non-targets and higher TS post-0 was related to greater decreases in 2-back accuracy on all and non-target trials. Higher TS was related to more fatigue at post-0, but the relationship was weak. However, this could still have partially contributed to the diminished accuracy that was seen. There was also a moderate relationship between average HR during the cognitive tests and TS, revealing that higher TS was related to higher physiological stress (HR) during the post drill cognitive tests. The difficulty in making solid conclusions about the relationships between TS and working memory is that the 2-back was assessed at many different points in the testing time continuum.

Heat acclimation was addressed briefly in the introduction to the current study. Though this was not directly measured, it can generally be acknowledged that participating in a live-fire maneuver after spending 4-5 weeks of 8-hour days at a live-burn training academy, would have allowed some heat, as well as PPE carrying, acclimation. There would definitely have been more than would be encountered by an average career firefighter, as emergency fire response accounts for only 1-5% of calls (Kales, Soteriades, Christophi, & Christiani, 2007). So, any small decrements in performance seen here may be exaggerated in individuals who are not used to such conditions.

Respiratory distress. Respiratory distress was greatest at post-0 and, though still elevated, had begun declining back to pre drill levels by the end of testing. The increase seen here was almost twice as large compared to a previous examination following 18 minutes of firefighting activity (Greenlee et al., 2014). Respiratory distress likely increased in response to the high demands of oxygen uptake required by firefighting activities (Holmér & Gavhed, 2007). In the current study, respiratory distress did not appear to relate to cognitive performance. Although it was not measured between post-0 and end of cognitive testing, it is thought that this could probably be explained by a steep decline closely following the post-0 measurement point. Measurements taken while the firefighters still had their masks on may have resulted in different outcomes, as many seemed very relieved to remove them at the entrance to the computer lab.

Fatigue. On a 10-point visual analogue scale, fatigue in the current study increased almost 4-fold from pre to post-0, and remained about three times higher at the end of all testing. It was anticipated that higher fatigue would relate to slower RT and lower accuracy on the executive control tasks and greater variability in RT on these tasks. Fatigue post-0 was actually weakly related to shorter RT on the 2-back, thus suggesting the opposite of what was hypothesized. However, when fatigue increased from post-0 to end, it did appear to relate to a slowing of RT and better accuracy on the 2-back task. Flanker showed this same trend, that is, greater fatigue post-0 was associated with shorter RT and worse accuracy, but when there was a greater increase in fatigue from pre to post, post drill RT was longer and accuracy was better on the difficult tasks (incongruent flanker trials).

In terms of performance of simple discrimination tasks, previous research has shown young adults are able to withstand combinations of physical fatigue from having exercised and mental fatigue from having completed multiple cognitive tasks following exercise (Moore, Romine, O'Connor, & Tomporowski, 2012). Fatigue has also been shown to increase following intermittent exertion under heat stress in parallel with decrements in higher-level, executive control performance (as measured by a random movement generation task; McMorris et al., 2006). Evidence from a test of working memory (tested 25 minutes after 55 minutes of cycling at 90% VT), has revealed support for the compensatory-control model (Hockey, 1997), such that the use of cognitive resources on a 40-minute working memory vigilance test following exercise appeared to be so demanding that performance on a simple perceptual discrimination task completed after the working memory task suffered (Moore, Romine, O'Connor, & Tomporowski, 2012). A continued examination of the impact of fatigue on cognitive performance of firefighters is especially important because it is one of the symptoms of shift work disorder, which could affect them at some point in their career, and could influence their attentional capacity (Elliot & Kuehl, 2007).

Valenced affect. In the current study, firefighters went from a positive affective state pre drill to a negative affective state immediately post drill, which had begun to dissipate by the end of all testing, but the larger variability in responses seen post drill appears to indicate varied reactions to the stress of firefighting. It was anticipated that affective valence would decrease (i.e., become less positive/more negative) following firefighting, but the change was more dramatic than what has been shown in previous studies. Greenlee et al. (2014) had shown a mean decrease of 1.36 units on the Feeling Scale compared to the 4.27 unit change seen here. Affective changes to exercise in heat have also demonstrated this same negative swing following exercise in heat, but not cold or neutral temperatures (Maw, Boutcher, & Taylor, 1993). It was hypothesized that more positive affect would relate to better cognitive performance. For the flanker task, higher positive affect post-0 was related to more favorable changes in accuracy on all and congruent trials from pre to post drill (accuracy did not decrease as much from pre to post when affect was more positive); however, these relationships were both weak. Also, higher positive affect post-0 had a moderate, positive relationship with RT on incorrect congruent trials post drill, indicating that those who felt more positive had longer RTs on incorrect congruent trials. Greater positive affect at the end of all testing was also moderately associated with less variability in RT for the flanker task on all and incongruent trials. Evidence from fMRI studies has shown that individuals who are experiencing negative affective states appear to work harder to maintain interference control than if they were not in such a state (Melcher, Born, & Gruber, 2011). Firefighters in the current study were experiencing the most negative affect at post-0, closest to when cognitive inhibition was assessed. They also demonstrated decrements in performance, suggesting that they may have been struggling to maintain interference control. Whether or not they were working harder at the neural level or not is something that could be examined from a neuroscience perspective in the future, but the link between negative affect and greater variability would support this notion. For attention, fewer relationships emerged, but higher target accuracy did relate to higher positive affect. In terms of working memory, though a few sporadic correlations were significant, a general pattern could not be discerned between affective state and working memory performance. These results would seem to mimic findings of Hogan, Mata, and Carstensen (2013), showing that working memory performance (i.e., 2-back task) had no relationship with high activation positive affect following acute exercise.

Energy and felt arousal. Perceived Energy and Felt Arousal were different from the other perceptual responses in that they deviated from the general pattern of large increases followed by slight decreases. Perceived Energy did not change, remaining just as high post-0 as it was pre drill. At ~30 minutes post firefighting It then declined to a significantly lower level than both pre and post-0. This range of energy levels is similar to what has been reported previously with live-fire maneuvers (Greenlee et al., 2014).

Felt Arousal showed an increase, but fully returned to pre drill levels by the end of cognitive testing. This is somewhat counterintuitive, because RPE, Respiratory Distress, and HR did remain elevated and felt arousal usually reflects physiological stress like these measures do and has been shown to increase with increasing intensity of exercise participation (and paralleled increases in HR) (Chang & Etnier, 2009). However, perceived arousal may respond differently to firefighting, the Felt Arousal Scale may just not be sensitive enough to reflect slight changes, or Felt Arousal at pre drill was already elevated in anticipation of stress.

It was predicted that felt arousal and perceived energy would be inversely associated with RT and this was true for our measure of simple attention, but not for higher-level cognitive performance measures. Higher felt arousal post-0 was related to shorter RT on 0-back target trials, predicting 9.8% of variance. Higher energy at the end of all testing was also related to shorter RT on the 0-back, predicting 16.1% of variance on correct target trials. Previous work had shown higher baseline energy was associated with shorter, less variable RT at baseline and 120 mins post firefighting, but not immediately post, suggesting that beginning a drill with more energy helped preserve performance afterward (Greenlee et al., 2014). The current results extend this relationship to feelings of energy post drill relating to shorter RT. Weng et al. (2015) have speculated that lower arousal (relative to arousal from moderate exercise) might relate to worse inhibitory control, but the findings are unable to address this due to the fact that felt arousal was relatively high for firefighters at the time that cognitive inhibition was assessed.

