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[Original Article]

The adverse impact of personal protective equipment on firefighters' cognitive functioning

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Abstract

Firefighters wear Personal Protective Equipment (PPE) for protection from environmental hazards. However, due to the layers of protective functions, the PPE inevitably adds excessive weight, bulkiness, and thermal stress to firefighters. This study investigated the adverse impact of wearing PPE as an occupational stressor on the firefighter's cognitive functioning. Twenty-three firefighters who had been involved in firefighting at least for 1 year were recruited. The overall changing trend in the firefighter's cognitive functioning (short-term memory, long-term memory, and inductive reasoning) was measured by the scores of three standardized cognitive tests at the baseline and the follow-up, after participating in a moderate-intensity physical activity, wearing a full ensemble of the PPE. The study findings evinced the negative impact of the PPE on the firefighter's cognitive functioning, especially in short-term memory and inductive reasoning. No significant influence was found on the firefighter's long-term memory. The results were consistent when the participant's age and BMI were controlled. The outcomes of the present study will not only fill the gap in the literature, but also provide critical justification to stakeholders, including governments, policymakers, academic communities, and industry, for such efforts to improve human factors of the firefighter's PPE by realizing the negative consequences of the added layers and protective functions on their occupational safety. Study limitations and future directions were also discussed.

Keywords: personal protective equipment, firefighters, cognitive functioning, memory, inductive reasoning

I. Introduction

According to the National Fire Protection Association (NFPA) (Haynes & Molis, 2015), in 2014, 63,350 injury cases were reported in the United States; of these, 27,025 cases (41%) occurred at the fireground. Furthermore, the line-of-duty casualty rate of US firefighters is three times higher than that of all other workers (Clarke & Zak, 1999). The National Fire Fighter Near-Miss Reporting System (Grorud & Smith, 2008) claimed that 58% of casualties were caused by poor information management or decision-making. In this data set, 29% of accidents were engendered by poor situational awareness, 25% by poor decision-making, and 10%

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by poor communication. Another firefighter injury report (Moore-Merrell, Zhou, McDonald-Valentine, Goldstein, & Slocum, 2008) determined lack of situational awareness as the most dominant cause for the firefighters' line-of-duty injuries, followed by lack of wellness/fitness and human error. To wit, occupational injuries in firefighters are frequently caused by the absence of appropriate comprehension of a situation and the projection of its status, which are probable consequences of cognitive dysfunction.

Given the high risks of firefighters' occupational injury, a fire-ground is considered as one of the most challenging work environments. To protect themselves and save others from environmental hazards, firefighters have to make right decisions in a dynamically changing situation, under mental and time pressure. They have to be aware of potentially important incoming information about the fire or rescue situations, while comprehending this large amount of complex information in short periods of time (Krasuski, Jankowski, Skowron, & Slezak, 2013). Therefore, firefighters are required to possess a good set of technical skills and cognitive abilities to make instantaneous judgments and decisions and to give careful attention to those being rescued, while maintaining a proper level of coordination and reasoning for their own safety (O*net Online, n.d.). On top of the risk causes embedded in the firefighting occupation by nature, the occupational stress that firefighters experience in the work field results in the increased risk of injury. Generally, unfavorable working conditions, such as long work hours or strenuous physical tasks, are negatively linked to a worker's general health (Grosch, Caruso, Rosa, & Sauter, 2006), cognitive functioning (Mendl, 1999; Proctor, White, Robins, Echeverria, & Rocskay, 1996; Virtanen et al., 2008), attention and memory processes (McEwen & Sapolsky, 1995; Schwabe & Wolf, 2010), perceived self-efficacy (Bandura, 1993), and psychological well-being (Baker & Williams, 2001) as well as the overall job performance that can lead to the increased risk of injury or illness (Dembe, Erickson, Delbos, & Banks, 2005).

