Defence Research and Development Canada
Recherche et développement pour la défense Canada

CAN UNCLASSIFIED

DRDC | RDDC
technologysciencetechnologie

Can-LEAP Simulated Combat Mobility Performance: Summary Results of Testing With Varying In-Service Chemical, Biological, Radiological and Nuclear (CBRN) Equipment Conditions (Borden, 2013)

Jordan Bray-Miners
Alison E. Kelly
HumanSystems Inc.

Prepared
HumanSystems Inc.
111 Farquhar Street
Guelph (Ontario) N1H 3N4
Canada

PSPC Contract Number: W8486-151643/001/ZH
Technical Authority: Linda Bossi, Defence Scientist
Contractor's date of publication: February 2016

Defence Research and Development Canada

Contract Report
DRDC-RDDC-2018-C262
March 2019

CAN UNCLASSIFIED

Canada

IMPORTANT INFORMATIVE STATEMENTS

This document was reviewed for Controlled Goods by Defence Research and Development Canada using the Schedule to the *Defence Production Act*.

HSI®
HUMANSYSTEMS®
INCORPORATED

CAN-LEAP SIMULATED COMBAT MOBILITY PERFORMANCE: SUMMARY RESULTS OF TESTING WITH VARYING IN-SERVICE CBRN EQUIPMENT CONDITIONS (BORDEN, 2013)

by:

Jordan Bray-Miners and Alison E. Kelly

Human*Systems*® Incorporated
111 Farquhar Street
Guelph, ON N1H 3N4

HSI® Project Manager Alison E. Kelly
(519) 836-5911

PWGSC Contract No. W8486-151643/001/ZH
Task Authorization No. 4501375119

On Behalf of

Department of National Defence

As represented by
DRDC Toronto
1133 Sheppard Ave W
Toronto, ON, M3K 2C9

Project Scientific Authorities:

Michel DuCharme, PhD, DRDC (418) 844-4000 ext 4224,

and Linda Bossi, CD, DRDC, 416-635-2197

February 2016

Abstract

The Canadian Load Effects Assessment Program (CAN-LEAP) was developed in order to determine the implications of soldier equipment configurations and loads on soldier mobility and simulated combat task performance. A study of opportunity was conducted at CFB Borden while participating in the development and validation of a user evaluation protocol for the Joint General Service Respirator (JGSR) acquisition project. Twenty-one Regular Force volunteers participated in one week of data collection. Participants completed the CAN-LEAP course in four different in-service test conditions: two CBRN Mission Oriented Protective Posture (MOPP) levels (MOPP 1 and MOPP 4), a crowd control variant (respirator only), and a non-CBRN battle load baseline condition. The CAN-LEAP consisted of an instrumented obstacle course, marksmanship component, vertical and horizontal weight transfers, vertical jump and a subjective questionnaire. A significant difference between conditions was found during all of the CAN-LEAP components. The addition of the respirator and the CBRN clothing in the closed state were found to cause the most noteworthy performance decrements.

Résume

Le Programme canadien d’évaluation des effets de la charge (CAN-LEAP) a été mis au point afin de déterminer les incidences des configurations et des charges de l’équipement des soldats sur la mobilité des soldats et la performance des tâches de combat simulées. Une étude d’opportunité a été réalisée à la BFC Borden, tout en participant à l’élaboration et à la validation d’un protocole d’évaluation des utilisateurs pour le projet d’acquisition du respirateur général mixte (JGSR). Vingt et un volontaires de la Force régulière ont participé à une semaine de collecte de données. Les participants ont suivi le cours CAN-LEAP dans quatre conditions de test en service différentes: deux niveaux de posture de protection orientée mission (MOPP) CBRN (MOPP 1 et MOPP 4), une variante de contrôle des foules (respirateur uniquement) et une charge de combat non CBRN. condition de base. Le CAN-LEAP consistait en un parcours d’obstacles instrumenté, une composante de tir, des transferts de poids verticaux et horizontaux, un saut vertical et un questionnaire subjectif. Une différence significative entre les conditions a été constatée pour toutes les composantes de CAN-LEAP. L'addition du respirateur et des vêtements CBRN à l'état fermé s'est avérée causer les baisses de performance les plus notables.

Executive Summary

Combat Movement Testing With Varying Load Conditions: Canadian Load Effects Assessment Program (CAN-LEAP), Borden

The Canadian Load Effects Assessment Program (CAN-LEAP) was created in order to determine the implications of soldier equipment and load configurations on soldier mobility and simulated combat tasks and to determine the threshold at which the degradation in performance occurs.

Twenty-one Regular Force personnel volunteers participated in one week of CAN-LEAP data collection. The data collection was part of a collaboration with the Joint Chemical, Biological, Radiological, Nuclear General Service Respirator (J CBRN GSR) baseline benchmarking trial. Participants completed the CAN-LEAP course in four different test conditions: two CBRN Mission Oriented Protective Posture (MOPP) levels (MOPP 1 and MOPP 4), a crowd control variant (respirator only, a condition that might be used in an Aid to Civil Power scenario), and a battle load baseline condition. The same baseline battle load was worn across all conditions.

In addition to the obstacle/mobility course, the CAN-LEAP comprised a marksmanship component, vertical and horizontal weight transfer, vertical jump, and a subjective questionnaire. The results of each component were analysed separately to determine the effects of the load condition on combat performance and user acceptability.

The general performance trends on the obstacle course were:

- Non-CBRN Battle Load (A) resulted in the fastest mean time,
- Mean timing for MOPP 1 (C) was faster than Crowd Control (B) and MOPP 4 (D), and
- MOPP 4 (D) had the slowest mean time.

For overall course performance, all conditions had significantly different performance results from each other. However, for the individual obstacle interval times, the degree to which the difference in performance was significant changed from obstacle to obstacle. The results of participants' subjective ratings of their performance, as well as their Rating of Perceived Exertion (RPE), showed a relationship with the actual performance effect of the carried or worn load.

The Noptel marksmanship station results showed that fatigued shooting resulted in significantly larger average group size than rested. In both the fatigued and rested state the prone shooting posture resulted in significantly smaller average group size than both kneeling and standing. In reference to the test conditions, there were no significant differences found in the rested state, however in the fatigued state, MOPP 4 resulted in significantly higher average group size than all other conditions.

The weight transfer station results also showed that the fatigued state resulted in significantly slower vertical and horizontal weight transfer times. Both horizontal and vertical weight transfers showed significant differences between conditions in both the rested and fatigued states. For the horizontal transfer the conditions with a respirator were significantly slower than conditions without a respirator in both fatigued and rested states. For the vertical weight transfer in both the rested and fatigued states, MOPP 4 was significantly different than all other conditions, and the only other significant pairwise condition was Battle Load (D) vs Crowd Control (B) in the fatigued state.

The vertical jump task resulted in no significant difference between rested and fatigued states, but overall did show a significant difference in performance between conditions. Battle Load resulted in higher average vertical jump heights than all other conditions, and MOPP 4 resulted in lower average jump heights than all other conditions.

Table of Contents

List of Figures

List of Tables

1. Background

Lightening the load of the soldier has been a focus for the military ever since the advent of the foot soldier. The negative effects of overloading the soldier, such as fatigue, heat stress, injury, and performance degradation are still a reality for the modern warfighter. With the introduction of new technologies and the shifting demands of the modern battlefield, the soldier's load must be modified and re-evaluated to accommodate and adapt to these changes. Although load weight has a large impact on combat effectiveness and performance, load distribution, bulk, and stiffness cannot be ignored. Soldiers who are laden with excess bulk have difficulty traversing through small openings and maneuvering through tight quarters, whereas soldiers who struggle with a lack of flexibility caused by the stiffness of worn equipment and protective gear will have trouble with agility and getting into proper postures and positions. Collectively, weight, bulk, and stiffness, as they pertain to the effectiveness and performance of a dismounted infantry soldier, have been termed "Soldier Burden". Identifying the cause and effect of this burden in different equipment configurations can allow informed decisions to be made about future military clothing and equipment in combination with the effectiveness of the individual soldier.

Previous research has tended to focus on effects of additional weight on the soldier with respect to physiological, psychological, and biomechanical outcomes. For example, Majumdar, Pal, Pramanik, and Majumdar (2013); Attwells, Birrell, Hooper, and Mansfield (2006); Seay, Fellin, Sauer, Frykman, and Bensel (2014); and Birrell, Hooper, and Haslam (2007) have studied biomechanical effects, while Beekley, Alt, Buckley, Duffey, and Crowder (2007); Patton, Kaszuba, Mello, and Reynolds (1991); and Holewijn and Meeuwsen (2000) have examined physiological effects of load-weight carried or worn by the soldier. Several studies, such as Bigard (2000); Devroey, Devroey, Jonkers, de Becker, Lenaerts, and Spaepen (2007); Johnson, Pelot, Doan, and Stevenson (2000); and Grenier, Peyrot, Castells, Oullion, Messonnier, and Morin (2012), have investigated both the biomechanical and physiological outcomes of varying the carried or worn load. Other studies such as Park, Branson, Petrova, Peksoz, Jacobson, Warren, Goad, and Kamenidis (2013); Birrell and Hooper (2007); Mahoney, Hirsch, Hasselquist, Lesher, and Lieberman (2007); and Orr, Johnson, Coyle, and Pope, (2011) measured indices such as participant comfort levels, injury rates, cognitive impacts and load carriage with female soldiers (respectively). These studies suggest that carrying heavy loads results in decrements in physiological and cognitive function, compensatory alterations in biomechanics, decreased levels of comfort, and increased reports of injury.

Some studies have quantified soldier performance using marksmanship, obstacle course, or short task outcomes. For example, LaFiandra, Lynch, Frykman, Harman, Ramos, and Mello (2003), studied the effects of various load carrying equipment; Hasselquist, Bensel, Corner, Gregorczyk, and Schiffman (2008) examined the effects of various body armour configurations on soldier performance; and Treloar and Billing (2011) studied the effects of load carriage on soldier performance in an explosive sprint task. Very little research exists in the area of combat-specific performance outcomes under different load, weight, bulk and stiffness conditions and body armour configurations, particularly within the Canadian Military.

The Canadian Load Effects Assessment Program (CAN-LEAP) was built in order to determine the implications of "Soldier Burden" and alternative soldier equipment and load configurations on mobility and simulated combat task performance, and to determine the threshold at which the degradation in performance occurs. LEAP was originally developed in consultation with subject matter experts (SME) in combat maneuvers, for the Program Manager (PM) of the Marine

Expeditionary Rifle Squad (MERS) of the United States Marine Corps (USMC). It has since been adopted by DRDC and several allied military organizations (DST Australia, and PEO Soldier of the US Army) for various purposes. LEAP facilities combine an obstacle course of specifically designed obstacles with marksmanship testing and other accessory performance-based tasks, predominantly but not solely aimed for systematic examination of the effects of soldier equipment, and in Canada specifically, to determine the contributions of equipment parameters such as weight, bulk, and stiffness, on relevant combat performance.

The obstacles were designed to replicate or represent real life obstacles or mobility challenges in the field, such as traversing through windows, over walls, over logs and ditches, etc. and testing can be performed in a controlled environment to ensure accurate and repeatable results. The marksmanship station provides a measureable method to determine the effect of the test condition shooting performance.

The objective of the CAN-LEAP Borden 2013 study was to evaluate the effect of wearing Chemical Biological Radiological Nuclear (CBRN) gear on combat performance. This objective was accomplished by having soldiers complete combat-relevant tasks, which included an obstacle course, a marksmanship task, a weight transfer task, and a vertical jump. Each participant completed all of these stations in each test condition, using a counter-balanced condition presentation order, and results were compared to determine the effect of the test condition on the soldiers' simulated combat performance.

The CBRN test conditions were coordinated with Joint Chemical, Biological, Radiological and Nuclear General Service Respirator (J CBRN GSR) as part of another benchmarking trial (Angel, Ste-Croix, & Osborne, 2013). The goal of that trial was to benchmark the user acceptability of the in-service C4 respirator for use in future bid evaluations as well as recommend evaluation criteria for the J CBRN GSR System Requirement Specifications (SRS). Although not a mandatory requirement, the CAN-LEAP obstacle course was used to determine acceptability of high physiological exertion compatibility.

Collaboratively between the two projects, four test conditions were chosen that allowed the soldiers to complete the course in a variety of different protective levels. The conditions included a battle load baseline (replicating a condition from a previous CAN-LEAP in-service baseline study), a condition that might be used for crowd control in an Aid to Civil Power Scenario, hereafter referred to as the Crowd Control variant (which added the C4 respirator, worn), and two conditions that represented different Mission Oriented Protective Posture (MOPP) levels (MOPP 1 and MOPP 4). For the CAN-LEAP research program, comparing between these conditions will allow for the determination of effect of increasing levels of CBRN equipment on soldiers' combat performance.

2. Aim

This project aimed to study the performance implications of wearing Chemical Biological Radiological Nuclear (CBRN) protective clothing and equipment on combat performance, using the CAN-LEAP instrumented obstacle and combat effectiveness course.

3. Methods

The following section describes the methodology for all facets of the CAN-LEAP experiment, including the participants and participant characterization, load configurations, course and station descriptions, and protocols.

3.1 Participants

Twenty-one (21) Regular Force combat service support personnel participated in this study. The participants were recruited from the Canadian Forces Support Training Group (CFSTG) at CFB (Canadian Forces Base) Borden. The study was one week in duration, with all research tasks taking place at CFB Borden grounds. All participants were required to be physically fit enough for deployment (as determined by their units).

Volunteers were pre-selected by tasked army units and were asked to participate after a briefing given by the investigators. Participants were informed about the study and its requirements in advance of volunteering; as the Department of National Defence (DND) requires all research participation to be voluntary, all potential participants were informed that just showing up fulfills the requirement of the tasking. Their actual participation to the study, as per DND Defence Administrative Orders and Directives (DAOD), was completely up to them.

3.1.1 Participant Characterization

Participant factors, such as sex, size, weight, age, strength, aerobic fitness (VO_2 max) and combat experience, may have had an influence on the soldiers' performance outcome. It was therefore important to characterize the soldiers for these factors to help explain any associated variability in the data and to improve the interpretation of results. The following background demographic information was collected for all participants:

- Age
- Military Occupational Specialty (MOS)
- Rank
- Billet (position within a unit)
- Years of service
- Number of deployments
- Sex
- Pre-existing injury(s) – Note that it is unlikely that any soldier with deployment experience will have been injury-free during his or her career in the military.
- Semi-nude weight - measured using a weigh scale
- Participant semi-nude height
- Adiposity - measured as described in Annex A: Adiposity Testing
- Static strength – measured as described in Annex B: Strength Testing respectively

3.1.1.1 Fitness Testing

A sub-maximal fitness test (Modified Canadian Aerobic Fitness Test, mCAFT [1]) was conducted to estimate each participant's aerobic (endurance) fitness, usually referred to as the maximal rate of oxygen consumption (VO_2 max).

3.1.1.2 Adiposity Testing

Each participant's body fat was estimated by measuring the skinfold thickness at five locations on the body (triceps, subscapular, suprailiac, abdominal, and quadriceps) using a caliper instrument. Refer to Annex A: Adiposity Testing for further details on the specific methodology.

3.1.1.3 Range of Motion (ROM)

The participants' ROM measurements were taken during each test condition, including an unencumbered semi-nude condition. Measurements were taken using a combination of a goniometer, a Wells and Dillon Sit and Reach apparatus, an inclinometer and a digital level. The following ranges of motion were measured:

- trunk forward flexion (modified Wells and Dillon Sit and Reach),
- trunk lateral flexion (standing), and
- trunk rotation.

Refer to Annex C: Range of Motion Testing for further details on the specific methodology

3.1.1.4 Heart Rate

The participants' heart rate (HR) was monitored using a Polar Heart Rate Monitor (Polar RS 400) that was strapped to the participant's chest under their clothing and monitored remotely through a wrist-watch that the participant wore. The participant's HR was monitored to ensure it had returned to within 15% of the resting HR prior to being permitted to commence the next course run-through. An alarm was set on the HR monitor whereby an audible signal emitted if the participant exceeded 95% of his/her maximum HR. This value had been determined as an upper safe limit of exercise for a healthy, fit adult by the American College of Sports Medicine (ACSM, 2005). If the HR monitor alarm sounded, the participant was monitored by the on-course researcher for any signs of distress and if any were observed, the participant was removed.

3.1.1.5 Strength Testing

Static strength was characterized as upper limb static strength. A force gauge, platform, a chain, and a pull handle were utilized during these tests. Refer to Annex B: Strength Testing for further details on the specific methodology.

3.2 Participant Briefings and Safety

Participants were provided with an in-brief and background information on the CAN-LEAP, the aim of the project, and the study protocol. If interested in participating, they were required to review and sign the informed consent form as well as complete a personal demographic information form (refer

[1] The mCAFT is a predictive VO2 max step test. The test is performed on a two-step platform and consists of stepping up and down the platform with an increasing cadence. The test consists of measuring the time to achieve a sub-maximal target HR, which typically takes about 10 min.

to Annex D: Demographic Information Questionnaire). The in-brief concluded with a participant number assignment.

Prior to any use of the CAN-LEAP course, participants were given a safety briefing and walk-through, in which proper and safe techniques of traversing obstacles were discussed and demonstrated. During this (or any other) time, participants were free to ask any questions they may have had concerning the obstacles or the method of traversing them.

The safety of the participants was a top priority during the entire study. During the practice and test runs, at least one person qualified in First Aid was available at all times. Participants were given a minimum of 60 minutes of sedentary recovery time after completion of the obstacle course in order for the cardiovascular and thermoregulatory systems to adequately recover. During the latter half of this hour, the participant was issued another test condition, and at the end of the hour, they repeated the CAN-LEAP tasks for a second time. No participant was asked to complete the course more than twice in a day. Drinking water was available to the participants at all times.

No more than two participants were permitted to run on the course at any one time. This prevented the participants from passing/colliding into one another, as well as prevented the attention of human factors observers and safety personnel from becoming too divided. There was always at least one researcher or assistant present on the course, walking alongside the participants. The researcher provided the participant with reminders of the correct course path and proper protocol, offered encouragement, observed the participant for any signs of unsafe levels of fatigue or exhaustion, and watched the course for any other safety concerns.

3.3 Load Configurations and Participant Matrix

Four conditions were created to represent different MOPP levels and other closely related configurations. Table 1 displays the kit list and load configuration associated with each condition. The conditions will be referred to by their assigned letter for all of the data analysis in this report.

Table 1: Load Configuration by Condition

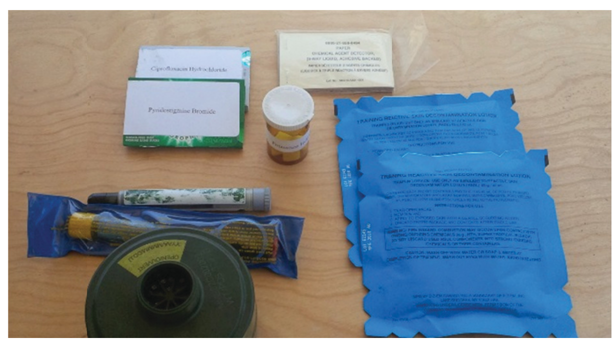
Condition	Kit List
A	**Battle Load (no CBRN equipment):** Combat trousers, t-shirt, combat shirt, combat boots, ballistic eyewear (BEW), soft hat, C7A2 rifle and sling (with one fully weighted magazine), personal role radio (PRR), in-service helmet (CG634), tactical vest with standard combat load (4 loaded dummy magazines, 2 dummy frag, 2 dummy smoke, 1L canteen, 2 field dressings).
B	**Crowd Control Load (Respirator only) with Battle Load:** Combat trousers, t-shirt, combat shirt, combat boots, soft hat, C7A2 rifle and sling (with one fully weighted magazine), personal role radio (PRR), in-service helmet (CG634), tactical vest with standard combat load (4 loaded dummy magazines, 2 dummy frag, 2 dummy smoke, 1L canteen, 2 field dressings), C4 mask (with C7A canister) worn, carrier bag (slung)
C	**MOPP 1 (Suited up in open state, unmasked) with Battle Load -** Combat trousers, t-shirt, combat shirt, combat boots, BEW, soft hat, C7A2 rifle and sling (with one fully weighted magazine), personal role radio (PRR), in-service helmet (CG634), tactical vest with standard combat load (4 loaded dummy magazines, 2 dummy frag, 2 dummy smoke, 1L canteen, 2 field dressings), CBRN suit (hood down, no gloves or boots, pant and shirt sleeves open), carrier bag (with C4 & C7 canister, slung)
D	**MOPP 4 (Suited up in closed state, masked) with Battle Load -** Combat trousers, t-shirt, combat shirt, combat boots, soft hat, C7A2 rifle and sling (with one fully weighted magazine), personal role radio (PRR), in-service helmet (CG634), tactical vest with standard combat load (4 loaded dummy magazines, 2 dummy frag, 2 dummy smoke, 1L canteen, 2 field dressings), CBRN suit (hood on, inner and outer gloves and boots worn), C4 mask (with C7A canister) worn, carrier

Condition	Kit List
	bag (slung)

Photos of different pieces of equipment and weapons are outlined in Figure 1 through Figure 6 below.

Figure 1: Tactical Vest with Standard Combat Load *(Source: DRDC Toronto Research Centre)*

a)



b)

Figure 2: a) C4 mask with C7A canister and b) gas mask carrier contents *(Source: DRDC Toronto Research Centre)*

Figure 3: Condition A *(Source: J. Clark, DRDC)*

Figure 4: Condition B *(Source: J. Clark, DRDC)*

Figure 5: Condition C *(Source: J. Clark, DRDC)*

Figure 6: Condition D *(Source: J. Clark, DRDC)*

Every participant wore each condition once throughout the week (counterbalanced design). Assignment to the first condition a participant experienced was randomized. The order of presentation of conditions was counterbalanced to counteract any learning or order effects. The approximate weight of each condition was tabulated based on measured weight of individual components that make up each condition. For equipment that may have been provided in different sizes to fit each individual participant the weight of the large size was used to approximate the condition weight. Condition weights are summarized in Table 2.

Table 2: Mean Condition Weights

Condition	Mean Weight (kg)
A	16.5
B	17.8
C	20.2
D	21.8

3.4 CAN-LEAP Course and Stations Configuration

Participants followed the same flow-through of stations for each condition being tested. The following sections describe each station and its methodology, and the order in which each station was completed.

3.4.1 Flow-through of Stations

Following the briefings and safety demonstrations participants were asked to perform a sub-maximal fitness test and undergo basic anthropometric measures (such as height and weight), an adiposity measurement and strength testing, as described in section 3.1.1.

Participants were then given time to perform two training runs (in conditions A and B) on the course, including a dynamic warm-up (as described in Section 3.4.2.1) beforehand. Ample rest time between practice runs was provided. When a participant was in “down time” (i.e. not completing practice or test runs of the CAN-LEAP course) he was taken through any Anthropometry and ROM tests that were yet to be completed (referred to in Section 3.1.1.3) while clad in boots, combat pants and a t-shirt.

For the test (data) runs, each participant was provided with one of four different test conditions, two per day, to complete all four conditions within the week.

Once fitted with a test condition, the participant performed a dynamic warm-up, followed by the marksmanship task, the horizontal and vertical weight transfer, and the vertical jump task. These activities, along with the Questionnaire kiosk (which was only completed after the obstacle course) are referred to as the Accessory Stations.

After finishing the warm-up and Accessory Stations, the participant completed the obstacle course comprised of sequential test segments and the Accessory Stations (Figure 7).

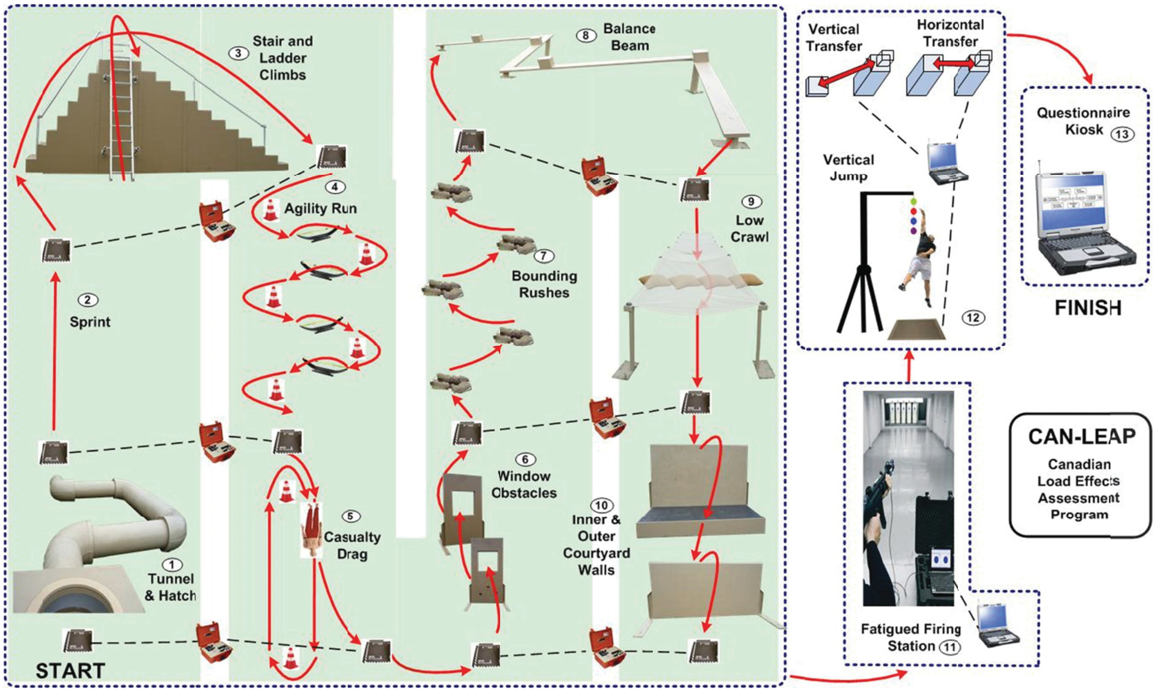


Figure 7: CAN-LEAP Course Configuration

The CAN-LEAP course and stations are traversed sequentially, starting at the Tunnel and Hatch and concluding with the Questionnaire kiosk.

