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ASSESSING THE IMPACT OF CLOTHING AND INDIVIDUAL EQUIPMENT (CIE) ON SOLDIER PHYSICAL, BIOMECHANICAL, AND COGNITIVE PERFORMANCE

PART II: DATA ANALYSIS

by
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June 2016 – October 2016

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14. ABSTRACT
The objective of this study was to establish a test methodology utilizing an operational scenario for assessing the effects of clothing and individual equipment (CIE) on Soldier physical and cognitive performance. This objective was accomplished by translating established scientifically based cognitive and physical metrics into an integrated field test battery/scenario. The 4-hour scenario was undertaken on each of 3 days wearing CIE configurations entailing load carriage ranging from approximately 10 to over 50 kg. The complete methodology was previously reported in Hasselquist et al. (2018) Part 1: Test Methodology. The results are reported herein, Part II: Data Analysis Cognitive results showed that performing a road march wearing CIE degrades cognitive control processes, primarily response inhibition. Human factors results showed that the Load Effects Assessment Program (LEAP) obstacle course and both static and dynamic marksmanship scenarios are sensitive to difference in equipment configuration, whereas the Military Operations in Urban Terrain (MOUT) exercise was sensitive to differences in configuration for measures of mobility, but not lethality or decision making. Biomechanics results showed that measurement techniques could be successfully implemented in field settings, and that measures such as inertial measurement unit (IMU) derived performance degraded with heavier body-borne loads. Together, the results suggest that physical and cognitive measures of Soldier performance change as a function of CIE, and that the present operationally-relevant scenario is sensitive to detect such changes.

15. SUBJECT TERMS
TARGETS WALKING BIOMECHANICS MAXIMAL EFFORT FATIGUE(PHYSIOLOGY)
RUNNING CRAWLING METHODOLOGY RANGE OF MOTION PERFORMANCE(HUMAN)
BALANCE OBSTACLES DATA ANALYSIS DATA COLLECTION COGNITIVE PERFORMANCE
METRICS FIELD TESTS LOAD CARRIAGE OBSTACLE COURSES EQUIPMENT CONFIGURATION
MISSIONS SCENARIOS MARKSMANSHIP TEST METHODOLOGY POSITION(LOCATION)
MOBILITY MOVEMENTS FOOT MARCHING CIE(CLOTHING AND INDIVIDUAL EQUIPMENT)
TRAINING LOADS(FORCES) HUMAN FACTORS PPE(PERSONAL PROTECTIVE EQUIPMENT)

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PREFACE

The study reported here was carried out by personnel of the Biomechanics and Engineering, Cognitive Science, Human Factors, Anthropometry Teams and personnel from the Warfighter Directorate, U. S. Natick Soldier Research, Development and Engineering Center (NSRDEC) (now the U.S. Army Combat Capabilities Development Command Soldier Center). Work was performed form June 2016 to October 2016. Additional personnel support was provided by the U. S. Army Test and Evaluation Center. The effort was funded in house by NSRDEC under the entitled Program 14-021, "Soldier Equipment Configuration Impact on Performance: Establishing a Test Methodology for the Assessment of Clothing and Individual Equipment". The researchers were tasked with developing an operationally relevant methodology and scenario for the assessment of clothing and individual equipment.

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EXECUTIVE SUMMARY

The work for this project was performed from June 2016 to October 2016 by the Natick Soldier Research, Development and Engineering Center (NSRDEC), now known as the U.S. Army Combat Capabilities Development Command (CCDC). The Army continually seeks to improve the clothing and equipment used to protect the individual Soldier. The Army has typically assessed the acceptability of next-generation or novel protective equipment, as well as of field clothing, through limited user evaluations of the items by Soldiers. The results of these assessments have consisted mainly of subjective data regarding the test items, in the form of participants' comments and opinions after performing simulated mission activities. While previous assessments have gleaned useful information, these assessments have been limited in how they have investigated the quantitative effects that the test items have on Soldiers' performance of militarily relevant activities. And while laboratory studies provide a rich literature on cognitive and physical performance under conditions of load carriage that simulate some of the mission relevant conditions Soldiers are asked to perform, there is additionally a need to assess equipment in a more operationally relevant environment and context. There is a need to create and validate a reliable and operationally relevant test-bed for a science-based evaluation of the cognitive, physical performance, and human factors impacts due to clothing and individual equipment (CIE). From a cognitive science perspective, findings suggest that performing a foot march wearing CIE such as the plate carrier body armor and IOTV degrades cognitive control processes, primarily response inhibition. From a human factors perspective, the timing portion of the obstacle course was found to be sensitive to the differences in configuration and, even with the hard stops before and after each obstacle, can still be used to assess the effects of equipment on physical performance. For marksmanship, findings suggest that both static and dynamic marksmanship scenarios are necessary to fully assess the effects of equipment on the marksmanship process in its entirety. These scenarios were found to be sensitive to changes in CIE configuration. The MOUT scenario was only sensitive to configuration changes for measures of mobility, but not lethality or decision making. From a biomechanics perspective, the IMU-derived performance measures generally revealed marked degradations in performance with heavier body-borne loads. Together, the results suggest that physical and cognitive indices of Soldier performance change, and often degrade, as a function of CIE, and that the present operationally-relevant scenario is sensitive to detect such changes.