This paper investigated firefighters' personal protective equipment (PPE) as a source of occupational stress. Firefighters wear PPE to protect themselves from fire and other environmental hazards. A full ensemble of the PPE consists of turnout coats and pants, boots, gloves, hood, helmet, and a 45-min SCBA air pack, as guided by NFPA 1971. It typically weighs 75-85 lbs. While the PPE provides necessary protection, due to the layers of protective functions, it inevitably adds excessive weight, bulkiness, and thermal stress, thus impeding a firefighter's job performance (Park, Park, Lin, & Boorady, 2014). Especially on the fire grounds, in which critical, life-threatening incidents are likely to happen, the heavy, cumbersome, and hot PPE tends to impose additional occupational stress on firefighters while performing the required tasks (Guidotti, 1998). Studies have determined the adverse impact of the PPE in various aspects, including a firefighter's mobility (Coca, Williams, Roberge, & Powell, 2010), postural balance (Sobeih, Davis, Succop, Jetter, & Bhattacharya, 2006), heat stress (McLellan & Selkirk, 2004; Raimundo & Figueiredo, 2009; White & Hodous, 1987), physical fatigue (Park, Rosengren, Horn, Smith, & Hsiao-Wecksler, 2011), and psychological stress (Ha et al., 2008; Smith & Petruzzello, 1998). Additionally, studies in literature mentioned the potential influences of PPE on a firefighter's cognitive functioning (Barr, Gregson, & Reilly, 2010; Coca et al., 2010; Sobeih et al., 2006; White & Hodous, 1987). However, to the best of the author's knowledge, no research, to date, has been conducted to evince the scientific evidence of the adverse impact of wearing the PPE as an occupational stressor on the firefighter's cognitive performance. Therefore, the specific purpose of this research was to investigate the overall changing trend in the firefighter's cognitive functioning at the baseline and the follow-up, after participating in a moderate-intensity physical activity, wearing a full ensemble of the PPE. To achieve the research goal, this study focused on examining the three particular psychological attributes in the firefighter's cognitive functioning that included short- term memory, long-term memory, and inductive reasoning, and the following hypotheses guided the investigation:

H_1: Involving in a moderate-intensity physical activity wearing a full ensemble of the PPE negatively affects a firefighter's short-term memory.

H_2: Involving in a moderate-intensity physical activity wearing a full ensemble of the firefighter PPE negatively affects a firefighter's long-term memory.

H_3: Involving in a moderate-intensity physical activity wearing a full ensemble of the firefighter PPE negatively affects a firefighter's inductive reasoning.

Ⅱ. Methods

1. Recruitment

A total of 23 male firefighters, career or volunteer, who had been involved in firefighting at least for 1 year were recruited for this study. The recruitment of firefighters was conducted by email distribution through key contacts at local fire departments. Interested firefighters were directed to contact the researcher to schedule a lab visit. Firefighters were instructed to bring a complete set of their own PPE to their scheduled visit, including turnout coats and pants, boots, gloves, hood, helmet, and 45-min SCBA air pack. Prior to their study participation, the potential participants received an email containing the human subject consent and descriptions of the study procedures. They were given an opportunity to review the shared information and withdraw if they were not interested in participating. The participant recruitment and data collection procedures were approved by the institutional review board (IRB) of the researcher's university.

2. Procedures

Each experiment consisted of the three data collection sessions: (a) cognitive tests at baseline, (b) treadmill walking and (c) cognitive tests at follow-up. On the day of an experiment, once the interested participants signed the informed consent and indicated their readiness to begin the experiment, they were escorted to a conference room inside the research lab, in which a quiet ambiance was kept. Then they were asked to complete a background survey, and participate in a battery of the three standardized cognitive tests. The battery of cognitive tests contained a short-term memory test (test 1), a verbal fluency test (test 2), and Raven's advanced progressive matrices (test 3). The administrative procedures of the short-term memory test (test 1) and verbal fluency test (test 2) were based on Virtanen et al.'s study (2008), while the original advanced progressive matrices (test 3) were retrieved from Raven's classic book (1965), *Advanced Progressive Matrices Set I & II*. Each of the test questions was shown on a high-resolution computer screen. When a participant completed the pre-cognitive tests, he was offered a 20-min break to rest from cognitive fatigue that he might experience from taking the tests. After the break, he was asked to put on a full ensemble of his PPE, over a casual t-shirt and pants, following the typical wearing procedure of the firefighter PPE. To simulate a moderate-intensity occupational environment, the participant was asked to walk on a treadmill at 3 mph with 3% incline for 30 minutes. The setting of the physical activity was chosen based on the Centers for Disease Control and Prevention (CDC)'s guideline (CDC, 2016) to measure the influences of wearing the PPE on the firefighter's cognitive performance at moderate intensity, rather than the excessive physical fatigue and strain caused by strenuous physical activities. Thus, the data collected from the experimental procedure could reflect the main focus of this study, i.e., the investigation of the adverse impact of wearing the PPE on the firefighter's cognitive functioning, while the physical activity set a reasonable amount of physical movement and energy consumption for firefighters in a typical low-to-moderate work environment.