Each of the ten segments of the obstacle course are separated by Radio Frequency Identification (RFID) race timing mats. An additional three tests (firing accuracy, vertical jump testing, and a weight transfer station) are performed independently of the RFID timing system. The subjective rating questionnaire station concludes the CAN-LEAP course.

Performance in each of the physical tasks was measured and recorded, and included total obstacle course completion time, completion time of individual obstacles, firing precision (shot X and Y coordinates), jump height, and weight transfer times.

3.4.2 Station Descriptions

The following sections describe each of the CAN-LEAP stations (including individual obstacles), including the proper method of traversing obstacles, how the station is operated, and brief descriptions of station or obstacle assembly if required.

The purpose of the descriptions is to give the reader a broader understanding of the course and its components, not to build and assemble it. In depth details of the CAN-LEAP assembly process can be found in the CAN-LEAP User Manual.

3.4.2.1 Dynamic Warm-up

Prior to the participants completing their first run of the day, they underwent a researcher-led dynamic warm-up in order to mitigate the risk of injury and prepare for the physical nature of the tasks to follow. The dynamic warm-up consisted of the following components run as a sequence over a three minute period:

- Component 1 – light jog
- Component 2 – high stepping with arms rotating at the shoulder
- Component 3 – strike kicks to the front
- Component 4 – hamstring kicks (heels striking the buttocks while stepping)
- Component 5 – hip rotations (inside/outside rotation while stepping)
- Component 6 – hip rotations (outside/inside rotation while stepping)
- Component 7 – side shuffle in a squatted position
- Component 8 – back shuffle in a squatted position
- Component 9 – burpees (done in place)

Participants were allowed to perform any component in any order for the duration of the three minutes as long as they kept the activities and order the same for every warm-up each day. They were also instructed that a minimum of two of the three minutes must elicit a cardiovascular response, while one minute could be dedicated to stretching.

3.4.2.2 CAN-LEAP Course and RFID Timing System

The obstacle course section was a series of ten mobility test stands (1-10) with the objective of determining when a soldier's performance is degraded due to various donned or carried equipment sets or configurations relative to a baseline. Of the ten segments, six contained semi-transportable obstacles, which have been constructed specifically for the CAN-LEAP project.

The sections below outline the physical specifications and the method of traversing each of the ten (10) obstacles (segments) within the RFID-instrumented CAN-LEAP course. Participants complete all obstacles, in sequence, with no rest breaks. Total course completion time, time for each obstacle, and transition time between obstacles will be recorded.

Tunnel and Hatch

The tunnel and hatch obstacle consisted of a four-step riser with a hatch located in the floor on the top of the stairs. Attached to this was a 'C' shaped tunnel (of varying diameters) that participants traversed through in a crawl position (refer to Figure 8).

Figure 8: Tunnel and Hatch Obstacle

The tunnel and hatch obstacle was comprised of the stair portion and nine separate tunnel segments as shown in Figure 9. The beginning of the tunnel was attached to the opening of the stair platform via screws and a connector ring. The lengths of each tunnel segment are outlined in Figure 9. The diameter of the tunnel segments varied between segments, with the smaller diameter measuring 24” and the larger diameter measuring 30” across.

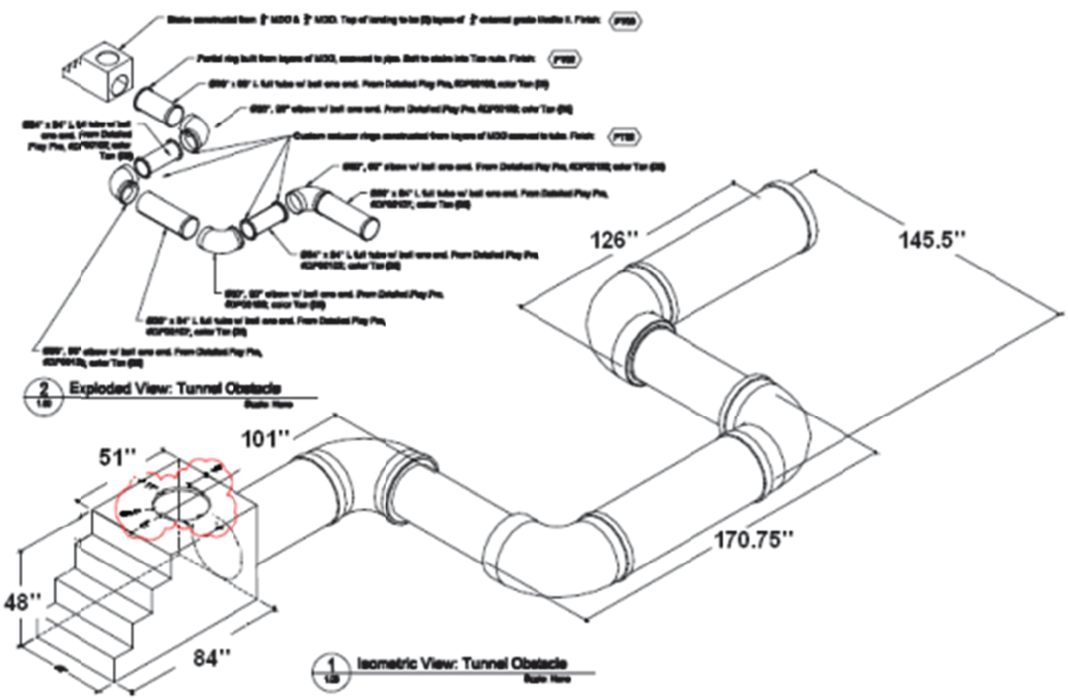


Figure 9: Dimensions of the Tunnel and Hatch Obstacle

To traverse the obstacle, the participant approached the stair portion of the tunnel and hatch and climbed up the stairs one step at a time. The participant then lowered himself (feet first) into the hatch opening, lowered himself into a crouch position, and entered the opening of the tunnel on all fours. The participant continued traversing through the tunnel until he emerged out the other end. Upon completing the length of the tunnel, the participant returns to a standing position and runs across the timing mat.

Sprint

After emerging from the tunnel obstacle, the participant crossed the mat which signifies the start of the sprint segment (refer to Figure 10). The participant sprinted at his fastest capable running speed for 60 feet (18.3 m), and the sprint ended when the second timing mat is crossed.

Figure 10: Sprint Segment

Stair and Ladder

The stair and ladder obstacle consisted of two sets of stairs (one with a short run and high rise, the other with a low rise and long run), a platform at the top, and a ladder on each side (one angled, and one vertical) (refer to Figure 11). The stair and ladder obstacle was comprised of five separate segments that were connected with “roto-lock” connectors. The dimensions of the segments are shown in Figure 12.

Figure 11: Stair (steep and gradual rises) and Ladder (straight and angled)

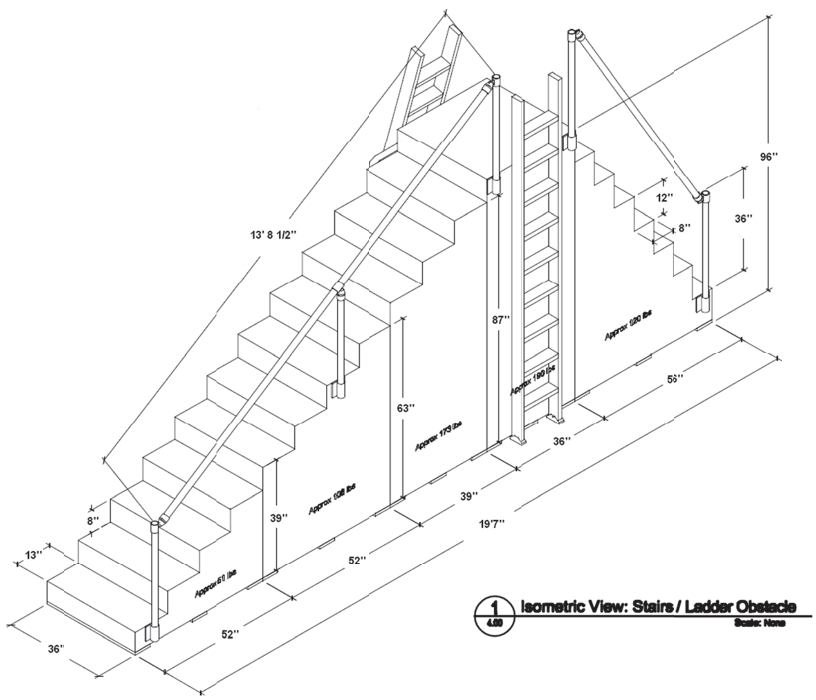


Figure 12: Dimensions of the Stair and Ladder Obstacle

Upon crossing the timing mat that divides the sprint from the stair and ladder obstacle, the participant progressed through this obstacle in the following order:

1) climb up the short run/high rise stairs
2) climb down the long run/low rise stairs
3) place two feet on the ground
4) climb up the long run/low rise stairs
5) climb down the short run/high rise stairs
6) climb up the straight ladder
7) climb down the angled ladder
8) place two feet on the ground
9) climb up the angled ladder
10) climb down the straight ladder

The participant finished this segment of the obstacle course by crossing over the timing mat at the end of the stair/ladder obstacle.

Agility Run

The agility run obstacle was a sprint around five poles set in a weaving pattern, with a step-over obstacle placed between each pole (refer to Figure 13). An RFID timing mat was placed at the beginning and end of the agility run. There was a distance of 21’ (6.4 m) between each pole, and a step-over obstacle (hurdle) was placed halfway between each set of poles, requiring the participant to jump or stride over it (see Figure 13). This segment was complete when the participant crossed over the timing mat after the fifth hurdle.

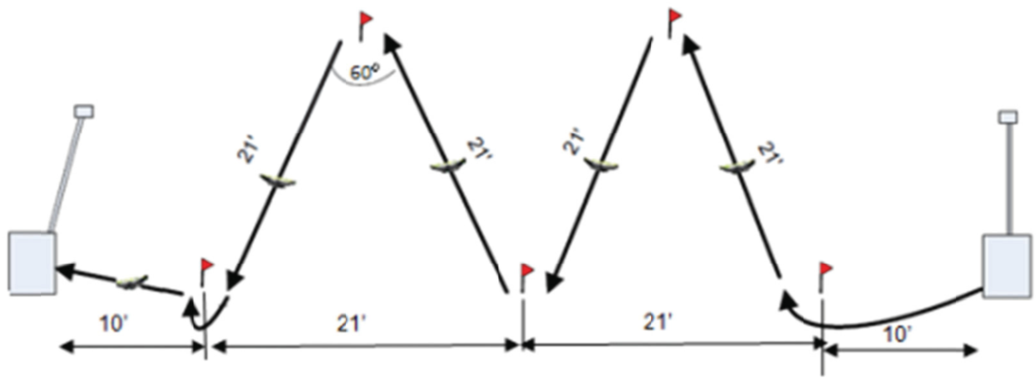


Figure 13: Agility Run Layout

Casualty Drag

For the casualty drag portion of the obstacle course, the participant dragged a "Rescue Randy" mannequin out to a turn-around point 10 yards (9.1 m) away and back to the original position in which the mannequin was located (refer to Figure 14).

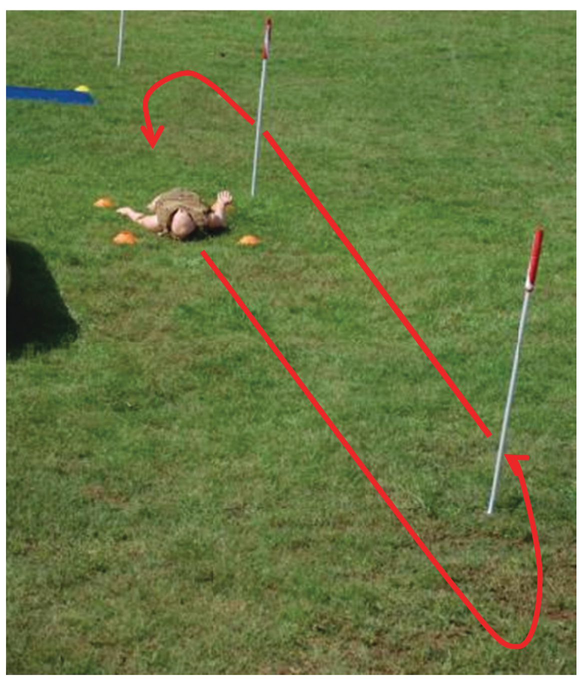


Figure 14: Casualty Drag Set Up

The participant used either the casualty extraction strap on the tactical vest or the shoulder straps to drag the mannequin. The start/finish position of the mannequin was set up by a tape box bounded by small cones. The mannequin weighed 180 lbs (81.8 kg) and was clad in a tactical vest.

Windows

The window component was comprised of two different obstacles: Window #1 and Window #2 (refer to Figure 15). Window #1 consisted of a 5’(w) × 10’(h) × 8”(d) (1.5 m (w) x 3 m (h) x 0.2 m(d)) obstacle with a 36”×36” (0.9 m x 0.9 m) window cut-out, with its bottom ledge situated 5’ (1.5 m) (h) from the ground. There was a 4’1½”(d) × 5’(w) (11cm x 1.5m) landing platform on the opposite side. The surface of Window #1 was covered with a textured resin and three toe holds (all protruding) were placed on the approach side to aid in mounting the obstacle. Window #2 consisted of a 5’(w) × 10’(h) × 8”(d) (1.5 m (w) x 3 m (h) x 0.2 m(d)) obstacle with a 36” × 36” (0.9 m x 0.9 m) window cut-out, with its bottom ledge situated 4’ (1.2 m) (h) from the ground. The surface of the wall was smooth and there were no toe holds present. The windows were supported by two metal stanchions, each attached with two fasteners.

Figure 15: Window #1 and Window #2 *(Source: J. Clark, DRDC)*

To complete the window obstacles, the participant first went through the opening of Window #1; the participant was free to choose whether or not he wanted to use the toe holds to assist him in climbing up the wall. After landing on the platform, the participant ran to Window #2, climbed through the window opening, and landed on the lightly padded platform on the opposite side. For safety purposes, the participant was required to land on his feet on the landing platform (as opposed to diving or rolling through the window opening). This segment of the obstacle course was completed when the participant crossed over the timing mat after the second window.

Bounding Rushes

The Bounding Rushes segment of the obstacle course consisted of five rushes to staggered prone firing positions, as displayed in Figure 16. Each firing position was marked with a sandbag, and the segment started and ended with an RFID timing mat. The sandbags were placed in a staggered pattern with the first one 7 feet (2.1 m) away from the timing mat in front of it. The second sandbag was placed 15 feet (4.6 m) from the first on an angle 45 degrees to the right.

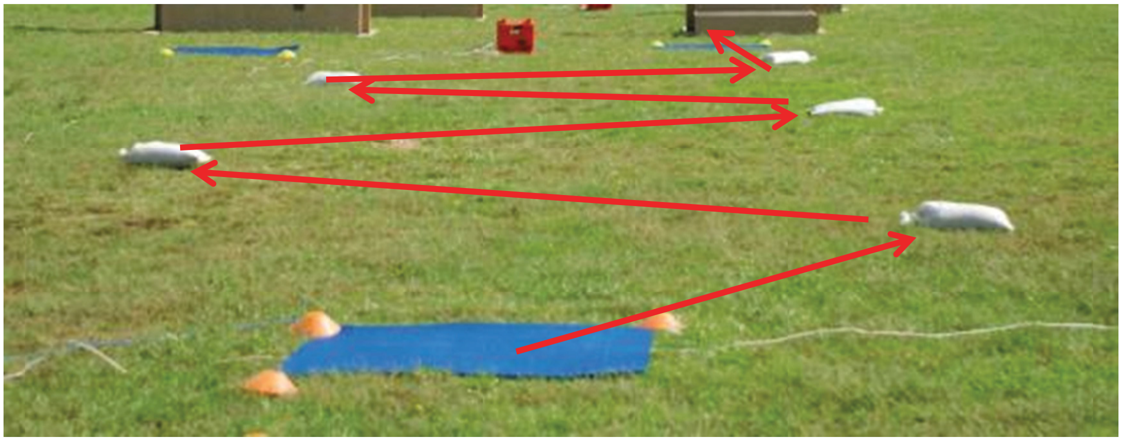


Figure 16: Bounding Rushes

The participant began the bounding rushes segment by crossing over the first timing mat and running to the first pile of sandbags. Upon arriving at the first set of sandbags, the participant assumed a prone position, acquired a sight picture, and then leapt up to a running position. The participant then sprinted to the next (staggered) sandbag, assumed the prone position, and acquired a sight picture. This cycle was repeated for the remaining sandbag locations, and the segment ended when the participant crossed over the timing mat at the end.

Balance Beam

The balance beam obstacle consisted of a series of four sloped metal 'plank' segments connected together at right angles. Four box-shaped obstacles were located on top of the planks (one on each segment) to provide an additional challenge for the participant as they traversed the beam. Refer to Figure 17.

Figure 17: Balance Beam

The first segment started at a height of 6" (15 cm) off the ground and sloped upwards at approximately 15°, reaching a maximum height of approximately 2'7" (0.79 m). The second segment sloped downwards, reaching a height of 6" (15cm) from the ground at the end. The third segment sloped upwards and the fourth downwards, to the same specifications as the first two planks. Each of the 'plank' segments was 10' (3 m) long. The box-shaped obstacles, measuring 8" × 8" × 8" (20 × 20 × 20 cm) were permanently affixed to the plank segments at locations of 41" (104 cm), 40" (101 cm), 28" (71cm), and 12" (30 cm) in from the edge of the first, second, third, and fourth segment respectively.

To traverse this obstacle, the participant kept to the outside of the line of cones and stepped up on to the beam from the end. Jumping up onto the beam from the side was not permitted. The participant walked across the balance beam while stepping over the box-shaped obstacles; stepping on top of the box obstacles was not permitted. The participant exited the balance beam by stepping off the end (not the side) then kept to the outside of the line of cones, and ran towards the next timing mat.

Crawl

The low crawl obstacle consisted of 14 poles that supported a length of nylon fabric to create an obstacle under which participants were required to crawl (refer to Figure 18).

Figure 18: Crawl (with participant on course)

The height of the low level support poles was 20” (50 cm). The transition pole was a double-supported pole, with the first half reaching 20” (50 cm) and the second half 26” (66 cm). The high level support poles were 26” (66 cm). The low crawl obstacle was 4’ (1.2 m) wide and 30’ (9.1 m) long. Two rows of sandbags were located on the ground at the 10’ (3 m) mark, and 20’ (6 m) mark.

To complete the low crawl obstacle, the participant began by crossing the RFID timing mat, and then crawling underneath the canvas as fast as he could. For the first 10’ (3 m), the participant performed a low crawl. At the 10’ (3 m) sandbag line, the participant crawled over the sandbags, turned on his back, and performed a back-crawl to the 20’ (6 m) sandbag line. He then turned onto his front and traversed over the sandbags and performed a high crawl to the end where they ran to the next timing mat.

Courtyard Walls

The wall component of CAN-LEAP consisted of two different wall obstacles; an outer and an inner courtyard wall (refer to Figure 19).

Figure 19: Inner and Outer Courtyard Walls

The outer courtyard wall consisted of an 8'(w) × 6'(h) × 1.5'(d) (2.4 m (w) × 1.8 m (h) × 0.45 m (d)) obstacle with a 4'1½"(d) × 8'(w) (1.3 m (d) × 2.4 m (w)) landing platform on the opposite side. The textured wall surface contained 9 toe holds (5 protruding, 4 receding) on the approach side to aid in mounting the obstacle. The inner courtyard wall consisted of an 8'(w) × 4'(h) ×6"(d) (2.4 m (w) × 1.2 m (h) × 0.15 m (d)) obstacle, with a smooth surface, and no toe holds. The walls were set up in a staggered formation, with 15 feet (4.6 m) between the edge of the landing platform of the outer courtyard wall and the inner courtyard wall. The walls were supported by two metal stanchions attached to the wall with two fasteners each.

The participant began by traversing over the outer courtyard wall as quickly as possible and landing on the padded platform on the opposite side. Any manner of traversing was permitted, and the participant was able to use the foot holds to assist him if he wished. After traversing the outer courtyard wall, the participant sprinted to the inner courtyard and crossed over it as fast as possible. To complete this segment (and the timed course), the participant ran over the final timing mat.

3.4.2.3 Noptel Marksmanship Stand

Marksmanship performance was recorded using the Noptel ST-2000 Expert Marksmanship System, an integrated rifle marksmanship training and data collection device that attached on to either the barrel or picatinny rail of the rifle.

The Noptel System consisted of an optical unit (Figure 20) that was connected to a laptop computer (containing the Noptel Software) via a USB cable, a Noptel target equipped with reflective prisms, and proprietary software.

Figure 20: Noptel Optical Unit (left) and Reflective Target (right) *(Source: DRDC Toronto Research Centre)*

The system worked by emitting an infra-red LED light towards the target upon the rifle being fired. The light was then reflected back to the optical receiver by prisms mounted on the target and the software converted this to a target score. The targets were mounted 150 feet (45.7m) away from the firing line.

At the beginning of each testing session (or each time the optical unit gets mounted onto the rifle) the optical unit was zeroed.

The participant was instructed to pick up the rifle and approach the firing line in a tactical kneeling, standing or prone position, depending on the randomized order. The researcher then issued a “Threat” command, to which the participant reacted by aiming for the centre of the target and taking one shot as quickly as possible. The “Threat” command and shot response was completed a total of five times for every firing posture. After each shot, but before the next “Threat” command was issued, the participant was required to lower the weapon to 45-degrees (in standing and kneeling; in prone the participant moved his head away from the optical sight) as well as put on the safety. Lowering the weapon and putting the safety on maintained the safety protocol of the study while also providing the researcher with a cue to issue the next “Threat” command.

3.4.2.4 Weight Transfer

The weight transfer station was used to measure the participant’s ability to quickly transfer a weight from one platform to another while wearing each of the test conditions. There were two components to the weight transfer station: horizontal transfer and vertical transfer.

The horizontal transfer platforms were both 48” (122 cm) from the ground. The first vertical platform sat just above ground height, and the second platform was 68” (173 cm) from the ground.

A 30 lb (13.6 kg) ammunition can was used as the lifting load for both the vertical transfer and the horizontal transfer. For both types of transfers, six lifts (with back and forth being considered one lift) were performed, and the time it took to complete this set of six lifts was recorded.

3.4.2.5 Vertical Jump

The vertical jump station consisted of a rubberized mat with an embedded sensor, a hand-held display unit, and a connector cable (refer to Figure 21).

Figure 21: ‘Just Jump’ Equipment *(Source: DRDC Toronto Research Centre)*

When the participant jumped, the sensor measured the time off the mat, and the software on the handheld unit converted that time to a jump height.

In order to increase the participant’s motivation, a vertical jump target (refer to Figure 22) was fabricated out of a set of 6 balls hanging vertically on a rope. The idea was to have the participant jump and reach as high as possible, using the target to facilitate goal setting for a maximal jump.

Figure 22: Vertical Jump Target

The participant completed a series of three maximal-effort jumps at this station. The database software identified the maximum jump height and calculated the average jump height. The participant was instructed to step on the mat and then make one maximal vertical jump. They then were required to step off the mat, then back on, and take another maximal jump. This was repeated for a third (final) jump.

3.4.2.6 Rating of Perceived Exertion (RPE)

Immediately after completing the obstacle course, the participants were presented with a scale known as the Borg Scale, which ranges from 6 to 20 and measures perceived exertion. The Borg scale can be seen in Figure 23.

6	NO EXERTION AT ALL
7	
	EXTREMELY LIGHT
8	
9	VERY LIGHT
10	
11	LIGHT
12	
13	SOMEWHAT HARD
14	
15	HARD (HEAVY)
16	
17	VERY HARD
18	
19	EXTREMELY HARD
20	MAXIMAL EXERTION

Figure 23: Borg Scale

The participants were asked to choose their rating, from 6 to 20, based on how they felt at that exact moment of finishing the course. It is important that the rating be chosen immediately after completing the task being rated so that there is no second-guessing or misinterpretation of exertion level if the participant was asked after cardiovascular and thermoregulatory recovery had already begun.

3.4.2.7 Questionnaire and RPE

The questionnaire kiosk consisted of a stand-alone computer terminal that ran a program containing a two-page questionnaire. The questionnaire collected subjective data regarding the participant's acceptability rating of various parameters of their test condition and their RPE upon completion of the course. The rating scale ranged from 1 (completely unacceptable) to 7 (completely acceptable) and is shown in Figure 24.

