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The effects of personal protective equipment Level A suits on human task performance

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THE EFFECTS OF PERSONAL PROTECTIVE EQUIPMENT LEVEL A SUITS ON HUMAN TASK PERFORMANCE

by

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ABSTRACT

First response teams dealing with hazardous substances often require the highest level of protection provided by Level A suits. These suits are fully encapsulating, bulky, and heat retentive. The effect of these suits on the wearer's ability to perform various tasks is of interest when it comes to human performance analysis. This research effort examined the effect of the Level A suit on fine motor and gross motor dexterity. Seven members of the National Guard's Civil Support Team (CST) performed a battery of six tasks designed to test these abilities. Tasks comprised the Minnesota Dexterity test and the Mirror Tracer test at varying levels of difficulty. The measures of performance considered were time to complete and accuracy, and these were used to obtain a correlation between the Level A suit and performance. The results indicated that there was a significant detrimental effect from wearing the suit for both measures of performance. Also of interest is whether there exists a time-in-suit effect. Tests of repeated measures and regression analysis concluded that a significant detrimental time-in-suit effect was not identified. This could be due to a learning effect, or due to a limitation of the tasks not being sufficiently challenging. Regardless of the time-in-suit effect, the cumbersome Level A suits themselves have a proven negative effect on human performance. Based on the current results, substantial allowances should be provided when planning or modeling work to be performed in the protective suits. Additionally, there should be an appreciation for the associated increase in errors due to the level of discomfort and confinement brought about by these suits.

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I would like to thank my parents, Elizabeth and Simon, who have constantly urged me to be my best and to never question my abilities, and my sister, Michelle, who has been a role model to me through the years.

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1. INTRODUCTION

Events over the past decade have led to an increased awareness of the importance of effective crisis response. As General Pershing said in 1919, shortly after the First World War, "…but the effect is so deadly to the unprepared that we can never afford to neglect the question." Between then and now countless crisis situations requiring complex responses have arisen, ranging from natural disasters like hurricane Katrina to deadly man-made ones such as anthrax terrorist attacks. In these scenarios, effective management is required to execute a rapid, coordinated response in order to avoid catastrophic outcomes.

First response teams, fire fighters, and hazardous materials (HAZMAT) personnel are often called on to lead responses. In these situations they can be required to work in contaminated environments on a frequent basis. When threatening situations involve unknown or potentially dangerous substances, the responders must wear personnel protective equipment (PPE) to minimize their susceptibility to the potential threats. There are various types of PPE depending on the threat. A low level of protection would include gloves, safety glasses, and/or footwear. Higher threat levels would require protective suits, which range from semi-permeable protective uniforms to impermeable systems that include breathing systems to reduce the danger of inhaling toxins.

Protective clothing can negatively impact the users' performance in several ways including increasing heat stress on the body, reducing task efficiency, and reducing the individual’s range of motion (Adams, Slocum, & Keyserling, 1994). In most chemical, biological, radiological, or nuclear (CBRN) scenarios, first responders wear multiple layers of gloves, elaborate hooded suits, and breathing apparatuses. This can cause severe detrimental effects on performance due to restricted peripheral vision and limited motor dexterity. Task completion tends to become exponentially more difficult in terms of time and effort (Gertman, Bruemmer, & Hartley, 2007). While these detrimental effects caused by PPE have been established, it is important to quantify their impact on performance. Such information is key to the development of realistic emergency preparedness plans.

Figure 1.1. Civil Support Member in Level A Suit

Level A suits are a form of PPE that provide the wearer protection from a wide variety of chemical and/or biological threats. Figure 1.1 shows a member of the Civil Support Team (CST) during a routine training session. These are maximum protection chemical suits worn by trained individuals when dealing with highly hazardous or unknown substances. According to OSHA regulations, Level A suits are to be selected "when the greatest level of skin, respiratory, and eye protection is required" (Occupational Safety and Health Standards, Standard Number 1910.120 App B). A Level A suit typically includes a fully encapsulating chemical-resistant suit, gloves and boots, and a pressure-demand, self-contained breathing apparatus (SCBA) or a pressure-demand supplied air respirator (air hose) and escape SCBA. Level A suits provide maximal protection against vapors and liquids. Because of the breathing equipment, Level A suits tend to be bulky. The requirement to be fully encapsulating results in suits being highly heat retentive.

United States military researchers have undertaken efforts to increase the level of thermal comfort in protective clothing and some progress has been made; however, human performance is compromised within the full encapsulation of low permeability protective suits (Endrusick, Gonzalez, & Gonzalez, 2005). The United States Army currently uses a human performance modeling software IMPRINT Pro to model the effects of stressors such as temperature, sleeplessness, and protective clothing on human performance. Previous studies have focused primarily on the effects of the less cumbersome protective clothing called Mission Oriented Protective Posture (MOPP) as a stressor. To date, there is insufficient literature on the effects of Level A protective suits on task execution and human performance. A practical application of this study will be to augment IMPRINT Pro's existing database in modeling response situations that involve Level A protective suits.

The aim of this research is to quantify the effect of Level A suits on human performance and to determine if this effect changes significantly with time-in-suit. Members of a highly specialized Civil Support Team were asked to perform a set of standardized tasks in the Level A suit during this research project. The team members were trained and had experience wearing the protective suits. The performance parameters considered in the study were time to complete a task and level of accuracy.

2. LITERATURE REVIEW

2.1 PERSONAL PROTECTIVE EQUIPMENT

The effect of protective equipment on the performance of the wearer has been of interest for several decades now. Bensel, Teixeira, and Kaplan (1987) examined the effect of the Army's standard chemical protective clothing (CPC) system on various aspects of a soldier's performance. Tests were designed to assess speech intelligibility, visual field, body mobility, and psychomotor coordination. Twelve men participated in the speech intelligibility and the visual field testing; and eleven men participated in the body mobility and the psychomotor coordination testing. Through the investigation of body mobility and psychomotor coordination, various components of the CPC system were tested individually, as well as in various combinations. This was done in order to isolate the effect of each component and to determine the extent to which the components interact and affect performance. Results suggested that the use of the mask and hood impeded the user's ability to understand spoken words and to be understood when speaking. The mask also limited the user's visual field. The impact of the protective clothing on physical mobility and psychomotor coordination varied with the task being performed and the particular CPC item, or the combinations of items worn. Compared to the Battle Dress Uniform (BDU), the use of the complete chemical protective clothing system restricted visual-motor coordination or manual dexterity.

More recently, another study carried out by Bensel (1997) examined the effect of the chemical protective uniform used by the U.S. Army on soldier performance. It was observed that the clothing imposed a thermal as well as a mechanical burden. The study concluded that body movement is limited by the clothing. Manual dexterity capabilities and psychomotor performance can also be negatively impacted, and the protective clothing can induce psychological stress. Symptoms observed included breathing distress, tremors, and claustrophobia. Further, respirators restricted the visual field and affected speech intelligibility.

The effect of CPC on soldier performance has been researched in more detail. Headley and Hudgens (1997) concluded that when worn during military operations, CPC compromises a soldier’s dexterity, mobility, command, control, communications, and endurance. Field studies were conducted to ascertain the degree to which mission degradations occurred as a result of protective clothing. The tests compared task performance and endurance between soldiers wearing the protective ensemble and those wearing the standard military uniform. Nineteen studies related to combat, combat support, and combat service support systems were reviewed and they suggested that most military tasks could be performed satisfactorily while wearing CPC, but usually additional time is required to perform such tasks. Higher ambient temperatures and higher workloads were specifically found to negatively impact soldier endurance (Headley, & Hudgens, 1997).

Chemical-biological protective clothing (CBC) imposes significant physiological, psycho-physiological, and biomechanical effects on the performance of individuals (Krueger, 2001). The study concluded that cumbersome protective gear worn by first responders, including gas masks, rubber gloves, and overboots, slowed down performance. Participants required up to 30% more time for completing tasks.

Focusing more specifically on the loss in dexterity due to PPE is of interest to health care professionals required to care for the ill prior to decontamination. Castle, Owen, Hann, Clark, Reeves, and Gurney (2009) examined the effect of PPE on the fine motor skills of CBRN health care professionals. In this study, 64 clinicians were tested in their ability to administer various commonly used procedures, namely intubation, Laryngeal Mask Airway (LMA) placement, insertion of an Intra Venous (IV) cannula and Intra Osseous (IO) needle, while in CBRN-PPE. Each clinician had two attempts at each of the tasks while in PPE, and one attempt unsuited. This study was aimed at determining time to complete each task while suited; it was not a direct comparison of suited versus unsuited performance. While suited, 25 instances of skill failure occurred. Mean times differed according to the type of skill involved. There was a universal learning effect that was observed. Completion times for attempt two were shorter than attempt one, with the reduction in time dependent on the type of task.

There are several factors that can impact performance while in PPE. Adams et al. (1994) proposed a conceptual model that provided a systematic approach for studying the negative effects of PPE on its user. The study related four factors namely clothing parameters, task requirements, worker characteristics, and environmental conditions to the worker's performance. The three immediate effects caused by these factors are:

- Reduction in movement speed, range of motion, accuracy, and degradation in ability to receive visual and auditory feedback
- Physiological responses such as increased heart rate, blood pressure, oxygen consumption, and fatigue

- Disagreeable sensations like thermal discomfort, localized pressure, chafing, skin wetness, and restriction.

The above immediate effects led to net effects such as reduced productivity, reduced comfort, and increased physiological strain. The negative effects pertaining to reduced productivity included increased time to complete and decreased accuracy. Recently, Dorman and Havenith (2009) studied the effects of protective clothing on energy consumption during different activities. Results reported that users' metabolic rates were 2.4% - 20.9% higher when wearing PPE compared to control conditions.

2.2 LEVEL A SUITS

According to the Centers for Disease Control and Prevention (2001), first responders should use a NIOSH-approved, pressure-demand SCBA with a Level A suit when responding to a suspected biological incident where the type of airborne agent, or the dissemination method is unknown, or when the event is uncontrolled.

The duration for which a Level A suit provides the user with protection differs based on the suit design, the degree to which the suit fits the user, the body motions required, and the concentration of the chemical agent present in the environment (Belmonte, 1998). However, many subject matter experts believe that it is highly unsafe for a person to remain in the Level A suit beyond 60 minutes. Medical monitoring needs to be conducted and the person may be required to remove the suit sooner if deemed necessary.

The Occupational Safety and Health Standards (Standard Number 1910.120 App B, 1994) has put forth a comprehensive listing of the various levels of PPE (Levels A, B, C, and D) categorized based on the degree of protection it affords the user. This is summarized in Table 2.1.