After 10 minutes of treadmill walking, while still performing the physical activity, the participant started taking the same battery of the standardized cognitive tests that he took during the pre-tests, but with different question sets (further details about the test questions are discussed in the following section). The post-tests questions were shown on the computer screen at the participant's eye level (placed on a tall column), and answers were recorded by a researcher when they were verbally reported by the participant. This post-testing procedure was designed to prevent the participant from resting while taking the post-tests, as well as to avoid the need to get off the treadmill or take off PPE, to take the tests. When the participant completed the post-tests, he was allowed to end walking and take off the PPE. The total time commitment per participant was approximately 1 ½ hours.

3. Validation of cognitive tests with control group

Researchers (Hausknecht, Halpert, Di Paolo, & Moriarty Gerrard, 2007) have noted about the practice effect in that scores tend to improve when people retake the same test. Also, even though the same battery of cognitive tests was used in this study, the questions sets were different in the baseline and follow-up test settings. Therefore, to assess the practice effect of the test batteries and gauge the difficulty level of the question sets, a control group of 30 convenient samples who were males, 18 years or older, and had no history of chronic mental problems were recruited from the researcher's university. They were asked to take the same batteries of the cognitive tests at the baseline and the follow-up with a 20-min break in between the tests, following the same procedure as the firefighter participants did. However, the control group did not involve in the physical activity nor wearing the PPE. The score changes in the control group from the baseline to the follow-up were used as the reference comparison data to the experimental group of firefighters.

4. Data analysis

Statistical analyses were performed using IBM SPSS 24.0. To ensure the normality of the cognitive data, Shapiro-Wilk tests were performed, and the significance in all test items (baseline and follow-up) was higher than .05, which indicated that the data were normally distributed. Given the normality of the data, paired-samples *t*-tests, independent-samples *t*-tests, and analysis of covariance (ANCOVA) were used to examine the changing trend in the firefighters' cognitive functioning at the baseline and the follow-up. Descriptive data were presented as mean ($\bar{x}$), standard deviation (*SD*) for continuous variables, and frequency percentage (%) for categorical variables. All analyses were evaluated at the 95% confidence level.

Ⅲ. Results

1. Participant profiles

〈Table 1〉 summarizes the participants' demographic and physical backgrounds. The mean age of the study participants (N=23) was 39.57 (range 27-57, *SD*=7.91), and the average height and weight of the group were 69.96 in. (177.70cm, *SD*=3.89) and 179.09lbs. (81.23kg, *SD*=38.29). Mean body mass index (BMI) of the experimental group was 25.52kg/m^2 (*SD*=3.79). Twenty-one firefighters (n=21, 91.3%), of 23, were structural firefighters and 15 (n=15, 65.2%) were also involved in wildland firefighting. Two firefighters (n=2, 8.7%) were wildland only. The average duration of the firefighter career was 12.80 years (range 1-26.67, *SD*=7.64). Two (n=2, 8.7%) were volunteer firefighters, and the rest were career firefighters (n=21, 91.3%). All firefighters participated in this study (n=23, 100%) were Caucasians.