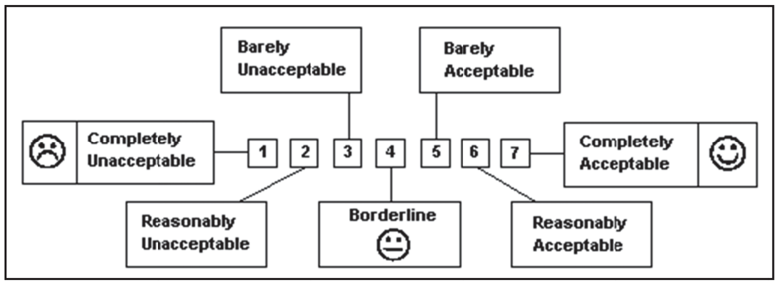


Figure 24: Acceptability Rating Scale

The participant was presented with the two screens as shown in Figure 25 and Figure 26. He was required to fill in his participant number and test condition, as well as an answer for each of the seven questions before the "Next" button became active.

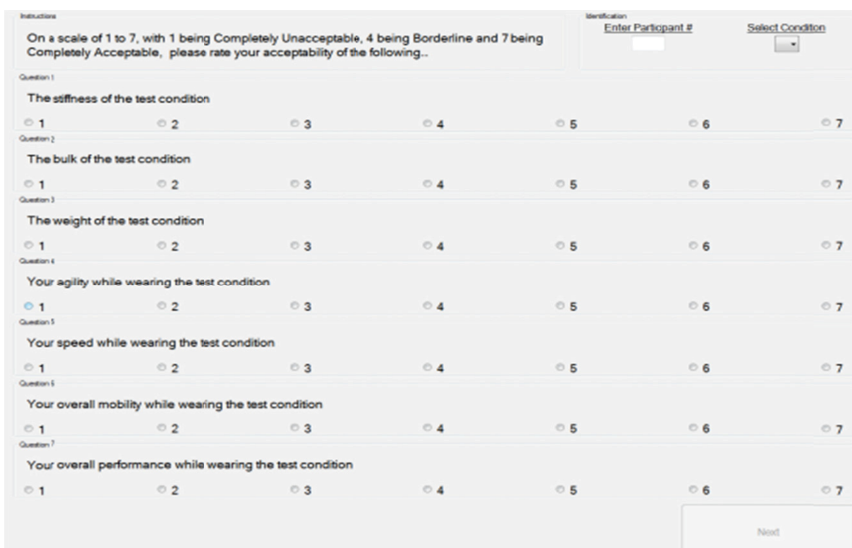


Figure 25: Questionnaire Kiosk – First Screen

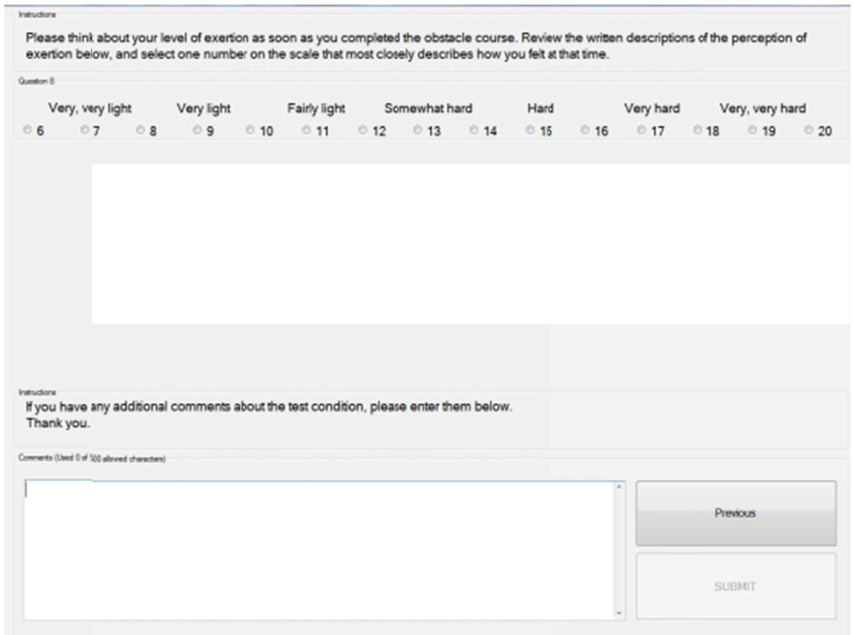


Figure 26: Questionnaire Kiosk - Second Screen

Entry of the RPE was required before the "SUBMIT" button became active. The participant was able to click the "Previous" button if he wished to return to the previous page at any time.

4. Results

The following section presents all of the information obtained and analyses completed within all levels of the CAN-LEAP study. These include participant characterizations, obstacle course performance by total time, individual obstacle, and transition time, and the result of all of the accessory stations. For all statistical analyses completed, $p \leq 0.05$ was used as threshold of statistical significance, unless otherwise stated. For all charts, the whiskers denote the standard error, unless otherwise stated.

4.1 Statistical Approach

As with most other forms of in-field data collection, situations arise where data points are missed, most often due to intermittent data collection equipment malfunction. This, along with other sources, can lead to missed data points within the data sets. Repeated measures ANOVAs are a common type of analysis performed on data collected from a within-subjects experimental design, however, one downfall of this type of statistical analysis is that if a participant is missing a data point from one condition, all other conditions (and thus, the participant) are dropped from the corresponding analysis.

Replacement by means is one method of preserving the n value. Averaging the scores or times for the rest of the participants in that test condition provides a data point that can be inserted in place of the missing data. A negative artefact of this, however, is that the standard deviation of the group will become artificially smaller. In order to mitigate this, replacement by means was only utilized in those situations where greater than 15% of the data points were missing for a particular test. In situations where less than 15% of the data points were missing, there were still sufficient data to perform statistical tests without having to replace the means.

For each data set, an analysis was performed to determine whether any outliers existed. Each identified outlier was examined against research notes and either removed, or kept within the data set, depending on the notes made.

4.2 Participant Characterization

Several different subjective and objective measures were recorded in order to characterize the soldier population that participated in this experimentation campaign. These results are outlined below.

4.2.1 Demographics

The group of participants (n = 21; one female) ranged in age from 18 to 36, with a mean age of 22.5 years (SD = 4.4). All but two of the participants were right-handed, and one did not specify. The two left-handed participants were also left-eye dominant for shooting. Eight of the participants wore prescription lenses. None of the participants had operational experience. All participants were Private rank. Table 3 presents a summary of participants' MOS.

Table 3: Military Occupational Speciality

MOS ID	Occupation	Participants
00129	Vehicle Technician	15
00130	Weapons Technician (Land)	1
00134	Materials Technician	1
00327	Electronic-Optronic Technician (Land)	2
-	Not specified	2
	Total	**21**

4.2.2 Physical Characteristics

The participants' mean weight and height was 79.8 kg (min = 59.8 kg, max = 117.7 kg, SD = 13.8), and 176.2 cm (min = 160.9 cm, max = 188.0 cm, SD = 8.3). Height was measured while not wearing shoes.

Adiposity testing revealed a range of participant body fat values from a minimum of 10.1% to a maximum of 30.3%, a mean of 17.7% (SD = 5.0 %) using the skinfold measurement technique.

4.2.3 Physical Capabilities

The physical capabilities that were measured included fitness levels, Range of Motion (ROM), and upper body strength.

Fitness testing results showed that the participant's average VO_2 max was 49.31 mL/(kg·min), with a minimum and maximum VO_2 max scores being observed at 38.2 and 58.8 mL/(kg·min) respectively (SD = 5.2).

ROM as measured for forward flexion, right and left lateral flexion, and axial rotation. Each of these measures was taken while the participant was semi-nude, and repeated while they were wearing each of the experimental conditions. The results are shown in Table 4 and Table 5.

Table 4: Forward Flexion Results

	Forward Flexion (FF) (cm)			
	Mean	Min	Max	SD
Semi nude	**24.4**	11.3	43.2	8.1
A	**25.1**	12.5	40.5	7.6
B	**24.4**	12.3	39.6	8.5
C	**20.3**	11.6	36.5	7.0
D	**19.1**	10.2	31.5	6.3

Table 5: Lateral Flexion and Axial Rotation Results

	Right Lateral Flexion (RLF) (deg)				**Left Lateral Flexion (LLF) (deg)**				**Right Axial Rotation (RAR) (deg)**				**Left Axial Rotation (LAR) (deg)**			
	Mean	Min	Max	SD	Mean	Min	Max	SD	Mean	Min	Max	SD	Mean	Min	Max	SD
Semi nude	**25.7**	12.8	35.7	6.4	**28.5**	13.5	53.3	9.3	**36.7**	27.5	55.9	7.9	**29.7**	21.1	42.8	5.7
A	**19.5**	2.7	32.7	9.1	**24.7**	9.9	46.6	9.6	**35.6**	15.4	59.7	9.7	**29.6**	14.7	44.9	8.1
B	**23.0**	4.4	42.2	9.4	**26.8**	12.9	44.8	9.1	**33.0**	15.4	48.7	8.9	**29.7**	11.1	47.9	10.6
C	**22.3**	9.3	40.4	8.8	**24.4**	9.7	41.1	7.8	**30.9**	5.7	50.9	9.3	**28.1**	2.5	46.5	10.8
D	**23.4**	11.1	43.4	10.2	**24.6**	9.2	42.5	7.2	**33.3**	20.2	48.5	8.3	**27.1**	12.6	41.9	7.6

A repeated-measures analysis of variance (ANOVA) was conducted on each of the five ROM measures. The only ROM measure that resulted in a significant difference between test conditions was forward flexion (FF - $F(4, 80)=14.040$, $p<.001$). No significant differences occurred in the other ROM tests (RLF - $F(4, 80)=1.782$, $p=.141$; LLF - $F(4, 80)=1.409$, $p=.238$; RAR - $F(4, 80)=2.189$, $p=.078$; LAR - $F(4, 80)=.505$, $p=.732$). A Duncan's post-hoc test on the forward flexion showed that Forward Flexion in condition C and D was significantly lower than Forward Flexion in the other three conditions, and there was no significant difference between conditions C and D.

Upper body strength was characterised using an upper limb static strength test that used a force gauge attached to immovable fixation point at ground level. The results are summarized in Table 6.

Table 6: Strength Testing Results

	Upper Body Strength (kg)
Mean	46.5
Minimum	27.0
Maximum	89.0
Standard Deviation	12.0

4.3 Total Course Performance

The results for the total course time, the participants' subjective performance rating, and their ratings of perceived exertion are given below. Figure 27 shows the results for the total obstacle course time.

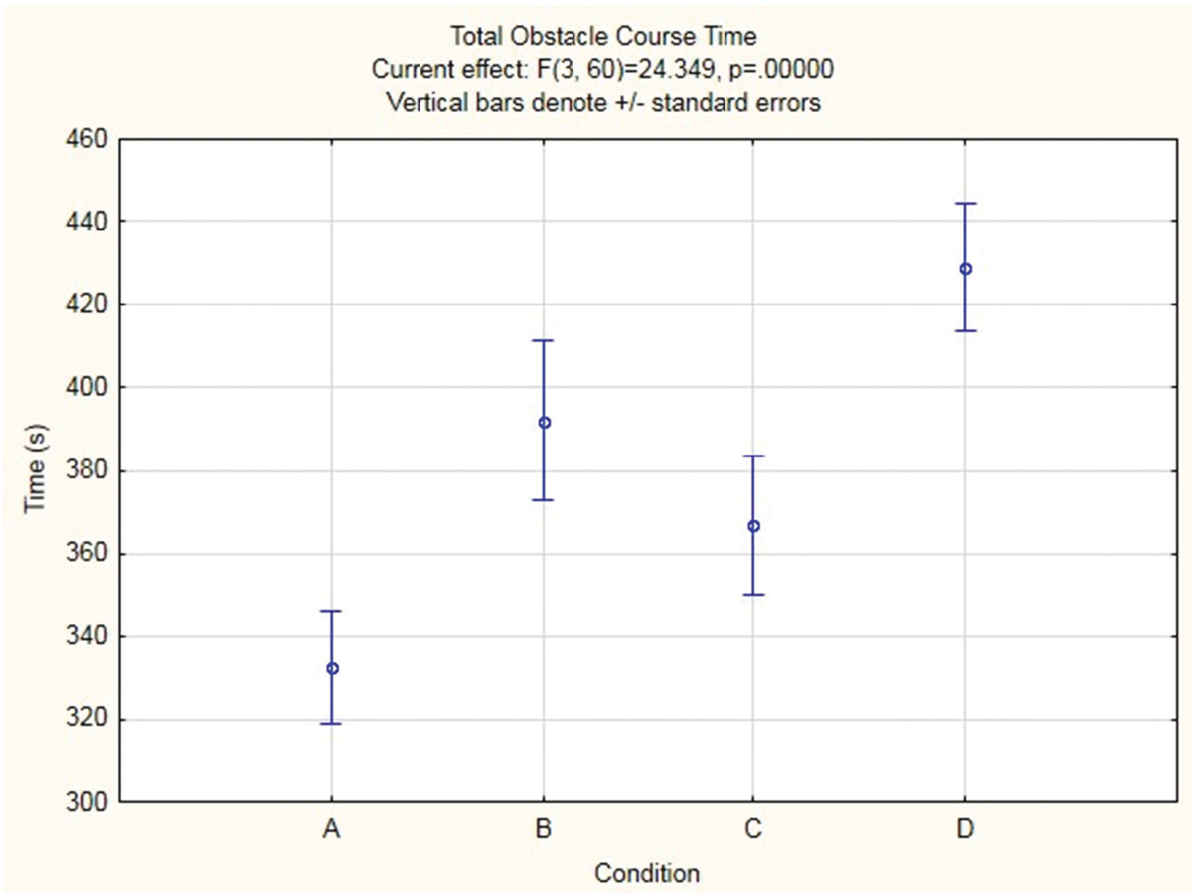


Figure 27: Total Obstacle Course Time

A repeated-measures analysis of variance (ANOVA) of total obstacle course time identified a significant difference between load order conditions (n=21, F(3, 60)=24.349, p<.001). A Duncan's post-hoc analysis revealed that all conditions were significantly different from each other. Table 7 summarizes the p-values for each post-hoc pairwise comparison.

Table 7: Summary of Post-Hoc Analysis – Total Obstacle Course Time

Condition	{1} 332.64	{2} 392.05	{3} 366.75	{4} 428.94
A		0.000063	0.004959	0.000052
B	0.000063		0.033928	0.002577
C	0.004959	0.033928		0.000060
D	0.000052	0.002577	0.000060	

The descriptive statistics for total obstacle course time can be found in Table 8.

Table 8: Descriptive Statistics – Total Obstacle Course Time

Condition	Mean (s)	Minimum (s)	Maximum (s)	Std. Dev. (s)
A	332.6	252.9	465.9	61.6
B	392.1	268.0	576.9	87.5
C	366.8	268.5	585.2	76.4
D	428.9	319.5	626.6	71.1

Figure 28 shows the subjective ratings of overall performance.

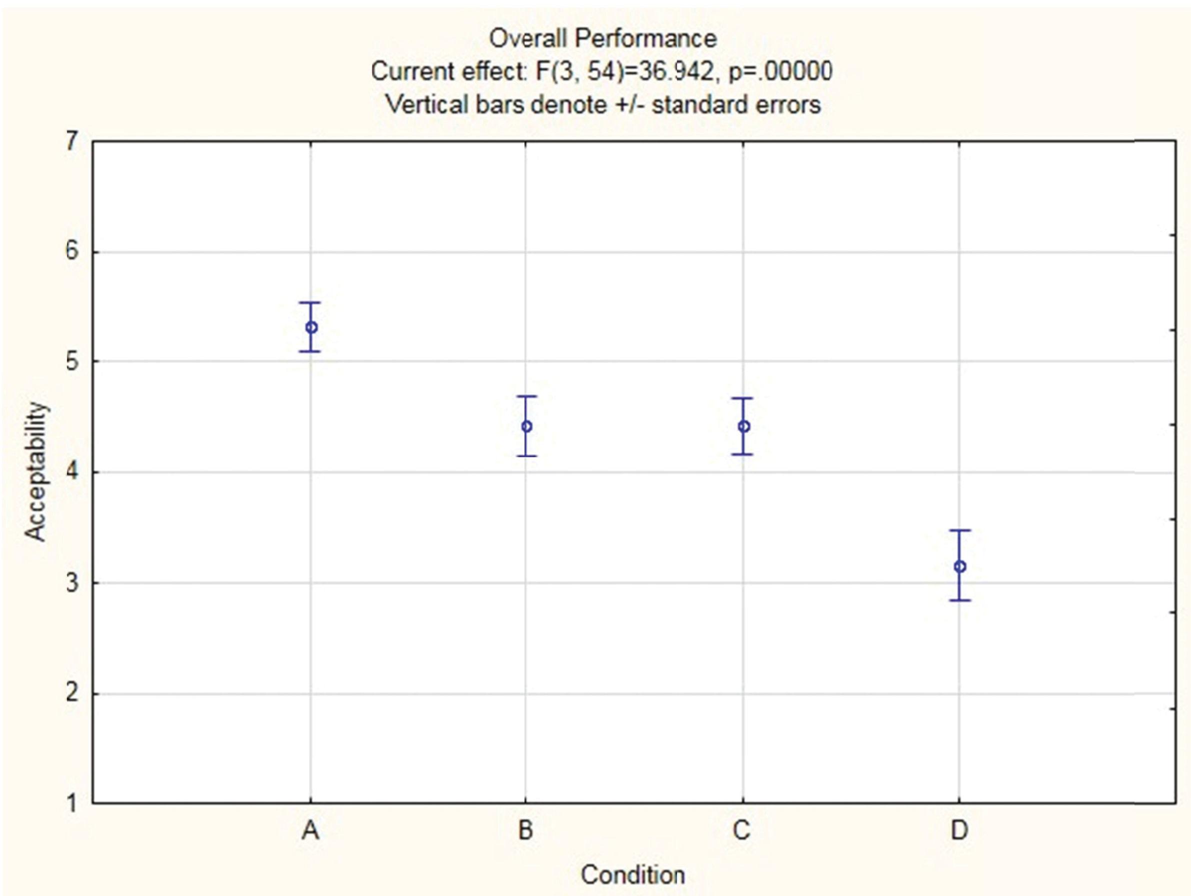


Figure 28: Participant Subjective Rating of Overall Performance

A repeated-measures ANOVA of subjective rating of overall performance identified a significant difference between load order conditions (n=19, $F(3, 54)=36.942$, $p<.001$). A Duncan's post-hoc analysis revealed that all conditions were significantly different from each other, except for the B-C pairwise comparison. Table 9 summarizes the post-hoc analysis.

Table 9: Summary of Post-Hoc Analysis - Subjective Rating of Overall Performance

Condition	{1} 5.3158	{2} 4.4211	{3} 4.4211	{4} 3.1579
A		0.000172	0.000148	0.000054
B	0.000172		1.000000	0.000061
C	0.000148	1.000000		0.000113
D	0.000054	0.000061	0.000113	

The descriptive statistics for subjective rating of overall performance can be found in Table 10.

Table 10: Descriptive Statistics – Subjective Rating of Overall Performance

Condition	Mean	Minimum	Maximum	Std. Dev.
A	5.3	3	7	1.0
B	4.4	3	6	1.2
C	4.4	2	6	1.1
D	3.2	2	6	1.4

4.3.1 RPE (Borg Scale Rating)

After each run of the obstacle course, the solider gave their RPE to the researcher using the "Borg Scale" immediately upon completion of the course. These ratings are shown in Figure 29.

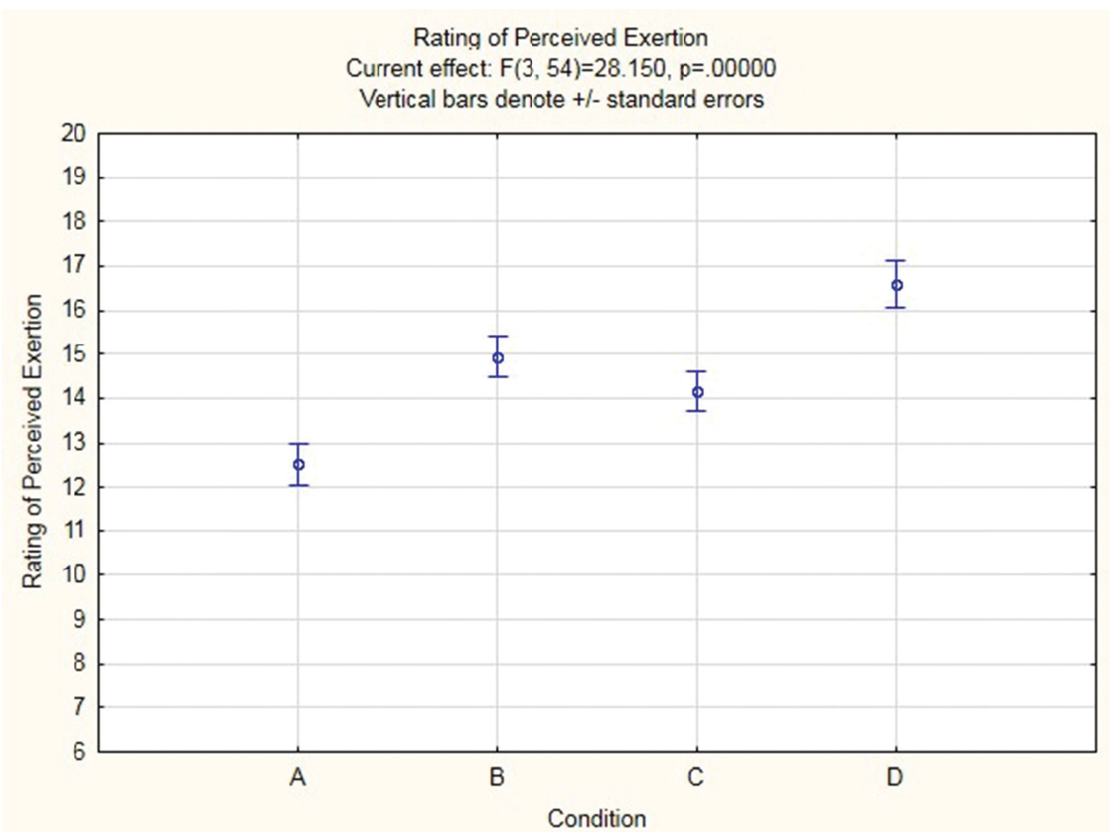


Figure 29: Subjective Borg Scale Rating

A repeated-measures ANOVA of the RPEs identified a significant difference between load order conditions (n=19, $F(3, 54)=28.150$, $p<.001$). A Duncan's post-hoc analysis revealed that all conditions were significantly different from each other, except for the B-C pairwise comparison. Table 11 summarizes the post-hoc analysis.

Table 11: Summary of Post-Hoc Analysis – RPE

Condition	{1} 12.526	{2} 14.947	{3} 14.158	{4} 16.579
A		0.000062	0.000739	0.000054
B	0.000062		0.084670	0.000739
C	0.000739	0.084670		0.000062
D	0.000054	0.000739	0.000062	

The descriptive statistics for RPE can be found in Table 12 .

Table 12: Descriptive Statistics – Rating of Perceived Exertion

Condition	Mean	Minimum	Maximum	Std. Dev.
A	12.5	8	16	2.0
B	14.9	8	18	2.0
C	14.2	9	18	2.0
D	16.6	9	19	2.3

4.4 Course Performance by Obstacle

The following section contains the soldiers' performance results for each individual obstacle, known as "interval time", of the CAN-LEAP course.

Figure 30 shows the Tunnel and Hatch interval time for each condition.