ASSESSING THE IMPACT OF CLOTHING AND INDIVIDUAL EQUIPMENT (CIE) ON SOLDIER PHYSICAL, BIOMECHANICAL, AND COGNITIVE PERFORMANCE PART II: DATA ANALYSIS

1. Introduction

Work for this project was performed from June 2016 to October 2016 by the Natick Soldier Research, Development and Engineering Center (NSRDEC), now the U.S. Army Combat Capabilities Development Command (CCDC).

1.1. General Overview

How clothing and individual equipment (CIE) impacts Soldier performance has been researched from various points of view: how is range of motion affected, how do gait and other kinematics change, how is the ability to make decisions affected? However, a more multi-faceted approach has not been taken where all of these impacts of equipment on physical, biomechanical, and cognitive performance are measured at the same time. The study reported here was part of a larger effort to develop a test methodology for assessing the impact of CIE on performance. It is beyond the scope of this paper to describe that methodology or motivation for developing the methodology. The reader is referred to the report: "Assessing the Impact of Clothing and Individual Equipment (CIE) on Soldier Physical, Biomechanical, and Cognitive Performance Part 1: Test Methodology" for specific details on the test methodology (Hasselquist et al., 2018). The current study implements the proposed methodology which simultaneously measures performance from these different domains while Soldiers participate in dynamic tasks mimicking training and operationally relevant scenarios. The goal of this study is to provide an assessment of the methodology and establish a broad view of the impact of equipment and clothing the Soldiers wear on all aspects of Soldier performance. By collecting these measures together, relationships between physical and cognitive aspects of performance can be investigated.

1.2. Literature Review

1.2.1. Human Performance and Load

In the following sections, literature from four different areas is reviewed: biomechanical, cognitive, physiological, and human factors to provide context for the method and outcome measures that have been chosen for this study.

1.2.2. Physical Performance with Equipment Load

Much of the research related to the carrying of loads by Soldiers has involved quantification of the effects that the mass of the external load has on energy consumption, with the rate of oxygen uptake ($\dot{V}O_2$) used as an indicator of energy consumption (Knapik, Harman, & Reynolds, 1996). Findings from the research have been used to guide development of military load-bearing equipment (Winsmann & Goldman, 1976), set design goals for maximum masses of Soldier loads (Kennedy, Goldman, & Slauta, 1973), and inform military commanders in the field regarding procedures for conducting foot marches (Department of the Army, 1990). There are few studies in which biomechanical measures have been recorded in association with prolonged bouts of load carrying. Gait data were acquired in a study conducted by Frykman, Harman, Knapik, & Han (1994), but only at the beginning and the end of a period of load carrying (Frykman, Harman, Knapik, & Han, 1994). In another study (Bobet & Norman, 1982), data were acquired intermittently over the course of a bout of walking with a load, but the data were limited to electromyographic (EMG) measures; gait kinematics were not recorded. Furthermore, no studies have been carried out in which physiological and biomechanical responses to prolonged load carrying have been recorded simultaneously in a field setting. The literature also suggests that, in addition to the mass it represents, ballistic protective equipment encumbers or restricts body movements, further contributing to negative effects on physical performance (Hasselquist, Bensel, Corner, & Gregorczyk, 2012).

1.2.3. Cognitive Performance with Equipment Load

Current knowledge on cognitive effects of CIE stems from extant research on physical exertion and cognition, as well as more applied work on load carriage and cognition. Physical exertion has both beneficial and detrimental effects on cognitive performance. The direction of the effects depends on factors internal to the individual, such as physical fitness, and those external to the individual, such as the cognitive domain, timing of cognitive testing, and physical exertion intensity and duration (Tomporowski, 2003, but see also Chang, Labban, Gapin, & Etnier, 2012). Certain cognitive domains improve as a function of physical exertion intensity, such as implicit, procedural processes including simple decisions and response time. Other domains of cognition, such as those requiring higher level cognitive processes, including executive functions, are more susceptible to impairment (Dietrich & Audiffren, 2011). Executive functions, also called cognitive control processes, consist of mental set shifting (moving back and forth between tasks, mental operations etc.), information updating (receiving updated intelligence on an operation), and inhibition (holding back a response such as firing a weapon), all of which are thought to rely on the frontal lobe (Miyake et al., 2000). These types of cognitive processes are integral to tasks that Soldiers are asked to perform during missions under conditions of physical fatigue.