State anxiety. Over the course of the night-burn drill, state anxiety rose significantly, ~5.5 units higher than Pre Drill, at the Post-0 time point. When measured again after Post Drill cognitive testing, it had returned to Pre Drill levels. This pattern of change has been seen previously in response to firefighting activities in full PPE and heat (Greenlee et al., 2014; Smith, Petruzzello, Kramer, & Misner, 1997). Perroni et al. (2009) reported no change in state anxiety when they examined pre-post differences in firefighters completing a circuit of firefighting activities. Though their circuit was physically taxing (70% of time spent at high-intensity), it was only 12 mins in duration and involved no fire, smoke, or heat. Youngstedt et al. (1993) did demonstrate a significant elevation in state anxiety following 20 minutes of passive heating, which exceeded the increase seen from thermoneutral cycling, potentially suggesting that heat might be a more significant contributor to the reported increases seen following firefighting. Smith, Petruzzello, Kramer and Misner (1997) also demonstrated this effect when they reported state anxiety increasing post-0 and remaining elevated 10 minutes post, while performance of the same task (still in PPE) in the absence of heat showed little change in state anxiety immediately post, and no lasting effects. Research by Sünram-Lea, Owen-Lynch, Robinson, Jones, and Hu (2012) suggests that consumption of blended energy drink (different concentrations of glucose and caffeine) may blunt this rise in state anxiety that occurs pre to post live-fire maneuvers.

For cognitive inhibition, no significant relationships were observed for state anxiety or changes in state anxiety with RT. However, state anxiety post-0 appeared to be a key factor in terms of predicting flanker accuracy on congruent trials. Since accuracy did decrease significantly for congruent trials, it is important to recognize that state anxiety predicted 23.1% of the variance in this change in accuracy from pre to post, and is a factor that needs closer examination. Extreme cases of clinical anxiety have shown impaired accuracy on sustained attention tasks (Aupperle, Melrose, Stein, & Paulus 2012), so it is be possible that exaggerated state anxiety responses might impair accuracy on higher level cognitive tasks. Wood, Mathews, and Dalgleish (2001) have previously demonstrated impairments in cognitive inhibition when individuals were faced with excess mental load due to performance of a concurrent task and also when individuals had previously experienced a traumatic event in their lives.

When changes in state anxiety from pre to post-0 were larger, RT was longer on working memory tasks (1-back commission errors on non-targets and 2-back target trials and correct trials) and shorter on the assessment of attention (0-back commission errors). For attention, it makes sense that if anxiety was elevated, arousal might also be elevated, leading to reductions in RT on a simple task. These faster responses could have been fast enough that they compromised accuracy. Likewise, it makes sense that on the most challenging task, the 2-back, if anxiety had increased, these individuals may have been paying very close attention to the targets, but might have some level of conflict (e.g., battle for resources between emotion and cognition) to make their responses to targets. Prior investigations of the cognition-emotion relationship have found that anxiety makes recruitment of working memory regions more inefficient (Bishop, 2007). However, the fact that 1-back RT on commission errors on non-targets was longer when state anxiety increased does not seem to follow the same logic as was presented for 2-back performance. As these both assess working memory, one might think they would reflect similar relationships to state anxiety. Closer examination of the data revealed that this may just be an artifact of the data, because only 22 of the 59 individuals made these errors on the 1-back, where 41 made these errors on the 2-back. Still, the fact that RT was longer for either non-targets or targets on these assessments of working memory and the lack of a relationship between accuracy on these tasks and state anxiety may reflect conflicts in processing efficiency (Eysenck & Calvo, 1992; Robinson, Vytal, Cornwell, & Grillon, 2013).

Individual Difference Characteristics

Trait anxiety. Barr, Gregson, & Reilly (2010) concluded that individual differences (e.g., trait anxiety, experience levels) might sometimes impact cognition beyond how it may be impacted by physical strain. Trait Anxiety mean score for the firefighters in the current study was just slightly higher in comparison to another sample of 43 firefighters who had just completed basic training (Heinrichs et al., 2005). However, their mean trait anxiety increased after 2 years serving as career firefighters, driven mainly by increases in individuals who initially presented with higher risk for PTSD symptoms (Heinrichs et al., 2005). In the current study, trait anxiety related to working memory only, not to attention or cognitive inhibition. The data indicated that higher trait anxiety was related to less variability in RT, at least for n-back tasks, which was opposite of the hypothesis. Eysenck, Derakshan, Santos, and Calvo (2007) revealed that high anxiety individuals needed relatively greater brain activation in regions related to working memory if they were going to perform as well as those with lower anxiety. So, it may be that high trait anxiety is be good for focusing attention and performing quickly when experiencing negative affect and high state anxiety (Derryberry & Reed, 1998).

Previous links have been made between anxiety, stress, and executive control. It has been suggested that trait anxiety may be unrelated to performance when individuals have higher relative baseline working memory capacity. However, when individuals have lower relative working memory capacity they may experience diminished processing efficiency with higher levels of stress, yet higher trait anxiety for those with lower capacities may facilitate performance under low stress conditions (Edwards, Moore, Champion, & Edwards, 2015). Although the participants of this experiment were also young adults, the stress encountered in this scenario was far from live-firefighting; it was a pressured counting task.

Resilience. In terms of dispositional resilience, average commitment, control, and challenge along with the total composite score for resilience reflect slightly lower resilience than average values recorded from military samples (Bartone, Kelly, & Matthews, 2013; Taylor, Pietrobon, Taverniers, Leon, & Fern, 2013). This was particularly true for the commitment subcategory. It was expected that more resilient individuals would have better accuracy and lower variability in their responding, because resilience has previously been linked to mental and physical health, including subjective distress, stress hormones, and coping (Taylor et al., 2013). The results do not support the hypothesis surrounding resilience and accuracy, but rather suggest the opposite. Higher resilience was related to lower accuracy on working memory tasks. These data do, however, partially support the hypothesis surrounding resilience and response variability, at least for 0 and 1-back tasks. Greater Commitment and Control (subscales of resilience) were linked to lower response variability on 0-back and 1-back tasks, respectively, but Challenge was linked to greater variability on for 2-back task. Interestingly in a cadet population from West Point, challenge also related to worse military performance while in academy, whereas commitment and control predicted future success for adaptability of performance as an army officer (Bartone et al., 2013).

Coping strategies. The coping strategies most salient to this group were active coping, reframing, and planning, while denial, substance use, and disengagement were reported as being used the least. It was initially thought that more negative coping strategies would relate to lower accuracy and greater variability. However, a more thorough review of the literature revealed that this generalization of negative and positive coping is not supported, and rather, that coping is a transient process that occurs throughout a stressful situation and different coping styles may be useful at different times throughout this process (Carver, Scheier, & Weintraub, 1989). That being said, Active Coping and Planning have been viewed as optimistic, adaptive, and resilient approaches, and have been inversely correlated to trait anxiety, whereas disengagement and denial coping are more pessimistic approaches positively correlated with trait anxiety and inversely correlated with resilience (Carver et al., 1989). These metrics appear to be supported by the results from 0-back task performance. Active Coping was moderately related to less variability in post drill 0-back RT, while Denial and Disengagement were moderately related to greater variability in RT. Disengagement coping has previously been correlated with lower accuracy on composite measures of executive functioning (Campbell et al., 2009). While attention shows signs of potential benefit from adaptive coping styles, working memory may have been impacted negatively by the greater use of these coping styles. In the current study, inverse relationships were present between both Active and Reframing Coping and Accuracy on the 1-back task. Intuitively, coping styles that require executive control resources (such as cognitive reappraisal that is involved with active and reframing coping) may compete for neural resources during a task demanding of working memory, where they may not have interfered with simple attention. It has been thought that use of problem-based coping strategies could be maladaptive in situations where the problem cannot be fixed (e.g., thermal stress, mental stress, and fatigue experienced by firefighters in our drill and cognitive testing scenario) (Allen & Leary, 2010).