Table 2.1. Levels of Personal Protective Equipment (PPE) adapted from the Occupational Safety and Health Standards, Standard Number 1910.120 App B (1994)

Suit Type	Selection Criteria	Components	Optional components
Level A	To be selected when the greatest level of skin, respiratory, and eye protection is required	Positive pressure, full self-contained breathing apparatus (SCBA), or positive pressure supplied air respirator with escape SCBA, totally-encapsulating chemical-protective suit, outer and inner chemical resistant gloves, chemical resistant boots with steel toe	Coveralls, long underwear, hard hat, disposable protective suit, gloves, and boots
Level B	To be selected when the highest level of respiratory protection is necessary, but a lesser level of skin protection is needed	Positive pressure, full SCBA, or positive pressure supplied air respirator with escape SCBA, hooded chemical-resistant clothing (overalls and long-sleeved jacket, coveralls, one or two-piece chemical-splash suit, disposable chemical-resistant overalls), outer and inner chemical resistant gloves, chemical resistant boots with steel toe	Coveralls, boot-covers (outer, chemical-resistant), hard hat, and face shield

Table 2.1. Levels of Personal Protective Equipment (PPE) adapted from the Occupational Safety and Health Standards, Standard Number 1910.120 App B (1994) (cont)

Level C	To be selected when the concentration and type of airborne substance is known and the criteria for using air-purifying respirators are met	Full-face or half-mask, air purifying respirators, hooded chemical-resistant clothing (overalls, two-piece chemical-splash suit, disposable chemical-resistant overalls), outer and inner chemical resistant gloves	Coveralls, boot-covers (outer, chemical-resistant, hard hat, escape mask, and face shield
Level D	A work uniform affording minimal protection: used for nuisance contamination only	Coveralls, and boots/shoes (chemical-resistant steel toe and shank)	Boots (outer, chemical-resistant and disposable), Safety glasses or chemical splash goggles, hard hat, escape mask, and face shield

2.3 MISSION ORIENTED PROTECTIVE POSTURE (MOPP) GEAR

Another type of PPE called the Mission Oriented Protective Posture (MOPP) ensemble provides successively greater levels of personal protection through increased levels of encapsulation. From lowest to highest protection these suits are classified as MOPP I, II, III, and IV (Kobrick, Johnson, & McMenemy, 1990). MOPP IV consists of a chemical protective over garment (suit), hood, gloves, boots, and mask with special filter (Fine & Kobrick,1987). Several studies have been conducted to determine the effect of MOPP on performance. In a study by Fine and Kobrick (1987) it was observed that when trained soldiers were exposed to a moderately hot environment for seven hours in MOPP IV gear, their cognitive performance began to deteriorate. The associated errors increased from 17% to 23% compared to control conditions. Productivity decreased by 40% after six hours of exposure to the PPE.

Schwirzke (1996) conducted a flight task performance test using four helicopter pilots. In the simulated missions, pilots performed tasks such as pushing touch sensitive keys and displacement type switches when wearing both protective flight gear and MOPP IV, as well as when unencumbered by MOPP IV gear. Tasks required 80% more time while wearing MOPP IV gear. From the survey results, it was determined that pilots reported a significant detrimental effect of MOPP IV gear on flight task performance, even when the objective measured effect was marginal or nonexistent.

These suits tend to hinder the wearer's ability to communicate, and its impact on team performance is of interest. Grugle (2001) used Targeted Acceptable Responses to Generated Events of Tasks (TARGETS), an event based team performance measurement methodology, to investigate the effects of MOPP. This study was designed to assess the extent to which MOPP degraded team performance during simulated rescue scenarios. Emergency medical technicians from rescue squads performed CPR and spinal injury management (SIM) in five two-member teams. They performed each task twice—once in their regular duty uniform and once in MOPP IV gear. Results indicated that team process performance was not degraded and the number of errors did not increase when teams were wearing MOPP IV. However, task completion time was significantly longer when teams were wearing MOPP IV. Regardless of the level of encumbrance, teams demonstrated adaptability to the situation and did not completely rely on communication or coordination.

The cumbersome MOPP gear was suspected to negatively impact the cognitive ability of the user. Rauch, Witt, Banderet, Tauson, and Golden (1986) evaluated the effects of the various MOPP levels on different cognitive problem solving abilities. The three cognitive tests comprised a simple addition test, a pattern recognition test, and a number comparison test. The participants' cognitive performance was significantly lower when in MOPP IV than when in MOPP II or no MOPP gear. They concluded that the impairment was in task completion rather than in task accuracy. The cognitive tests were self-paced; therefore, it was concluded that the participants employed a typical cognitive strategy that compromised speed to maintain accuracy over time. The rate of cognitive problem solving was also influenced by certain non-temporal factors. Presumably these factors were an end-spurt effect and fatigue effects.

Almost a decade later, Mullins, Fatkin, Modrow, and Rice (1995) conducted tests under various conditions to determine the connection between psychological stress responses and performance. A battery of cognitive and psychological measures was designed to test stress perceptions, coping resources, and cognitive performance. The cognitive tests included a memory test, a reasoning test, and a spatial decoding task. During testing, soldiers wore the complete MOPP IV gear. Consistent with other literature, results indicated that as participants experienced an increase in their perception of the situation as stressful, their corresponding performance declined.

In 1991, Taylor and Orlansky studied the degradation in performance while wearing Chemical Warfare (CW) protective clothing. The study found that heat stress negatively impacted task performance. In addition, the study concluded that even when heat stress was not a significant determinant, task performance still suffered some degradation.

2.4 TESTS OF FINE AND GROSS MOTOR DEXTERITY

There are standardized tests available to evaluate gross and fine motor dexterity. Gross motor skills were defined by Magill (1989) as those that "..involve the movement of large musculature and a goal where the precision of movement is not as important to the successful execution of the skill as it is for fine motor skills". The Minnesota Dexterity test (Complete Minnesota Dexterity Test Examiner's Manual, Lafayette Instruments 1998) is a standardized test used to measure a participant's arm-hand dexterity and gross motor skill. The test consists of two plastic templates that each have sixty holes provided to hold plastic disks. The object of the test is for participants to move the disks from the template farthest from them to one closer to them in a particular sequence. Tests are administered with the participant standing, and with the longer edge of the board placed parallel to the edge of the table (Robinette, Ervin, and Zehner, 1987).

The Minnesota Dexterity Test has been used to evaluate gross motor dexterity in a variety of research projects. In 1993, Bensel studied the effect of glove thickness on manual dexterity. She conducted five tasks of dexterity with three gloves of varying thickness. Bensel (1993) compared the mean completion time over 14 sessions based on five platforms. The platforms included the Minnesota Dexterity Test, the O'Connor Finger Dexterity Test, the Cord and Cylinder Manipulation Test, the Bennett Hand Tool Test, and the Rifle Disassembly/Assembly Test. The Minnesota Dexterity Test was used to determine finger and whole-hand dexterity (Bensel, 1993). Pourmoghani (2004) used the Minnesota Dexterity Test as a platform to determine participants' ability to move the small disks to certain pre-determined distances with various levels of gloves and visual acuity.

By comparison, fine motor coordination involves movements that require the manipulation of small objects (Elfant, 1977). Lafayette Instrument's Mirror Tracer is commonly used to test dexterity and hand-eye coordination. According to Robinette et al. (1987), the Mirror Tracer is useful to test a person's ability to visually determine an object's location and accurately place or follow it. The Mirror Tracer Test comprises a board with a six-pointed star pattern made up of two parallel lines, with a one-quarter inch path between them. On the board's edge farthest from the participant is an adjustable mirror that can be moved to be perpendicular to the star pattern. There is a shield that may be adjusted over the pattern so that the pattern is obscured from the participant's range of view. The mirror prevents participants from seeing their hands or the pattern directly; they must use the mirror for guidance. The object of this test is to use the stylus provided and draw a line between the parallel lines of the star pattern using visual cues, which are inverted and reversed in the mirror. The number of errors made is determined by an automatic error counter, which scores the test.

Salvi (2001) presented task taxonomy to define parameters such as visual ability, fine and gross motor dexterity, etc. This taxonomy was adapted from works by Allender et al. (1997). Table 2.2 summarizes the definitions provided by this taxonomy.

Table 2.2. Definition of Task Types (Adapted from Salvi's work citing Allender et al.)

Parameter or task type	Definition
Fine Motor Discrete	A fine motor discrete task is one that requires performing a set of distinct actions in a predetermined sequence. These actions mainly involve movement of the hands, arms, or feet and require little physical effort
Fine Motor Continuous	A fine motor continuous task is one that requires uninterrupted performance of an action needed to keep a system on a desired path or in a specific location
Gross Motor Light	A gross motor light task is one that requires moving the entire body (i.e., not just the hands) to perform an action without expending extensive physical effort
Gross Motor Heavy	A gross motor heavy task is one that requires expending extensive physical effort or exertion to perform an action

2.5 COMPONENTS OF PERSONAL PROTECTIVE EQUIPMENT

It is important to understand the impact that the various components of personal protective equipment, such as gloves and masks, have on performance. Pourmoghani (2004) examined the effects of gloves and visual acuity on task performance using standard dexterity tests. The study involved ten participants using four levels of gloves, and five levels of visual acuity (masked goggles). The participants performed tasks using the Purdue Pegboard, the grooved pegboard, and the placing task of the Minnesota Dexterity Test. The results indicated that the effect of gloves and goggles were significant across all platforms. The performance decrement increased with increased glove thickness.

Shibata and Howe (1999) studied the effects of gloves on performance of perceptual and manipulation tasks. It was found that on average, completion times were best when barehanded and were poorest while wearing gloves of thickness 1.91 mm. Krausman and Nussbaum (2007) conducted a study to determine the effects of glove thickness and masks on task performance and user preference. Sixteen participants used both a wearable mouse and touch pad to enter text while wearing different levels of chemical protective gloves (7-mil, 14-mil, and 25-mil), wearing a respirator alone, and wearing the respirator and each of three gloves. The measures of performance considered were task completion time and number of errors. Task completion times were 9% slower when the thicker 25-mil gloves were used compared to the 7-mil gloves. The results suggested that thinner protective gloves were more suitable than thicker gloves when using input devices, and that the use of masks did not affect task performance.

2.6 EFFECTS OF HEAT STRESS

The need to use personal protective clothing in harsh environments such as in CBRN situations can result in intolerable heat strain, since this protective gear tends to limit the workers' ability to dissipate heat (Cumo, Gugliermetti, & Guidi 2007). Decrements in endurance and vigilance performance are directly linked to heat stress (Enander, 1989). Hancock and Vasmatzidis (2002) summarized the effects of heat stress on cognitive performance. Several different theories were discussed and two common trends were identified: the first is that heat stress has a differential effect on cognitive performance with this effect being dependent on the type of task, and the second is that a relationship can be demonstrated between the effects of heat stress and deep body temperature.

Hot and cold temperatures have been reported to negatively impact performance on a wide range of cognitive-related tasks. In particular, hot temperatures of 90 degrees Fahrenheit Wet Bulb Globe Temperature Index or above were reported to result in a substantial decrement of 14.88% in human performance when compared to neutral temperature conditions. Hot exposure at temperatures above 80 degrees Fahrenheit caused a negative impact on reaction time tasks (Pilcher, Nadler, & Busch, 2002).