A growing body of research has examined the influence of acute bouts of exercise on cognitive control. Moderate intensity exercise has been shown to not affect or improve executive function (Davranche, Hall, & McMorris, 2009; Sibley & Beilock, 2007). Vigorous intensity physical exertion has been shown to impair executive function performance on tasks such as the Wisconsin Card Sorting Task (WCST), which asks participants to sort cards based on changing rules and measures set-shifting, and the Simon Task, which asks participants to respond to stimuli that are either on the same (i.e. congruent) or opposite (i.e. incongruent) sides of the screen and measures response inhibition (Davranche & McMorris, 2009; Del Giorno, Hall, O'Leary, Bixby, & Miller, 2010; Dietrich & Sparling, 2004). The majority of such studies investigating the influence of physical exertion on cognitive control have focused on relatively short bouts of exertion, ranging from 15 to 45 min, and fewer have examined prolonged physical exertion. For instance, 3 h of vigorous intensity physical exertion enhances attention allocation between the first and second hour of exercise but produces decrements in information processing speed upon beginning the second hour of exercise (Grego et al., 2004). Similar results were found for participants' processing speed (i.e. their ability to distinguish between rapidly presented stimuli), and map recognition (i.e. their recognition of previously encoded maps), which improved after the first hour of cycling but declined after 2 h of cycling in trained athletes (Grego et al., 2005). Thus performance in both simple and complex cognitive domains may improve during exercise of up to 2 h, but it generally declines thereafter (Collardeau, Brisswalter, & Audiffren, 2001; Collardeau, Brisswalter, Vercruyssen, Audiffren, & Goubault, 2001; Grego et al., 2004, 2005).

Research demonstrating physical exertion effects on cognitive function under unloaded conditions is informative for athletes, but research on physical exertion under conditions of load carriage is necessary to understand cognition in physically exerting scenarios commonly undertaken by military personnel such as making decisions to change route during an approach march. A handful of studies have undertaken such applied work. First, Knapik and colleagues (1993) evaluated the influence load carriage (34, 48 and 61 kg in the All Purpose Lightweight Individual Carrying Equipment (ALICE) pack and an experimental doublepack for 20 km) on a cognitive task that simultaneously tested memory, arithmetic, visual, and auditory monitoring. Cognitive performance after the march did not differ from before the march (Knapik, Johnson, Ang, Meiselman, & Bensel, 1993). More recent studies evaluated cognition during load carriage. For instance, Mahoney and colleagues (2007) found that load carriage (40 kg for 30 min) impaired vigilance performance, particularly when walking over and around obstacles, relative to standing (Mahoney, Hirsch, Hasselquist, Lesher, & Lieberman, 2007). Kobus and colleagues (2011) assessed the influence of a 0, 98 or 61.2 kg combat load on cognition during 2 h of simulated dismounted patrol (treadmill walking at 2.0 mph, 0% grade). They found that carrying 61 kg impaired target detection and spatial and verbal memory (Kobus, Brown, Wu, Robusto, & Bartlett, 2010). In recent work from this group, Soldiers walked on a treadmill for 2 h at a constant or variable incline, while wearing 0 or 40 kg load, and completing a go/no-go task of response inhibition and a visual target detection task. Response inhibition performance declined in the loaded condition, as evidenced by an increased proportion of false alarms and slowed response times. Visual target detection response time also slowed in the loaded condition, but accuracy did not (Eddy et al., 2015). Thus, laboratory work suggests that CIE influences cognitive processes across a number of load configurations and exertion intensities and durations.

However, limited work has translated such laboratory research to more operationally-relevant scenarios. Among the few, Haas, Crowell, and Kehring (2014) examined the effect of carrying a 24 kg fighting load on navigation and radio check tests during a warehouse navigation task. Under loaded conditions, Soldiers exhibited slower navigation time but faster radio check response times, with no concurrent effects on accuracy (Haas, Crowell, & Kehring, 2014). However, average navigation time was 10 to 11 min, and thus research on longer durations is necessary to understand the effects of prolonged exertion.

Thus, preliminary evidence from both the laboratory and field suggest that load carriage during physical exertion impairs certain cognitive processes, particularly those requiring cognitive control. Thus, one objective of the present research was to extend previous laboratory findings that CIE influences response inhibition performance, in an operationally-relevant 3-mile foot march scenario. Based on previous evidence that response inhibition declines (Eddy et al., 2015), the project team predicts decrements in performance as a function of CIE on the same go/no-go response inhibition task, modified to be used in an operational scenario.

1.2.4. Human Factors Performance with Equipment Load

The focus area of human factors and ergonomics is on the interaction between the human user and product or surroundings, and how that interaction affects the ability for the human to conduct their required work. The effects of CIE on both human factors aspects of performance and the ability for a wearer to complete their work-related tasks have previously been documented primarily with personal protective equipment (PPE) and athletic gear.