The relationship between self-distraction coping and omission errors made on the flanker task may represent a maladaptive relationship between cognitive control and the use of this coping strategy. If cognitive inhibition subserves working memory and cognitive flexibility and cognitive inhibition is compromised, working memory and cognitive flexibility are likely to suffer. Self-distraction and disengagement coping styles have been linked to higher intensities of PTSD symptoms in firefighters (Ogińska-Bulik & Langer, 2007), which has been linked to cognitive dysfunction (Aupperle, Melrose, Stein, & Paulus, 2012). This could represent a predisposition for cognitive disruption that comes from experiencing stress. There is some rationale surrounding this relationship in that self-distraction coping occurs many times through suppression of stressors (i.e., trying to ignore them or passively letting time heal the situation), and individuals who report a more emotion-focused coping strategy like this, compared to problem-focused strategy use (such as active coping and planning), (Wells & Matthews, 1994).

Preference for and tolerance of intensity of exercise. We had hypothesized that individuals who tolerate higher intensity exercise (and work harder during the drill) would have faster RTs but make more commission errors Post Drill. Though we did not find any relationship with RT, higher tolerance was weakly related to accuracy on all, congruent, and incongruent flanker trials and regression analyses found that tolerance predicted 8.1%, 6.2%, and 7.5% of variance in post drill flanker accuracy on each, respectively. At first, it would seem that people who are more tolerant of high intensities would, in fact, tolerate them so well that they would not show cognitive decrement. However, it is also possible that the opposite may occur because these individuals may push themselves harder or stay in the drill longer than those with lower tolerances. However, Tolerance did not relate to average or peak HR during the drill and in fact was inversely correlated with the amount of time spent in the drill, and did not relate to arousal or RPE at post-0 or the end of testing.

This is not consistent with previous acute exercise research that has shown individuals with higher tolerance persevering longer when the intensity of the exercise becomes fairly aversive compared to those with lower tolerance (Ekkekakis, Lind, Hall, & Petruzzello, 2007). Higher tolerance did, however, correlate to higher fatigue at post-0. Interestingly, with fatigue at post-0 predicting 6.2% variance in 2-back RT on incorrect non-targets, tolerance still predicted 5.2% unique variance in 2-back RT on incorrect non-targets. Higher tolerance related to shorter RT on these trials. Thus, it could be that these individuals were able to get what they needed to accomplish in the drill done more quickly than people with lower tolerance, though it may have resulted in diminished cognitive inhibition immediately post-firefighting.

Personality. In the current study, Emotional Stability was the only Big 5 personality trait that was related to flanker performance and the only Big 5 trait that did not relate to working memory performance. Individuals scoring higher for Emotional Stability demonstrated smaller decrements in accuracy on congruent trials from pre to post, with Emotional Stability predicting 7.6% of unique variance beyond what was predicted by state anxiety at post-0. Emotional Stability and state anxiety post-0 were inversely correlated. This suggests that individuals with greater emotional stability have smaller anxiety reactions to firefighting activity and may be better at maintaining performance on easier tasks. One previous study has shown firefighter recruits to demonstrate higher scores for Extraversion and Conscientiousness relative to Agreeableness, Neuroticism, and Openness to Experience (Salters-Pedneault, Ruef, & Orr, 2010). Prior work has demonstrated moderate inverse relationships between Conscientiousness and RT such that individuals scoring higher on Conscientiousness had shorter RT on a simple information processing task when rare stimuli (20% of trials) followed frequent stimuli (80% of trials) post-firefighting (Greenlee et al., 2014). Extraversion has also previously been linked to faster RT (Sočan & Bucik, 1998). Neither extraversion nor conscientiousness were significant factors in the current model (when included in conjunction with perceptual responses).

Hierarchical multiple regressions provided some connection to personality and firefighter working memory performance. When arousal (post-0) and perceived exertion (end) were combined, they predicted 18% of the variance in pre to post change in 1-back d'. Contrary to the proposed model, self-distraction and active coping and the personality trait of intellect/openness together, explained 20.5% unique variance, beyond perceptual arousal and exertion, in the pre to post change in 1-back d'. Openness has previously been found to predict cognitive flexibility and aspects of working memory (updating and monitoring; Murdock, Oddi, & Bridgett, 2013) and has previously been noted as one personality type that seems to relate more closely to cognition (Soubelet & Salthouse, 2011). Preliminary neuroscience research has also suggested that people possessing higher relative scores on Big 5 personality traits may have personality-specific resting state brain activation patterns (Adelstein et al., 2011). The resting state regional activations may or may not help explain how personality relates to cognitive performance.

Firefighting experience. Data for firefighting experience was available only from a small sample, and although there did appear to be at least a few relationships between experience and cognitive performance, they will not be discussed in great detail here. Further exploration of these relationships should be performed as experience in a firefighting scenario may be reflected in how individuals respond to the stress of the event, and subsequently, how they perform on cognitive assessments following firefighting. Noteworthy findings from the current study were the relationships between the pre-post change in accuracy on the flanker task and years spent as a career firefighter, the shorter RT and smaller SD of on 0-back target trials with more time spent as a volunteer firefighter, and the pre-post change in accuracy on 1-back target trials and combined time spent as a career or volunteer firefighter. Research with pilots has suggested that situational awareness relies more on working memory when an individual has less expertise, and that when more experience is gained, working memory load can be compensated for by long term memories from their experiences (Sohn & Doane, 2004). McLennan et al. (2003) point out that years of experience, itself, is not a definitive marker of ability in good incident commanders. Although number of years does allow for more time practice on the job, performance appears to be more of a product of their general ability to anticipate future occurrence in a given scenario, based on prior experiences, and also the practice of recognizing and modifying their approach in order to work within their own limitations. Less experienced firefighters may make quicker decisions and review less environmental information prior to those decisions, compared to more experienced firefighters (Bayouth, Keren, Franke, & Godby, 2013). It should be noted that experience with stressful stimuli and task performance under stressful conditions seems to help individuals adapt to recurrent exposure to the same stress (Klonowicz, 1989 as cited in Bowers, Weaver, & Morgan, 1996). Experienced individuals tend to have exaggerated hormonal responses to exactly the same stress condition compared to novices (Weeks, McAuliffe, DuRussel, & Pasquina, 2010).

Model Testing Summary

It seems that many of the changes in perceptual variables did predict performance on their own, just not in conjunction with prior relationships between individual difference characteristics and cognition. In some cases, because everyone responded perceptually to firefighting in a similar way, there was less variance in those measures to determine any trends relative to individual difference characteristics. This makes predicting cognitive performance as proposed in the model difficult. For instance, it was interesting that the changes in RPE, anxiety, tension, or energy from pre to post-0 were not related to flanker performance in any way. However, since the state measurements at post-0 did relate, the firefighters had similar post-0 perceptions of RPE, anxiety and energy, resulting in less variability in the sample and less ability of the change score to predict flanker performance. If there were greater variations in perceptual responses, as may occur between groups of firefighters who differ more in experience, age, sex, or fitness, perhaps more relationships would be uncovered.

Working memory performance outcomes and their relation to perceptual measures are more difficult to tease apart due to counterbalanced ordering of the n-back tasks across academy groups. However, attention (0-back task) seemed to relate to RPE, state anxiety, felt arousal, tension, and calmness at post-0, as well as changes in fatigue, tension, energy, calmness, perceived exertion, thermal stress, respiratory distress and anxiety. State anxiety and thermal sensation seem to be more salient predictors of working memory. It has recently been proposed that people who perform better in extreme environments may be able to create contextualized optimal body states that allow them to maintain a sense of homeostasis in these situations (i.e., their top-down systems are able to predict how the body should be feeling in order to perform well), while lower performers may be thrown off by their perceptual responses to the stressful environment (Paulus et al., 2009).