2. Baseline cognitive abilities

The results of independent-samples *t*-tests indicated that there were no significant differences in the base-

<Table 1> Demographic profiles of study participants

Characteristics	Study participants (N=23)
Age mean (*SD*)	39.6 (7.9)
Height mean (*SD*)	70.0 in. (3.9)
Weight mean (*SD*)	179.1lbs. (38.3)
BMI mean (*SD*)	25.5 (3.8)
Ethnicity	
Caucasian (%)	23 (100.0)
Hispanic (%)	-- (0.0)
Multiracial (%)	-- (0.0)
Firefighting service	
Years of firefighting mean (*SD*)	12.8 (7.6)
Career (%)	21 (91.3)
Volunteer (%)	2 (8.7)
Structural only (%)	9 (39.1)
Wildland only (%)	2 (8.7)
Both structural and wildland (%)	12 (52.2)

line cognitive data between the experimental group (firefighters) and control group at the 95% confidence level. As shown in 〈Table 2〉, the mean score of the firefighters on the short-term memory test (test 1) was 8.14 (*SD*=1.81), while that of the control group was 7.00 (*SD*=1.73). In other words, on average, the participants in both groups could recall roughly seven to eight words after viewing the 20 short vocabularies in 2 minutes. The mean scores indicated no statistical difference in short-term memory between the firefighters and the control group (p=.155). The verbal fluency test (test 2), both in phonemic and semantic long-term memory analysis, also showed no difference between the experimental and control groups. In the phonemic test (test 2.1), the experimental group, on average, was able to list words starting with S as many as 19.3 (*SD*=3.77), while the control group could recall about 17.4 words. Although the total number of the words recalled was slightly higher among the firefighters, it was not statistically significant (p=.239). In the semantic test (test 2.2), the average score that the experimental group obtained from listing animal names was 24.4 (*SD*=6.98), while the control group could list as many as 23.4 (*SD*=3.74). On average, both groups could list 23-25 animal names in 1 minute, and there was no statistical significance in the test results (p=.727). The results of Raven's advanced progressive matrices (test 3) also showed that the cognitive abilities of both groups were within the same range at p<.05 (p=.841), based on the mean scores of the correct answers. That is, the average number of correct answers that the experimental group made from the nonverbal reasoning test (of 18 questions) was 10.82 (*SD*=2.76) and that

<Table 2> Comparison of cognitive test scores at baseline and follow-up between the groups

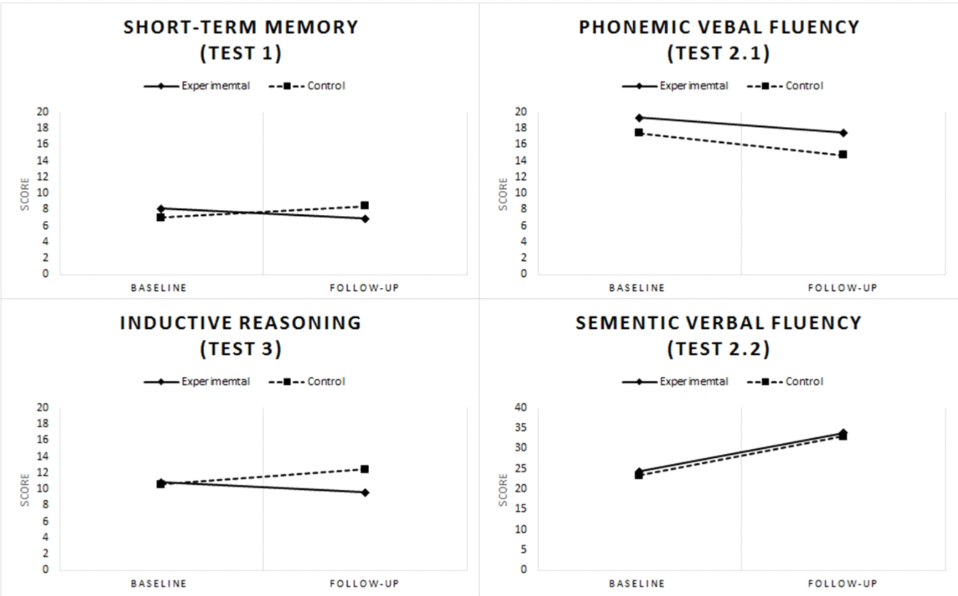
Test	Baseline (Pre)			Follow-up (Post)			Pre-post comparison		
	G1 Mean (*SD*)	G2 Mean (*SD*)	Sig	G1 Mean (*SD*)	G2 Mean (*SD*)	Sig	G1 Mean (*SD*)	G2 Mean (*SD*)	Sig
Test 1	8.17 (1.77)	7.00 (1.73)	.155	6.91 (2.50)	8.43 (2.70)	.179	−1.26 (2.22)	1.43 (1.62)	.006**
Test 2.1	19.27 (3.77)	17.43 (3.46)	.239	17.22 (4.06)	14.71 (4.75)	.180	−1.96 (4.49)	−2.71 (3.64)	.688
Test 2.2	24.42 (6.98)	23.43 (3.74)	.727	33.83 (7.69)	33.00 (3.65)	.787	9.61 (8.78)	9.57 (3.51)	.991
Test 3	10.82 (2.76)	10.57 (2.99)	.841	9.61 (3.54)	12.43 (2.76)	.064	−1.22 (2.56)	1.86 (1.86)	.007**