The primary work tasks in military mission performance include the ability to move, shoot, and communicate. Each of these areas have been explored in isolation, primarily in the laboratory setting. The interference of CIE on range of motion and mobility has been explored in recent years, particularly identifying the negative effects of torso-borne bulk and mass encumbrances on static range of motion (Mitchell, Choi, & Garlie, 2017) and the ability to move through a combat obstacle course (Batty, Coyne, DeSimone, Mitchell, & Bensel, 2016; Bray-Miners & Kelly, 2013; Dutton & Stryker, 2015; Hasselquist et al., 2013, 2012; Mitchell et al., 2016; Mitchell, Brown, Villa, & Garlie, 2018; Pandorf et al., 2002; Stevenson, Reid, Bryant, Pelot, & Morin, 2001; Tack, Kelly, Richter, & Bray-Miners, 2012) as well as isolated task-oriented activities such as jumping, crawling and climbing (Brainerd & Bruno, 1985; Brewster, 2014; LaFiandra et al., 2003). However, none of these studies integrated fully body fatiguing events prior to the testing scenario, mimicking the potential state a Soldier would be in while executing real mission tasks. Thus, one of the primary objectives of this current research includes studying the Soldier's ability to complete mission related movements both in a combat obstacle course and a building clearing task, after a fatiguing march during a field scenario.

Additionally, the effects of CIE on marksmanship precision and shooting ability has been assessed primarily utilizing a static, slow paced shooting scenario (Bensel, 1997; Carbone, Carlton, Stierli, & Orr, 2014; Johnson & Kobrick, 1997; Johnson, McMenemy, & Dauphinee, 1990; Kramlich, 2005; Smith, Taylor, Brammer, Toone, & Rubia, 2006). A majority of this work has been focused on PPE, specifically chemical biological protective suites (Bensel, 1997; Johnson & Kobrick, 1997; Taylor & Orlansky, 1991). However, not many previous studies have assessed the effects of general CIE typically worn by a Soldier on a daily basis on marksmanship performance. In addition, limited work has looked at the effects of CIE on shooting performance in a more dynamic and operationally relevant scenario (McNamara, Choi, Brown, Hennessy, & Mitchell, 2016; Palmer, Bigelow, & Van Emmerik, 2013). McNamara et al. (2016) and Choi et al. (2016) did examine the effects of CIE on marksmanship performance during a static marksmanship task that required transition and engagement of multiple targets, but both showed few differences in lethality performance across CIE encumbrance levels, primarily in timing or measures of shooting speed (Choi et al., 2016). However, subjective measures of perceived interference on marksmanship performance from worn CIE were reported as higher with increased encumbrance levels. Thus, one objective of this current study was to capture the perceived interferences in performance in an objective and quantifiable manner. This current study has expanded the marksmanship testing methodology to include two separate events. The marksmanship shooting scenario was more active, including greater transition arcs and a dynamic running, acquisition and engagement portion, requiring gross full-body movements of the participant. This results in the need to fully reposition the body, weapon, and realign the sights prior to each target engagement. Additionally, there is a building clearing scenario that integrates cognitive decision-making skills. The integrated assessment of movement and lethality makes the methodology more holistic and operationally relevant than previous research, and captures objective measures of marksmanship performance decrements across the marksmanship process in its entirety.

1.2.5. Overview of Methodology

For overview of methodology, see Test Methodology report (Hasselquist et al., 2018). Conditions I, II, and III refer to:

- Condition I: No body armor, ancillary equipment consisting of an advanced combat helmet (ACH), boots, Army combat uniform (ACU), and mock M4 carbine (7.3 kg, 9.3 kg with small tablet pack for foot march).
- Condition II: Plate carrier (Soldier Plate Carrier System (SPCS)) body armor with front, back, and side plates plus ancillary equipment consisting of ACH, boots, ACU, mock M4 carbine, and a representative fighting load (30.8 kg, 46.2 kg with loaded assault pack of soldier items).
- Condition III: Body armor vest Improved Outer Tactical Vest (IOTV) with front back and side plates, groin, kidney, shoulder, neck/throat protection plus ancillary equipment consisting of ACH, boots, ACU, mock M4 carbine, and a representative fighting load (35.7 kg, 51.1 kg with loaded assault pack of soldier items).

2. Methods

2.1. Test Participants

A total of 62 male, active duty Soldiers from the 82nd Airborne Division volunteered as participants. The group reported their military occupational specialty (MOS) as 11B (Infantry). The participants represented a healthy Soldier population and met all physical and injury screening criteria for the institutional review board (IRB) approved study. The demographics are listed in Table 1. Participants had a time in service of between 1-17 years (M=3.4, SD=2.8). Thirty-six of the participants (58%) had never deployed, while the remaining 26 (42%) had deployed 1-3 times. Of those with deployment experience, 25 had deployed to Afghanistan and one had deployment experience in Iraq.

Table 1. Participants' Demographics (n = 62).