A number of individual difference characteristics remained predictors of executive control performance even after accounting for the influence of perceptual variables. Self-distraction and active coping, tolerance, and intellect/openness personality trait predicted working memory performance post firefighting, while the personality trait of emotional stability may have been able to predict cognitive inhibitory performance. However, no individual difference variables remained for attention performance once perceptual states were accounted for. This does suggest that maybe the individual difference traits impact the way in which individuals experience firefighting, at a psychophysiological level, and this may have a greater impact on tasks that assess higher level cognitive functions. This certainly provides a starting point for future research into how individual differences and physiological and perceptual states, together and apart, predict cognitive performance of firefighters. However, the differing task orders and resulting differences in time point of assessment of working memory in the current study complicate the ability to decipher clear patterns from the data. Future research should examine separate aspects of executive control at distinct time points following, and eventually during, firefighting to truly determine the which factors reliably predict cognitive performance and the subsequent utility of those measures in terms of developing training programs or on-scene protocols to either slow or ameliorate cognitive decrement or enhance innate abilities.

The other surprisingly meaningful finding from hierarchical model testing was the determination of perceptual, heart rate, and individual difference variables, which showed no predictive relationships with each other. This provides insight as to what not to waste time or energy measuring in the future in a young firefighting population. Any factors removed from the model with respect to n-back performance should be interpreted with caution, and should still be included in future models until order effects are delineated.

Strengths

Strengths of this research were the population, naturalistic testing environment, quantity of quality data collected for analysis, sample size, and novelty of the cognitive investigation that took place. Much of the research on decision making in firefighting has been on the incident command role, or others in charge of managing personnel and equipment at an emergency scenario, but not front line firefighters (Gomez-Herbert, 2014; Klein, 1993; McLennan, Omodei, Holgate, & Wearing, 2003). Only a select few have assessed front-line firefighter cognition

(Greenlee et al., 2014; Kivimäki & Lusa, 1994; Smith, Petruzzello, & Manning, 2001), or replications of front line firefighter cognition in other populations (Robinson et al., 2013; Sünram-Lea, Owen-Lynch, Robinson, Jones, & Hu, 2012), and very few in relation to live-fire scenarios. The current study is the only one that has specifically examined executive control.

Testing in a live fire scenario with heavy PPE on as opposed to thermoneutral laboratory or environmental chamber conditions has received less attention in the literature (Louhevaara et al., 1995). On top of this, the current study involved a 2-bottle drill, whereas most live-fire research studies have been done under circumstances requiring less than 1 bottle of air (usually 20 mins or less), unless done in the laboratory. One study has examined a long-duration live-fire scenario and its effects on HR (Horn, Blevins, Fernhall, & Smith, 2013), but the current study adds to available knowledge in this area. The multitude of information collected within a very condensed time window, without interfering with academy training, is also noteworthy. Having the ability to connect perceptual responses to physiological and cognitive data proved to be particularly useful in determining significant predictors of cognitive performance, which can be used to inform future studies in terms of which variables are worth measuring, and which aren't, as well as which factors may be trainable, to help protect or enhance cognitive performance under firefighting conditions. The sample size first and foremost provided the opportunity to discover what appear to be real patterns in cognitive performance, and this sample is large compared to other available literature on cognitive assessment following both acute exercise and firefighting, especially given the complexity of the firefighting scenario. It was particularly good that individuals completed testing together in groups, making their "lab" experiences more similar, removing some of the variability that might occur if each individual had tested alone.

Limitations

As mentioned earlier, our sample was comprised of relatively young and healthy new recruit firefighters, so it remains to be determined if these results would be seen in older or less fit firefighters. Effects were also not addressed in female firefighters. Though also listed as a strength, lack of control over the situation is an issue inherent to field studies. Each night-burn fire scenario differed slightly in the way the fire acted, the specific strategies chosen, and length of time it took for the recruits to successfully complete the drill. Further, different cohorts were measured on different evenings, and their interactions could have contributed to the way in which the drill went and subsequently their subjective perceptual states. However, because each burn scenario followed the same basic format and required the same skills to be practiced in terms of an educational part of the academy, it is not likely that small differences in the evening contributed to different cognitive outcomes. Further, perceptual states followed the same patterns of change across the different academies when compared as a between subjects factor.

A few unfortunate limitations arise in the manner in which data was collected. First, the examination of task order effects was weak since data had been collected prior to Spring 2015. Some academies had fewer individuals, resulting in less statistical power. We did not assess a cohort with the 1-back task falling last in the sequence order, which would have been useful for comprehensive comparison of task order. The second limitation is task completion was not counterbalanced by handedness and handedness was not assessed. This particularly impacts the performance on non-target trials on the n-back tasks, because non-targets were always a left-handed response and most individuals are right-handed, leading to quicker selection of targets, relative to non-targets, regardless of when the task was completed. Thus, completion of n-back tasks in the future should account for counterbalancing of the starting hand to rule out any individual differences in performance related to handedness.

In addition, the baseline testing period could be designed more effectively. First, it would also be more appropriate to measure cognitive performance in the morning and evening of the baseline day to further reveal any learning or passage-of-day differences in performance.

Firefighters' baseline cognitive performance may not reflect a true baseline (prior to exposure to any firefighting drills), because baseline was measured in the 3rd or 4th week of academy. Baseline testing was done in the morning, prior to any participation in firefighting activity. This seems to be less of a potential confound, because a number of the individuals had prior experience as volunteer firefighters. The planning of baseline testing was also scheduled as to not interfere with regularly scheduled programming of the academy, as the research team wanted to be minimally invasive to the training program itself. Lastly, even though capturing their baseline performance prior to any academy exposure would have been ideal, they were not fatigued from a day of training yet, at least reflecting a neutral state. Not being in their first week of academy may have been even preferable, as testing on the first day of academy may have elicited anticipatory stress. If measurements had been taken during the first week, their cognitive abilities may also have been perturbed because of the long, intense training days that they were not used to prior to arriving at academy (no one spends hours a day in PPE, studying fire science and equipment nonstop, and performing station duties).

Dehydration sometimes appears to be a confounder when studying the cognitive consequences of physical activity in heat. Up to 1 kilogram of body weight can be lost in sweat during only 18-20 minutes of firefighting activity (Smith & Petruzzello, 1998, as cited in Smith & Haigh, 2006). Sünram-Lea, Owen-Lynch, Robinson, Jones, and Hu (2012) have reported improvement in attention and performance on a grammatical reasoning task immediately following a 60-min firefighting drill when participants were intentionally provided with a form of hydration (high glucose, high caffeine, or placebo drink), but there was no comparison to a control and no description of the consistency of the placebo. Dehydration has been associated with slower decision-making time and decreased short-term memory 30 minutes post-exercise (Cian, Barraud, Melin, & Raphel, 2001). Other exercise studies report no effect on cognitive performance (Adam et al., 2008). Because of physical exertion (i.e., increased requirements for oxygen) and heat stress (i.e., increased blood flow to the skin to regulate temperature), lowered blood volume and rise in brain temperature could contribute to cognitive impairment (Ando et al., 2015; González-Alonso, Crandall, & Johnson, 2008).