PAPER

1. Effects of Personal Protective Equipment Level A Suits on Fine and Gross Motor Dexterity

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Abstract

Objective: The effects of the Level A suit on gross motor and fine motor abilities were investigated. The measures of performance considered were task completion time and accuracy. **Background:** First response teams and others dealing with hazardous or unknown substances often require the highest level of protection provided by the bulky Level A suits. The effect of these suits on the user's ability to perform various tasks is of interest when it comes to human performance analysis. **Method:** Seven members of the Civil Support Team performed a battery of tasks designed to test gross and fine motor abilities. Tasks consisted of the Minnesota Dexterity test and the Mirror Tracer test at varying levels of difficulty. The time to complete and number of errors were measured. **Results:** A substantial effect from wearing the suit was found for both time and accuracy. Tests of repeated measures and regression analysis concluded that a significant detrimental time-in suit effect was not identified. **Conclusions:** The bulky and hot Level A suits have a significant effect on human performance which is quantified for gross motor and fine motor skills. A negative time-in-suit effect was not observed presumably

due to a learning effect. **Application:** Based on these results, substantial allowances should be provided when planning or modeling first response in protective suits.

INTRODUCTION

Recent events have led to an increased awareness of the importance of effective crisis response. When threats involving unknown or potentially dangerous substances arise, response teams must wear substantially insusceptible personal protective equipment (PPE). Level A suits provide the wearer protection from a wide variety of chemical and biological threats. These suits unfortunately also have significant effects on the physical abilities of the user as a result of heat stress and reduced movement (Grugle, 2001). As a result, any human performance model or emergency response plan that attempts to consider the capabilities of people wearing the Level A suit must take into account these detrimental effects.

Level A suits are maximum protection chemical suits worn by trained individuals when dealing with unknown substances threats. Due to the nature of the circumstances under which it is worn, a Level A suit is a maximum protection suit, which tends to be bulky and highly heat retentive. According to OSHA regulations, Level A suits are to be selected “when the greatest level of skin, respiratory, and eye protection is required” (Occupational Safety and Health Standards, Standard Number 1910.120 App B, 1994). It typically includes a fully encapsulating chemical-resistant suit, gloves and boots, and a pressure-demand, self-contained breathing apparatus (SCBA) or a pressure-demand supplied air respirator (air hose) and escape SCBA. Level A suits provide maximal protection against harmful vapors and liquids.

This research effort was designed to test the following hypotheses:

1. Level A suits degrade human task performance in terms of time and accuracy when compared to no suit

2. Time-in-suit has a negative impact on human task performance in terms of time and accuracy

For this research, members of a highly specialized Civil Support Team were asked to perform a set of standardized tasks in the Level A suit. Performance when in the suit was measured and analyzed. The results from this research provide useful insights on new parameters that can be included in developing models in crises response scenarios.

LITERATURE REVIEW

The duration for which Level A suits provide the user with protection differs based on the suit design, the degree to which the suit fits the user, the body motions required, and the concentration of the chemical agent present in the environment (Belmonte, 1998). However, many subject matter experts believe that it is highly unsafe for a person to remain in the Level A suit beyond 60 minutes. Medical monitoring needs to be conducted and the person may be required to remove the suit sooner if deemed necessary.

Another type of PPE called the Mission Oriented Protective Posture (MOPP) ensemble provides successively greater levels of personal protection through increased levels of encapsulation, from lowest to highest protection. These suits are classified as MOPP I, II, III, and IV (Kobrick, Johnson, & McMenemy, 1990). MOPP IV consists of a chemical protective over garment (suit), hood, gloves, boots, and mask with special filter

(Fine & Kobrick,1987). Several studies have been conducted to determine the effect of MOPP on performance. In a study by Fine and Kobrick (1987), it was observed that when trained soldiers were exposed to a moderately hot environment for seven hours in MOPP IV gear, their cognitive performance began to deteriorate. The associated errors increased from 17% to 23% compared to control conditions. Productivity decreased by 40% after six hours of exposure to the PPE.

Schwirzke (1996) conducted a flight task performance test using four helicopter pilots. In simulated missions, pilots performed tasks such as pushing touch sensitive keys and displacement type switches when wearing both protective flight gear and MOPP IV, as well as when unencumbered by MOPP IV gear. Tasks required 80% more time while wearing MOPP IV gear. The subjective results concluded that pilots reported a significant detrimental effect of MOPP IV gear on flight task performance, even when the objective measured effect was marginal or nonexistent.

MOPP hinders the wearer's ability to communicate, and its impact on team performance is of interest. Grugle (2001) used Targeted Acceptable Responses to Generated Events of Tasks (TARGETS), an event based team performance measurement methodology, to investigate the effects of MOPP. This study was designed to assess the extent to which MOPP degraded team performance during simulated rescue scenarios. Emergency Medical Technicians from rescue squads performed CPR and spinal injury management (SIM) in five two-member teams. They performed each task twice—once in their regular duty uniform and once in MOPP IV gear. Results indicated that team process performance was not degraded and the number of errors did not increase when teams were wearing MOPP IV. However, task completion time was significantly longer when teams were wearing MOPP IV. Regardless of the level of encumbrance, teams demonstrated adaptability to the situation and did not completely rely on communication or coordination.

Before MOPP became popular, Bensel, Teixeira, and Kaplan (1987) examined the effects of the Army's standard chemical protective (CP) clothing system on soldiers' performance. Tests were designed to assess speech intelligibility, visual field, body mobility, and psychomotor coordination. Through the investigation of body mobility and psychomotor coordination, the various components of the CP system were tested individually, as well as in various combinations. This was done in order to isolate the effects of each component and to determine the extent to which the components interact and affect performance. Results suggested that the use of the mask and hood impeded the user's ability to understand spoken words and to be understood when speaking. The mask also limited the user's visual field. Compared to the Battle Dress Uniform (BDU), the use of the complete chemical protective clothing system restricted visual-motor coordination or manual dexterity. Another research project carried out by Bensel (1997) studied the effects of chemical protective uniform, used by the US Army, on soldier performance. They found that the clothing imposed a thermal as well as a mechanical burden. They concluded that body movements are limited by the clothing - manual dexterity capabilities and psychomotor performance can also be negatively impacted and it can induce psychological stress. Symptoms observed included breathing distress, tremors, and claustrophobia. Further, respirators restricted the visual field and affected speech intelligibility.

Chemical protective clothing (CPC) worn during military operations compromises a soldier's dexterity, mobility, command, control, communications, and endurance. Headley and Hudgens conducted field studies in 1997 to ascertain the degree to which mission degradations occurred as a result of protective clothing. The tests compared task performance and endurance between soldiers wearing the protective ensemble to those wearing the standard military uniform. Nineteen studies related to combat, combat support, and combat service support systems were reviewed and they indicated that most military tasks could be performed satisfactorily while wearing CPC, but usually additional time is required to perform such tasks. Higher ambient temperatures and higher workloads were specifically found to negatively impact soldier endurance (Headley & Hudgens, 1997).

Chemical-biological protective clothing (CBC) imposes significant physiological, psycho-physiological, and biomechanical effects on the performance of individuals (Krueger, 2001). This study concluded that cumbersome protective gear worn by first responders, which include gas masks, rubber gloves, and over boots, produce performance slowdowns requiring up to 30% more time for completing tasks.

It is important to understand the impact that the various components of personal protective equipment, such as gloves and masks, have on performance. Pourmoghani (2004) examined the effects of gloves and visual acuity on task performance using standard dexterity tests. The study involved five men and five women, using four levels of gloves and five levels of visual acuity (masked goggles). The participants performed tasks using the Purdue Pegboard, the grooved pegboard, and the placing task of the Minnesota Dexterity test. Results suggested that the effect of gloves and goggles were significant across all platforms. The performance decrement increased with glove thickness. Shibata and Howe (1999) studied the effects of gloves on performance of perceptual and manipulation tasks. It was found that on average, completion times were best when barehanded and were poorest while wearing gloves of thickness 1.91 mm.

Krausman and Nussbaum (2007) conducted a study to determine the effects of glove thickness and masks on task performance and user preference. Sixteen participants used both a wearable mouse and touch pad to enter text while wearing different levels of chemical protective gloves (7-mil, 14-mil, and 25-mil), wearing a respirator alone, and wearing the respirator and each of three gloves. The measures of performance considered were task completion time and number of errors. Task completion times were 9% slower when the thicker 25-mil gloves were used compared to the 7-mil gloves. The results suggested that thinner protective gloves were more suitable than thicker gloves when using input devices, and that the use of masks did not affect task performance.

The cumbersome MOPP gear was suspected to negatively impact the cognitive ability of the user. Rauch, Witt, Banderet, Tauson, and Golden (1986) looked into the effects of the various MOPP levels on different cognitive problem solving abilities. The three cognitive tests comprised a simple addition test, a pattern recognition test, and a number comparison test. The participants' cognitive performance was significantly lower when in MOPP IV than when in MOPP II or no MOPP gear. They concluded that the impairment was in task completion rather than in task accuracy. The cognitive tests were self-paced; therefore, it was concluded that the participants employed a typical cognitive strategy that compromised speed to maintain accuracy over time. The rate of cognitive problem solving was also influenced by certain non-temporal factors. Presumably these were an end-spurt effect and fatigue effects.

Almost a decade later, Mullins, Fatkin, Modrow, and Rice (1995) conducted tests under various conditions to determine the connection between psychological stress responses and performance. A battery of cognitive and psychological measures was designed to test stress perceptions, coping resources, and cognitive performance. During testing, soldiers wore the complete MOPP IV gear. Consistent with other literature, results indicated that as participants experienced an increase in their perception of the situation as stressful, their corresponding performance declined. The photo in Figure 1 shows a research participant in a training exercise that pre-dated our study.

Figure 1. CST Member During a Training Exercise (January, 2009)

METHOD

Participants

Seven members (five male and two female) of the Missouri National Guard's Civil Support Team (CST) volunteered as study participants. The participants had training and experience working in Level A suits as part of their duty assignments. The members were both male and female and between 24 and 41 years of age.

Materials

Tests were designed to capture the effects of Level A suits on gross motor and fine motor abilities. The objective of the study was to identify the effect of the suit on performance, as well as the effect of time-in-suit on performance. Tests comprised variations of two tests: the Minnesota Dexterity test and a Mirror Tracer test.

The Complete Minnesota Dexterity Test: The Minnesota Dexterity test is a standardized test used to evaluate participants' arm-hand dexterity and gross motor skills. In the test, participants move small objects to and from various distances. It typically consists of three parts – placing, turning, and displacing. Disc shaped pieces are arranged on a board and the participant is asked to move them into the template closest to them. Scores are based on time taken to complete the whole tasks. The participants were required to use both dominant and non-dominant hands. Additional information about the test can be found online at the Lafayette Instrument website: (http://www.lafayetteevaluation.com/product_detail.asp?ItemID=165).