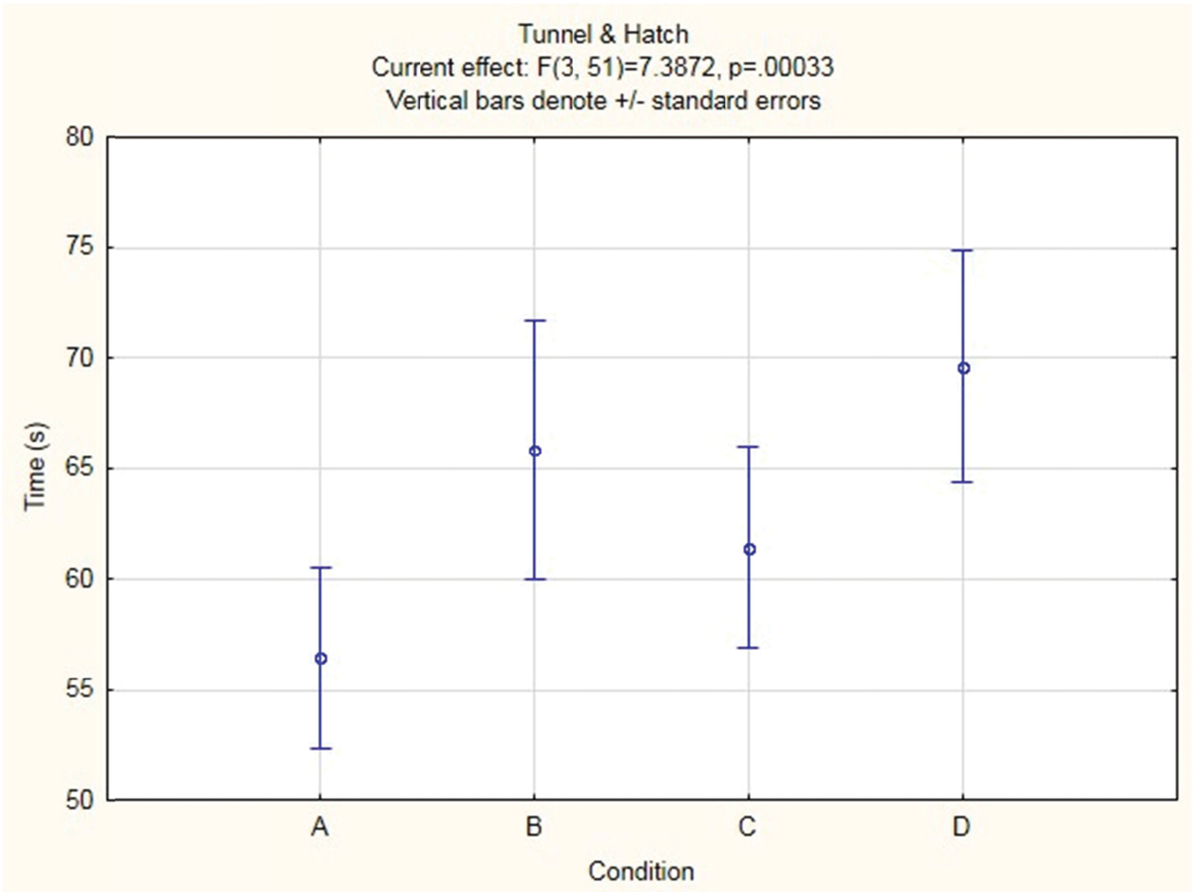


Figure 30: Tunnel and Hatch Interval Time

A repeated-measures ANOVA of tunnel and hatch interval time identified a significant difference between load order conditions (n=18), F (3, 51)=7.387, p<.001. A Duncan's post-hoc analysis revealed that the follow conditions were significantly different from each other: A-B, A-D, and C-D. Table 13 summarizes the results.

Table 13: Summary of Post-Hoc Analysis – Tunnel and Hatch

Condition	{1} 56.421	{2} 65.798	{3} 61.430	{4} 69.608
A		0.003622	0.096447	0.000133
B	0.003622		0.145775	0.203406
C	0.096447	0.145775		0.010683
D	0.000133	0.203406	0.010683	

The descriptive statistics for tunnel and hatch interval time can be found in Table 14.

Table 14: Descriptive Statistics – Tunnel and Hatch

Condition	Mean (s)	Minimum (s)	Maximum (s)	Std. Dev. (s)
A	56.4	29.0	86.2	17.3
B	65.8	32.9	119.3	24.7
C	61.4	29.6	97.1	19.2
D	69.6	37.7	121.8	22.2

Figure 31 shows the results for the Sprint obstacle.

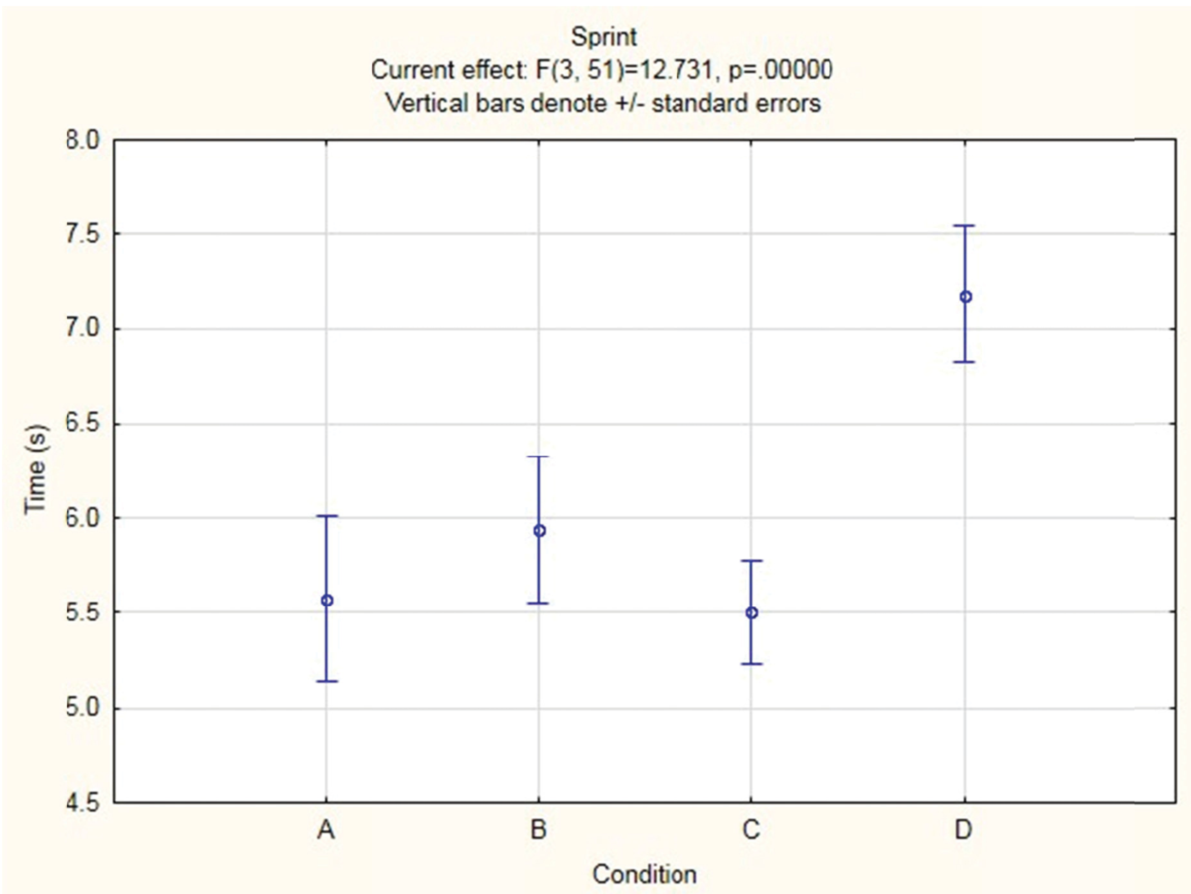


Figure 31: Sprint Interval Time

A repeated-measures ANOVA of sprint interval time identified a significant difference between load order conditions (n=18, $F(3, 51)=12.731$, $p<.001$). A Duncan's post-hoc analysis revealed that condition D was significantly different from all other conditions. Table 15 summarizes the post-hoc analysis results.

Table 15: Summary of Post-Hoc Analysis – Sprint

Condition	{1} 5.5733	{2} 5.9406	{3} 5.5067	{4} 7.1817
A		0.239201	0.829779	0.000065
B	0.239201		0.190565	0.000295
C	0.829779	0.190565		0.000057
D	0.000065	0.000295	0.000057	

The descriptive statistics for sprint time can be found in Table 16.

Table 16: Descriptive Statistics – Sprint

Conditions	Mean (s)	Minimum (s)	Maximum (s)	Std. Dev. (s)
A	5.6	3.2	10.0	1.8
B	5.9	3.4	10.3	1.6
C	5.5	3.3	7.4	1.2
D	7.2	4.3	11.2	1.5

Figure 32 shows the results for the Stair and Ladder obstacle.

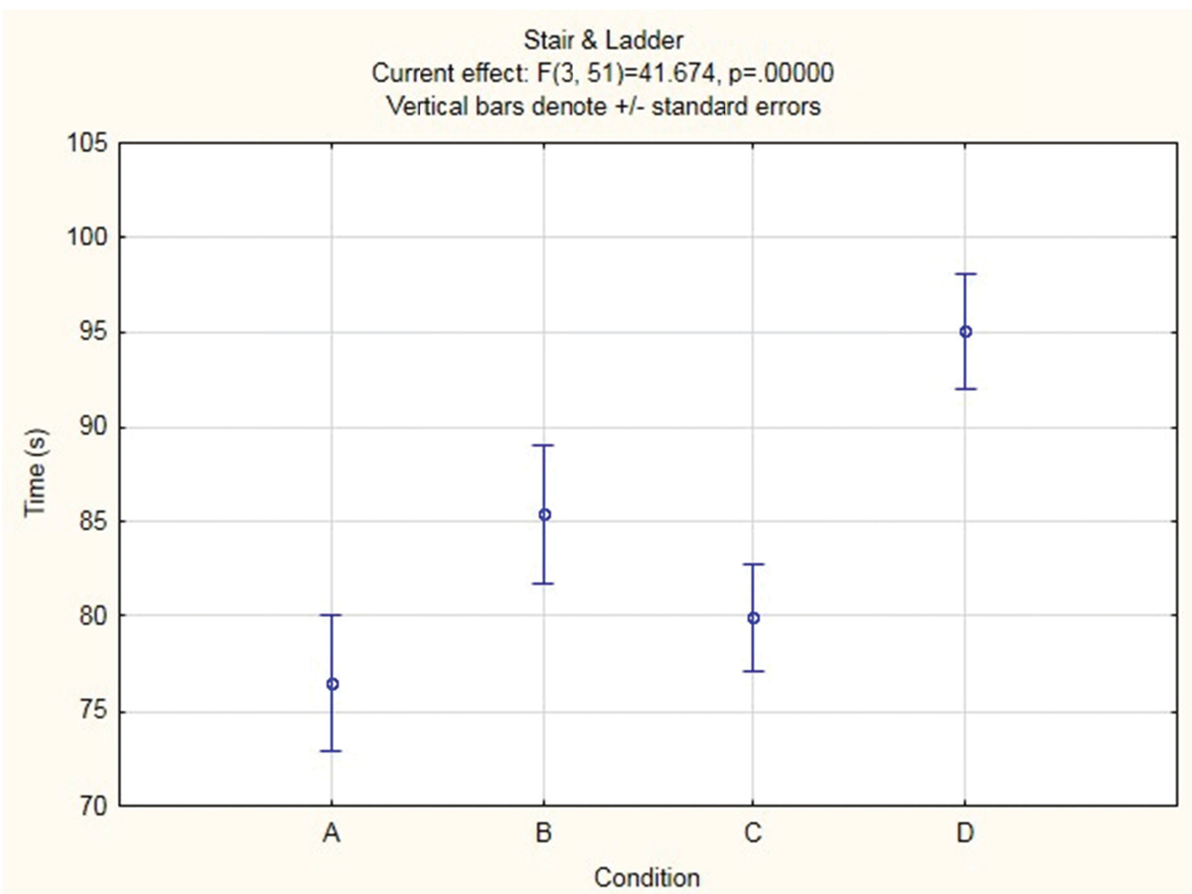


Figure 32: Stair and Ladder Interval Time

A repeated-measures ANOVA of this interval time identified a significant difference between load order conditions (n=18, $F(3, 51)=41.674$, $p<.001$). A Duncan's post-hoc analysis revealed significant differences between all conditions except A-C, as shown in Table 17.

Table 17: Summary of Post-Hoc Analysis – Stair and Ladder

Condition	{1} 76.485	{2} 85.451	{3} 79.943	{4} 95.042
A		0.000069	0.056874	0.000055
B	0.000069		0.003254	0.000116
C	0.056874	0.003254		0.000062
D	0.000055	0.000116	0.000062	

The descriptive statistics for stair and ladder obstacle can be found in Table 18.

Table 18: Descriptive Statistics – Ascending the Steep Stairs and Descending the Gradual Stairs

Condition	Mean (s)	Minimum (s)	Maximum (s)	Std. Dev. (s)
A	76.5	54.6	105.9	15.2
B	85.5	62.1	121.5	15.6
C	79.9	61.2	105.8	12.2
D	95.0	81.9	130.9	12.9

The results of the Agility obstacle are shown in Figure 33.

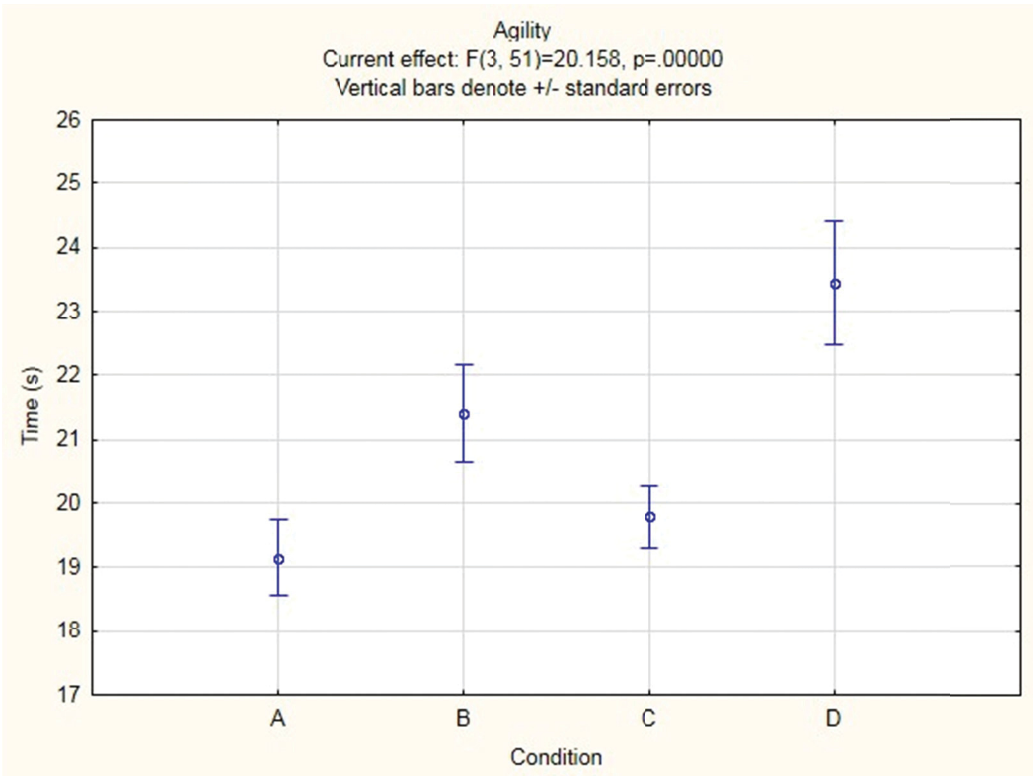


Figure 33: Agility Interval Time

A repeated-measures ANOVA of agility interval time identified a significant difference between load order conditions (n=18, $F(3, 51)=20.158$, $p<.001$). A Duncan's post-hoc analysis revealed that all pairwise comparisons significantly differed except for A-C. Table 19 summarizes the post-hoc analysis.

Table 19: Summary of Post-Hoc Analysis – Agility

Condition	{1} 19.148	{2} 21.408	{3} 19.781	{4} 23.452
A		0.000733	0.300545	0.000055
B	0.000733		0.009833	0.001533
C	0.300545	0.009833		0.000062
D	0.000055	0.001533	0.000062	

The descriptive statistics for agility can be found in Table 20.

Table 20: Descriptive Statistics – Agility

Condition	Mean (s)	Minimum (s)	Maximum (s)	Std. Dev. (s)
A	19.1	15.2	24.1	2.5
B	21.4	15.8	27.6	3.2
C	19.8	15.9	22.9	2.1
D	23.5	15.3	32.2	4.1

The results of the Casualty Drag obstacle are shown in Figure 34.

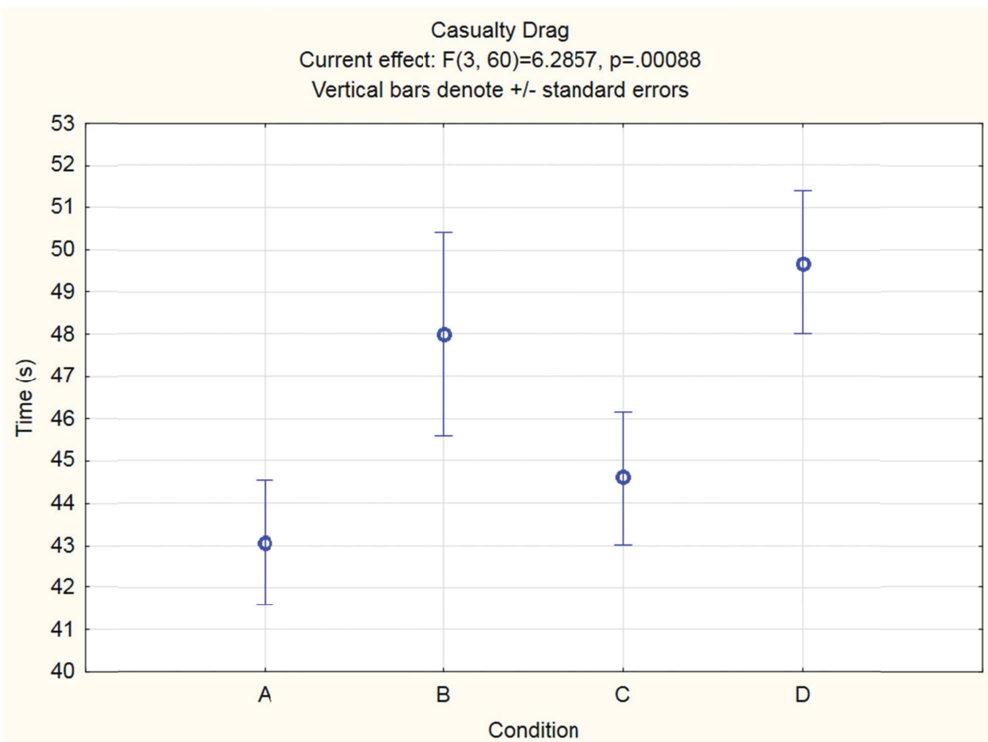


Figure 34: Casualty Drag Interval Time

A repeated-measures ANOVA of Casualty Drag interval time identified a significant difference between load order conditions (n=21, $F(3, 60)=6.286$, $p<.001$). A Duncan's post-hoc analysis revealed condition was significantly faster than conditions B and D, and condition C was significantly faster than condition D. The post-hoc analysis results for casualty drag are shown in Table 21.

Table 21: Summary of Post-Hoc Analysis – Casualty Drag

Condition	{1} 43.055	{2} 47.998	{3} 44.591	{4} 49.697
A		0.007683	0.375285	0.000550
B	0.007683		0.052228	0.326953
C	0.375285	0.052228		0.005937
D	0.000550	0.326953	0.005937	

The descriptive statistics for the casualty drag can be found in Table 22.

Table 22: Descriptive Statistics – Casualty Drag

Condition	Mean (s)	Minimum (s)	Maximum (s)	Std. Dev. (s)
A	43.1	33.1	57.9	6.8
B	48.0	30.4	81.6	11.0
C	44.6	36.4	71.6	7.2
D	49.7	38.2	67.8	7.7

The results of the Windows obstacle are shown in Figure 35.

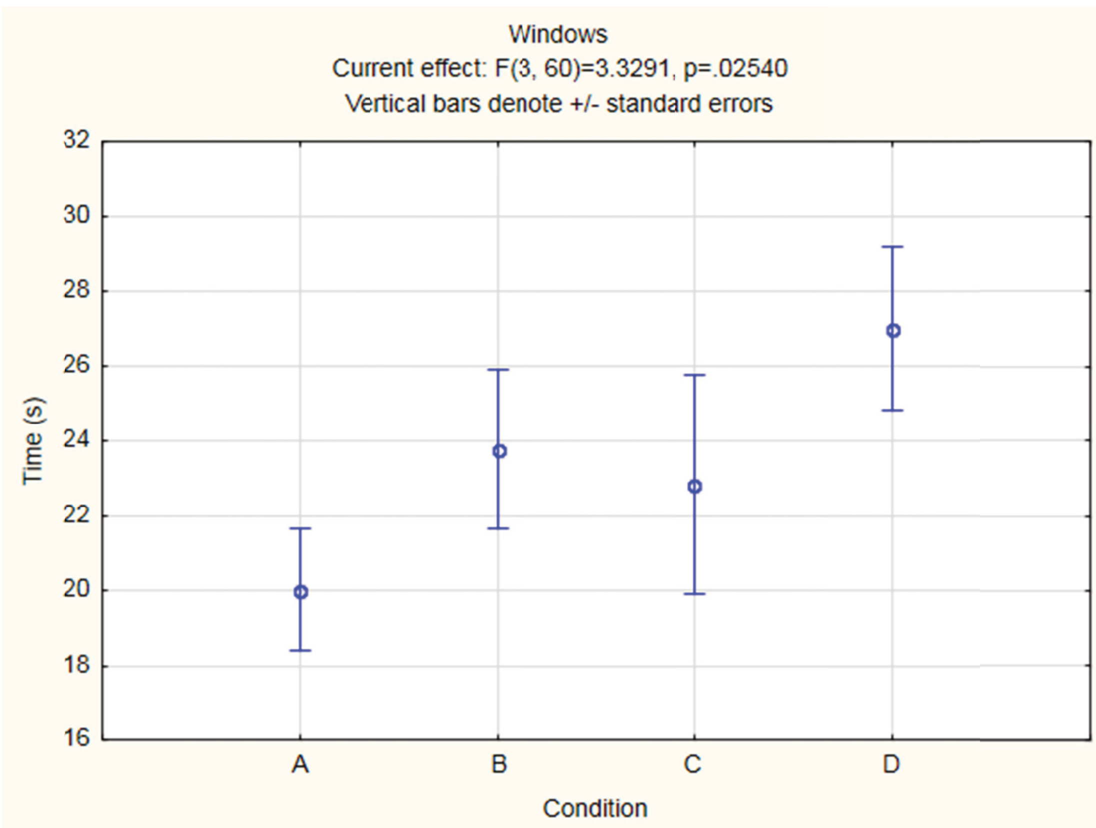


Figure 35: Windows Obstacle Time

A repeated-measures ANOVA of the Windows interval time identified a significant difference between load order conditions (n=21, $F(3, 60)=3.329$, $p=0.025$). A Duncan's post-hoc analysis revealed that only conditions A and D differed significantly. Table 23 summarizes the post-hoc analysis for the Windows obstacle.

Table 23: Summary of Post-Hoc Analysis – Windows

Condition	{1} 20.019	{2} 23.761	{3} 22.835	{4} 26.984
A		0.117136	0.210714	0.004716
B	0.117136		0.678680	0.152879
C	0.210714	0.678680		0.082383
D	0.004716	0.152879	0.082383	

The descriptive statistics for the Windows obstacle can be found in Table 24.

Table 24: Descriptive Statistics – Window Obstacle

Condition	Mean (s)	Minimum (s)	Maximum (s)	Std. Dev. (s)
A	20.0	12.1	42.1	7.4
B	23.8	13.8	57.7	9.7
C	22.8	13.8	78.7	13.4
D	27.0	16.8	58.6	10.0

The results of the Bounding Rush obstacle are shown in Figure 36.

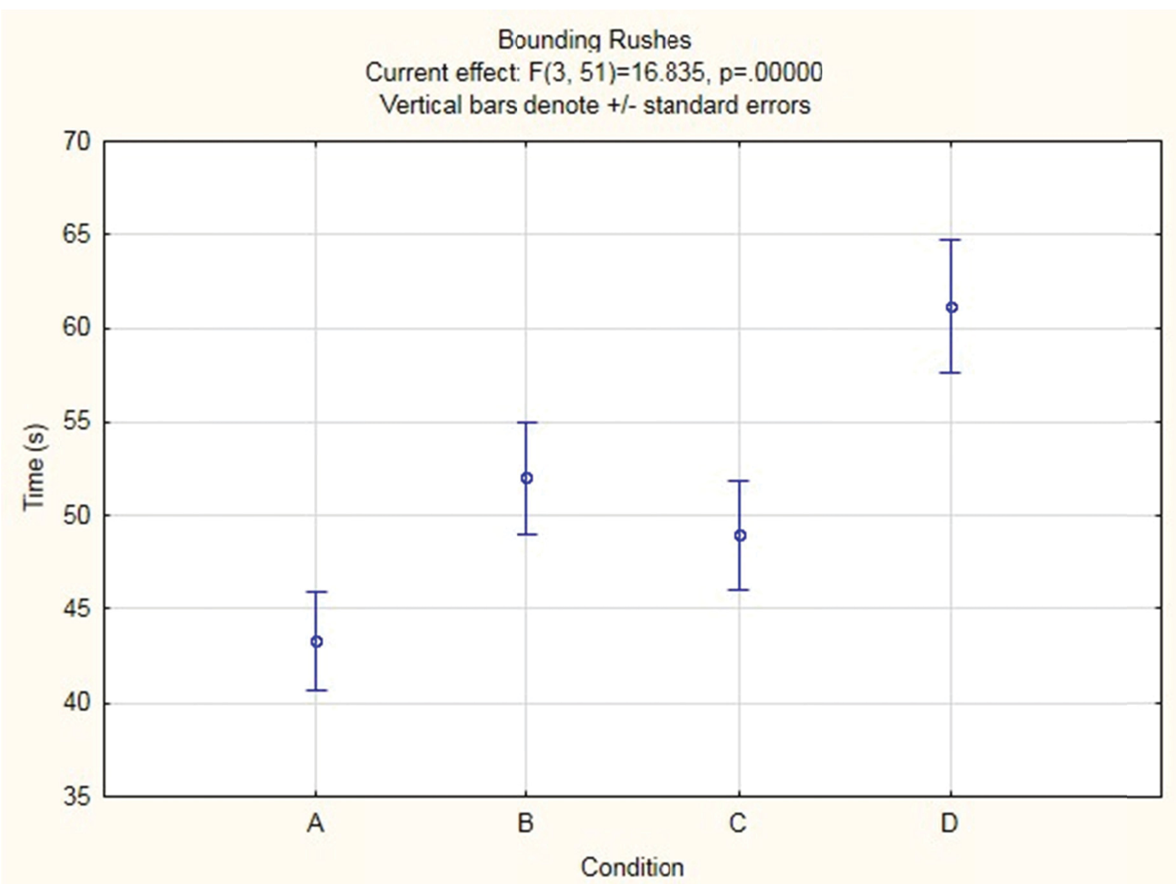


Figure 36: Bounding Rushes Interval Time

A repeated-measures ANOVA of the Bounding Rush interval time identified a significant difference between load order conditions (n=18, $F(3, 51)=16.835$, $p<.001$). A Duncan's post-hoc analysis revealed that all pairwise comparisons significantly differed except for B-C. Table 25 summarizes the post-hoc analysis.