	Range	Mean (SD)
Age (y)	19 - 35	24.1 (3.87)
Body Mass (kg)	57.51 - 107.39	80.63 (11.9)
Height (m)	1.58 – 1.91	1.75 (0.78)
$\dot{V}O_{2Peak}$(ml/kg/min)*	38.77 - 59.86	49.95 (5.16)
Respiratory Exchange Ratio (RER)*	1.12 - 1.38	1.23 (0.06)
Body Fat (%)*	6.76 – 27.00	18.94 (4.95)

*Refer to Section 2.1.1 for definition and calculation methods.

The group was comprised mostly of junior enlisted Soldiers, with 45 participants (73%) having a pay grade of E4 (rank of Specialist) or lower. The rest of the participant group (27%) was made up of non-commissioned officers (NCOs), 12 of whom were grade E5 (Sergeant) and 5 of whom were grade E6 (Staff Sergeant). The group was also made up of several ethnic/racial backgrounds. The majority (69%) reported their racial background as White, not Hispanic. The second largest racial group reported (15%) was Hispanic. Table 2 presents a breakdown of the participant group's Ethnic/Racial information.

Table 2. Participants' Reported Ethnic/Racial Groups (n = 62)

Ethnic/Racial Group	Count
White, not Hispanic	43 (69.4%)
Black, not Hispanic	2 (3.2%)
Hispanic	9 (14.5%)
Native American	1 (1.6%)
Asian/Pacific Islander	2 (3.2%)
Mixed	3 (4.8%)
Other	1 (1.6%)
Don't Know/Prefer Not to Answer	1 (1.6%)

2.1.1. Participants' $\dot{V}O_{2Peak}$ Aerobic Fitness, Respiratory Exchange Ratio, and Body Fat % Determination

The determination of peak maximum oxygen capacity ($\dot{V}O_{2Peak}$) was completed on a day on which no other physical activities were scheduled. Peak oxygen uptake was measured using a continuous, uphill, stepwise, treadmill protocol. No load was worn during the $\dot{V}O_{2Peak}$ assessment. A study team member experienced and credentialed in such testing monitored the participant's heart rate throughout the testing. The participant first warmed up by running on the treadmill for 5 min at 2.22 m/s on a level grade. After a 5-min rest, the participant began running on the treadmill at a 5% grade and at a speed determined to be easy-to-moderate based on the participant's heart rate during the warm-up run. The participant wore a lightweight mask that covered the oronasal portion of the face. The mask was connected by a flexible hose to a Quark CPET metabolic cart (COSMED, Rome, Italy), which monitored oxygen uptake. Every 2 min, the treadmill grade was increased by 2.5%, without changing the treadmill speed. The test continued until the participant achieved $\dot{V}O_{2Peak}$ based on American College of Sports Medicine (ACSM) criteria (American College of Sports Medicine, 2010). Specifically, three of the following criteria were met: VO2 plateaus (change no greater than 2.0 mL/kg/min over two collection cycles); Respiratory Exchange Ratio (RER) > 1.10; or Heart Rate > [220-age] bpm.

The respiratory exchange ratio (RER) is the ratio of the net output of carbon dioxide to the simultaneous net uptake of oxygen at a given site, both expressed as moles or STPD volumes per unit of time; in the steady state, RER is equal to the respiratory quotient of metabolic processes ($RER = VCO_2 / VO_2$). This formula determines the rate of metabolic energy expended per unit of time when measured by beats per minute. It is an effective means to evaluate aerobic capacity during strenuous activity. It measures how efficiently the lungs function within a single breath during exercise (American College of Sports Medicine, 2010).

The body fat percentage calculation followed the methods recommended for use in the Army Regulation 600-9 the Army Body Composition Program. This method for male Soldiers utilizes measurements of height, weight, neck and abdominal circumference to calculate percentage of body fat. Body composition is one indicator of physical readiness that is associated with an individual's fitness, endurance, and overall health. Individuals with desirable body fat percentages generally exhibit increased muscular strength and endurance, are less likely to sustain injury from weight bearing activity, and are more likely to perform at an optimal level (American College of Sports Medicine, 2010).

2.1.2. Participants' Reported Fitness and Health History

The participants reported their last Army Physical Fitness Test (APFT) and Rifle Marksmanship Qualification scores. Out of a possible APFT score of 300, the participants had a mean score of 267 (SD=23.51, min=205, max=300). Table 3 shows a breakdown of the APFT events, including score results for push-ups, sit-ups, and 2-mile run time. Marksmanship scores ranged between 25 and 40 points, with a mean of 36.8 (SD=2.51), out of a possible 40 points. The participants' marksmanship scores qualified 50 of them as Experts, 11 as Sharpshooters, and 1 as Marksman.