for the control group was 10.57 (*SD*=2.99). Overall, these results signified that the cognitive abilities between the experimental group and control group were not significantly different at the baseline comparison. The validation of the baseline cognitive abilities between the groups was critical to confirm, in order to compare the test results of the control group as reference data for subsequent analyses.

3. Pre-post score comparisons on cognitive tests

To illustrate the overall trend in changes of a firefighter's cognitive functioning, the test scores between the baseline and follow-up were compared (Fig. 1). The results of within-subject paired-samples *t*-tests indicated that the follow-up test scores of the control group improved in the three cognitive tests, including the short-term memory (test 1), semantic verbal fluency test (test 2.2), and inductive reasoning (test 3). However, the test scores did drop in the phonemic verbal fluency test (test 2.1). The analysis results suggest that there could be the practice effect in the cognitive tests, which scores improved after retaking. However, the decreased test scores in test 2.1 could be interpreted that the question set that asked to list words beginning with "A" (post-test) was generally perceived to be more difficult by participants than listing words beginning with "S" (pre-test). Moreover, this result could also be explained that the phonemic verbal fluency, which is correlated with one's long-term memory, cannot be learned in a short time, and each letter in the alphabet may present a different level of difficulty.

To compare the pre-post test score changes between the experimental and control group, independent-samples *t*-tests were performed. As 〈Table 2〉 illustrated, significant score differences between the groups were identified in short-term memory (p=.006) and inductive reasoning (p=.007), which supported H_1 and H_3. On the other hand, there were no significant differences in both of the verbal fluency tests and H_2 was rejected. That is, the firefighters showed noticeable score decreases in short-term memory and inductive reasoning after performing the moderate-intensity physical activity, while wearing a full set of the PPE, but this trend was not found in verbal fluency tests that measured verbal long-term memory.



<Fig. 1> Visual comparison of cognitive test scores between the groups

To further elaborate, the control group's scores improved as much as 1.43 in short-term memory and 1.86 in inductive reasoning after taking the cognitive tests twice; even though there could be practice effects in the experimental group, the firefighters scored less in post-test short-term memory (−1.26) and inductive reasoning (−1.22), compared with the scores in the pre-test setting, which implied the decrease in a firefighter's cognitive functioning after participating in the physical activity with the PPE on. However, the data did not show the impact of the PPE on a firefighter's long-term memory.

In addition to the between-subjects mean comparisons described above, to determine the effects of other background variables such as a firefighter's age and BMI on the decrease in cognitive functioning, analyses of covariance (ANCOVA) were performed at $p<.05$. 〈Table 3〉 presents the results of ANCOVA, which assessed the mean differences in test score changes between the baseline and follow-up tests, when the effects of age and BMI were controlled. The ANCOVA results affirmed the negative influences of wearing the PPE in the firefighter's short-term memory and inductive reasoning, even when the possible age and BMI factors were eliminated, at the 95% confidence level. As Field (2013) explained about the benefits of including covariates in mean comparisons, the results of ANCOVA affirmed within-group error variance and helped to eliminate possible confounding variables (in this case, age and BMI), allowing to predict the outcome of the experiment more accurately.

Ⅳ. Discussion

The results of this study evinced the overall trend in the negative impact of wearing the PPE on the firefighter's cognitive functioning, especially in short-term memory and inductive reasoning. The conclusion was drawn from the comparison of quantifiable changes in the battery of cognitive tests before and after a moderate-intensity physical activity, while wearing a full ensemble of the firefighter PPE. The trend of the study findings was consistent even when the participant's age and BMI were controlled. That is, regardless of age and body mass, the firefighter's short-term memory and inductive reasoning were negatively affected by wearing the PPE while involving in a physical activity at moderate intensity. However, the data did not demonstrate the strong impact of the experiment protocol on the firefighter's long-term memory.