The Mirror Tracer Test: The Mirror Tracer Test comprises a board with a six-pointed star pattern made up of two parallel lines, with a one-quarter inch path between them. On the board's edge farthest from the participant is an adjustable mirror that can be moved to be perpendicular to the star pattern. There is a shield that may be adjusted over the pattern so that the pattern is obscured from the participant's range of view. The mirror prevents participants from seeing their hands or the pattern directly; they must use the mirror. The object of this test is to use the stylus provided and draw a line between the parallel lines of the star pattern using visual cues, which are inverted and reversed in the mirror (Robinette, Ervin, & Zehner, 1987).

The data collection was conducted in a large covered garage in a controlled, and moderately cool environment.

Procedure

Figure 2 shows the Minnesota Dexterity Test and the Mirror Tracer Test. For this research, variations of the conventional placing test of the Minnesota Dexterity Test were incorporated in order to introduce three levels of difficulty. The three tasks were:

Task 1A (simple placing test): Participants used their dominant hand to move pegs from one board to the other. They picked up the bottom disk from the first board and placed it in the top hole of the second board. The next disk was then placed below the hole previously filled and so on. This is the standard procedure used with the test. This tested discrete gross motor abilities.

Task 1B (two handed turning and placing test): Participants used both hands for this test. They picked up the bottom disk from the first board with their dominant hand and passed it to their non-dominant hand, while flipping it over. This was then placed in the template closest to them. They continued to fill the first column in this way. When they came to the second column they started with their non-dominant hand, and continued to alternate hands with each column as they went on. This tested discrete gross motor abilities.

Task 1C (alternate hand-alternate column turning and placing test): Participants used both hands for this test, starting with their dominant hand for the first column and then proceeding to their non-dominant hand for the next. Participants picked up disk 1 from the first board and placed it in hole 1 of the second board using their dominant hand. They left the second disc in place and moved to the third disc and placed it in hole 3 of the second board. They then picked up disk 2 from the first board and turned it over, still using their dominant hand. Disk 2 was then inserted into hole 2 of the second board. The same was repeated with disk 4. This pattern was repeated across the board, with alternating hands for each column. This tested discrete gross motor abilities.

An error was defined as any time the participant released and regrasped a peg before getting the peg into its final position, or any time the participant placed the peg in the wrong location, released, and then regrasped it in order to correct the placement. If the participant did both of the above, it was counted as two errors. Similarly, if the participant released and regrasped a peg twice, it was counted as two errors.

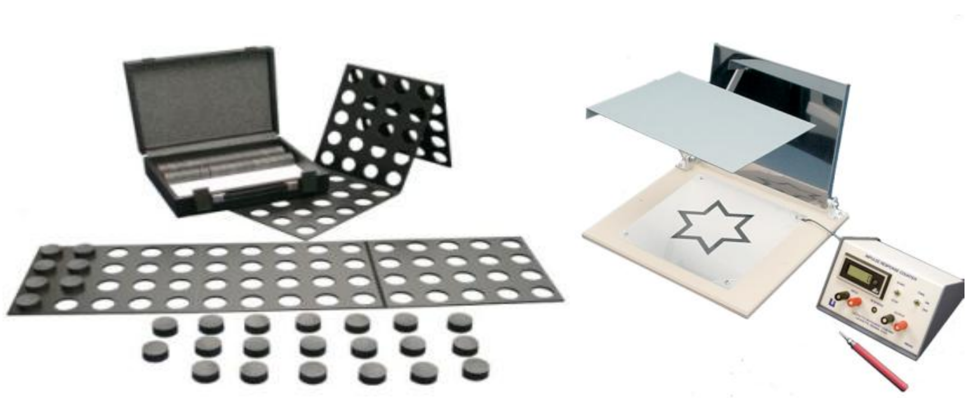

Figure 2. The Complete Minnesota Dexterity Test and the Mirror Tracer Test

Three levels of difficulty were incorporated for the Mirror Tracer Test as well. The three tasks were:

Task 2A (direct tracing of the star pattern without a mirror): Participants traced the star pattern directly without the use of the mirror. This tested continuous fine motor abilities.

Task 2B (tracing the star pattern with a mirror): Participants traced the star pattern while using its reflection off the mirror as a guide. This is the test's standard procedure. This tested continuous fine motor abilities.

Task 2C (marking the points of the star with a felt tipped pen, using a mirror): Participants used a felt tipped pen to mark the six highlighted corners of the star pattern that was traced on paper. Again, participants used the shield to obscure their view and the mirror as a guide. This tested discrete fine motor abilities.

The mirror tracer has its own counter, which was solely used in measuring error numbers for T2A and T2B. For T2C, an error was defined as any time that a participant marked any part of the paper star template other than the prescribed highlighted regions. The same measures were applied to all participants.

The method included a formalized training session, whereby participants practiced the battery of tasks three times using heavy rubber gloves. Gloves were incorporated to help simulate the effect of the suit on dexterity without having all the other encumbrance effects of the suit. The rubber gloves were only used during the training phase.

In the experimental phase, participants performed the tasks as they did during the training session, however they were also asked to walk outdoors for approximately four minutes between each battery of tasks while in the suit. This was to help simulate fatiguing effects typically experienced while wearing the suit. After training, all participants completed one repetition of all six tasks out-of-suit to serve as a baseline. In the experimental phase, five out of the seven participants completed three repetitions of the task battery in the suit, while the other two participants were asked to keep going till they ran out of air from their oxygen tanks. The order of task administration was kept identical for all participants so that each task was performed after approximately the same amount of time-in-suit for all repetitions. This was done to facilitate a more accurate analysis of repeated measures. Figure 3 shows a participant performing the Minnesota Dexterity Test during the experimental phase.

Figure 3. Experimental Phase

The Modified Experimental Procedure

In order to determine whether the learning effects would be eliminated if the participants were asked to perform more than three repetitions while in the suit, two of the seven participants were rerun through a slightly modified experimental session. These members were asked to keep performing the tasks for as long as they wished to, up to when the first alarm on their oxygen tanks sounded. They were asked to walk for 40 seconds, carrying a weight of twenty-five pounds after each task. Also, training for these participants was carried out in a half-suit: a Level A suit that was not completely sealed, and without the air tanks. This was done to better simulate the encumbrance effect of the suit during the training phase, thereby reducing the degree of learning that took place in the experimental phase. These members will be referred to as Participant A and Participant B. Participant A completed five and a half repetitions. This member stopped when the oxygen in the tank was exhausted. Participant B completed four full repetitions. Additional analyses were done using the greater number of repetitions for these two participants, and are presented later in this paper.

RESULTS

A t-test was conducted to test the effect of the Level A suit on performance. This test compared out-of-suit versus mean in-suit completion times (seconds), and out-of-suit versus mean in-suit error count. Results are displayed in Table 1. The highest percent increases in completion time and errors were for task T1B, the gross motor turning tasks, at 102.98% and 34.09%, respectively.

Table 1

Results from t-test

Task	Suit*	Time	% Change	Errors	% Change
T1A	0	62.21		2.71	
	1	116.93	87.94%	18.31	25.99%
T1B	0	63.83		4.57	
	1	129.57	102.98%	25.02	34.09%
T1C	0	71.9		3.86	
	1	141.66	97.01%	18.91	25.10%
T2A	0	23.73		0.71	
	1	31.28	31.80%	3.15	4.06%
T2B	0	41.01		18	
	1	42.47	3.57%	17.92	-0.13%
T2C	0	21.58		3	
	1	25.43	17.85%	2.85	-0.25%

*where ‘0’ indicates out-of-suit data and ‘1’ indicates in-suit data

The results indicate that the time to complete tasks in the Level A suit increases substantially for the Minnesota Dexterity tasks, and to a lesser degree for the Mirror Tracing tasks. The number of errors in suit increases by up to 34.09% for the Minnesota Dexterity test, while the changes in number of errors for the Mirror Tracing tasks were not as great. The results of the t-test indicated that there is a substantial effect of the Level A suit on completion time (p value = 0.0263) and for error count (p value = 0.0318).

Repeated measures tests were performed using SPSS to compare task performance for each repetition. Only in-suit data were considered for this test. For each participant, data points for three repetitions were considered. The factors analyzed were task and repetition. The within-subject variables were time and errors per task per repetition.

A performance comparison is shown in Table 2. The table examines mean completion times and errors for all six tasks over three repetitions. Results indicate that on average, completion time and accuracy improve with time-in-suit.

Table 2

Mean Completion Time and Errors Per Repetition

Repetition	**Time**	**Errors**
1	90.093	16.1667
2	83.37	14.023
3	76.717	13.761

A pair wise comparison of mean completion times and errors was generated for repetitions 1, 2, and 3. A positive difference indicates an improvement in performance. This is presented in Table 3.

Table 3

Pair Wise Comparison

i	**J**	**Mean difference (i-j)**	**Mean difference (i-j)**
		Completion time	Errors
Rep 1	Rep 2	6.723	2.1437
Rep 2	Rep 3	6.654	0.262

The mean completion times and number of errors for each repetition (only three repetitions were considered) of the six tasks are displayed in Table 4. In some instances, it is evident that there is some time-accuracy trade off; however there is a strong trend of improvement indicating that a universal learning effect occurs.

Table 4

Mean Performance Per Repetition

Task	Repetition	Mean completion time	Mean error
T1A	1	128.236	21.857
	2	122.656	18.285
	3	117.326	15.857
T1B	1	149.037	26
	2	129.547	26.667
	3	118.67	24.857
T1C	1	157.109	20.857
	2	147.983	17
	3	127.939	19.571
T2A	1	31.587	3.428
	2	32.689	3.285
	3	30.581	2.714
T2B	1	45.526	21.142
	2	42.503	17.428
	3	41.48	16.571
T2C	1	29.064	3.714
	2	24.846	2.142
	3	24.304	3

Separate analyses were run for completion time and accuracy, as shown in Figures 4 and 5. Figure 4 shows the task completion times for each of the six tasks, with the three lines representing each repetition. It is observed that the mean task completion time decreases with each repetition of the battery of tasks. The decrease in completion time over time is larger for tasks T1A, T1B, T1C, and T2C than they are for T2A and T2B.