Table 3. APFT Event Mean Scores (n=62)

	Mean		Range
Overall APFT score	267.0	± 23.51	205-300
Number of push-ups	67.9	± 10.20	48-87
Number of sit-ups	73.6	± 8.54	54-93
2 Mile run time (s)	851.7	± 73.11	668-1025

The participants reported on the amount of time they spent performing several weekly leisure and physical activities. In regards to physical activities, they noted engaging in cardiovascular activities a mean of 4.4 days a week (SD=1.18), 1.4 h a day (SD=1.22). Additionally, the participants stated they engaged in playing sports a mean of 2.2 days a week (SD=1.34), 1.3 h a day (SD=0.63) and weight lifting activates a mean of 4.6 days a week (SD=1.61), 1.5 h a day (SD=0.97). Regarding leisure activates, the group reported engaging a mean of 5.7 days (SD=1.56) and 4.7 days (SD=1.96) a week on watching TV/movies and playing video games, respectively. See Table 4 for further details of the time spent on these physical fitness and leisure activities.

Table 4. Typical Time Spent on Weekly Activities.

	Days Per Week			Hours Per Day		
Activity Type	Mean		Range	Mean		Range
Cardiovascular	4.4	± 1.18	1-7	1.4	± 1.22	0.5-8
Playing sports	2.2	± 1.34	1-7	1.3	± 0.63	0.5-3
Weight lifting	4.6	± 1.61	1-7	1.5	± 0.97	0.5-7
Watching TV/movies	5.7	± 1.56	1-7	2.3	± 1.36	1.0-8
Playing video games	4.7	± 1.96	1-7	1.9	± 1.30	0.5-6

The participants were also asked to provide information on prior serious injuries. Serious injuries were described as injuries that needed medical attention, changed daily activities, or caused missed days at school or work. Nine participants (15%) reported having been previously injured and needing surgery to repair the injury. Of these participants, five stated that the surgery occurred between 5-10 years prior to participating in the study. The surgeries of the other four participants had occurred greater than 10 years prior to participating in the study.

The participants were also asked to specify the body locations where they had suffered serious injuries and if said injuries had needed surgery to be repaired. The most common injury locations were the head and lower back, with six participants reporting injuries in each location. Analysis of the data found that surgery was needed in eight different injury locations. Though previously nine participants had reported needing surgery to repair injuries, this follow-up question found 10 instances in which surgery was needed (one participant reported four injuries that required surgery). A breakdown of the injury location data is displayed in Table 5.

Table 5. Body Injuries Reported by the TPs

Serious Injury Location	Number of responses who reported serious body injury	Within last 5 years?	Surgery required?
Head	6 (9.7%)	5	2
Neck	2 (3.2%)	1	1
Upper back	1 (1.6%)	1	-
Lower back	6 (9.7%)	5	1
Shoulder	3 (4.8%)	1	1
Arm	3 (4.8%)	1	1
Elbow	1 (1.6%)	1	-
Wrist	3 (4.8%)	1	-
Hip	-	-	-
Upper leg	-	-	-
Knee	5 (8.1%)	3	2
Lower leg	1 (1.6%)	-	1
Ankle	4 (6.5%)	3	1
Foot	4 (6.5%)	4	-

Information on the participants' dominant side for their extremities and eyes was also recorded. When asked with what hand they preferred writing, the majority of the group (87%) reported a preference for righthandedness. When asked which eye they preferred when shooting, most of the group (90%) stated a preference for the right eye. Regarding which leg side they preferred when kicking a ball, the group again showed a preference for the right side, with 95% of the group expressing this preference.

The participants also provided information on their use of vison correction items. Most of the group (79%) reported not using any form of vison correction. Of the 21% of soldiers who needed vision correction, eight (13%) reported using glasses and five (8%) reported using contacts.

The participants were asked to provide their habitual use of tobacco and caffeine. Regarding tobacco usage, 13 participants (21%) reported smoking/vaping tobacco and 21 (34%) reported chewing tobacco, 4 of these participants (7%) reported using both forms of tobacco. Those who used tobacco/electric cigarettes, smoked a mean of 7.2 times a day (SD=4.34). Those who chewed tobacco, reported using a mean of 3.7 times a day (SD=1.59). In regards to daily caffeine intake, the majority of the participant group (79%) reported using caffeine. Only about a fifth of the group (21%) did not consume caffeine. The 49 participants who reported they consumed caffeine were asked to state the daily amount of servings they consumed for several different sources of caffeine. The most common source of caffeine used was coffee, with 69% of participants consuming it a mean of 1.4 servings a day (SD=0.49). The second most commonly used source of caffeine was soda, with 37% of the group consuming it a mean of 1.9 servings a day (SD=1.08). Only three participants (6%) reported drinking energy drinks with a mean of 4.3 servings per day (SD=4.93). Energy drinks had the highest serving count per day, with one participant reporting consumption of 10 servings per day which increased the mean and standard deviation. A breakdown of the caffeine consumption data can be found in Table 6.

Table 6. Daily Servings of Caffeine Consumption.