Table 25: Summary of Post-Hoc Analysis – Bounding Rush

Condition	{1} 43.339	{2} 52.013	{3} 48.957	{4} 61.136
A		0.002008	0.033204	0.000055
B	0.002008		0.238929	0.000947
C	0.033204	0.238929		0.000083
D	0.000055	0.000947	0.000083	

The descriptive statistics for Bounding Rush can be found in Table 26.

Table 26: Descriptive Statistics – Bounding Rush

Condition	Mean (s)	Minimum (s)	Maximum (s)	Std. Dev. (s)
A	43.3	32.5	69.3	11.2
B	52.0	34.2	81.2	12.7
C	49.0	30.2	83.1	12.2
D	61.1	35.5	95.6	15.0

The results of the Balance Beam obstacle are shown in Figure 37.

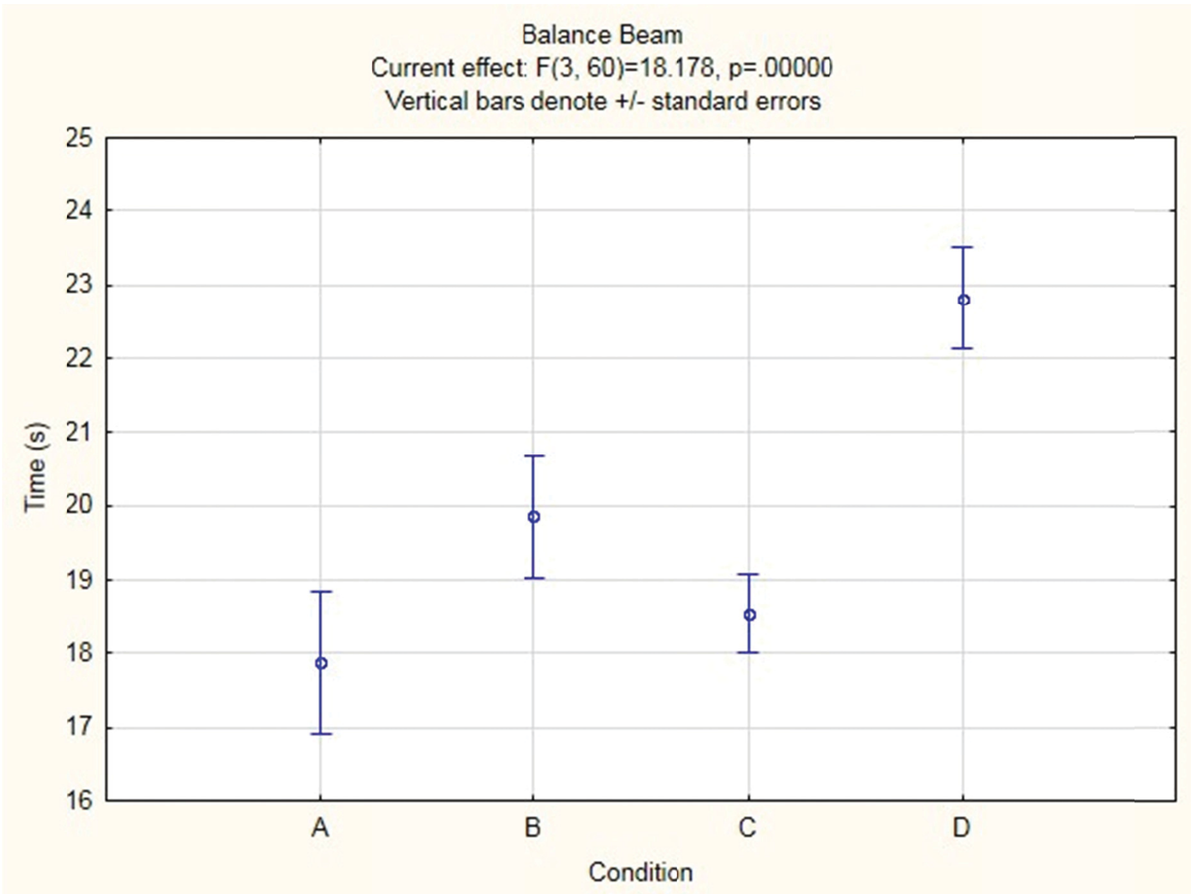


Figure 37: Balance Beam Interval Time

A repeated-measures ANOVA of Balance Beam interval time identified a significant difference between load order conditions (n=21, $F(3, 60)=18.178$, $p<.001$). A Duncan's post-hoc analysis revealed that all pairwise comparisons significantly differed except for A-C and B-C. Table 27 summarizes the post-hoc analysis.

Table 27: Summary of Post-Hoc Analysis – Balance Beam

Condition	{1} 17.882	{2} 19.853	{3} 18.539	{4} 22.819
A		0.011753	0.370054	0.000052
B	0.011753		0.075390	0.000241
C	0.370054	0.075390		0.000059
D	0.000052	0.000241	0.000059	

The descriptive statistics for the Balance Beam can be found in Table 28.

Table 28: Descriptive Statistics – Balance Beam

Condition	Mean (s)	Minimum (s)	Maximum (s)	Std. Dev. (s)
A	17.9	11.5	29.0	4.5
B	19.9	13.7	29.2	3.8
C	18.5	13.5	22.0	2.5
D	22.8	18.7	29.6	3.2

The results for the Crawl obstacle are shown in Figure 38.

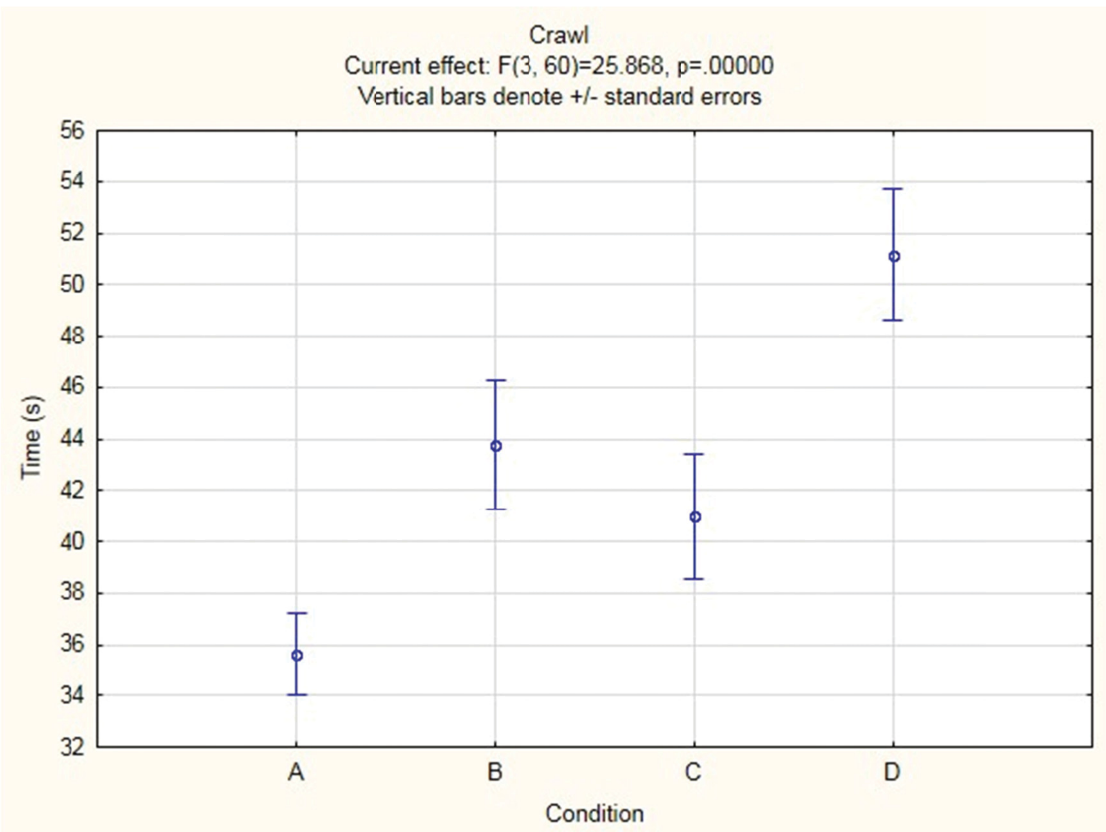


Figure 38: Crawl Interval Time

A repeated-measures ANOVA of the Crawl interval time identified a significant difference between load order conditions (n=21, $F(3, 60)=25.868$, $p<.001$). A Duncan's post-hoc analysis revealed that all pairwise comparisons significantly differed except for B-C.

Table 29 summarizes the Crawl post-hoc analysis.

Table 29: Summary of Post-Hoc Analysis – Crawl

Condition	{1} 35.622	{2} 43.776	{3} 40.952	{4} 51.159
A		0.000097	0.004527	0.000052
B	0.000097		0.122049	0.000234
C	0.004527	0.122049		0.000059
D	0.000052	0.000234	0.000059	

The descriptive statistics for the Crawl can be found in Table 30.

Table 30: Descriptive Statistics – Crawl

Condition	Mean (s)	Minimum (s)	Maximum (s)	Std. Dev. (s)
A	35.6	23.4	48.0	7.3
B	43.8	21.5	68.6	11.5
C	41.0	22.1	61.0	11.2
D	51.2	33.8	78.3	11.7

The results for the Wall obstacle are shown in Figure 39.

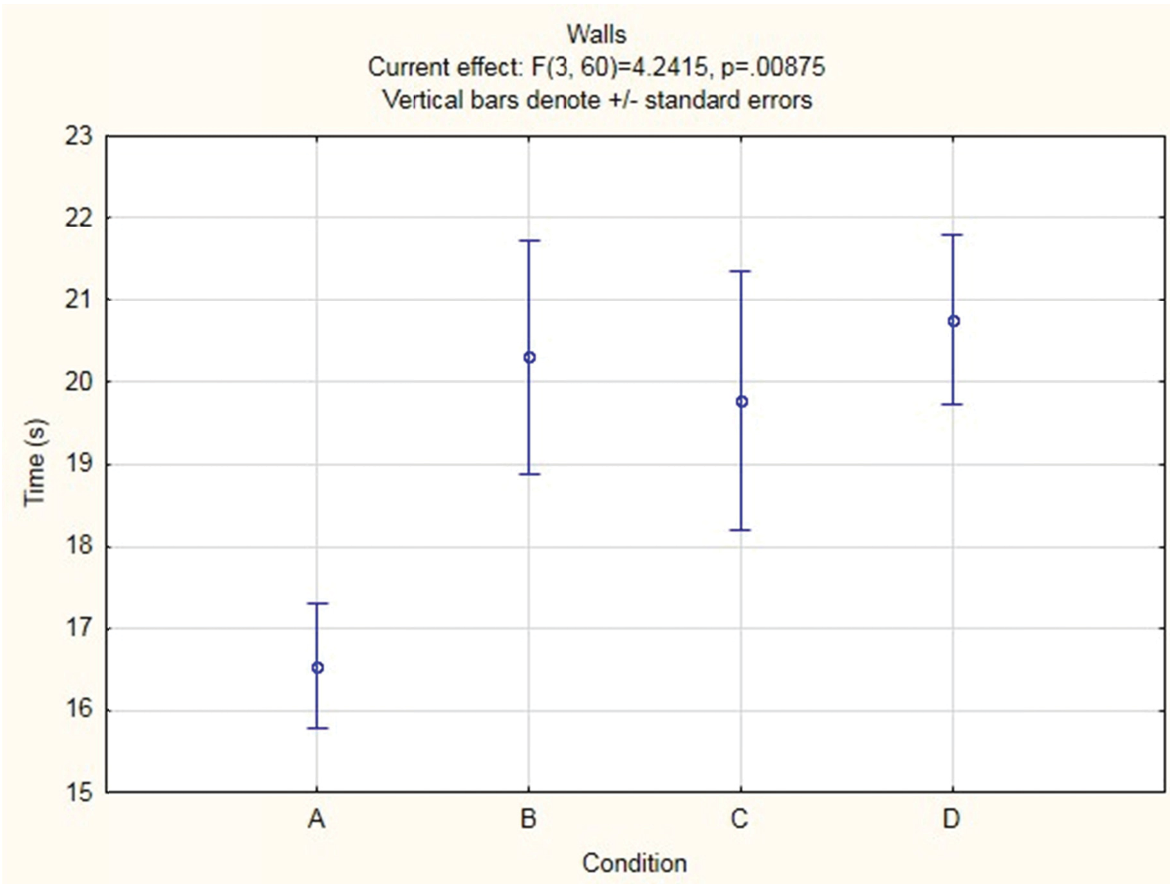


Figure 39: Walls Interval Time

A repeated-measures ANOVA of the Outer Wall interval time identified a significant difference between load order conditions (n=21, F(3, 60)=4.242, p<.001). A Duncan's post-hoc analysis revealed that condition A was significantly different than all other conditions. Table 31 summarizes the post-hoc analysis.

Table 31: Summary of Post-Hoc Analysis – Walls

Condition	{1} 16.536	{2} 20.306	{3} 19.781	{4} 20.763
A		0.007888	0.016620	0.003741
B	0.007888		0.691793	0.729526
C	0.016620	0.691793		0.487382
D	0.003741	0.729526	0.487382	

The descriptive statistics for the Walls can be found in Table 32.

Table 32: Descriptive Statistics –Walls

Condition	Mean (s)	Minimum (s)	Maximum (s)	Std. Dev. (s)
A	16.5	11.6	23.7	3.4
B	20.3	12.7	39.5	6.5
C	19.8	12.7	48.7	7.2
D	20.8	13.0	36.9	4.8

4.5 Accessory Station Performance and Results

There were a total of four different accessory stations in the CAN-LEAP course, three of which produced performance-based outcomes (Noptel Marksmanship, Weight Transfer and Vertical Jump Stations), and one which produced a subjective rating score with associated comments (Questionnaire Station). The results of each of these stations are outlined below.

4.5.1 Noptel Marksmanship

Two different types of analyses are commonly performed with marksmanship data: mean point of impact (accuracy), and group size (precision). The CAN-LEAP Noptel marksmanship rifle used only a universal zero; participants did not zero the rifle individually. For this reason, the precision data (group size) is deemed to be a more realistic representation for the CAN-LEAP marksmanship results, and is presented in the subsequent section.

4.5.1.1 Group Size

Nineteen (19) data sets were used in the group size analysis. Figure 40 shows the results for group size by condition, fatigue level, and posture.

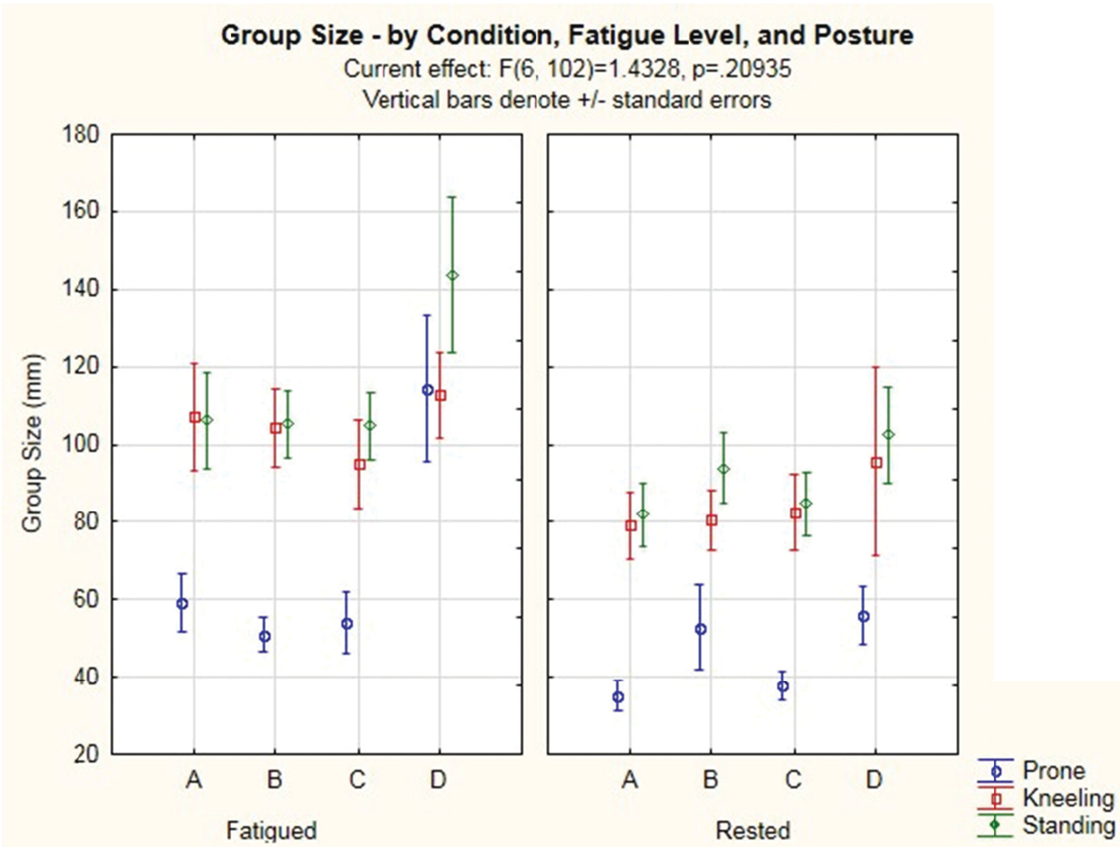


Figure 40: Group Size – By Condition, Fatigue Level, and Posture

A three-way repeated-measures ANOVA identified a significant difference in mean group size between fatigue levels (n=19, $F(1,17)=29.334$, $p<.001$), where soldiers were more precise when shooting in the rested state. Separate analyses were conducted on the fatigue and rested state data. In reference to the fatigued state, a two-way repeated-measures ANOVA identified a significant difference between conditions (n=19, $F(3, 54)=7.841$, $p<.001$) and shooting posture (n=19, $F(2, 36)=20.264$, $p<.001$). A Duncan's post-hoc analysis on conditions revealed that the average group size for Conditions D was significantly larger than all other conditions. For postures, the Duncan's post-hoc analysis showed that shooting in the prone posture resulted in significantly smaller average group size than both kneeling and standing. The Duncan's post-hoc values of condition and posture for fatigued shooting are shown in Table 33 and Table 34 respectively.

Table 33: Summary of Post-Hoc Analysis between Conditions – Fatigued Shooting

Condition	{1} 90.681	{2} 87.018	{3} 83.076	{4} 122.89
A		0.692742	0.442520	0.001079
B	0.692742		0.670653	0.000450
C	0.442520	0.670653		0.000173
D	0.001079	0.000450	0.000173	

Table 34: Summary of Post-Hoc Analysis between Postures – Fatigued Shooting

Posture	{1} 68.329	{2} 105.20	{3} 114.22
Prone		0.000143	0.000064
Kneeling	0.000143		0.245218
Standing	0.000064	0.245218	

The descriptive statistics of condition and posture for fatigued shooting are shown in Table 35 and Table 36 respectively.

Table 35: Descriptive Statistics of Condition for Fatigued Shooting – Group Size

Condition	Mean (mm)	Minimum (mm)	Maximum (mm)	Std. Dev. (mm)
A	90.7	8.7	302.0	52.0
B	87.0	18.1	176.9	41.7
C	83.1	16.7	204.6	44.7
D	122.9	18.1	365.6	70.8

Table 36: Descriptive Statistics of Posture for Fatigued Shooting – Group Size

Posture	Mean (mm)	Minimum (mm)	Maximum (mm)	Std. Dev. (mm)
Prone	68.3	8.7	320.6	51.9
Kneeling	105.2	30.9	302.0	47.5
Standing	114.2	39.6	365.6	56.2

In reference to the rested state, a two-way repeated-measures ANOVA identified no significant difference between conditions ($n=19$, $F(3, 51)=1.642$, $p=.191$), but there was a significant difference between shooting postures ($n=19$, $F(2, 34)=24.190$, $p<.001$). A Duncan's post-hoc analysis showed that shooting in the prone posture resulted in significantly smaller average group size than both kneeling and standing. The Duncan's post-hoc values of posture for rested shooting is shown in Table 37.

Table 37: Summary of Post-Hoc Analysis between Postures – Rested Shooting

Posture	{1} 45.435	{2} 84.460	{3} 90.810
Prone		0.000123	0.000063
Kneeling	0.000123		0.375235
Standing	0.000063	0.375235	

The descriptive statistics of condition and posture for rested shooting are shown in Table 38 and Table 39 respectively.

Table 38: Descriptive Statistics of Condition for Rested Shooting – Group Size

Condition	Mean (mm)	Minimum (mm)	Maximum (mm)	Std. Dev. (mm)
A	65.7	15.4	180.8	36.3
B	74.9	12.4	219.7	41.8
C	67.5	13.7	170.6	38.1
D	83.5	12.8	483.8	69.7

Table 39: Descriptive Statistics of Posture for Rested Shooting – Group Size

Posture	Mean (mm)	Minimum (mm)	Maximum (mm)	Std. Dev. (mm)
Prone	44.9	12.8	219.7	30.8
Kneeling	84.5	12.4	483.8	58.1
Standing	89.0	27.4	235.8	40.6

4.5.2 Weight Transfer

The Horizontal Weight Transfer accessory station results are based upon the data from 19 soldiers. The results for the total calculated time to perform six horizontal transfers in each condition by state of fatigue is shown in Figure 41.

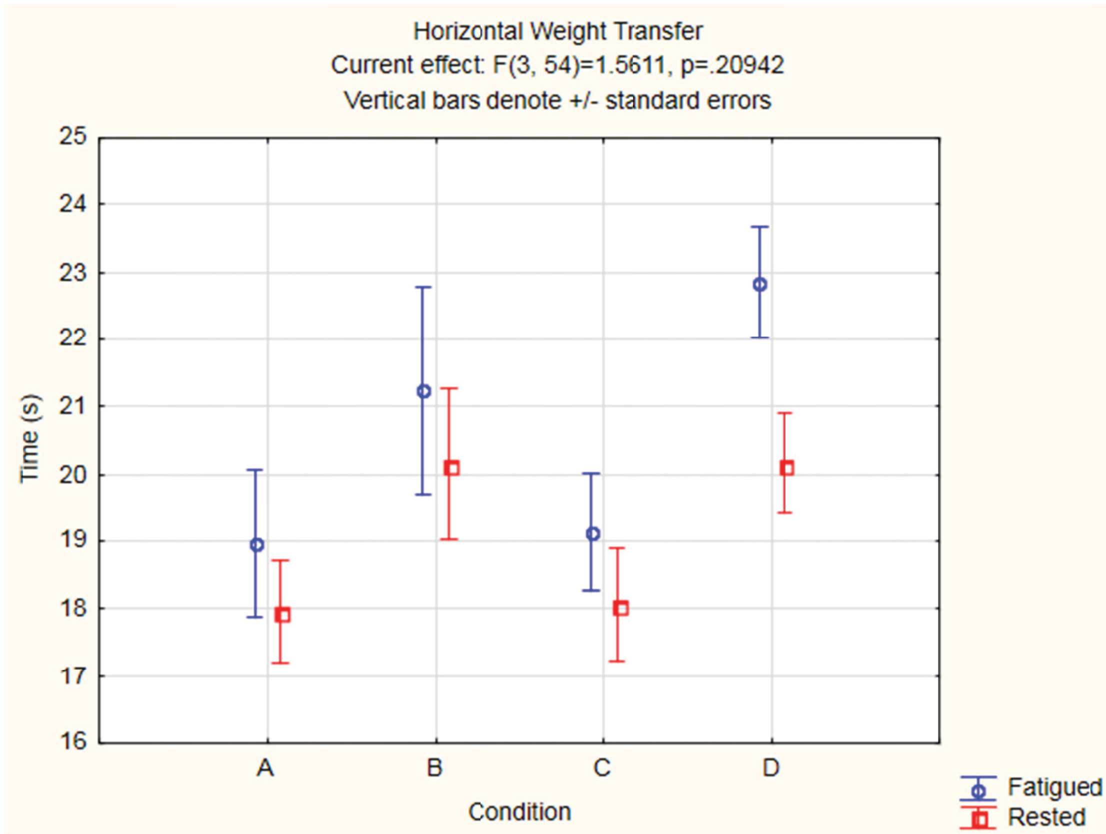


Figure 41: Horizontal Weight Transfer Times Across all Conditions by State of Fatigue

A two-way repeated-measures ANOVA was conducted on the horizontal weight transfer data and it showed a significant difference between rest state (n=19, F(1, 18)=12.668, p=.002). Separate analyses were conducted on the fatigued and rested state data. In reference to the fatigued state, a repeated-measures ANOVA identified a significant difference between conditions (n=20, F(3, 57)=6.051, p=.001). A Duncan's post-hoc analysis showed that the following pairwise comparisons for horizontal weight transfer times in the fatigued state were significantly different: A-B, A-D, B-C, and C-D. In reference to the rested state, a repeated-measures ANOVA identified a significant difference between conditions (n=20, F(3, 57)=6.066, p=.001). A Duncan's post-hoc analysis showed that the following pairwise comparisons for horizontal weight transfer times in the fatigued state were significantly different: A-B, A-D, B-C, and C-D. The Duncan's post-hoc values for fatigued and rested horizontal weight transfer times are shown in Table 40 and Table 41, respectively.