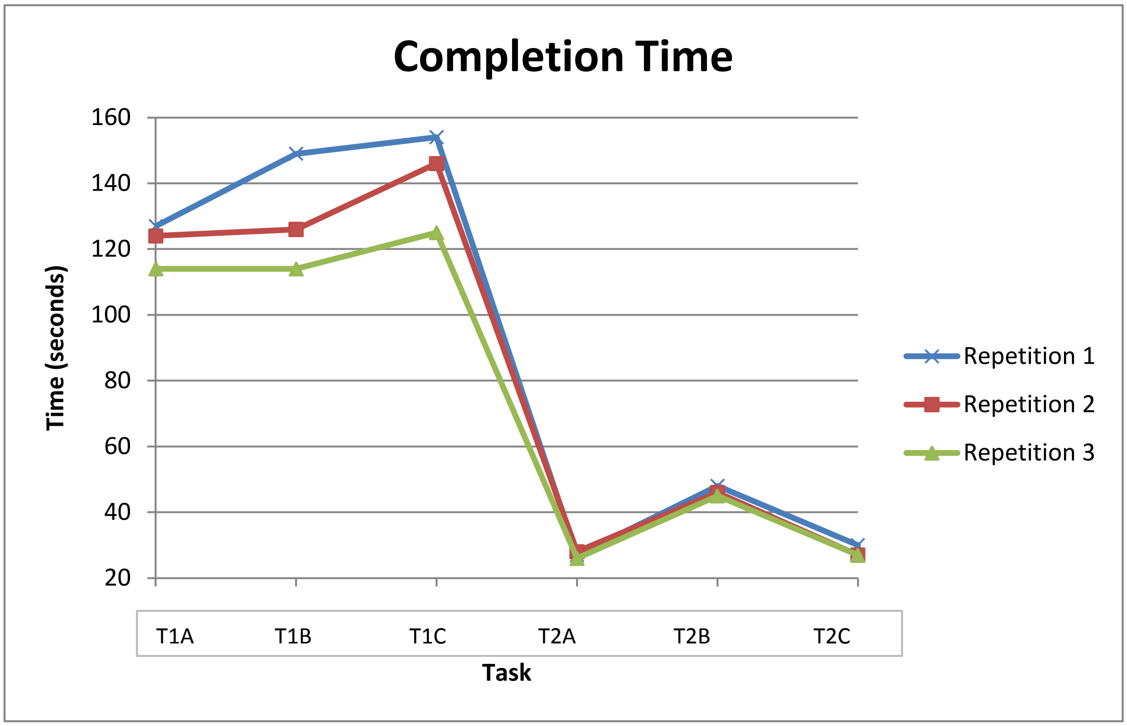

Figure 4. Estimated Means for Task Completion Time

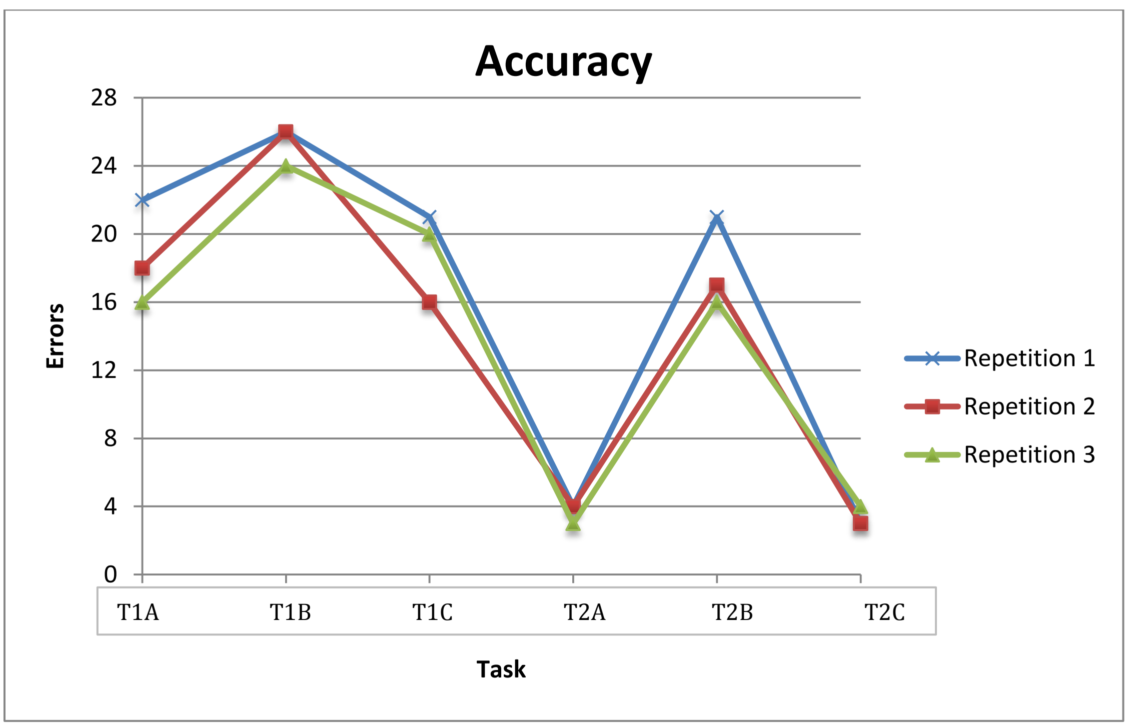

Figure 5. Estimated Means for Accuracy

Figure 5 shows the average errors committed for each of the six tasks, with the three lines representing each repetition. For certain tasks such as T1A, T1C, and T2B a significant performance improvement is observed: the number of errors decrease with each repetition of the battery. This could be caused either by a learning effect, or because participants paid more attention to accuracy when they fatigued.

Task wise completion times and errors for three repetitions are presented in Figures 6 and 7 respectively. The inference from these figures is that completion times and errors decrease with time-in-suit.

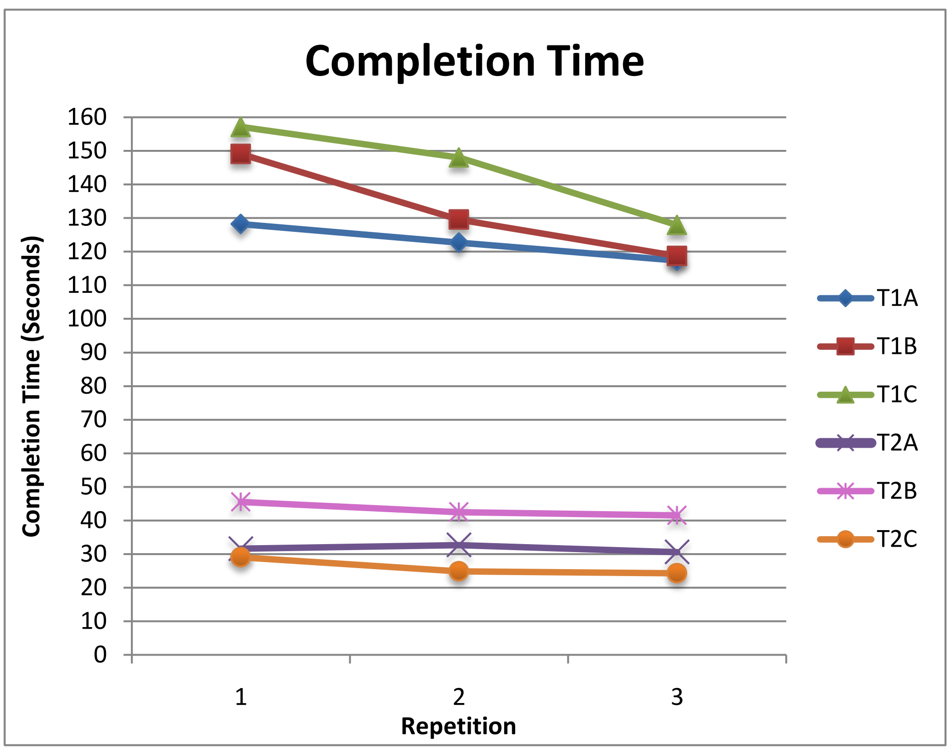

Figure 6. Task Wise Completion Times for Three Repetitions

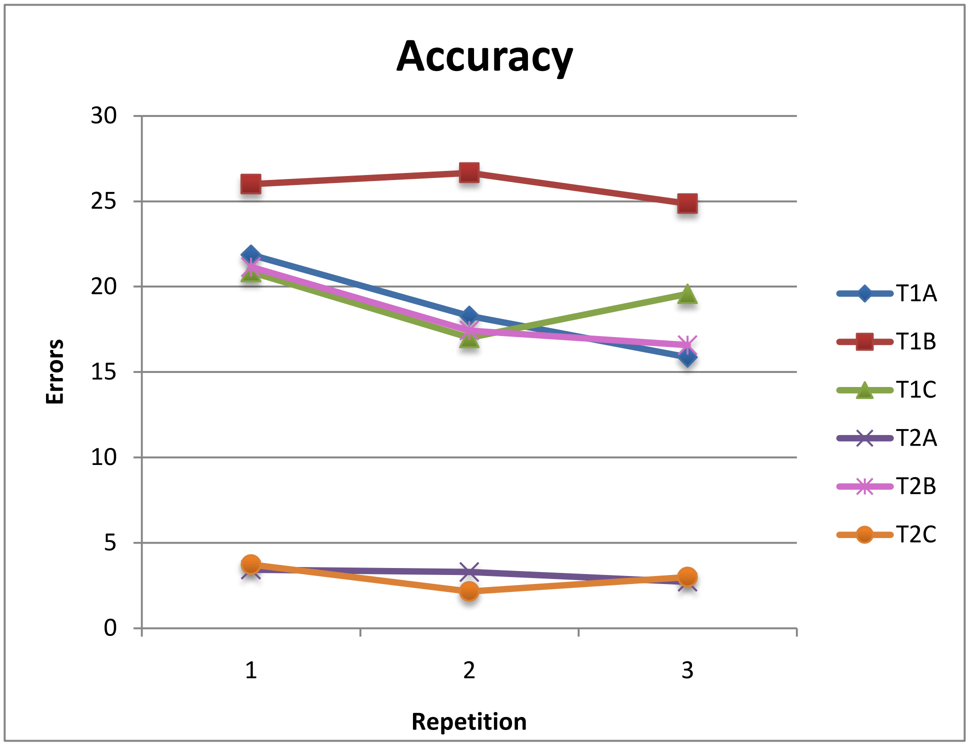

Figure 7. Task Wise Errors for Three Repetitions

A regression analysis was performed for each of the six tasks to determine the effect of time-in-suit on task performance, with separate statistical analyses conducted for completion time and accuracy data. Only in-suit data were considered. The predictor was time-in-suit and the dependent variables were completion time and error count. R Square indicates the percentage of variance in task performance explained by time-in suit. The data are presented in Tables 5 and 6.

In the case of T1A, almost 10 percent of the change observed in time to complete is a result of the effect of time spent in the suit. Time-in-suit did not significantly affect the performance measures.

In the case of T2A, time-in-suit is responsible for 15 percent of the change observed in completion time through three repetitions. The data related to completion time is marginally significant with a value of 0.053. Time-in-suit did not significantly affect accuracy. Results indicate that 29.7 percent of the change observed in the case of T2B is a result of the time-in-suit effect. For this task, time-in-suit substantially affects completion time, but not accuracy. Time-in-suit does not affect completion time or accuracy for T2C.