Dehydration could be an issue resulting in cognitive deficits; however, the current study sought to test cognition in a time-sensitive manner and not burden participants with another task (e.g., urine sampling). Further, participants had been hydrating throughout the day at academy (carry water bottles around), some hydrated during the drill, and they drank from their water bottles immediately before, and between, cognitive tests post drill. Theoretically, this should have at least kept them hydrated to the point that they would be in natural settings, providing us with ecologically valid data. There is some evidence for no difference in RT or accuracy on simple and choice RT tests, short-term spatial memory, and grammar-based logical reasoning in hypohydrated versus euhydrated states following 3 hours of intermittent light exercise under differing levels of heat exposure (Ely et al., 2013). Interestingly, previous reports of decreased attention and working memory performance (slowed RT) in dehydration conditions have been reported in tandem with increases in fatigue and tension/anxiety (Ganio et al., 2011). Thus, part of the influence that dehydration may have on cognitive performance could be partially mediated by the perceptual changes that occur.

Conclusion

Attending to relevant sensory information from the environment, ignoring irrelevant stimuli, and manipulating that information to make quick and accurate decisions, as simple as they may seem (e.g., open a door or do not open a door) and being able to quickly switch their focus to another problem, task, or decision, is why properly functioning executive control is so necessary in firefighters. Cognitive performance was measured in new-recruit firefighters immediately before and after their participation in a 2-bottle, live-fire, emergency response drill during academy training. Executive control does appear to be affected by participation in a live-fire firefighting maneuver, at least when measured within 5-30 minutes post-firefighting.

After a broad examination of RT trends from the data collected, it appeared that both cognitive inhibition and working memory were impacted by firefighting performance, with RTs becoming generally shorter immediately post activity, with longer RTs occurring as time passed post drill. Response variability only had a detectable change pre to post for the 0-back and 1-back tasks. Generally, 0-back response variability was larger post firefighting, and this effect was driven by increases in variability of RT on non-target trials. For the 1-back, only Spring 2014 and Spring 2015 (cohorts whose task orders placed 1-back in the middle of the other n-back tasks) demonstrated greater post drill target trial response variability. From the available data, accuracy on a task assessing cognitive inhibition appears to be negatively impacted when assessed immediately post firefighting and on a task assessing attention between ~5 and 22 minutes post firefighting. Working memory, on the other hand, seemed to be negatively impacted or not change, and was more negatively impacted the more time had passed from the end of the drill, potentially indicating fatigue or maybe the influence of the order in which certain tasks were completed in. It remains to be seen if cognitive flexibility would also be altered following firefighting; however, it would be predicted that it might be, given the impact that firefighting had on working memory and inhibition tasks from pre to post.

The effects vary as a function of a number of different factors such as time point of assessment, levels of physiological and perceptual strain, and individual differences. This is consistent with the acute exercise literature, because firefighting is more strenuous, not moderate (where beneficial effects of exercise are seen). The intermingling of other stressors (e.g., thermal strain), and other perceptual effects of firefighting may also contribute to these cognitive effects. The most confident interpretations of changes in cognitive performance following firefighting can be made for the cognitive inhibition findings, because all academies completed the modified flanker task first (within ~5 mins after completing the night-burn drill). Cognitive inhibition is clearly impacted, and it appears that the stimulation of the firefighting activity may result in rushed responding, resulting in decreased accuracy of performance.

Working memory performance results were slightly more difficult to interpret, given the timing of assessment and ordering of the tasks. However, 1-back target accuracy did appear to be detrimentally affected by the firefighting activity, with RT findings being equivocal. 2-back RT results seemed to reveal a decrease in RT following firefighting, with equivocal results for accuracy. Perhaps firefighters recognized the difficulty of the 2-back task and focused their attention on it more than on the 1-back task, resulting in retained performance, as only the group who completed the 2-back last in their task order showed any decrement in performance. As discussed earlier, the working memory performance may also have been influenced specifically by task order, such that having a working memory task precede another (1-back before 2-back, or 2-back before 1-back) may have facilitated performance on the subsequent working memory assessment, due to activation of the neural systems involved in working memory.

It was previously thought that individuals who were acclimated to high temperature environments would show no cognitive decline on simple attention tasks (Radakovic et al., 2007). Though the firefighters in this study were not undergoing a particular acclimatization procedure, they were definitely more acclimated to participating in live-fire suppression, forcible entry, and search and rescue, and performing physical work in PPE then they generally will be once they are out in the force. And, they still showed decrements to performance. The knowledge gained from this study may seem trivial at first, because time spent performing fire suppression only accounts for 1% of on-duty time, on average, for firefighters in the United States, increasing up to 5% for firefighters in a large metropolitan area (Kales, Soteriades, Christophi, & Christiani, 2007). However, 42.6% of all injuries occur during line-of-duty on the fire ground (Haynes & Molis, 2014). So, even though disruptions seemed small, they warrant genuine concern for firefighter safety. The new recruits in this study may even differ from same-age, same-fit peers in that they had been acclimating to live-fire, high heat, frequent stress, and repeated donning of PPE. Peers who have maybe been working as career firefighters for 1-2 years would likely not have had as much or as frequent of exposure to these things as the current sample. Approaching this problem from many fronts, such as equipment and fitness, and now from a cognitive perspective, is absolutely necessary.

Future Directions

Minimally, this research has provided replication of the psychophysiological demands of firefighting as well as novel insight as to how firefighting influences executive control. These results seem to open the door to future investigation of the timing of cognitive changes, the extent to which the computerized assessments might relate to real-life performance, the possible manipulation of the predictive factors to enhance performance through training, and the ability to recognize the need for rehabilitation and recovery in terms of cognitive function beyond physical needs. The independent relationships between individual difference characteristics, heart rate variables, and perceptual states as predictors of cognitive performance, outside of the framework of the model proposed here, definitely require further attention. A more thorough review of the cognitive data, such as post-error slowing, baseline performance differences, and relative interference on error versus correct trials, in relation to psychophysiological responses to firefighting is also warranted. Comparisons between AD ACL measures of Calmness and Tension and visual analog measures of the same constructs are something to examine in the future to test validity, as such measures can be assessed more quickly.

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APPENDIX: ADDITIONAL ANALYSES

ADDITIONAL ANALYSES INCLUDED TO PROVIDE FURTHER DETAIL ABOUT THE NIGHT-BURN DRILL, FIREFIGHTER SAMPLE, AND FULL CORRELATION MATRICES FOR RELATIONSHIPS BETWEEN MEASURED VARIABLES AND COGNITIVE PERFORMANCE OUTCOMES

Table A.1: Actual Amount of Time Spent in Night-burn Drill

Date	Company	n	Time Spent in Night-burn Drill	
			M	SD
Fall 2013		25	0:44:28.80	0:06:34.16
10/08	Alpha	7	0:42:00.00	0:08:37.30
10/09	Bravo	9	0:46:20.00	0:02:38.04
10/10	Charlie	9	0:44:33.33	0:07:35.08
Spring 2014		12	0:49:56.75	0:06:37.99
04/08	Alpha	6	0:47:24.67	0:03:32.01
04/09	Bravo	6	0:52:28.83	0:08:18.01
Fall 2014		20	0:53:21.00	0:05:11.55
10/06	Alpha	7	0:56:56.29	0:04:52.20
10/07	Bravo	6	0:51:40.33	0:05:55.34
10/08	Charlie	7	0:51:12.00	0:03:02.07
Spring 2015		28	0:48:33.11	0:02:48.36
04/06	Alpha	10	0:48:47.10	0:03:06.97
04/07	Bravo	9	0:48:57.56	0:01:40.92
04/08	Charlie	9	0:47:53.11	0:03:28.42
TOTAL		85	0:48:40.80	0:06:06.93

Table A.2 Correlations Between Perceptual & Affective Responses and Modified Flanker Performance