Table 40: Summary of Post-Hoc Analysis – Fatigued Horiztonal Weight Transfer

Condition	{1} 18.796	{2} 21.011	{3} 18.907	{4} 22.555
A		0.047317	0.915469	0.001179
B	0.047317		0.047585	0.142671
C	0.915469	0.047585		0.001292
D	0.001179	0.142671	0.001292	

Table 41: Summary of Post-Hoc Analysis – Rested Horiztonal Weight Transfer

Condition	{1} 17.848	{2} 20.158	{3} 18.107	{4} 20.023
A		0.003145	0.715154	0.004340
B	0.003145		0.007010	0.849179
C	0.715154	0.007010		0.008688
D	0.004340	0.849179	0.008688	

The descriptive statistics for fatigued and rested horizontal weight transfer times are shown in Table 42 and Table 43, respectively.

Table 42: Descriptive Statistics–Fatigued Horizontal Weight Transfer

Condition	Mean (s)	Minimum (s)	Maximum (s)	Std. Dev. (s)
A	18.8	13.1	36.0	4.7
B	21.0	12.5	45.3	6.6
C	18.9	13.1	25.8	3.9
D	22.6	16.7	30.6	3.7

Table 43: Descriptive Statistics–Rested Horizontal Weight Transfer

Condition	Mean (s)	Minimum (s)	Maximum (s)	Std. Dev. (s)
A	17.8	12.8	25.4	3.3
B	20.2	14.7	36.0	4.7
C	18.1	13.7	27.8	3.6
D	20.0	16.7	28.3	3.2

The results for the total calculated time to perform six vertical transfers in each condition by state of fatigue is shown in Figure 42.

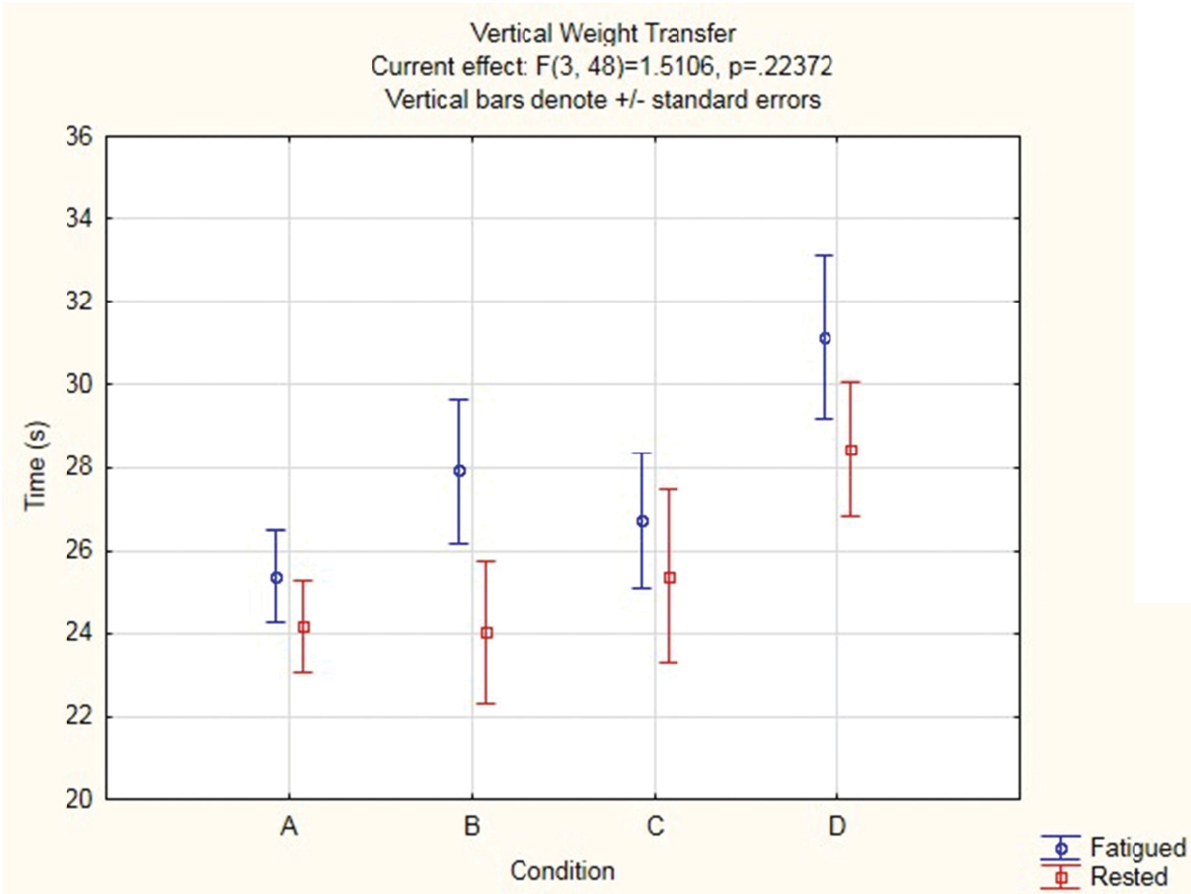


Figure 42: Vertical Weight Transfer Times Across all Conditions by State of Fatigue

A two-way repeated-measures ANOVA was conducted on the vertical weight transfer data and showed a significant difference between rest state (n=17, F(1, 16)=17.369, p=.001). Separate analyses were conducted on the fatigued and rested state data. In reference to the fatigued state, a repeated-measures ANOVA identified a significant difference between conditions (n=20, F(3, 57)=13.161, p<.001). A Duncan's post-hoc analysis showed that the following pairwise comparisons for vertical weight transfer times in the fatigued state were significantly different: A-B, A-D, B-D, and C-D. In reference to the rested state, a repeated-measures ANOVA identified a significant difference between conditions (n=18, F(3, 51)=6.107, p=.001). A Duncan's post-hoc analysis showed that the condition D was significantly different than all other conditions. The Duncan's post-hoc values for fatigued and rested vertical weight transfer times are shown in Table 44 and Table 45, respectively.

Table 44: Summary of Post-Hoc Analysis – Fatigued Vertical Weight Transfer

Condition	{1} 24.826	{2} 27.119	{3} 25.962	{4} 30.729
A		0.032528	0.259137	0.000053
B	0.032528		0.251087	0.000750
C	0.259137	0.251087		0.000076
D	0.000053	0.000750	0.000076	

Table 45: Summary of Post-Hoc Analysis – Rested Vertical Weight Transfer

Condition	{1} 24.264	{2} 24.240	{3} 25.602	{4} 28.509
A		0.983172	0.249691	0.000816
B	0.983172		0.269919	0.000954
C	0.249691	0.269919		0.014614
D	0.000816	0.000954	0.014614	

The descriptive statistics for fatigued and rested vertical weight transfer times are shown in Table 46 and Table 47, respectively.

Table 46: Descriptive Statistics – Fatigued Vertical Weight Transfer

Condition	Mean (s)	Minimum (s)	Maximum (s)	Std. Dev. (s)
A	24.8	19.2	38.9	4.4
B	27.1	20.6	50.9	7.0
C	26.0	17.4	47.4	6.4
D	30.7	17.4	55.5	7.6

Table 47: Descriptive Statistics – Rested Vertical Weight Transfer

Condition	Mean (s)	Minimum (s)	Maximum (s)	Std. Dev. (s)
A	24.3	17.7	38.4	4.5
B	24.2	8.5	42.3	6.9
C	25.6	16.6	57.1	8.4
D	28.5	20.1	45.6	6.5

4.5.3 Vertical jump

The results for the average vertical jump height each condition by state of fatigue is shown in Figure 43.

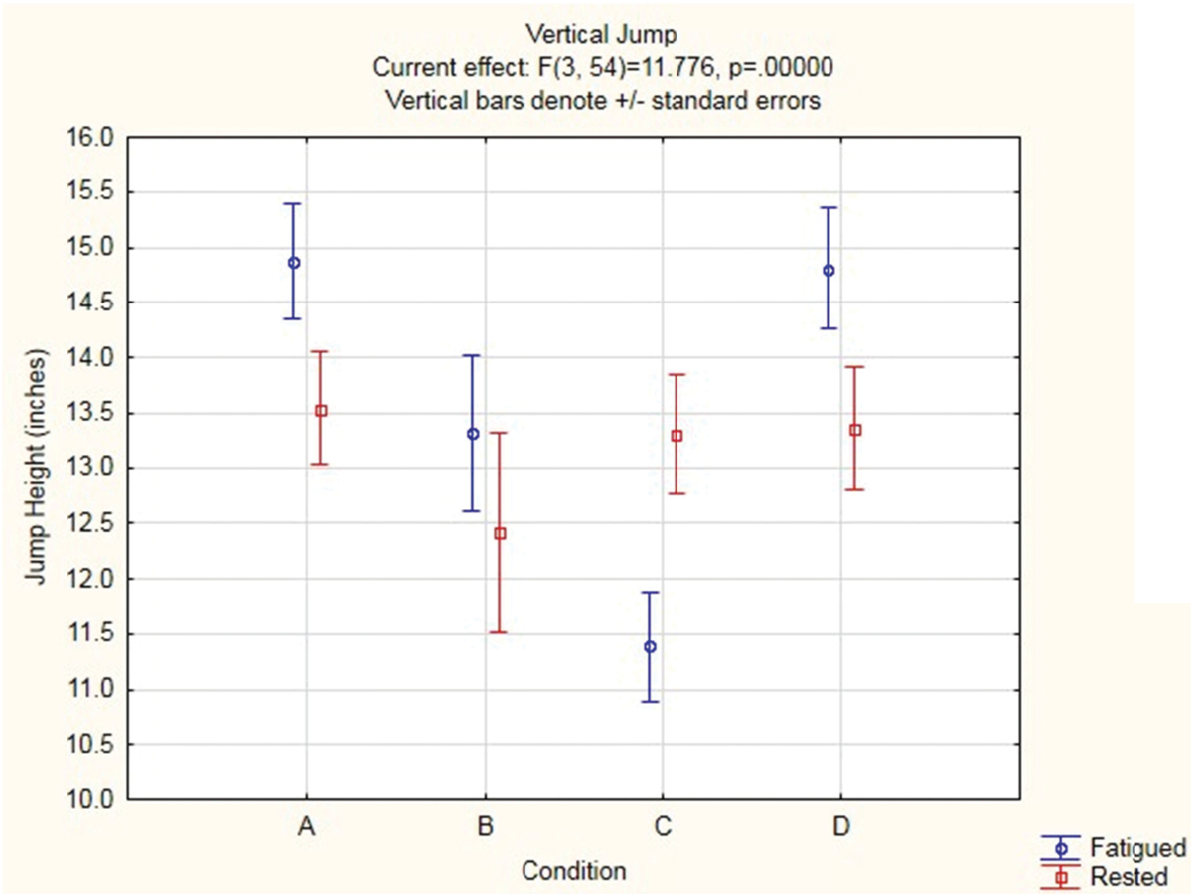


Figure 43: Vertical Jump Height Across all Conditions by State of Fatigue

A two-way repeated-measures ANOVA was conducted on the vertical jump data and showed no significant difference between rest state (n=19, F(1, 18)=1.508, p=.235) but did find a significant difference between condition (n=19, F(3, 54)=23.139, p<.001). A Duncan's post-hoc analysis showed that all conditions were significantly different from each other except for B-C. The Duncan's post-hoc values for vertical jump height are shown in Table 48.

Table 48: Summary of Post-Hoc Analysis – Vertical Jump

Condition	{1} 14.837	{2} 13.338	{3} 13.423	{4} 11.899
A		0.000177	0.000299	0.000054
B	0.000177		0.810413	0.000255
C	0.000299	0.810413		0.000152
D	0.000054	0.000255	0.000152	

The descriptive statistics for vertical jump height are shown in Table 49.

Table 49: Descriptive Statistics–Vertical Jump

Condition	Mean (in)	Minimum (in)	Maximum (in)	Std. Dev. (in)
A	14.8	9.8	19.2	2.3
B	13.3	6.7	18.5	2.7
C	13.4	9.0	17.3	2.3
D	11.9	5.1	24.0	3.2

4.5.4 Questionnaire Results

The subjective ratings obtained from the questionnaires are broken down into six categories in this section: stiffness, bulk, weight, agility, speed, and mobility. Note that the overall rating obtained from Question 7 of the questionnaire was already presented in Section 4.3, Figure 28, and will not be reported again here.

4.5.4.1 Stiffness

The results from the subjective ratings of stiffness are shown in Figure 44.

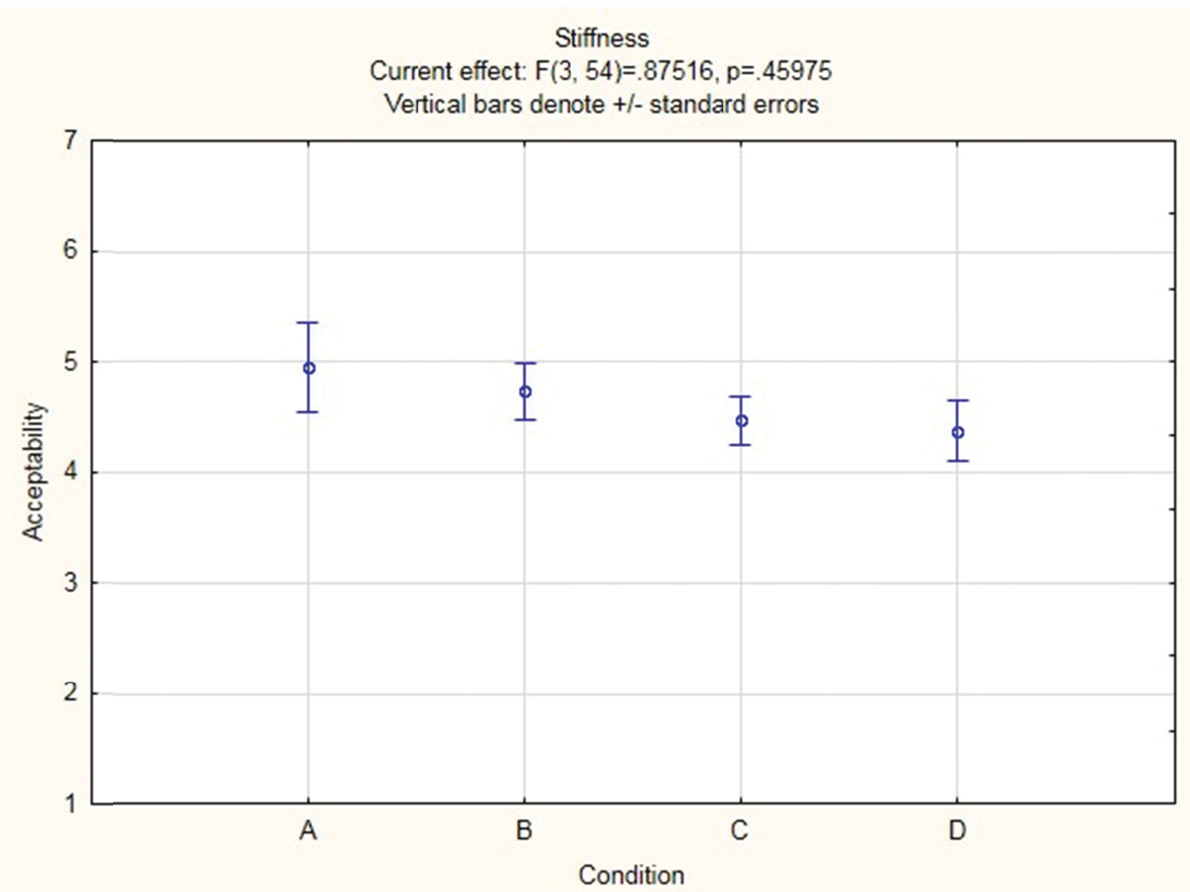


Figure 44. Subjective Ratings of Stiffness Across Conditions

Repeated-measures ANOVAs were performed on the stiffness ratings. No statistically significant differences were observed between conditions (n=19, F(3, 54)=0.875, p=.460).

4.5.4.2 Bulk

The results from the subjective ratings of bulk are shown below in Figure 45.

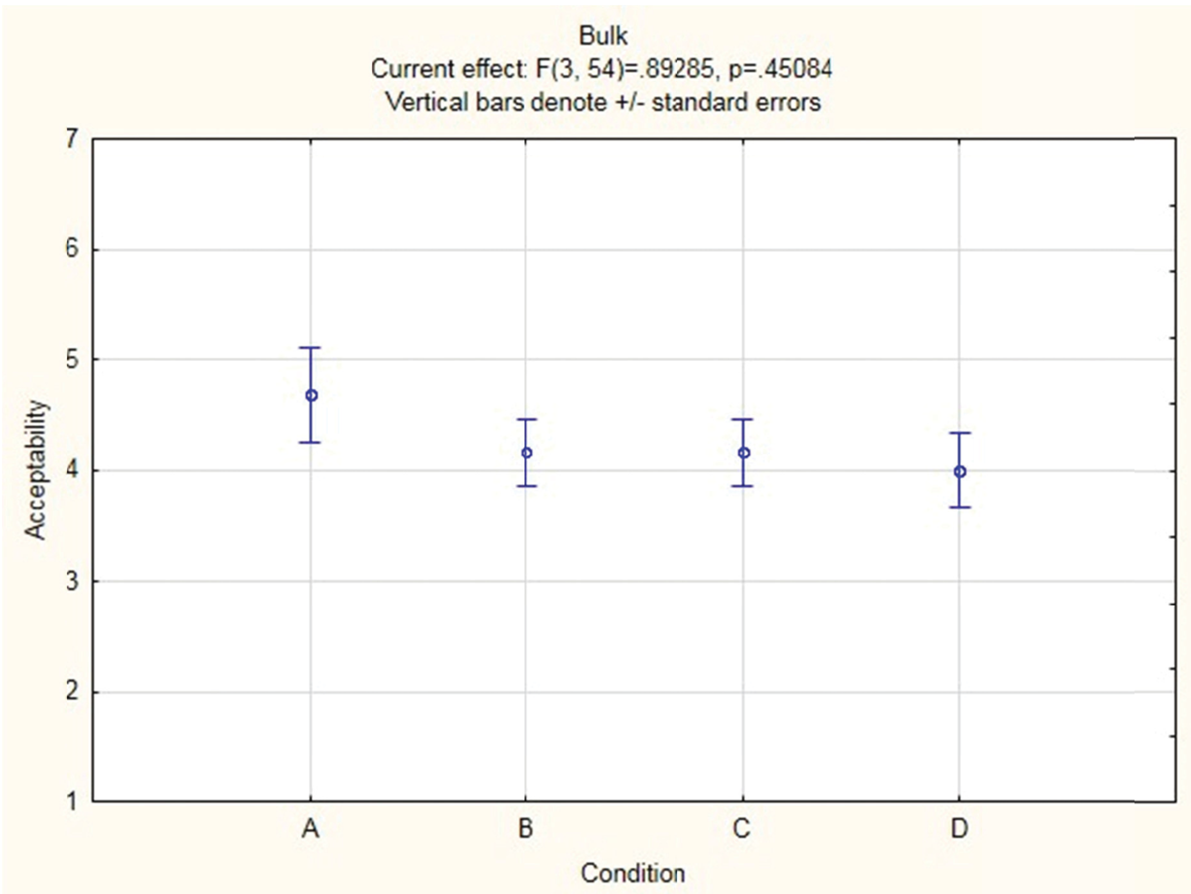


Figure 45. Subjective Ratings of Bulk Across Conditions

Repeated-measures ANOVAs were performed on the bulk ratings. No statistically significant differences were observed between conditions (n=19, F(3, 54)=.893, p=.451).

4.5.4.3 Weight

The results from the subjective ratings of weight are shown below in Figure 46.

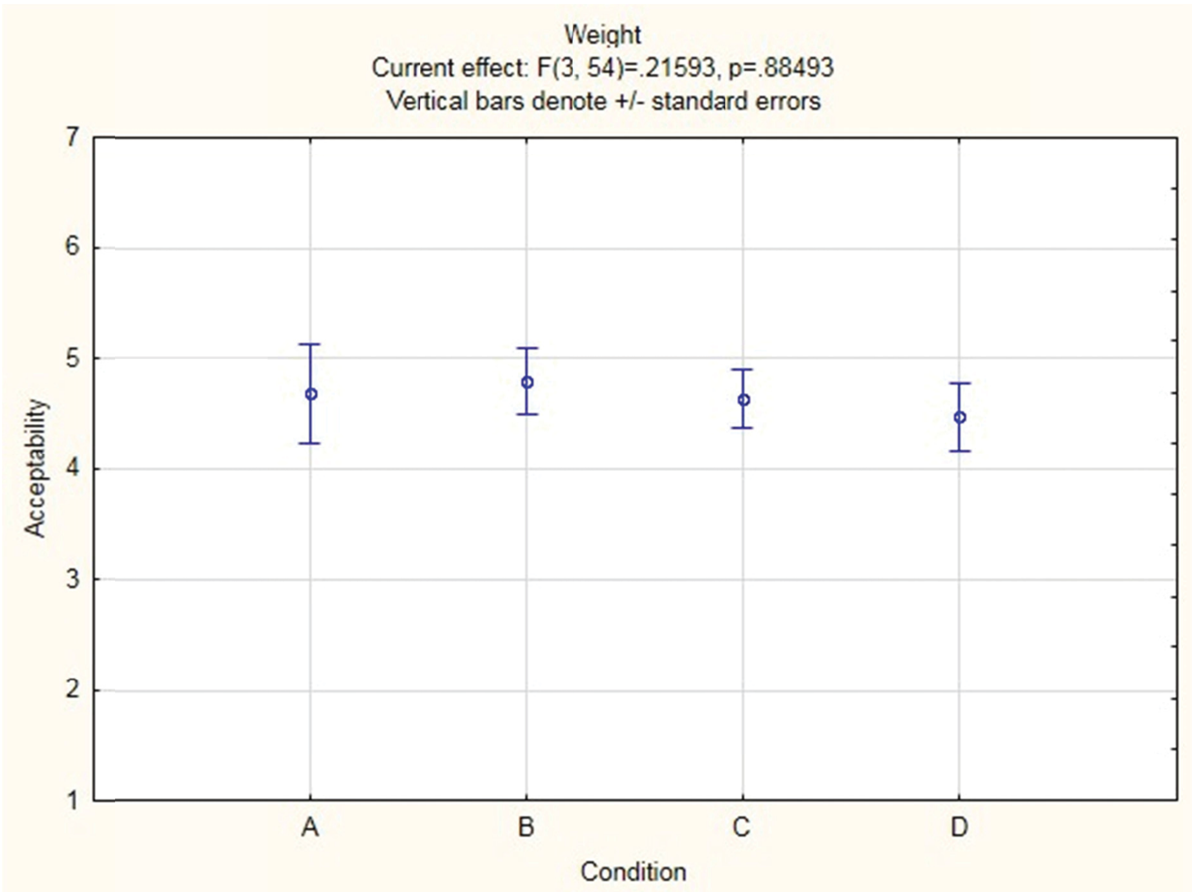


Figure 46. Subjective Ratings of Weight Across Conditions

Repeated-measures ANOVAs were performed on the weight ratings. Statistically significant differences were observed between conditions (n=19, F(3, 54)=.216, p=.885).

4.5.4.4 Agility

The results from the subjective ratings of agility are shown below in Figure 47.