Table 5

R Square Results from Regression

Task	**Predictor**	**Dependent Variable**	**R**	**R Square**	**Adjusted R Square**	**Std. Error of the Estimate**
T1A	Time-in-suit	Time to complete	0.304	0.092	0.056	26.627
T1A	Time-in-suit	Errors	0.021	0.000	-0.040	11.429
T1B	Time-in-suit	Time to complete	0.031	0.001	-0.039	53.870
T1B	Time-in-suit	Errors	0.236	0.056	0.018	16.328
T1C	Time-in-suit	Time to complete	0.009	0.000	-0.042	47.267
T1C	Time-in-suit	Errors	0.276	0.076	0.038	10.539
T2A	Time-in-suit	Time to complete	0.383	0.147	0.111	6.954
T2A	Time-in-suit	Errors	0.174	0.030	-0.010	2.579
T2B	Time-in-suit	Time to complete	0.545	0.297	0.268	6.579
T2B	Time-in-suit	Errors	0.023	0.001	-0.041	8.819
T2C	Time-in-suit	Time to complete	0.112	0.012	-0.029	9.375
T2C	Time-in-suit	Errors	0.150	0.022	-0.018	2.678

Table 6

Significance Values from Regression

Task	Predictor	Dependent Variable	Un-standardized Coefficients B	Std. Error	Standardized Coefficients Beta	t	Sig. (p)
T1A	Time-in-suit	Time to complete	-0.393	0.246	-0.304	-1.59	0.123
T1A	Time-in-suit	Errors	0.011	0.106	0.021	0.10	0.919
T1B	Time-in-suit	Time to complete	0.072	0.465	0.031	0.15	0.878
T1B	Time-in-suit	Errors	0.172	0.141	0.236	1.21	0.235
T1C	Time-in-suit	Time to complete	-0.02	0.444	-0.009	-0.04	0.964
T1C	Time-in-suit	Errors	0.139	0.099	0.276	1.40	0.172
T2A	Time-in-suit	Time to complete	-0.136	0.067	-0.383	-2.03	0.053
T2A	Time-in-suit	Errors	-0.022	0.025	-0.174	-0.86	0.395
T2B	Time-in-suit	Time to complete	-0.2	0.063	-0.545	-3.18	0.004
T2B	Time-in-suit	Errors	0.01	0.084	0.023	0.11	0.91
T2C	Time-in-suit	Time to complete	0.048	0.087	0.112	0.55	0.587
T2C	Time-in-suit	Errors	0.018	0.025	0.15	0.74	0.466

The results from the modified experimental procedure showed that in the case of Participant A, there is an initial learning effect that is soon replaced by presumably a fatigue effect as the time to complete tasks begins to increase. This can be seen in Figure 8. The increase in completion time is not overly steep, nor is it in the case of every task.

For most of the tasks, the completion time for the last repetition is improved, potentially indicating an emotional factor, and end-spurt effect, or perhaps an adrenaline rush that might have played a role. Looking at Figure 9, one can see there is some time-accuracy tradeoff. For example, in the cases of T1B and T1C, as time to complete decreases, the number of errors committed increases. In the case of Participant B, completion time (Figure 10) stays relatively flat while accuracy (Figure 11) is a bit more erratic, once again indicating some time accuracy tradeoff.