Post Drill Performance Outcomes		TS post-0	TS end	PeSI B_0	FS post-0	FS end	FAS end	Energy end	Tension post-0	Tired post-0	Tired end	Calm post-0	Fatigue post-0	Fatigue end	Nerv. post-0
ACC_Cong	*r*	-.285*	0.029	-0.273	0.204	0.177	-.325*	0.212	-0.012	-0.169	-.353**	0.015	-0.206	0.039	-.266*
ACC_InCong	*r*	-0.13	-0.051	0.109	0.047	0.063	-0.126	0.132	-0.045	-0.221	-.283*	0.052	-0.101	-0.065	-0.253
RT_Cong	*r*	0.203	0.051	0.281	-0.099	-.259*	0.101	-0.186	0.041	-0.02	0.183	0.147	.268*	0.139	-0.145
RT_Incong	*r*	0.176	-0.088	.296*	-0.09	-.259*	0.149	-0.161	0.071	0.052	0.114	0.177	.289**	0.141	-0.152
SD_Cong	*r*	.323*	0.048	.296*	-0.062	-0.235	0.02	-.284*	-0.024	0.121	.373**	0.237	0.193	0.024	0.096
SD_Incong	*r*	.278*	0.124	.303*	-.265*	-.448**	0.161	-.309**	.266*	.294*	.435**	.323*	.383**	.276*	0.18
Interference_ACC	*r*	0.009	0.069	-0.214	0.044	0.013	-0.014	-0.025	0.044	0.164	0.13	-0.051	-0.01	0.089	0.153
Interference_RT	*r*	-0.022	-.326*	0.076	-0.001	-0.056	0.138	0.058	0.081	0.171	-0.164	0.107	0.053	0.034	-0.046

Note: *Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed)

Table A.3 Correlations Between Perceptual & Affective Responses and 0-back Performance

Post Drill 0-back Performance Outcomes		TS pre	RPE end	PeSI pre_end	FS end	SAI post-0	SAI end	Energy end	Tension end	Tired end	Fatigue pre	Tension end
ACC_NonTarg	*r*	-0.146	-0.027	-0.017	-0.119	0.102	-0.129	0.176	0.021	-.257*	-.299*	-0.052
ACC_Targ	*r*	0.028	-.276*	-.288*	.298*	-.289*	-.341**	0.122	-.259*	-.277*	-.275*	-.304*
Correct_NT_RT_Pst	*r*	.288*	-0.015	-0.158	-0.187	-0.096	0.044	-.246*	-0.004	0.125	-0.115	0.194
Correct_Targ_RT_Pst	*r*	0.169	0.116	0.007	-.273*	-0.08	0.09	-.380**	0.019	0.205	-0.041	0.192
Correct_NT_SD_Pst	*r*	0.151	0.05	-0.085	-0.186	0.053	0.128	-0.017	0.115	0.096	-0.026	0.091
Correct_Targ_SD_Pst	*r*	0.086	-0.071	-0.046	0.034	-.291*	-0.015	-.244*	-0.099	0.144	-0.011	-0.068
Pst_N0_dprime	*r*	0.027	-0.253	-.259*	0.241	-0.246	-.336**	0.144	-.239*	-.296**	-.301*	-.278*

Note: *Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed)

Table A.4 Correlations Between Perceptual & Affective Responses and 1-back Performance

Post Drill 1-back Performance Outcomes		PeSI B_0	PeSI B_end	FS post0	FAS post0	SAI post0	SAI end	Tension pre	Tension post0	Tension end	Tired end	Calm end	Tension pre	Nerv. pre	Nerv. end
ACC_NonTarg	*r*	0.097	0.055	-0.011	-0.248	-0.154	-0.068	0.066	0.093	0.115	-.301**	0.154	0.065	-.333*	-0.165
ACC_Targ	*r*	0.277	0.151	0.047	-0.229	-.289*	-.378**	-0.215	-0.12	-.267*	-.261*	.335**	-0.14	-0.157	-0.015
Correct_NT_RT	*r*	.354*	.296*	0.054	-0.107	-0.13	-0.032	-.444**	-0.211	-0.123	0.073	0.026	-0.201	0.127	.266*
Correct_Targ_RT	*r*	0.271	0.264	0.122	-0.022	-0.149	-0.015	-.417**	-0.245	-0.194	0.177	-0.08	-0.201	0.088	0.097
Correct_NT_SD	*r*	.302*	0.154	0.131	-0.068	-0.132	-0.045	-.383**	-0.187	-0.125	0.142	0.027	-.294*	0.081	0.206
Correct_Targ_SD	*r*	0.091	0.102	.260*	0.148	-0.198	-0.097	-.331*	-.286*	-.247*	0.105	-0.136	-.262*	-0.082	-0.009
dprime	*r*	0.214	0.111	-0.004	-.261*	-0.252	-.255*	-0.121	-0.02	-0.11	-.308**	.279*	-0.054	-0.253	-0.122

Note: *Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed)

Table A.5 Correlations Between Perceptual & Affective Responses and 2-back Performance

Post Drill 2-back Performance Outcomes		FAS end	SAI pre	SAI end	Tension pre	Tension end	Tired end	Calm post-0	Fatigue pre	Fatigue post-0	Tension pre	Calm pre	Calm end	Nervous pre
ACC_NonTarg	*r*	-0.202	-0.115	-0.07	-0.193	-0.084	-0.206	0.107	0.027	-0.066	-0.165	-0.054	-0.001	-.297*
ACC_Targ	*r*	-.318*	-0.138	-0.095	-0.17	-0.029	-.245*	0	-0.023	-0.08	-0.171	0.043	-0.131	-0.244
Correct_NT_RT	*r*	-0.125	-.441**	-0.172	-.449**	-0.135	-0.096	0.231	-0.2	-0.214	-.290*	0.234	0.175	-0.001
Correct_Targ_RT	*r*	-0.121	-.369**	-0.122	-.394**	-0.103	0.014	0.169	-.263*	-0.162	-.319*	.267*	0.056	-0.041
Correct_NT_SD	*r*	-0.21	-.430**	-0.205	-.403**	-.233*	-0.048	.262*	-0.197	-.239*	-.377**	.313*	.321*	-0.105
Correct_Targ_SD	*r*	-0.082	-.358**	-.275*	-.352**	-.258*	-0.008	0.155	-0.241	-0.09	-.293*	.277*	0.125	0.012
dprime	*r*	-0.246	-0.133	-0.08	-0.193	-0.05	-.252*	-0.028	-0.029	-0.054	-0.19	0.002	-0.102	-.292*

Note: *Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed)

Table A.6 Correlations Between HR and Modified Flanker Performance

Post Drill Modified Flanker Performance		HR POC	HR AVG Drill	% Time in Mod Zone	HR AVG POC To Lab	HR AVG Cog To End	HR SD Cog To End	HR SD Entire	HR Change POC To Lab	HR Change POC To End	HR Change Lab To End	HR AVG POC To End	HR SD POC To End	HR Recovery
ACC_Cong	*r*	-.482**	-.448*	.393*	-.448*	-.463*	-0.308	-.445*	-0.13	-0.354	-0.168	-0.358	-0.166	-0.09
ACC_InCong	*r*	-0.216	-0.32	0.254	-0.008	-0.019	0.285	-0.172	-.572**	-0.23	0.368	-0.089	0.106	0.327
RT_Cong	*r*	0.248	-0.182	0.157	0.266	0.284	.638**	0.111	-.421*	0.072	.472*	0.064	0.374	.601**
RT_Incong	*r*	0.284	-0.163	0.103	0.278	0.32	.677**	0.135	-0.264	0.136	0.372	0.137	.413*	.623**
SD_Cong	*r*	.478*	0.057	-0.1	0.36	.522**	.601**	0.334	-0.135	0.242	0.333	.432*	0.362	.713**
SD_Incong	*r*	.541**	0.145	-0.224	.440*	.522**	.589**	.414*	0.013	.441*	0.354	.469*	.466*	.576**
Interference_ACC	*r*	0.071	0.203	-0.147	-0.155	-0.135	-.414*	0.034	.600**	0.147	-.465*	-0.014	-0.171	-0.387
Interference_RT	*r*	0.141	0.014	-0.109	0.081	0.149	0.218	0.082	0.257	0.172	-0.109	0.191	0.198	0.169