As mentioned in the introduction (Grorud & Smith, 2008; Moore-Merrell et al., 2008), poor decision making and lack of situational awareness are the main

<Table 3> Results of ANCOVA with age and BMI as covariates

Test	Pre-post comparison								
	No covariate			Age			BMI		
	G1 Mean (*SD*)	G2 Mean (*SD*)	Sig	*F*	*df*	Sig	*F*	*df*	Sig
Test 1	−1.26 (2.22)	1.43 (1.62)	.006**	4.910	3	.005**	3.899	3	.015*
Test 2.1	−1.96 (4.49)	−2.71 (3.64)	.688	.516	3	.673	1.268	3	.296
Test 2.2	9.61 (8.78)	9.57 (3.51)	.991	1.824	3	.156	2.317	3	.088
Test 3	−1.22 (2.56)	1.86 (1.86)	.007**	3.503	3	.023*	3.217	3	.031*

Note. G1=experimental group, G2=control group; * $p<.05$, ** $p<.01$ (two-tailed) causes of the firefighter injuries. Situational awareness corresponds to attention and understanding of the surrounding environment; thus, the deficiency of situational awareness can lead to flawed decision-making processes or wrong assessment of a situation, which generally results from problems related to acquisition and processing of relevant information (Krasuski et al., 2013). Therefore, the decreased cognitive abilities in short-term memory and inductive reasoning could lead to the increased risks of injuries in a firefighter's line of duty, in which he or she is required to encode and selectively process information quickly in a life-threatening environment, predict unknown consequences, and make prompt decisions based on the information encoded.

The approach of this study, however, involved several limitations. First, the sample size was small. Firefighters who participated in this study were from a geographical region in the United States. Although normality of the data was statistically confirmed, it is still probable that the homogeneous geographical background may not represent the firefighters in different locations in the United States and globally. In addition, this study gauged the effects of the participants' backgrounds, i.e., age and BMI, on the degree of the decrease in cognitive functioning. However, additional efforts are desirable to identify the comprehensive relationships between the impact of PPE on the firefighters' cognitive performance and various background and physical variables, such as gender, ethnicity, fitness level, years of service, types of firefighters, history of injuries, and VO_2 max intake. With the increased number of variables, a larger sample size is recommended for future research. Additionally, it will be desired to compare individual variations in the metabolic stress for the moderate-intensity physical activity or measure changes in the metabolic stress by different intensity of physical activities. Furthermore, this study was conducted in a laboratory setting. It will be appropriate to verify the findings of this study in real firefighting contexts.

Ⅴ. Conclusion

Despite of the aforementioned study limitations, this research effort was able to evaluate the study's hypotheses and determined the adverse impact of wearing PPE on the firefighter's cognitive functioning, when a moderate-intensity physical activity was performed, to the extent of the statistically meaningful level. The study results suggest that in order to lessen the occupational stress and physical burden of PPE on firefighters, researchers and manufacturers should consider novel solutions to reduce the weight and heat stress of PPE. Over the years, with technological advancement, protective layers have been added to the firefighter PPE, with an intention to keep firefighters from workplace hazards. In turn, the added protection to the PPE results in impedance of physical and cognitive performance in firefighters. Although the potential negative impact of the firefighter PPE was mentioned in previous studies (e.g., Barr et al., 2010; Coca et al., 2010; Sobeih et al., 2006; White & Hodous, 1987), this study presents the first scientific attempt to determine the negative influences of wearing the PPE in the firefighter's cognitive functioning. Exploratory in nature, this study leaves a doorway open for future research and invites researchers from across academic disciplines to explore and expand research discoveries on this research topic. The outcomes of the present and future research will not only fill the gap in the literature, but also provide critical justification to stakeholders, including governments, policymakers, academic communities, and industry, for such efforts to improve human factors of the firefighter's PPE by realizing the negative consequences of the added layers and protective functions on their occupational safety.

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