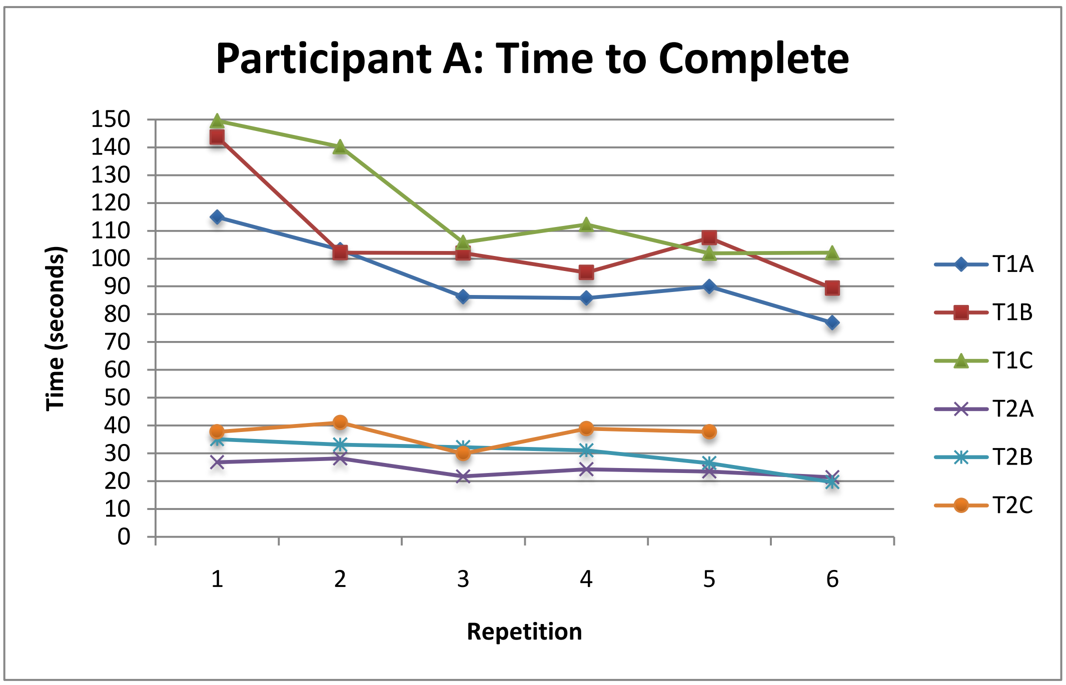

Figure 8. Participant A –Task Wise Completion Times

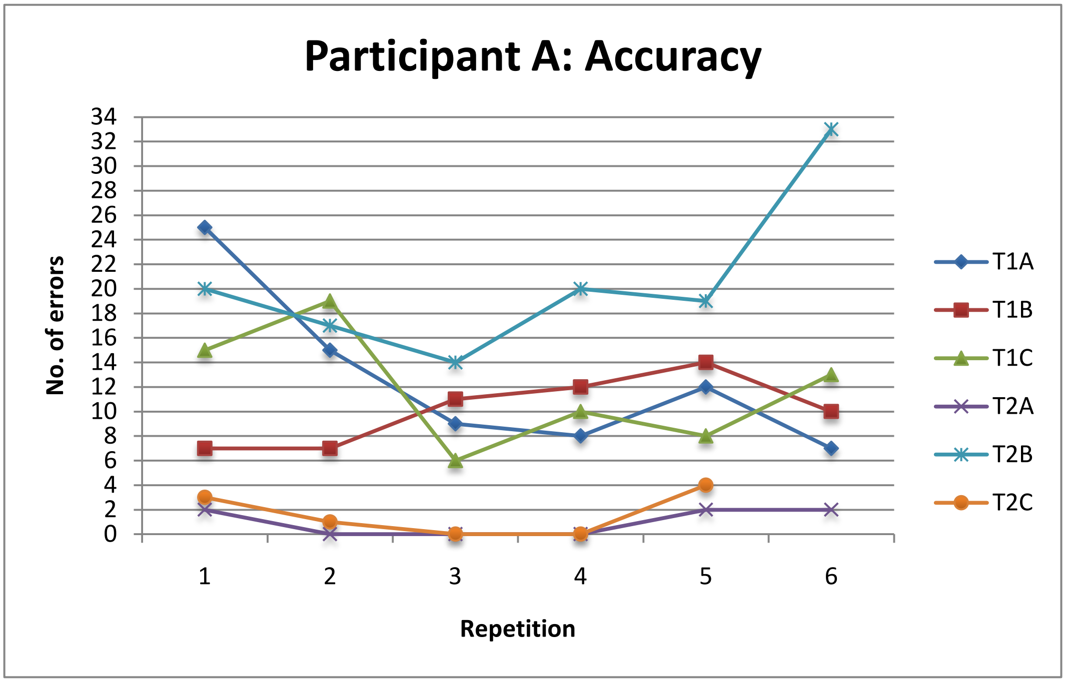

Figure 9. Participant A – Task Wise Errors

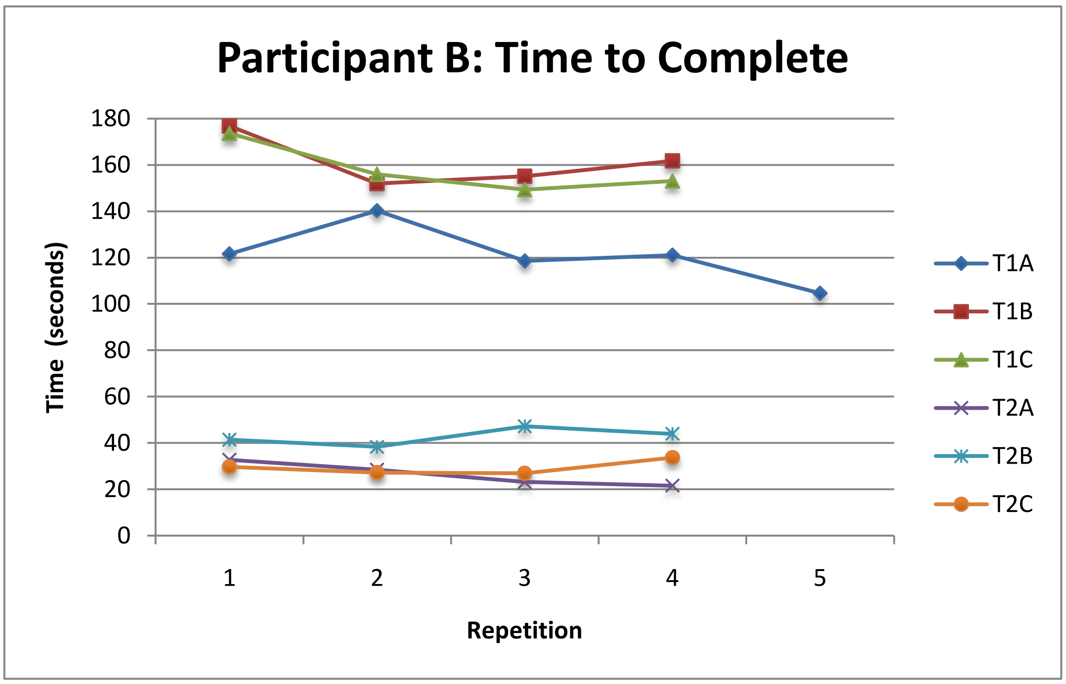

Figure 10. Participant B – Task Wise Completion Times

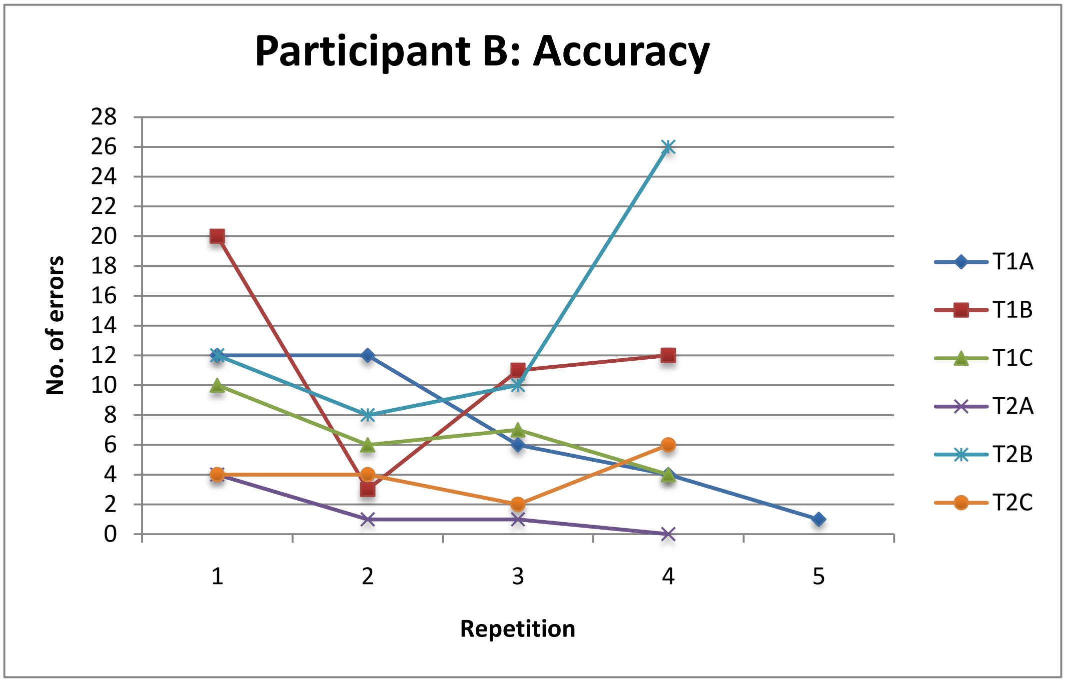

Figure 11. Participant B – Task Wise Errors

These data might not be generalizable, since only two members completed this more intensive protocol; however, the slight upward trend in completion time as repetitions increased is interesting to note. Perhaps with more participants, and an increased number of repetitions, a fatigue effect might be captured.

CONCLUSION

The effect of the Level A suit on performance is substantial, as the results from the t-test indicated. An increase in completion times up to 102.98% is significant. The decrease in accuracy was less profound; it was seen to substantially affect only the gross motor tasks. The increase in time required for task completion and the decrease in accuracy due to the Level A suit is significantly large, and must be taken into consideration during modeling and planning phases.

Contrary to prior belief, degradation in performance as time-in-suit increased was not found. The outcome did not change even when training was administered with an encumbrance factor applied to fine motor dexterity, and when physical fatiguing factors were incorporated. When the experimental protocol was later modified for two participants, incorporating a more intense fatiguing effect, and more rigorous training efforts, there was an increase in task completion time as the number of repetitions increased. As stated previously, the data related to this finding is from only two members.

An explanation for the lack of correlation between time-in-suit and performance might lie in the fact that the tasks were very repetitive in nature and without sufficient physical exertion. This might be a limitation of the study and its inability to capture the real-world scenario and effect of the suit. Alternatively, it might be a result of certain other factors not as easily captured, such as resoluteness, determination to succeed, competitiveness, and motivation. Having observed the participants, it can be said that competitiveness was unmistakably a factor throughout the study. However, whether this was the sole driver for some of the variations seen while in the suit, cannot be told for certain.

ACKNOWLEDGMENTS

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2. Modeling Human Performance in Chemical Protective Suits

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Abstract

First responders who respond to crises involving hazardous or unknown materials are often required to wear a high level of protective equipment. This research explored the performance of individuals wearing the highly cumbersome Level A suit, which offers maximum protection via a fully encapsulating suit. The suits are heat-retentive and can cause fatigue that affects performance by increasing response time and decreasing accuracy. Members of Missouri's Civil Support Team (CST) were subjected to varying difficulty levels of fine and gross motor tests, and their completion times and accuracy were used to obtain a correlation between the Level A suit and performance.

K**eywords**

Crisis Management, Human Performance Modeling, Level A Suits, Personal Protective Equipment, IMPRINT Pro

1. Introduction

Events over the last several years have highlighted the importance of emergency planning for events ranging from natural disasters to terrorist attacks. Crises are rare but proper planning is critical. Given their unique nature, we do not have sufficient historical data to use in analysis. Most crises scenarios have one element in common: a short decision time frame for response. Exercises and drills are often cost prohibitive. Human performance modeling is an effective management tool for emergency planning. IMPRINT Pro (a human performance modeling software) can be used evaluate systems and procedures. It can be used as a trade-off analysis tool. The software is capable of providing requirements, abilities, and limitations that can greatly improve the response in emergency situations [1].

When threats involving unknown or potentially dangerous substances arise, response teams must wear substantially insusceptible personal protective equipment (PPE). Level A suits provide the wearer protection from a wide variety of chemical and biological threats. These suits unfortunately also have significant effects on the physical abilities of the user as a result of heat stress and reduced movement [2]. As a result, any human performance model that attempts to predict the capabilities of a person wearing the Level A suit necessarily has to take into account these detrimental effects as well.

2. Human Performance Modeling

Before human performance modeling can be applied to emergency management, it is important to understand it. Simply put, human performance modeling can be defined as the modeling of the various processes and effects related to human behavior [3]. It is done early in the design process to impact system design, cost, and performance.

Human performance models have been used by the military as an aid in the decision-making process throughout a system or process's life cycle. It can serve as a cost-cutting approach during the design and procurement of expensive systems. Modeling is the application of the powers of present day technology to design, as well as a way to extend our knowledge of a system's use, strengths, weaknesses, effectiveness, cost etc. When looking at the overall system, human performance must be considered in order to get a clear picture of the best and worst case scenarios, thereby understanding the range of the system's performance in its entirety [4].

Human behavior representations are developed to serve as tools in training and analyses. The models generated are useful during training sessions and mission rehearsals to prepare for various operations. As an analysis tool the models assist evaluations of systems, staffing, and tactics [3].

3. IMPRINT Pro

IMPRINT Pro is a human performance modeling and human systems integration tool developed by the U.S. Army Research Laboratory. It takes into account the effect of stressors on various "taxons" namely fine motor, gross motor, visual, auditory, communication, numerical and cognitive. Stressors are typically categorized into cold, wind, heat, humidity, noise, protective equipment and sleepless hours, besides other user-defined stressors. A model that can predict the decrement in each of the taxons depending on the type of stressor, and provide first responders with a realistic interpretation of a consequence management scenario is desired [5]. For this research, the taxons considered are those most specific to protective equipment, namely gross motor and fine motor ability.

IMPRINT Pro is also used to estimate human-centered requirements early during the decision-making processes. As a research tool, the software manages task analysis, workload evaluation, degradation functions, and stressor analysis. IMPRINT Pro works on Micro Saint, which is an embedded discrete event task network modeling language [5].

4. The Level A Suit

In the event of nuclear, biological, or chemical terrorist attacks or emergency situations, first response teams are required to respond and perform efficiently while wearing protective equipment [6]. The Level A suits are a type of personal protective equipment worn by highly specialized consequence management teams throughout the country, when the need to deal with an unknown substance threat arises. The Level A suit is a maximum protection suit due to the nature of the circumstances under which they need to be worn. As a result, they tend to be bulky and highly heat retentive. There is a corresponding effect on performance time and accuracy of the person wearing the suit, and this is significant enough to warrant intensive data collection, analyses and provision of conclusive numerical results. It typically includes a fully encapsulating, chemical-resistant suit, gloves and boots, and a pressure-demand, self-contained breathing apparatus (SCBA) or a pressure-demand supplied air respirator (air hose) and escape SCBA. Level A provides maximal protection against harmful vapors and liquids.

According to OSHA regulations, Level A suits are to be selected “when the greatest level of skin, respiratory, and eye protection is required”[7]. Figure 1 shows a CST member in a Level A suit during a training session.

Figure 1: CST Member Collecting Chemical Samples During Training

A study conducted by NASA concluded that when the temperature around a person is 95 degrees for an extended period, they could make 60 mistakes per hour and not even realize it. When one perspires, almost half of one’s blood moves to the skin to produce moisture in the form of perspiration to naturally cool the body. The heart is pumping up to 150 beats per minute with less volume to get the blood to the skin. This causes the rest of one’s organs, including the brain and muscles, to operate only on half the blood normally needed. This interferes with cognitive thinking skills and can provoke strong emotions like anger [8]. This is of importance because the temperature inside a Level A suit can reach very high levels and cause measurable fatigue effects that can impact systems and processes.

Fine and Kobrick demonstrated that when trained soldiers were exposed to a moderately hot environment for seven hours in MOPP IV gear, their cognitive performance began to deteriorate. The associated errors increased from 17% to 23% compared to control conditions. Productivity decreased by 40% after six hours of exposure to the PPE [9].

The duration for which Level A suits provide the user with protection varies with the suit design, the degree to which the suit fits the user, the body motions required, and the concentration of chemical agent present in the environment [10]. However, subject matter experts are of the opinion that it is highly unsafe for a person to remain in the Level A suit beyond 60 minutes. Medical monitoring is compulsorily conducted and the person may be required to remove the suit sooner if deemed necessary.

5. Research Methodology

Seven members of the highly specialized Civil Support Team from the state of Missouri were tested. Tasks were designed to test participants' gross motor and fine motor capabilities. The tasks testing these consisted of the Minnesota Dexterity test, the Mirror Tracer test, and variations of difficulty levels within these. Participants were asked to practice the dexterity tests with rubber gloves first to reduce learning effects. They were also asked to walk between each trial battery, with the intention of replicating fatigue effects as closely as possible.

Complete Minnesota Dexterity Test (CMDT): The starting position of the setup requires that both boards are lined up on a table, one in front of the other, and the circular disks are in place on the board farthest from the participant. This is shown in Figure 2. When asked to start, the participant picked up disks from the top board and placed them into the holes of the bottom board one at a time in a given sequence, using one or both hands, as instructed. Each time that a peg was dropped or re-grasped counted toward an error. Three levels of difficulty were incorporated into the study. The tasks at each level of difficulty were labeled T1A, T1B, and T1C, respectively.

Figure 2: Data Collection in Chemical Suit – Minnesota Dexterity Test

Mirror Tracer Test: Participants were asked to trace a star-shaped pattern with a stylus using its reflection off a mirror as a guide, as shown in Figure 3. Each time that they allowed the stylus to stray from the prescribed pattern was considered to be an error.

Three increasing levels of difficulty were incorporated here as well, and were labeled T2A, T2B, and T2C, respectively.