Note: *Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed)

Table A.7 Correlations Between HR and 0-back Performance

Post Drill 0-back Performance Outcomes		HR POC watch	HR AVG Drill	% Time in Mzone	% Time in VEH zone	HR AVG POC To Lab	HR AVG Cog To End	HR SD Cog To End	HR Change POC To Lab	HR Change Lab To End	HR AVG POC To End	HR SD POC To End	HR Recovery
ACC_NonTarg	*r*	-0.338	-.428*	.376*	-.511**	-0.248	-0.145	-0.004	-0.075	-0.238	-0.237	-0.229	0.373
ACC_Targ	*r*	0.071	0.116	-0.093	0.254	0.273	0.33	0.304	-.463*	0.354	0.286	0.168	0.073
Correct_NT_RT	*r*	.405*	0.145	-0.147	0.091	.430*	.637**	.551**	-0.144	0.322	.598**	0.317	.555**
Correct_Targ_RT	*r*	0.29	0.185	-0.11	0.099	0.313	0.382	.565**	-0.159	.412*	0.378	.540**	0.218
Correct_NT_SD	*r*	0.158	0.074	-0.057	-0.105	0.08	0.363	-0.026	0.317	-0.262	.461*	-0.028	0.338
Correct_Targ_SD	*r*	0.116	0.105	-0.104	0.208	0.124	0.118	0.154	-0.068	0.289	0.165	0.248	-0.046
dprime	*r*	0.033	0.08	-0.07	0.19	0.265	0.294	0.301	-.488*	0.338	0.238	0.146	0.13

Note: *Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed)

Table A.8 Correlations Between HR and 1-back Performance

Post Drill 1-back Performance Outcomes		HR POC Watch	HR Mininum Drill	HR SD POC To Lab	HR AVG Cog To End	HR SD Cog To End	HR Change POC To Lab	HR Change Lab To End	HR AVG POC To End	HR Recovery
ACC_NonTarg	*r*	-0.182	-0.079	-.502**	-0.168	-0.167	-0.334	0.241	-0.187	-0.04
ACC_Targ	*r*	-0.209	0.007	-0.345	-0.159	0.155	-.515**	.414*	-0.16	-0.114
Correct_NT_RT	*r*	0.275	.432*	0.06	.398*	.415*	-0.103	0.152	0.373	0.311
Correct_Targ_RT	*r*	0.157	0.143	0.059	0.273	.447*	-0.207	0.252	0.27	0.354
Correct_NT_SD	*r*	.397*	.443*	0.058	.458*	0.37	0.114	0.007	.501*	.399*
Correct_Targ_SD	*r*	.430*	0.28	0.051	.409*	0.316	0.117	-0.059	0.399	.473*
dprime	*r*	-0.266	-0.013	-.400*	-0.24	0.023	-.478*	0.363	-0.244	-0.177

Note: *Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed)

Table A.9 Correlations Between HR and 2-back Performance

Post Drill 2-back Performance Outcomes		HR POC watch	HR Minimum Drill	HR AVG POC to End	HR Recovery
ACC_NonTarg	*r*	-0.245	0.026	-0.14	-0.216
ACC_Targ	*r*	-.438*	-0.146	-0.253	-.424*
Correct_NT_RT	*r*	0.151	.385*	.421*	.467*
Correct_Targ_RT	*r*	-0.044	0.05	0.268	.499*
Correct_NT_SD	*r*	0.251	0.286	0.385	.483*
Correct_Targ_SD	*r*	0.06	-0.091	0.316	.568**
dprime	*r*	-0.363	-0.069	-0.198	-0.383

Note: *Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed)

Table A.10 Correlations Between Individual Differences and Modified Flanker Performance

Post Drill Modified Flanker Performance Outcomes		BMI	estimated VO2	Tolerance	Resilience: Control	Self Distraction Coping	Emotional Support Coping	Self Blame Coping	Big-5 Emotional Stability
ACC_Cong	*r*	0.097	-0.098	-.249*	-0.05	-.274*	0.202	-.278*	.328*
ACC_Incong	*r*	0.143	-0.039	-.274*	-0.209	-0.142	0.116	-0.168	0.203
RT_Cong	*r*	-0.105	0.135	-0.107	-0.125	-0.035	-0.179	0.067	0.041
RT_Incong	*r*	-0.09	0.131	-0.103	-0.118	-0.132	-0.159	-0.034	0.076
SD_Cong	*r*	-.238*	0.207	-0.057	-0.047	0.221	-0.23	0.212	-0.186
SD_Incong	*r*	-.261*	.260*	0.207	-0.026	0.215	-.250*	.266*	-0.264
Interference_ACC	*r*	-0.125	-0.018	0.194	.246*	-0.006	-0.01	0.019	-0.064
Interference_RT	*r*	0.036	-0.011	0.01	0.01	-0.228	0.043	-.282*	0.093

Note: *Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed)

Table A.11 Correlations Between Individual Differences and 0-back Performance

Post Drill 0-back Performance Outcomes		Years Career Or Volunteer FF	Tolerance	Active Coping	Substance Use Coping	Planning Coping	Humor Coping	Acceptance Coping
ACC_NonTarg	*r*	0.106	-0.197	-0.035	0.055	.279*	.260*	.268*
ACC_Targ	*r*	-0.055	-0.176	-0.169	-0.102	0.139	0.121	0.142
Correct_NT_RT	*r*	-0.269	-.256*	-.393**	0.15	-0.113	-0.112	0.024
Correct_Targ_RT	*r*	-.420*	-0.143	-.258*	0.203	-0.006	0.03	-0.004
Correct_NT_SD	*r*	-0.336	-.219*	-0.056	.246*	-0.075	-0.125	0.124
Correct_Targ_SD	*r*	-.371*	0.025	-0.103	0.037	-0.016	-0.088	-0.018
dprime	*r*	-0.038	-0.177	-0.168	-0.077	0.177	0.137	0.165

Note: *Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed)

Table A.12 Correlations Between Individual Differences and 1-back Performance

Post Drill 1-back Performance Outcomes		Years Career Or Volunteer FF	Resilience: Control	Resilience: Challenge	Self Distraction Coping	Active Coping	Big-5 Extraversion	Big-5 Intellect-Openness
ACC_NonTarg	*r*	0.217	-0.191	-0.089	-.291*	-0.136	-.308*	-.420**
ACC_Targ	*r*	.359*	-0.183	-.361**	-.259*	-.319**	-0.192	-.359**
Correct_NT_RT	*r*	-0.054	0.028	-0.048	0.07	-0.17	0.166	-0.046
Correct_Targ_RT	*r*	-0.128	0.033	-0.022	0.212	0.064	.371**	0.111
Correct_NT_SD	*r*	-0.098	0.066	-0.081	0.115	0.002	0.204	0.044
Correct_Targ_SD	*r*	-0.052	0.181	0.027	0.188	0.183	.289*	0.089
dprime	*r*	0.316	-.238*	-.249*	-.294*	-.264*	-0.236	-.365**

Note: *Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed)

Table A.13 Correlations Between Individual Differences and 2-back Performance

Post Drill 2-back Performance Outcomes		Trait Anxiety	Preference	Resilience: Commitment	Active Coping	Denial Coping	Reframing Coping	Big-5 Extraversion	Big-5 Agreeableness	Big-5 Conscientiousness
ACC_NonTarg	*r*	0.135	-.359**	-0.093	-0.136	0.094	0.067	-0.226	-.305*	-.304*
ACC_Targ	*r*	-0.074	-0.189	-0.056	0.042	-0.001	0.04	-0.025	-0.143	-0.083
Correct_NT_RT	*r*	-0.093	0.019	0.089	-0.014	-0.025	0.141	0.136	0.143	0.089
Correct_Targ_RT	*r*	-0.146	0.138	.229*	0.111	-0.184	.318**	0.247	0.095	0.234
Correct_NT_SD	*r*	-0.155	0.09	0.026	0.046	-0.109	0.059	0.191	0.101	0.189
Correct_Targ_SD	*r*	-.248*	0.093	0.123	.232*	-.236*	.273*	.345*	0.148	0.242
dprime	*r*	0.035	-.234*	-0.098	-0.048	0.064	0.048	-0.08	-0.189	-0.201

Note: *Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed)

Perceptual Strain Index

Univariate ANOVA revealed no significant difference in PeSI_post0 by academy [F(2,56) = 1.39, *p* = 0.26, partial $\eta^2 = 0.047$].