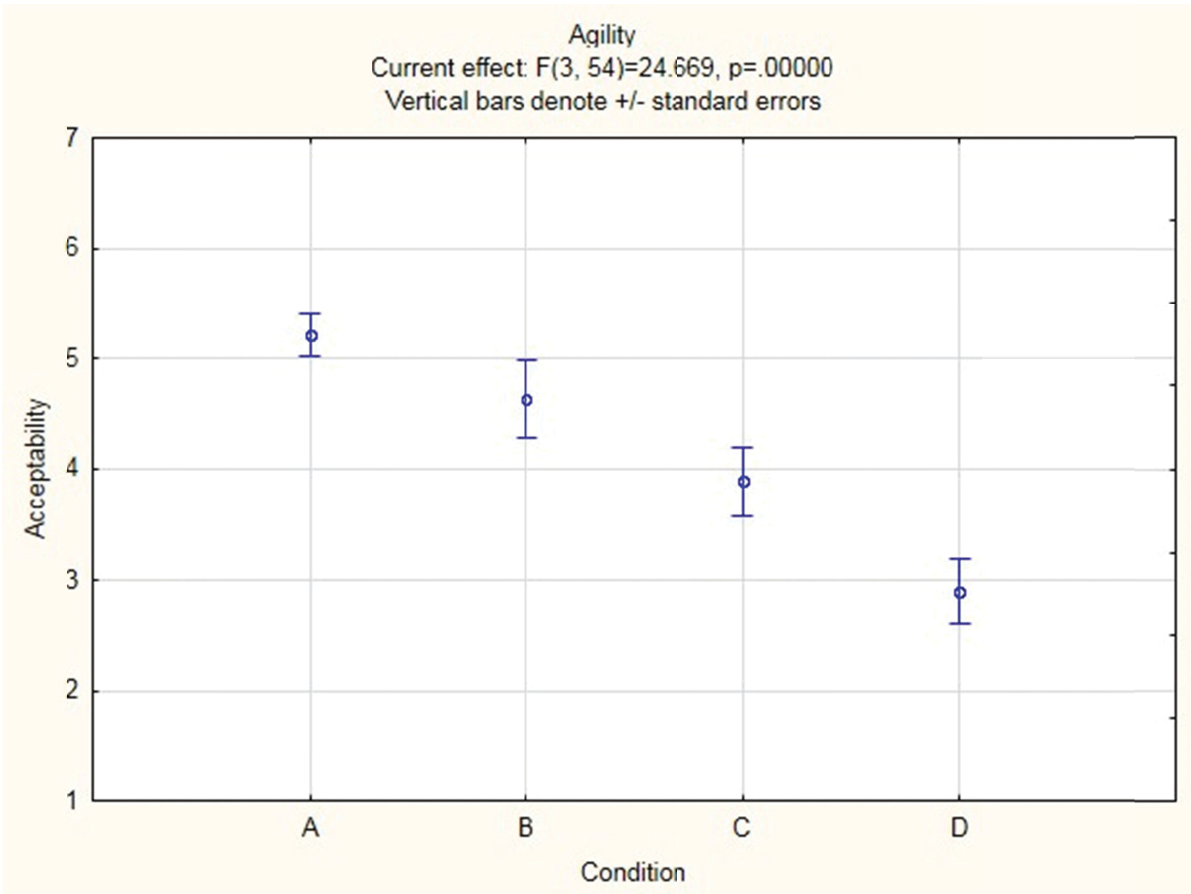


Figure 47. Subjective Ratings of Agility Across Conditions

Repeated-measures ANOVAs were performed on the agility ratings. Statistically significant differences were observed between conditions (n=19, F(3, 54)=24.669, p<.001). A Duncan's post-hoc analysis revealed that all conditions were significantly different from each other. Table 50 shows the detailed Duncan's post-hoc analysis results.

Table 50. Summary of Post-Hoc Analysis – Subjective Ratings of Agility

Condition	{1} 5.2105	{2} 4.6316	{3} 3.8947	{4} 2.8947
A		0.046939	0.000092	0.000054
B	0.046939		0.012457	0.000061
C	0.000092	0.012457		0.001026
D	0.000054	0.000061	0.001026	

4.5.4.5 Speed

The results from the subjective ratings of speed are shown below in Figure 48.

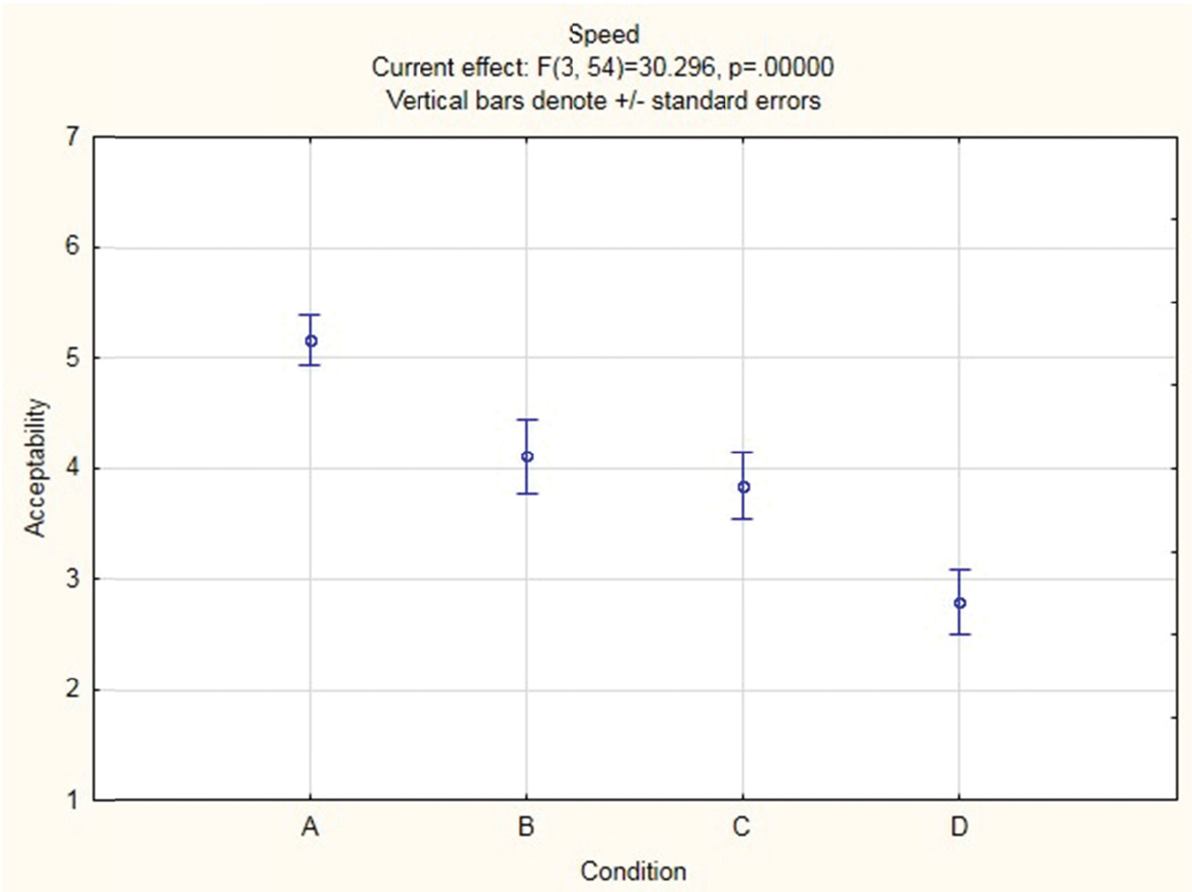


Figure 48. Subjective Ratings of Speed Across Conditions

Repeated-measures ANOVAs were performed on the speed ratings. Statistically significant differences were observed between conditions (n=19, $F(3, 54)=30.296$, $p<.001$). A Duncan's post-hoc analysis revealed that all conditions were significantly different from each other except for B-C. Table 51 shows the detailed Duncan's post-hoc analysis results.

Table 51. Summary of Post-Hoc Analysis – Subjective Ratings of Speed

Condition	{1} 5.1579	{2} 4.1053	{3} 3.8421	{4} 2.7895
A		0.000203	0.000063	0.000054
B	0.000203		0.297228	0.000063
C	0.000063	0.297228		0.000203
D	0.000054	0.000063	0.000203	

4.5.4.6 Mobility

The results from the subjective ratings of mobility are shown below in Figure 49.

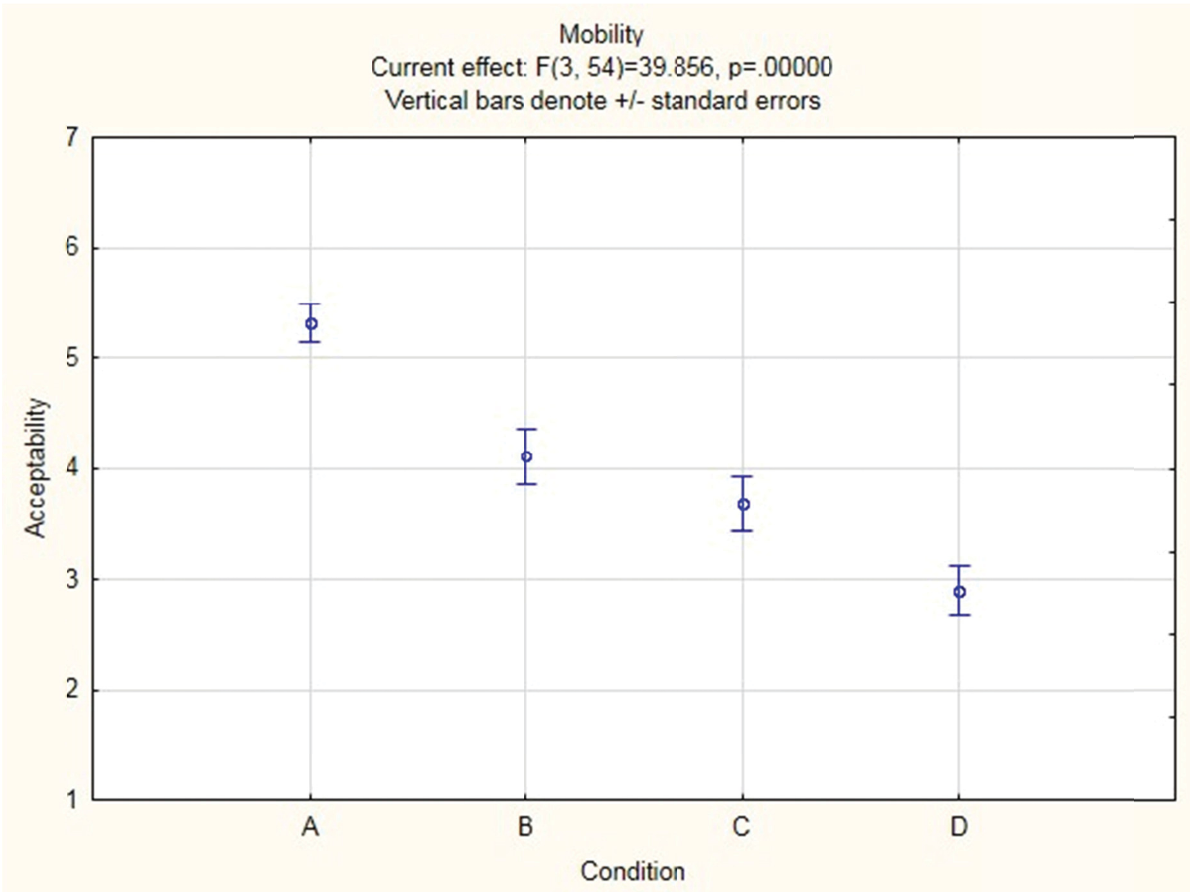


Figure 49. Subjective Ratings of Mobility Across Conditions

Repeated-measures ANOVAs were performed on the mobility ratings. Statistically significant differences were observed between conditions (n=19, $F(3, 54)=39.856$, $p<.001$). A Duncan's post-hoc analysis revealed that all conditions were significantly different from each other except for B-C. Table 52 shows the detailed Duncan's post-hoc analysis results.

Table 52. Summary of Post-Hoc Analysis – Subjective Ratings of Mobility

Condition	{1} 5.3158	{2} 4.1053	{3} 3.6842	{4} 2.8947
A		0.000114	0.000060	0.000054
B	0.000114		0.068449	0.000062
C	0.000060	0.068449		0.001100
D	0.000054	0.000062	0.001100	

5. Discussion

The 2013 CAN-LEAP Borden experiment aimed to investigate the combat performance implications of wearing varying levels of CBRN equipment. The battle load test condition (A) provided the baseline results and the three additional test conditions were designed to represent increasing levels of protection, crowd control (B), MOPP 1 (C), and MOPP 4 (D). The conducted analysis compared all conditions against each other but post-hoc pairwise comparisons indicated the following:

- Battle Load vs Crowd Control – effect of wearing the C4 respirator and carrier bag
- Battle Load vs MOPP 1 – effect of wearing CBRN suit in the open state
- Battle Load vs MOPP 4 – effect of wearing the CBRN suit in the closed state with respirator (MOPP 4 dress level)
- Crowd Control vs MOPP 4 – effect of wearing CBRN suit only in the closed state
- MOPP 1 vs MOPP 4 – combined effect of wearing CBRN suit in closed state (compared to open state) and wearing the C4 respirator

5.1 Range of Motion

The range of motion analysis showed that the only significant difference when comparing conditions was with the forward flexion test. A post-hoc test determined that both MOPP 1 and MOPP 4 resulted in significantly lower forward flexion results than the other two conditions. The two MOPP conditions were the only conditions where the CBRN suit was worn and therefore the additional bulk or encumbrance of the CBRN suit was hypothesised to be the main contributor to the decrement in forward flexion. One possible explanation as to why the decrement in ROM was only significant in the forward flexion test is because it was the only test administered in the seated position. The CBRN suit is a one-piece suit and therefore the ROM of the upper body would be limited if the weight of the participant was preventing movement in the lower body section of the suit. In addition, feedback from researchers conducting these tests indicated that consistency of measurements was very challenging given that the clinical tests are difficult to administer while participants are wearing clothing (i.e., unable to see and difficult to palpate joint centres).

5.2 Obstacle Course

The analyses for the obstacle course were divided into two main sections: total course performance, and obstacle performance. The total course performance was the metric used to determine where significant differences between load conditions existed, and was used as a point of reference when examining performances in the individual obstacles.

5.2.1 Total Course Performance

Post-hoc analysis of the total course time showed that all test conditions resulted in significantly different total course time. The performance results for each condition were:

- Battle Load condition had the fastest timings (mean of 332.6 s),
- MOPP 1 (mean 366.8 s) performance was faster than that for Crowd Control (mean 392.1 s) and MOPP 4, and

- MOPP 4 condition had the slowest timings (mean 428.9 s).

Investigating the individual pairwise comparisons showed that the biggest decrement to performance came from adding the C4 respirator (Battle Load vs Crowd Control) and adding the CBRN suit in the closed state (Crowd Control vs MOPP 4). Adding the C4 respirator and carrier bag increased the average course time from 332.6 s to 392.1 s, which is an increase of 59.4 s. The large decrement in performance caused by the addition of the respirator is primarily due to the restriction in air intake imposed by the respirator air filter. Adding the CBRN suit in the closed state increased the average course time from 392.1 to 428.9 s, which is an increase of 36.8 s. The decrement in performance caused by the addition of the CBRN suit in the closed state is primarily due to the encumbrance of the CBRN suit, boots, and gloves. The portion of that encumbrance that is simply adding the CBRN suit in the open state with the respirator carrier bag increased the average course time from 332.6 to 366.8 s, which is an increase of 34.2 s (Battle Load vs MOPP 1).

5.2.2 Performance by Obstacle

In addition to total obstacle course times, the results were analysed separately for each individual obstacle. All of the individual obstacle results showed the same trend as overall course performance where:

- Battle Load condition performance was the fastest,
- MOPP 1 performance was faster than that for Crowd Control and MOPP 4, and
- MOPP 4 condition had the slowest timings.

The statistical significance between pairwise comparisons, however, differed from obstacle to obstacle.

Battle Load vs Crowd Control

The addition of the C4 respirator (Battle Load vs Crowd Control) had a significant effect on average interval time for all the individual obstacles except for the sprint and windows. The decrement in performance was hypothesised to be due to the restriction in air intake caused by the respirator filter. The likely reason that no significant decrement in performance was found during the sprint was because it is a short duration task near the beginning of the obstacle course and therefore there is minimal impact of breathing gas deprivation. With regards to the window obstacle, the battle load itself may have been the bigger hindrance to complete this task, as the bulk and weight imposed by the loaded tactical vest may have been the more prominent factor in impeding progress through the windows, thus preventing the participants from completing this task quickly.

Battle Load vs MOPP 1

The addition of the CBRN suit in the open state only had a significant impact on individual obstacle interval times for the Bounding Rushes, Low Crawl and Wall obstacles. The decrement in performance for these obstacles would be due to the added encumbrance of the CBRN suit. Even though it was in the open state and only added approximately 3.6 kg, there was added bulk and limitations on range of motion. In reference to the bounding rushes and low crawl, those particular obstacles required a great deal of mobility from arms and legs in order to traverse the overall obstacle quickly. Therefore limiting range of motion had a direct impact on the soldiers' ability to traverse the obstacles as quickly as they did without wearing the CBRN suit. In reference to the wall obstacle, it was hypothesised that the decrement in performance was due to the limiting range of motion in the lower body because, in order to traverse the wall obstacle quickly, the soldiers had to propel themselves up onto the wall using their legs and then quickly swing their legs over the wall. It can be hypothesized that the increased bulk on the lower legs had an effect on the soldiers' ability to traverse the walls, slowing then down compared to traversing the obstacles without the CBRN suit on.

Battle Load vs MOPP 4

As would be expected, the combination of adding the CBRN suit in the closed state and wearing the C4 respirator had a significant impact on individual obstacle interval times for every obstacle.

Crowd Control vs MOPP 4

The addition of the CBRN suit in the closed state had a significant impact on individual obstacle interval times for all of the obstacles except for the Tunnel and Hatch, casualty drag, and window obstacles. The decrement in performance in this case is similar to the Battle Load vs MOPP 1 comparison such that it would be attributed to the added encumbrance of the CBRN suit, however in addition the suit is now in the closed state and worn with the CBRN gloves and boots. The added encumbrance of wearing the CBRN gloves and boots, and changing the suit from the open to closed state has decreased performance on six additional obstacles compared to just wearing the suit in the open state.

MOPP 1 vs MOPP 4

The combined effect of wearing the C4 respirator and changing from open to closed state with the CBRN suit had a significant impact on individual obstacle interval times for all of the obstacles. This is to be expected since adding the respirator alone (Battle Load vs Crowd Control) had a significant effect on eight of the ten obstacles and the added effect due to the additional encumbrance of changing the suit to the closed state has already been discussed.

5.3 Accessory Stations

The goal for including accessory stations in the CAN-LEAP (i.e. those other than the timed obstacle course) was to gather objective combat-related performance metrics and subjective ratings (as in the case of the Questionnaire Kiosk) that could not effectively be captured within the parameters of the timed obstacle course.

5.3.1 Marksmanship

For the Noptel Marksmanship station, participants were required to perform three sets of five shots, with each set being performed in a different randomized shooting posture (standing, kneeling, or prone). The shooting task was performed in a rested state prior to the obstacle course being run, and immediately following the completion of the obstacle course in a fatigued state. The shots were analyzed using a common marksmanship method, group size.

As hypothesised, there was a significant difference between group size results with respect to rest state, where rested shooting resulted in smaller group sizes than fatigued. For both fatigued and rested shooting there was a significant difference found between shooting postures, where prone resulted in significantly smaller group sizes than both kneeling and standing. This is an anticipated result since traditional prone is thought as the most stable shooting posture.

In reference to the comparison between conditions there was only a significant difference found while shooting in the fatigued state, where MOPP 4 resulted in significantly larger group sizes than all other conditions. Due to the fact that this is the only significant difference it is hypothesized that the decrement in performance from adding both the respirator and CBRN suit in the closed state is more correlated with the increased level of fatigue that the participants were shooting under as seen in their RPE results.

The lack of difference found between the other conditions in the fatigued state and no difference found in the rested state may also suggest that an individual firing zero is required, or that the firing task was not challenging enough to elicit a sufficient level of heterogeneity in the results. Suggestions for increasing the difficulty of this task include making the target distance further, imposing an external time pressure, or instituting a friend/foe decision into the firing sequence.

Another possible explanation for the lack of difference found between conditions is that the participant group (non-infantry, no deployment experience) was relatively inexperienced with marksmanship and had received limited marksmanship training and practice. This conclusion is drawn from the fact that only three of the 21 participants had more than one year of experience in the military. Inexperience with marksmanship techniques would generally lead to inconsistent marksmanship results which was evident by the relatively large standard deviation for the average group size results. On average for both fatigued and rested states the standard deviation was found to be greater than 50% of the mean value.

5.3.2 Weight Transfer

The weight transfer task was performed twice in each condition (rested and fatigued). Both the horizontal and vertical weight transfer task analyses showed a significant difference between the results in the rested state versus the fatigued state. In both cases the fatigued state resulted in significantly slower average weight transfer times than the rested state. Separate analyses were completed on the rested and fatigued data for both the horizontal and vertical weight transfer tasks.

For the horizontal weight transfer, there was a significant difference found between conditions in both the rested and fatigued states. In both cases, participants performed significantly faster in the Battle Load compared to the Crowd Control and the MOPP 4 loads, and significantly slower in the Crowd Control load compared to the MOPP 1 and MOPP 4 loads.

In both the fatigued and rested states the conditions that included wearing the C4 respirator resulted in significantly slower horizontal weight transfer times than the conditions without the respirator. Similar to the obstacle course results it was hypothesized that the decrement in performance with the addition of the respirator was due to the restriction of oxygen intake caused by the respirator filter. In both the fatigued and rested states the addition of the CBRN suit in either open or closed states did not have a significant effect on horizontal weight transfer performance.

For the vertical weight transfer, there was a significant difference found between conditions in both the rested and fatigued states. In the fatigued state participants performed significantly faster in the Battle Load compared to the Crowd Control and MOPP 4 loads, significantly faster in the Crowd Control load compared to the MOPP 4 load, and significantly faster in the MOPP 1 load compared to the MOPP 4 load. The two conditions that included a C4 respirator (Crowd Control and MOPP 4) both resulted in significantly slower vertical weight transfer times than the Battle Load. The MOPP 1-MOPP 4 pairwise comparison also included the addition of a C4 respirator, and the condition that included wearing the respirator resulted in slower vertical weight transfer times. The other pairwise comparison that was significantly different was Crowd Control-MOPP 4 which indicated the performance degradation due to adding the encumbrance of the CBRN suit in the closed state including the CBRN boots and gloves.

In the rested state, the MOPP 4 condition resulted in significantly different vertical weight transfer times than the other three conditions. That decrement in performance was due to the combined effect of wearing the C4 respirator and CBRN suit in the closed state with CBRN boots and gloves.

5.3.3 Vertical Jump

The vertical jump task was performed twice in each condition (rested and fatigued). The analysis showed no significant difference between the results in the rested state versus the fatigued state, but overall there was a significant difference in jump height between conditions. A post-hoc analysis showed that all conditions were significantly different from each other except for the Crowd Control-MOPP 1 pairwise comparison. The trend in vertical jump height performance was:

- Jumps were highest in the Battle Load,
- Jumps in MOPP 1 and Crowd Control were similar, and both higher than MOPP 4, and
- Jumps in MOPP 4 were the lowest.

The highest jumps occurring in the Battle Load condition can be explained by the fact that this condition was the lightest and least encumbered test condition. Similarly MOPP 4 resulting in the lowest vertical jump heights can be explained by the fact that it was the heaviest and most encumbered test condition. For the vertical jump test the lower limb encumbrance and added weight from the CBRN boots was hypothesised to be the biggest contributor to the performance decrement. The vertical jump test is not an operational relevant task on its own but is a good indicator of the effect of the test conditions on leg power that can be generated and this is a core component of many operationally relevant tasks as evident from the similar decrement in performance while wearing the MOPP 4 condition on the obstacle course.

5.3.4 Subjective Questionnaire and Ratings of Perceived Exertion

Soldiers were asked to subjectively rate their overall performance on a 1 (completely unacceptable) to 7 (completely acceptable) Likert scale. The ratings were averaged across the participant group and the following trend was observed:

- Battle Load was rated the highest (5.3),
- Crowd Control and MOPP 1 were equally rated (4.4), and
- MOPP 4 was rated the lowest (3.2).

The trend in subjective rating of performance and obstacle course timing results corresponded to each other such that participants rated their performance lower when they actual were slower, meaning that their perceived decrement in performance agreed with their actual decrement in performance.

Immediately upon completion of each run of the obstacle course, soldiers were asked to give their RPE from 6 (no exertion at all) to 20 (maximal exertion) on the Borg Scale. Results showed a similar trend to the obstacle course timing results where:

- Battle Load was rated lowest,
- MOPP 1 was rated lower than MOPP 4, and
- MOPP 4 was rated the highest.

Similar to the subjective rating of overall performance statistical analysis showed that all conditions were significantly different from each other except for the Crowd Control-MOPP 1 pairwise comparison. One unavoidable potential confounding factor that may have had an influence on the subjective results (both the questionnaire ratings and the RPE) is the fact that it was impossible to make the participants blind to the contents of their worn load (conditions) potentially creating a confirmation bias.

6. Lessons Learned

6.1 Difficulty of Test Conditions

One of the challenges encountered during this data collection effort was the high physiological demand of completing the obstacle course while wearing the respirator. The task was very challenging in condition B, but once the burden was increased to condition D there were multiple participants that had to walk and take breaks just to complete the course. Furthermore, three of the 21 participants were unable to complete the course while in condition D, and had to stop and remove the respirator. One of the lessons learned, and implemented, was the necessity for the respirator to have a new clean respirator filter, otherwise the air flow restriction was too high for the participants to complete the task.

6.2 Fitlight Timing System

The concurrent activity taking place during the trial was testing a new timing system on the obstacle course. The system being tested was Fitlight, which is a wireless timing system consisting of a series of light-emitting diodes (LED) and a hand-held personal digital assistant (PDA) controller. This system captures time between de-activation of each light in order as the soldier passed by. The dimly lit Fitlight sensors send out an invisible beam of 80 cm (distance is adjustable). Breaking this beam triggers the light to illuminate brightly and marks the start/end of a split time. The Fitlight sensors can be seen in Figure 50.