Caffeine Serving Type	Caffeine Users (n=49)		Mean		Range
Coffee	34	(69.4%)	1.4	± 0.49	1-2
Soda	18	(36.7%)	1.9	± 1.08	1-4
Energy Drink	3	(6.1%)	4.3	± 4.93	1-10
Other	12	(24.5%)	1.3	± 0.62	1-3

2.1.3. Reported Body Armor/Military Gear Used and Carried

The participants provided information on the body armor vest system they used during their last deployment. Those with no deployment experience were asked to provide information on the vest system they are currently issued or typically wear during training scenarios. Overall, most (74%) reported using the SPCS. The next most commonly used body armor was the IOTV, which 15% of the participants reported using. Of those with deployment experience, 3 reported wearing the IOTV, 22 the SPCS, and 1 the Modular Tactical Vest (MTV). The majority of the participants (47%) reported wearing body armor sized Small. The next most common (29%) body armor size worn was Medium. Only six (10%) of the participants reported using a size Large body armor vest. Table 7 displays a breakdown the usage and sizes of the reported body armor vest systems worn.

Table 7. Reported Body Armor Vest System Usage and Sizes Worn

Body Armor Vest System

Vest System	All Participant (n=62)		Deployed Participants (n=26)	
OTV (front opening)	-		-	
IOTV (overhead/shoulder opening)	9	(14.5%)	3	(11.5%)
SPCS (plate carrier)	46	(74.2%)	22	(84.6%)
MTV (Modular Tactical Vest)	1	(1.6%)	1	(3.8%)
None	6	(9.7%)	-	

Body Armor Size Worn

Size	All Participant (n=62)		Deployed Participants (n=26)	
Extra Small (XS)	9	(14.5%)	4	(15.4%)
Small (S)	29	(46.8%)	11	(42.3%)
Medium (M)	18	(29%)	8	(30.8%)
Large (L)	6	(9.7%)	3	(11.5)
Extra Large (XL)	-		-	

The researchers measured the participants to find their predicted and best-fitting body armor vest sizes. Only 21 (34%) reported wearing a vest size that matched the best-fitting armor vest size. As stated earlier, most of the participants reported wearing Small size armor. However, after being measured and fitted, most (33, 53%) aligned better with a size Medium. Table 8 displays the count for the number of body armor sizes reported worn versus the actual best-fitting vest size worn during this evaluation.

Table 8. Reported Armor Size versus Actual Best-Fitting Size Worn

Body Armor Size	Reported Size Worn	Best-Fitting Size Worn
Extra Small (XS)	9	1
Small (S)	29	8
Medium (M)	18	33
Large (L)	6	19
Extra Large (XL)	-	1

Information on the type of armor plates the participants used with their body armor vest system was recorded. The participants were asked to report which of the possible armor plates (front, back, sides, none) they typically used with their vests. All 62 participants reported using the front armor plates. Fifty-nine participants (95%) reported using the back-armor plates and only 11 (18%) reported using the side plates. More information on the group's armor plate usage is displayed on Table 9.

Table 9. Reported Body Armor Plate Usage

Plate Type Used	All Participants (n=62)	Deployed Participants (n=26)
Front	62 (100%)	26 (100%)
Back	59 (95.2%)	25 (96.2%)
Sides	11 (17.7%)	10 (38.5%)

In addition to the armor plates used, the participants were also asked about the armor vest add-ons components they wore. All but 2 of the 62 participants (97%) reported using no add-on armor components. One participant reported using both the yoke and groin protector add-ons. One participant noted using the leg extremity armor add-on.

The participants were asked to estimate the number of hours a day they wore body armor during a deployment. Though the majority of the participants (58%) had no deployment experience, 26 (42%) were able to provide an estimate. The amount of wearing time ranged between 3 and 15 h, with a mean of 9.6 h a day (SD=3.59) for those with deployment experience.

Information on the weapons used and carried by the participants was also gathered. Most of the participants (76%) reported using an M4 carbine during deployments or when training in dismounted patrol type activities. The second most used weapon was the Squad Automatic Weapon (SAW), with 16% of participants reporting using this weapon. Only three (5%) reported using the M240L weapon. One participant reported using the MK14 EBR and another one did not provide an answer. None of the participants reported using the M16 carbine.

The group was also asked to provide information on the load they typically carry on dismounted patrols during deployments and/or training, and were specifically asked to estimate the mass they typically carried. Sixty participants responded, and estimated carrying loads of between 18-73 kg (M=40.7, SD=13.8). Additionally, they noted the items they typically carried in their load. There appeared to be some confusion by the respondents and therefore, not all 62 participants responded to each equipment item of this part of the questionnaire. Responses ranged from 18 to 61 participants. A breakdown of this information can be found in Table 10.

Table 10. Equipment Typically Carried on Dismounted Patrols During Deployment/Training.