Table A.14 Changes in Perceptual Strain Index

Descriptive Statistics			
	Mean	Std. Deviation	N
PeSI_B_0	5.67	2.08	45
PeSI_B_end	1.88	2.15	45
PeSI_pre_0	6.01	1.63	60
PeSI_pre_end	2.28	1.99	60

Note: PeSI = Perceptual Strain Index; B_0 = baseline to post-0; B_end = baseline to end; pre_0 = pre-firefighting to post-0; pre_end = pre-firefighting to end

Table A.15 Change in Perceptual Strain Index from Pre to Post-0 by Academy

Descriptive Statistics			
Academy	Mean	Std. Deviation	N
Spring 2014	5.75	2.09	12
Fall 2014	5.68	1.61	19
Spring 2015	6.41	1.36	28
Total	6.04	1.62	59

Table A.16 Correlations Between PeSI and HR Variables

		HRchange_POCtoEnd	Duration of Drill	HRavg_POCtoEnd	Minutes it took to get within 20% of RHR after POC
PeSI_B_0	*r*	-0.14	-0.28	0.52*	0.88*
	p	0.55	0.06	0.02	<0.001
	n	22	45	21	12
PeSI_B_end	*r*	-0.05	-0.33*	0.27	0.67*
	p	0.81	0.03	0.24	0.02
	n	22	45	21	12
PeSI_pre_0	*r*	-0.46*	-0.11	0.15	0.74*
	p	0.02	0.41	0.50	< 0.01
	n	25	60	24	12
PeSI_pre_end	*r*	-0.14	-0.23	-0.07	0.36
	p	0.52	0.08	0.76	0.25
	n	25	60	24	12

Firefighting Experience

Table A.17 Firefighting Experience Descriptive Statistics

Descriptive Statistics					
	N	Minimum	Maximum	Mean	Std. Deviation
Years Served as Career FF	25	0.00	6.00	0.93	1.56
Years Served as Volunteer FF	30	0.00	12.00	4.21	3.49
Years_CareerorVolunteer	32	0.00	12.00	4.67	3.73

Table A.18: Changes in Modified Flanker Performance Over Time (n = 58)

	Baseline	Pre	Post
	M (SD)	M (SD)	M (SD)
% ACC			
Cong	98.72 (1.90)	98.91 (1.99)[c]	97.76 (3.31)[b]
Incong	91.76 (7.93)	93.41 (6.30)[c]	90.35 (7.41)[b]
RT on Correct Trials (ms)			
Con	483.53 (55.78)[b,c]	471.55 (46.51)[a,c]	437.64 (40.50)[a,b]
Incong	542.61 (48.43)[b,c]	532.51 (43.21)[a,c]	489.41 (44.45)[a,b]
SD on Correct Trials (ms)			
Con	68.91 (20.27)[b]	60.41 (16.85)[a]	63.27 (21.83)
Incong	71.80 (21.82)[b]	64.94 (15.50)[a]	64.15 (18.57)
Interference RT (Incong – Cong)	59.08 (25.56)[c]	60.95 (20.84)[c]	51.77 (18.52)[a,b]
Interference ACC (Cong – Incong)	6.97 (7.04)	5.5 (6.35)[c]	7.41 (6.76)[b]

Note: a = significantly different from Baseline; b = significantly different from Pre;
c = significantly different from Post; significance level set at *p* < .05

Table A.19: Changes in 0-back Performance Over Time (n = 56)

	Baseline M (SD)	Pre M (SD)	Post M (SD)
% ACC			
Nontarg	99.75 (0.77)	99.69 (0.86)	99.58 (0.76)
Targ	96.09 (5.27)	96.88 (4.77)	94.87 (7.55)
Correct Trial RT (ms)			
Nontarg	537.58 (65.58)	524.03 (53.20)^{c}	545.43 (71.67)^{b}
Targ	564.08 (56.51)	552.21 (53.08)	562.59 (63.86)
Correct Trial SD of RT (ms)			
Nontarg	109.60 (51.87)^{c}	109.05 (47.77)^{c}	152.35 (63.70)^{a,b}
Targ	92.10 (50.68)	98.72 (87.53)	86.65 (37.90)
d-prime (d’)	3.87 (0.32)	3.92 (0.26)	3.82 (0.38)

Note: a = significantly different from Baseline; b = significantly different from Pre; c = significantly different from Post; significance level set at $p < .05$

Table A.20: Changes in 1-back Performance Over Time (n = 54)

	Baseline M (SD)	Pre M (SD)	Post M (SD)
% ACC			
Nontarg	98.75 (1.48)^{c}	98.53 (2.23)	97.11 (4.36)^{a}
Targ	95.00 (5.66)^{c}	94.54 (5.16)^{c}	89.07 (11.41)^{a,b}
Correct Trial RT (ms)			
Nontarg	760.17 (126.56)^{b,c}	711.25 (109.97)^{a}	696.37 (131.41)^{a}
Targ	660.17 (93.83)^{b}	628.32 (75.34)^{a}	640.33 (113.79)
Correct Trial SD of RT (ms)			
Nontarg	208.06 (78.19)	203.94 (82.02)	217.36 (99.85)
Targ	166.88 (61.33)	152.12 (70.81)^{c}	194.33 (117.61)^{b}
d-prime (d')	3.73 (0.37)^{c}	3.68 (0.45)^{c}	3.29 (0.74)^{a,b}

Note: a = significantly different from Baseline; b = significantly different from Pre; c = significantly different from Post; significance level set at p < .05

Table A.21: Changes in 2-back Performance Over Time (n = 56)

		Baseline M (SD)	Pre M (SD)	Post M (SD)
% ACC				
	Nontarg	91.97 (6.68)	93.47 (7.61)	92.83 (7.13)
	Targ	84.45 (11.55)	85.63 (13.38)	82.23 (16.12)
Correct Trial RT (ms)				
	Nontarg	1189.10 (247.57)^{b,c}	1058.25 (214.60)^{a,c}	916.19 (210.83)^{a,b}
	Targ	927.86 (203.01)^{b,c}	860.50 (165.94)^{a,c}	779.25 (156.32)^{a,b}
Correct Trial SD of RT (ms)				
	Nontarg	376.74 (103.11)^{b,c}	343.27 (106.60)^{a}	326.47 (104.59)^{a}
	Targ	350.28 (133.13)^{c}	315.96 (132.99)	292.57 (114.93)^{a}
d-prime (d’)		2.64 (0.75)	2.87 (0.89)	2.67 (0.99)

Note: a = significantly different from Baseline; b = significantly different from Pre; c = significantly different from Post; significance level set at *p* < .05