Figure 50: Exemplar Fitlight Sensor

One of the benefits of the Fitlight timing system is that it is more easily adaptable to the obstacle course and allows for more interval times to be captured throughout the course. Figure 51 shows how the Fitlights were positioned throughout the obstacle course during the system piloting.

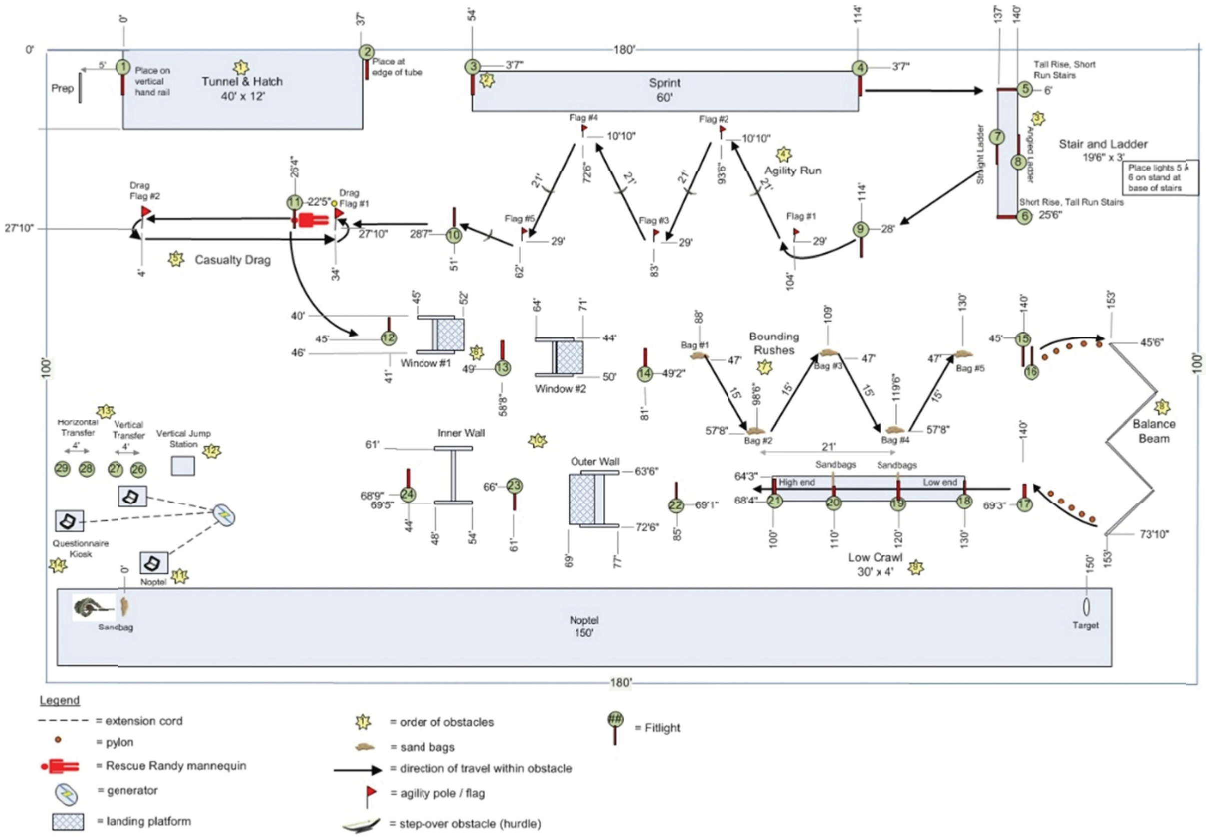


Figure 51: Fitlight Layout

Piloting the Fitlight system demonstrated that it was going to be possible to implement the new timing system effectively to provide a more detailed data set. Issues identified with the timing system that need to be corrected before full implementation into a future user trial were:

- wireless communication between the PDA and sensors was not reliable,
- the sensors sometimes did not trigger when a participant broke the IR beam, and
- sensors were frequently false triggered.

6.3 Participant Pool

The participants for this trial were recruited from the Canadian Forces Support Training Group (CFSTG) at CFB Borden and consisted primarily of vehicle technicians. Therefore, they were relatively inexperienced with infantry tasks and more specifically, marksmanship techniques. This is anticipated to have had an impact on the marksmanship results and could also factor into how difficult in general the participants found the obstacle course to be. For future studies it is recommended that experienced infantry soldiers be recruited.

6.4 Range of Motion Assessment

The range of motion tasks were only able to discriminate a significant difference between conditions for forward flexion while wearing the CBRN suit. It was hypothesised that the encumbrance of the suit would have had a significant effect on all the range of motion tasks. It was observed that the clinical range of motion methods used during this study were difficult to administer when a participant was wearing bulky clothing and equipment and therefore may have led to inconsistent measurements. It also was hypothesised that conducting the forward flexion in the seated posture might have had an unforeseen impact on the upper body ROM because the CBRN suit is a one-piece suit. A new range of motion assessment more suitable for encumbered measurements should be developed for future studies.

Furthermore, there are several obstacles in the CAN-LEAP course that require good mobility in the arms or mobility at the hips in order to traverse them quickly and effectively. Upper and lower limb range of motion assessments should also be developed for future studies to allow for more insightful explanations of performance decrements on individual obstacles.

.

7. Conclusion

The CAN-LEAP obstacle course provided excellent insight into how the participants' performance was affected by the load condition they were wearing. The general performance trends on the obstacle course were:

- Performance in the Battle Load (A) condition was the fastest,
- MOPP 1 (C) performance was faster than that for Crowd Control (B) and MOPP 4 (D), and
- MOPP 4 condition performance was the slowest (D).

For overall course performance all conditions resulted in significantly different outcomes. However for the individual obstacle interval times the degree to which the difference in performance was significant changed from obstacle to obstacle. Adding the C4 respirator had a significant effect on all individual obstacles except for the sprint (Battle Load vs Crowd Control), and therefore as would be expected adding the CBRN suit in the closed state as well as the respirator had a significant effect on every obstacle (Battle Load vs MOPP 4). The significant reduction in performance observed when the C4 respirator was added to the test condition was hypothesised to be primarily due to the restriction of air intake imposed by the respirator filter.

Adding the CBRN suit in the open state (Battle Load vs MOPP 1) only caused a significant decrement in performance for the bounding rushes, low crawl and wall obstacles. Adding the CBRN suit in the closed state (Crowd Control vs MOPP 4) caused a significant decrement in performance for all the obstacles except the tunnel and hatch.

The Noptel marksmanship station identified a significant difference between rested and fatigued shooting, where fatigued shooting resulted in significantly larger average group size than rested. In both the fatigued and rested state there was also found to be a significant difference between shooting postures where prone resulted in significantly smaller average group size than both kneeling and standing. In reference to the test conditions there were no significant differences found in the rested state, however in the fatigued state MOPP 4 resulted in significantly higher average group size than all other conditions. The lack of significant difference found between test conditions was also hypothesised to be due to the relatively low marksmanship experience of the participant pool.

The weight transfer station also identified a significant difference between rested and fatigued states, where the fatigued state resulted in significantly slower vertical and horizontal weight transfer times. Both horizontal and vertical weight transfers showed significant differences between conditions in both the rested and fatigued states. For the horizontal transfer the conditions with a respirator were significantly slower than conditions without a respirator in both fatigued and rested states. For the vertical weight transfer in both the rested and fatigued states, MOPP 4 was significantly different than all other conditions, and the only other significant pairwise condition was Battle Load vs Crowd Control in the fatigued state.

The vertical jump task results showed no significant difference between rested and fatigued states, but overall did show a significant difference in performance between conditions. Battle Load resulted in higher average vertical jump heights than all other conditions, and MOPP 4 resulted in lower average jump heights than all other conditions.

The results of participants’ subjective rating of their performance, as well as their RPE, showed a relationship with the actual performance effect of the carried or worn load. These subjective assessments could be considered a useful and valid measure if a ‘quick-and-dirty’ approach to the evaluation of performance decrement was required.

8. Way Ahead

There are several recommendations and considerations that can be made with regards to the way ahead for the CAN-LEAP program and future studies:

- For future testing that involves a respirator it is essential that clean filters are provided to all participants prior to running the obstacle course.
- The MOPP 4 condition was very physiologically challenging and for future studies that require testing of that condition it will be necessary to anticipate that some participants will not be able to complete the obstacle course.
- More piloting needs to be conducted with the Fitlight system before full implementation into the CAN-LEAP facility. Technical issues need to be corrected in partnership with the Fitlight development team, and logistical issues with applying the Fitlight system to the obstacle course need to be addressed with the CAN-LEAP research team.
- Investigate methods for making the marksmanship task more challenging.
- Develop new ROM assessments that will allow for more consistent encumbered measurements and an upper limp ROM assessment.
- Use experienced infantry or combat arms soldiers whenever possible.

9. References

American College of Sports Medicine (2005). ACSM guidelines for Exercise prescription, 7th edition. Philadelphia, PA: Lippincott Williams and Wilkins.

Angel, H., Ste-Croix, C., & Osborne, A. (2013). Joint Chemical, Biological, Radiological and Nuclear General Service Respirator (J CBRN GSR): Benchmarking Technical Memorandum. In-press for the Defence Research and Development Canada – Toronto

Attwells, R.L., Birrell, S.A., Hooper, R.H., and Mansfield, N.J. (2006). The influence of carrying heavy loads on soldiers' posture, movements, and gait. *Ergonomics*. 49 (14), 1527-1537.

Beekley, M.D., Alt, J, Buckley, C.M., Duffey, M. and Crowder, T.A. (2007). Effects of heavy load carriage during constant-speed, simulated road marching. *Military Medicine*, 172 (6). 592-595.

Bigard, A.X. (2000). A combination of biomechanical and physiological approaches for determination of optimal load distribution. Proceedings from*: NATO research and technology 56 - Soldier Mobility: Innovations in Load Carriage System Design and Evaluation*.

Birrell, S.A., and Hooper, R.H. (2007). Initial subjective load carriage injury data collected with interviews and questionnaires. *Military Medicine,* 172(3), 306-311.

Birrell, S.A., Hooper, R.H., and Haslam, R.A. (2007). The effect of military load carriage on ground reaction forces. *Gait and Posture*. 36 (4), 611-614.

Devroey, C., Devroey, A. Jonkers, I., de Becker, A., Lenaerts, G., Spaepen, A. (2007). Evaluation of the effect of backpack load and position during standing and walking using biomechanical, physiological, and subjective measures. *Ergonomics*. 50(5), 728-742.

Grenier, J.G., Peyrot, N., Castells, J., Oullion, R., Messonnier, L., and Morin J.B. (2012). Energy cost and mechanical work of walking during load carriage in soldiers. *Medicine and Science in Sports and Exercise.* 44 (6), 1131-1140.

Hasselquist, L., Bensel, C.K., Corner, B., Gregorczyk, K.N., & Schiffman, J.M. (2008). *Understanding the physiological, biomechanical and performance effects of body armor use.* Proceedings of the 26th Army Science Conference, Orlando, FL.

Holewijn, M., and Meeuwsen, T. (2000). Physiological strain during load carrying: effects of mass and type of backpack. Proceedings from*: NATO research and technology 56 - Soldier Mobility: Innovations in Load Carriage System Design and Evaluation*.

Jackson, A.S., and Pollock, M.L. (1978). Generalized equations for predicting body density of men. *British Journal of Nutrition*, 40(3):497-504.

Johnson, R.C., Pelot, R.P., Doan, J.B., and Stevenson, J.M. (2000). The Effect of load position on biomechanical and physiological measures during a short duration march. Proceedings from*: NATO research and technology 56 - Soldier Mobility: Innovations in Load Carriage System Design and Evaluation*.

LaFiandra, M., Lynch, S., Frykman, P., Harman, E., Ramos, H., & Mello, R. (2003). *A comparison of two commercial off the shelf backpacks to the modular lightweight load carrying equipment*

(MOLLE) in biomechanics, metabolic cost, and performance. U.S. Army Research Institute of Environmental Medicine, Natick, MA.

Mahoney, C.R., Hirsch, E., Hasselquist, L., Lesher, L.L., and Lieberman, H.R. (2007). The effects of movement and physical exertion on soldier vigilance. *Aviation and Space Environmental Medicine*, 78(5), B51-57.

Majumdar, D., Pal, M.S., Pramanik, A., and Majumdar. D. (2013). Kinetic changes in gait during low magnitude military load carriage. *Ergonomics.* 56 (12), 1917-1927.

Orr, R.M., Johnston, V., Coyle, J., & Pope, R. (2011). Load carriage and the female soldier. *Journal of Military and Veterans' Health.* 19 (3), 25-34.

Park, H., Branson, D., Petrova, A., Peksoz, S., Jacobson, B., Warren, A, Goad, C., Kamenidis, P. (2013). Impact of ballistic body armour and load carriage on walking patterns and perceived comfort. *Ergonomics.* 56 (7), 1167-1179.

Patton, J.F., Kaszuba, J, Mello, R.P., and Reynolds, K.L. (1991). Physiological responses to prolonged treadmill walking with external loads. *European Journal of Applied Physiology & Occupational Physiology*, 63(2), 89-93.

Seay, J.F., Fellin, R.E., Sauer, S.G., Frykman, P.N., and Bensel, C.K. (2014). Lower extremity biomechanical changes associated with symmetrical torso loading during simulated marching. *Military Medicine.* 179 (1), 85-91.

Treolar, A.K., and Billing, D. (2011). Effect of load carriage performance of an explosive, anaerobic military task. *Military Medicine.* 176 (9), 1027-31.

Annex A: Adiposity Testing

The following methodologies provide a detailed explanation of the Adiposity testing performed during the CAN-LEAP study:

i) *Skinfold thickness* - Skinfold measurements were taken at seven sites: triceps, chest, axilla, subscapular, suprailiac, abdominal, and thigh, according to the Jackson and Pollock (1978) seven-skinfold equation. Each site was located and marked with a cross using a non-toxic, washable marker, to decrease variation between measurement trials. All measurements were taken on the right side of the body. Each site was measured at least twice, allowing at least 3 minutes between trials for skin and underlying fat to return to resting thickness. If the first two measurements differed by more than 2mm, a third measurement was taken. If only two trials were required, the average of the two was used in the calculation. If three measurements were taken, the average of the two closest measurements was used. Once the skinfold measures were taken, the following equations were used to calculate body fat percentage, using a the sum of the seven skinfolds (SS_7) and the participant's age:

Males:
$$\mathrm{BD} = 1.112 - 0.00043499(\mathrm{SS}_7) + 0.00000055(\mathrm{SS}_7{}^2) - 0.00028826(\mathrm{age})$$
(Jackson and Pollock, 1978)

Females:
$$\mathrm{BD} = 1.097 - 0.00046971(\mathrm{SS}_7) + 0.00000056(\mathrm{SS}_7{}^2) - 0.00012828(\mathrm{age})$$
(Jackson et al., 1980)

Jackson and Pollock's equations for BD using the sum of three skinfolds (SS_3) (males: chest, abdomen, and thigh, females: triceps, thigh, and suprailiac) was also used to calculate BF%, to be compared to the seven-site estimation.

Males: $\mathrm{BD} = 1.10938 - 0.0008267(\mathrm{SS}_3) + 0.0000016(\mathrm{SS}_3{}^2) - 0.0002574(\mathrm{age})$
(Jackson and Pollock, 1978)

Females: $\mathrm{BD} =$
$$1.0994921 - 0.0009929(\mathrm{SS}_3) + 0.0000023(\mathrm{SS}_3{}^2) - 0.0001392(\mathrm{age})$$
(Jackson et al., 1980)

Following the calculation of BD, the equation developed by Siri (1961) was used to determine BF%:

$$\%\mathrm{BF} = \left(\frac{4.95}{\mathrm{BD}} - 4.5\right) \times 100$$

Annex B: Strength Testing

The following methodologies provide a detailed explanation of the strength testing performed during the CAN-LEAP study:

Upper limb static strength: To measure upper limb static strength, a force gauge is attached to a sturdy steel chain, which is attached to an immoveable fixation point at ground level. The force gauge is attached to a point in the chain which coincides with the participants' elbow being flexed 90 degrees forward. The participant is instructed to stand feet shoulder width apart with the chain attachment point midway between the feet. The participant grasps the force gauge (palms up) and flexes their arms using their maximal strength. Encouragement is given by the researchers to help elicit a maximal effort. The force value (in kilograms) is noted from the force gauge and recorded.

Annex C: Range of Motion Testing

The participant's range of motion measurements were taken during each test condition, including the unencumbered baseline (boots, t-shirt & combat clothing). Measurements were taken using a combination of a goniometer, a Wells and Dillon Sit and Reach apparatus, an inclinometer and a digital level. The following ranges of motion will be measured:

Trunk Forward Flexion (Modified Wells and Dillon Sit and Reach)

- The participant sits with legs fully extended with the soles of the feet placed flat against the horizontal crossboard of the apparatus.
- Both inner edges of the feet should be placed 2 cm from the scale.
- Keeping the knees fully extended, arms evenly stretched, palms down, the participant bends and reaches forward pushing the sliding marker along the scale with their fingertips as forward as possible.
- The position should be held for approximately 2 seconds

Refer to Figure 52.

Figure 52: Modified Wells and Dillon Sit and Reach Test *(Source: J. Clark, DRDC)*

Trunk Lateral Flexion (Standing)

- Place a single inclinometer at the mid-level (T6) of the thoracic vertebra using a digital level as a vertical guide

- Adjust the level and inclinometer until a zero degree reading is observed and centered on the spine
- Instruct the participant to bend the trunk to the side (their right) as far as possible and record the inclinometer angle

Trunk Rotation

- Have the participant assume a forward flexed posture, as shown in Figure B6, with the thoracic spine in as horizontal a position as can be achieved
- Position the inclinometers on T1 and T12 as shown in Figure B6, and keep the inclinometers vertical
- Instruct the participant to rotate the trunk maximally to the right, and record both inclinometer angles (Refer to Figure B7)
- Repeat this process three times
- Rotation angle is calculated as the difference between the T12 and T1 inclinometer readings

Figure 53: Measuring Trunk Rotation (initial posture) *(Source: J. Clark, DRDC)*

Figure 54: Measuring Trunk Rotation (rotated posture) *(Source: J. Clark, DRDC)*

Annex D: Demographic Information Questionnaire

PERSONAL INFORMATION

Please provide the requested information in the spaces provided:

Participant Number	Service Number	MOS	Gender	
			☐ Male	☐ Female

Age (years)	Rank	Section Number	Platoon Number

Shooting Eye		Handedness	
O Right	O Left	O Right	O Left

Length of Service (Regular and Reserve)	
Years in Regular:	Years in Reserve:

What type of Weapon do you carry?

Operational Experience (by theatre) & Tour Duration (months) (eg. Afghanistan 12 months)

Fragmentation Vests

Do you have any experience with Fragmentation Vests? O Yes O No

If yes, please answer the following:

How many times have you worn a Fragmentation Vest?

O 1-5 training exercises O 6-10 training exercises O > 10 training exercises

Months since last Personal Weapons Test (PWT) (please circle)												
<1	2	3	4	5	6	7	8	9	10	11	12	>12

Vision

Do you wear glasses or contact lenses? O Yes, glasses O Yes, contact lenses O No

Nicotine Use

Do you smoke cigarettes? O No O Yes If so, approximately how many cigarettes per day: ______

Do you use chewing tobacco? O No O Yes If so, approximately how many times per day: __________

Humansystems® Incorporated

List of Acronyms/Abbreviations

Acronym	Referent
ANOVA	Analysis of Variance
BEW	Ballistic Eyewear
CAN-LEAP	Canadian Load Effects Assessment Program
CBRN	Chemical Biological Radiological Nuclear
CF	Canadian Forces
CFB	Canadian Forces Base
CFSTG	Canadian Forces Support Training Group
DAOD	Defence Administrative Orders and Directives
DND	Department of National Defence
GSR	General Service Respirator
HR	Heart Rate
LED	Light-Emitting Diode
mCAFT	Modified Canadian Aerobic Fitness Test
MERS	Marine Expeditionary Rifle Squad
MOPP	Mission Oriented Protective Posture
MOS	Military Occupational Specialty
PDA	Personal Digital Assistant
PM	Program Manager
PRR	Personal Role Radio
RFID	Radio-Frequency Identification
ROM	Range of Motion
RPE	Rating of Perceived Exertion
SD	Standard Deviation
SME	Subject Matter Expert
SRS	System Requirement Specifications
USMC	United States Marine Corps

DOCUMENT CONTROL DATA

*Security markings for the title, authors, abstract and keywords must be entered when the document is sensitive

1. ORIGINATOR (Name and address of the organization preparing the document. A DRDC Centre sponsoring a contractor's report, or tasking agency, is entered in Section 8.)

   HumanSystems Inc.
   111 Farquhar Street
   Guelph (Ontario) N1H 3N4
   Canada

2a. SECURITY MARKING (Overall security marking of the document including special supplemental markings if applicable.)

   CAN UNCLASSIFIED

2b. CONTROLLED GOODS

   NON-CONTROLLED GOODS
   DMC A

3. TITLE (The document title and sub-title as indicated on the title page.)

   Can-LEAP Simulated Combat Mobility Performance: Summary Results of Testing With Varying In-Service Chemical, Biological, Radiological and Nuclear (CBRN) Equipment Conditions (Borden, 2013)

4. AUTHORS (Last name, followed by initials – ranks, titles, etc., not to be used)

   Bray-Miners, J.; Kelly, A.E.

5. DATE OF PUBLICATION (Month and year of publication of document.)

   February 2016

6a. NO. OF PAGES (Total pages, including Annexes, excluding DCD, covering and verso pages.)

   93

6b. NO. OF REFS (Total references cited.)

   21

7. DOCUMENT CATEGORY (e.g., Scientific Report, Contract Report, Scientific Letter.)

   Contract Report

8. SPONSORING CENTRE (The name and address of the department project office or laboratory sponsoring the research and development.)

   DRDC – Toronto Research Centre
   Defence Research and Development Canada
   1133 Sheppard Avenue West
   Toronto, Ontario M3K 2C9
   Canada

9a. PROJECT OR GRANT NO. (If appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant.)

   02ab - Soldier System Effectiveness (SoSE)

9b. CONTRACT NO. (If appropriate, the applicable number under which the document was written.)

   W8486-151643/001/ZH

10a. DRDC PUBLICATION NUMBER (The official document number by which the document is identified by the originating activity. This number must be unique to this document.)

   DRDC-RDDC-2018-C262

10b. OTHER DOCUMENT NO(s). (Any other numbers which may be assigned this document either by the originator or by the sponsor.)

   Task Auth 4501375119

11a. FUTURE DISTRIBUTION WITHIN CANADA (Approval for further dissemination of the document. Security classification must also be considered.)

   Public release

11b. FUTURE DISTRIBUTION OUTSIDE CANADA (Approval for further dissemination of the document. Security classification must also be considered.)

12. KEYWORDS, DESCRIPTORS or IDENTIFIERS (Use semi-colon as a delimiter.)

Mobility; CanLEAP; Human/Soldier Performance; Human Performance; Load-induced performance impairment; Performance; CBRN (Chemical Biological Radiological Nuclear); Protection; Physical Protection; Marksmanship

13. ABSTRACT/RÉSUMÉ (When available in the document, the French version of the abstract must be included here.)

The Canadian Load Effects Assessment Program (CAN-LEAP) was developed in order to determine the implications of soldier equipment configurations and loads on soldier mobility and simulated combat task performance. A study of opportunity was conducted at CFB Borden while participating in the development and validation of a user evaluation protocol for the Joint General Service Respirator (JGSR) acquisition project. Twenty-one Regular Force volunteers participated in one week of data collection. Participants completed the CAN-LEAP course in four different in-service test conditions: two CBRN Mission Oriented Protective Posture (MOPP) levels (MOPP 1 and MOPP 4), a crowd control variant (respirator only), and a non-CBRN battle load baseline condition. The CAN-LEAP consisted of an instrumented obstacle course, marksmanship component, vertical and horizontal weight transfers, vertical jump and a subjective questionnaire. A significant difference between conditions was found during all of the CAN-LEAP components. The addition of the respirator and the CBRN clothing in the closed state were found to cause the most noteworthy performance decrements.

Le Programme canadien d’évaluation des effets de la charge (CAN-LEAP) a été mis au point afin de déterminer les incidences des configurations et des charges de l’équipement des soldats sur la mobilité des soldats et la performance des tâches de combat simulées. Une étude d’opportunité a été réalisée à la BFC Borden, tout en participant à l’élaboration et à la validation d’un protocole d’évaluation des utilisateurs pour le projet d’acquisition du respirateur général mixte (JGSR). Vingt et un volontaires de la Force régulière ont participé à une semaine de collecte de données. Les participants ont suivi le cours CAN-LEAP dans quatre conditions de test en service différentes: deux niveaux de posture de protection orientée mission (MOPP) CBRN (MOPP 1 et MOPP 4), une variante de contrôle des foules (respirateur uniquement) et une charge de combat non CBRN condition de base. Le CAN-LEAP consistait en un parcours d’obstacles instrumenté, une composante de tir, des transferts de poids verticaux et horizontaux, un saut vertical et un questionnaire subjectif. Une différence significative entre les conditions a été constatée pour toutes les composantes de CAN-LEAP. L’ajout du respirateur et des vêtements CBRN à l’état fermé s’est avéré causer les baisses de performance les plus notables.