Figure 3: Data Collection in Chemical Suit – Mirror Tracer Test

All the tests were timed and recorded. A baseline measure of time and accuracy was recorded for each participant without the suit. Then they were asked to perform each battery of tasks again repeatedly in the Level A suit. Analyses were performed using SPSS and percentages of changes in task time and accuracy as well as trends will be incorporated into IMPRINT Pro to allow modeling of crises scenarios involving Level A PPE.

6. Results

The results from the study are presented in the following exhibits. A t-test was performed to quantify the effect of the suit on task performance. This test compared out-of-suit versus mean in-suit completion times (seconds), and out-of-suit versus mean in-suit error count. The results from the t-test are shown in Table 1. The results indicate that there is a substantial effect of the Level A suit on completion time (p value = 0.0263) and for error count (p value for = 0.0318).

Table 1: Results for Effect of Suit Using t-test

Task	Suit*	Time	% Change	Errors	% Change
T1A	0	62.21		2.71	
	1	116.93	87.94%	18.31	25.99%
T1B	0	63.83		4.57	
	1	129.57	102.98%	25.02	34.09%
T1C	0	71.9		3.86	
	1	141.66	97.01%	18.91	25.10%
T2A	0	23.73		0.71	
	1	31.28	31.80%	3.15	4.06%
T2B	0	41.01		18	
	1	42.47	3.57%	17.92	-0.13%
T2C	0	21.58		3	
	1	25.43	17.85%	2.85	-0.25%

*where ‘0’ indicates out-of-suit data and ‘1’ indicates in-suit data

Tests of repeated measures were performed in order to obtain the effect of time-in-suit on performance. The results from the tests of repeated measures are presented in Figures 4 and 5. A separate plot was prepared for time (Figure 4) and accuracy (Figure 5) and shows the trend for each time the task battery was repeated. Contrary to expectations, the results indicate that the participants’ performance improved with each repetition as time-in-suit increased. The improvement is more significant for the tasks related to the Minnesota Dexterity test (T1A, T1B and T1C) than those related to the Mirror Tracer test (T2A, T2B and T2C).

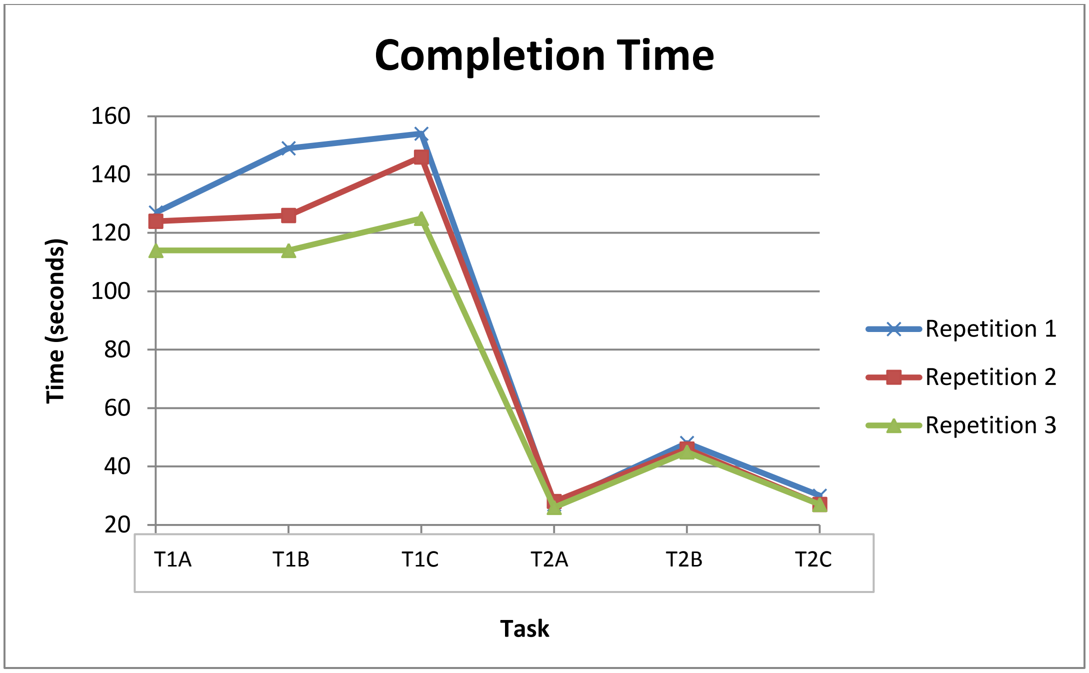

Figure 4: Estimated Means for Task Completion Time

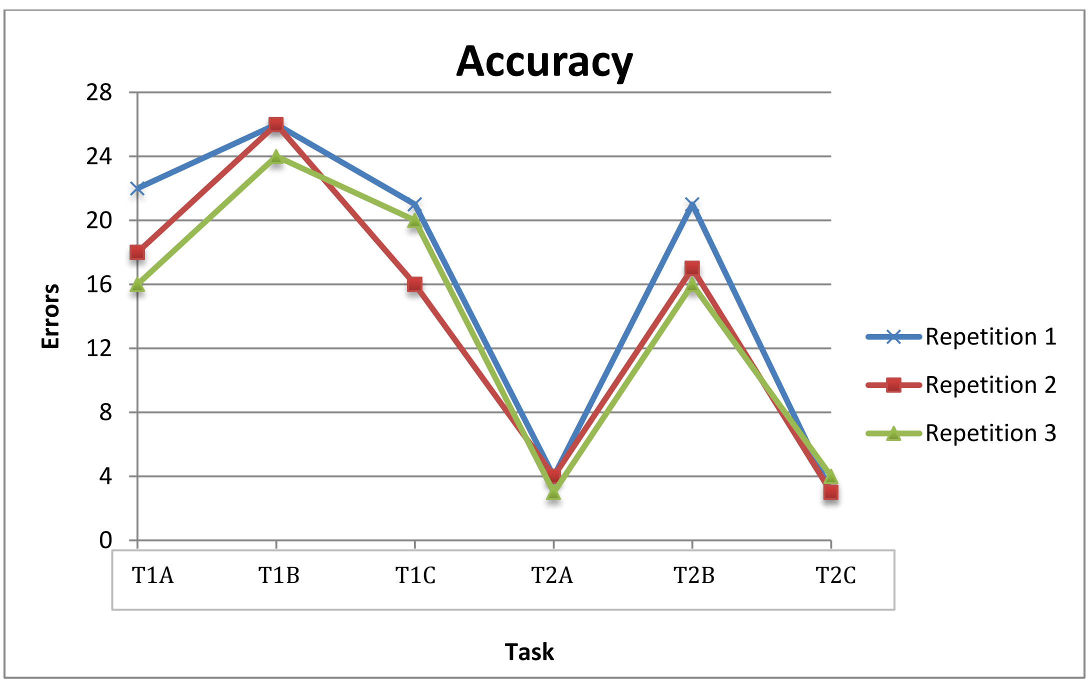

Figure 5: Estimated Means for Accuracy

7. Conclusion

The results from the t-test indicate that there is a significant effect due to the Level A suit, impacting both completion time as well as accuracy. However, contrary to prior belief, degradation in performance as the time-in-suit increased was not found. These results related to time-in-suit may not be indicative of the true level of performance in Level A suits as time increases. This could be a limitation of the study itself, and be indicative of a learning effect as opposed to a fatigue effect.

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SECTION

3. CONCLUSION AND FUTURE WORK

3.1 CONCLUSION

This study was designed to test the following hypotheses:

1. Level A suits degrade human task performance in terms of time and accuracy when compared to no suit

2. Time-in-suit has a negative impact on human task performance in terms of time and accuracy

Hypothesis 1 was confirmed from the results of the t-test. The effect of the Level A suit on human performance is statistically significant when compared to no suit, with p values of 0.0263 for completion time and 0.0318 for accuracy. When in the suit, increases in completion times up to 102.98% were observed. The decrease in accuracy, although substantial, was less profound. The suit was seen to have a definite effect on tasks testing gross motor dexterity. The results indicate that even trained members of the Civil Support Team may take up to double the time to complete tasks while in the suit.

Hypothesis 2 was not supported by the results obtained. Contrary to prior belief, degradation in task performance as time-in-suit increased was not found. The outcome was not altered even when training was administered with an encumbrance factor applied to fine motor dexterity, and when physical fatiguing factors were incorporated. When the experimental protocol was later modified for two participants, incorporating a more intense fatiguing effect and more rigorous training efforts, there was an increase in task completion time as the number of repetitions increased. This may be an indication that as the learning effect wears away and when a stronger fatiguing factor is applied, there is a discernible performance decrement. However, the data related to this finding is from only two participants.

One plausible explanation for the lack of correlation between time-in-suit and performance might be the fact that the tasks were repetitive in nature and without sufficient physical exertion. This might be a limitation of the study and its inability to capture the real-world scenario and effect of the suit.

Another possible reason could be the unrealistic nature of the controlled environment and conditions. Being in an actual crisis situation might entail one or more uncontrolled parameters such as high levels of noise and stress, extreme temperatures, low levels of light, and so on. The comfort of carrying out tasks in the comfort of controlled and familiar territory, in addition to the fact that the tasks may not have been sufficiently physically challenging, could have led to an improved performance in the lab setting that might not necessarily be mirrored in real life.

Alternatively, the rejection of hypothesis 2 might be a result of certain other factors not as easily captured by this testing method, such as resoluteness, determination to succeed, competitiveness, and motivation. Having observed the participants, it can be said that competitiveness was unmistakably a factor throughout the study. However, whether this was the sole driver for some of the variations seen while in the suit, cannot be told for certain.

In conclusion, the increase in time required for task completion and the decrease in accuracy due to the Level A suit is significantly large, and must be taken into consideration during modeling and planning phases.

Priority should be given to the development of a better-designed Level A suit that allows more movement and the quick dissipation of heat. Gloves, masks, over-suit, and boots that are more fitted to each individual would provide a greater degree of comfort and motion flexibility. For now, the results highlight the need to focus on training while in Level A suits, such that its impact on dexterity may be overcome to some extent. Allowances need to be made for the loss in dexterity that cannot be eliminated with additional training. There is also a design implication associated with the suit. When designing objects, controls, displays, and interfaces for use while in the Level A suit, it is important to take into consideration the loss in dexterity as well as the variability in the environment in which it is used, and design for use in less than ideal conditions.

3.2 FUTURE WORK

The investigation of the effect of Level A suits in task execution is valuable when planning for emergency response. Future research should be aimed at determining whether there exists a time-in-suit effect under more strenuous, realistic conditions. Having participants perform tasks that are more representative of what would be required on site, placing the experimental procedure in locations unfamiliar to participants, and imposing a level of stress representative of real-life scenarios might help replicate a real-world situation. Further, it would be interesting to analyze the cognitive effect that these protective suits have on the wearer over time.

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