Item	Number of Responses	Number Who Reported They Carried the Item*		Number of Items Reported Being Carried By Each Participant**		
				Mean		Range
Hygiene kit	59	40	(64.50%)	1	± 0.00	1
IR chems	60	59	(95.20%)	3.4	± 2.21	1-10
Individual first aid kit (IFAK)	61	60	(96.80%)	1	± 0.13	1-2
Multipurpose tool	61	41	(66.10%)	1	± 0.00	1
Night vision device, with batteries	41	4	(6.50%)	5.8	± 4.19	3-12
Infrared strobe, small	59	25	(40.30%)	1	± 0.00	1
Strap cutter	44	32	(51.60%)	1	± 0.00	1
Body armor	61	59	(95.20%)	1	± 0.00	1
Hydration system (100 oz), with water	61	59	(95.20%)	1.1	± 0.25	1-2
ESAPI plates (front, back)	61	58	(93.50%)	1.2	± 0.37	1-2
Tactical assault panel (TAP)	60	37	(59.70%)	1	± 0.00	1
Helmet	61	60	(96.80%)	1	± 0.00	1
Spectacles	59	40	(64.50%)	1.2	± 0.45	1-3
Goggles	59	19	(30.60%)	1	± 0.00	1
Magazines	61	58	(93.50%)	7.3	± 1.64	1-14
Water canteen (1 qt), with water	60	41	(66.10%)	1.5	± 0.74	1-5
HE rounds	58	15	24.20%	9.1	± 5.80	3-21
Frag grenades	58	11	17.70%	2	± 0.45	1-3
Smoke grenades	58	16	25.80%	1.8	± 0.83	1-3
Batteries	41	40	64.50%	7.9	± 5.92	1-24
Radio	18	18	29%	1	± 0.00	1

* Non-respondents counted as not carrying the item.
** Not carried items were disregarded for these calculations

2.2. Materials/Stimuli

2.2.1. Questionnaires

Prior to execution of the test, participants completed a demographics questionnaire that was administered on a tablet computer. Following execution of each configuration, an additional configuration focused questionnaire was also administered on a tablet.

2.2.2. *Mission Performance (Heart rate, Rating of Perceived Exertion, Pain and Discomfort ratings)*

The heart rate of each participant was monitored during all testing sessions using the Garmin Forerunner 220. The Forerunner 220 measures essential data including distance, pace, and heart rate. In addition to using GPS to calculate distance and pace, the 220 has a built-in accelerometer. The accelerometer can also track distance when GPS is unavailable. This system consists of a wrist monitor and a chest strap. For this test event, each participant donned the chest strap prior to initiating each test session and wore it throughout testing. Data were collected continuously throughout each test session. The chest strap contained a transmitter that sensed heart rate and sent information about heart rate to the Garmin unit. The heart rate monitor was then interfaced with the Garmin software and information was stored for later analysis. Initial resting heart rate (HR) was recorded after sitting and after standing quietly for ~5 min. The HR monitor watch was started at the beginning of the dynamic marksmanship tasks, both foot march tasks, Load Effects Assessment Program (LEAP) and Military Operations in Urban Terrain (MOUT), and at the completion of each of these tasks. The participant's HR data were then downloaded at the end of the day from the Garmin Forerunner 220 Heart Rate Monitor into data files within the Garmin computer software. For each equipment condition, maximum and mean HRs were then calculated during specific tasks of the scenario (foot marches, LEAP, and MOUT tasks). The heart rate reserve (HRR) was then calculated as a measure of percentage of exertion (%Exertion) for each task using a modified equation from the Karvonen Method:

$$\textit{Target HR} = (\textit{fractional intensity})(HR_{max} - HR_{rest}) + HR_{rest} \qquad (1)$$

This method required the use of the HR_{max} recorded for each individual during their $\dot{V}O_{2Peak}$ test, the HR_{rest} recorded at the start of the day's trial, and the mean or maximum HR achieved during the task under analysis (i.e., foot march, LEAP, or MOUT). HRR relative to the maximum HR exhibited during each task ($HRR_{maxtask}$) was calculated by rearranging terms after the substitution of %Exertion for fractional intensity and $HR_{maxtask}$ for Target HR:

$$HRR\mathit{maxtask} = \%\text{Exertion} = \frac{HR_{maxtask} - HR_{rest}}{HR_{max} - HR_{rest}} \times 100 \qquad (2)$$

Similarly, HRR relative to the mean HR exhibited during each task ($HRR_{meantask}$) was calculated by substituting $HR_{meantask}$ for $HR_{maxtask}$:

$$HRR_{\text{meantask}} = \%\ \text{Exertion} = \frac{HR_{meantask} - HR_{rest}}{HR_{max} - HR_{rest}} \times 100 \qquad (3)$$

*Example: Assume a soldier achieved a $HR_{maxtask}$ of 195 bpm and a $HR_{meantask}$ of 165 bpm for the LEAP section. Their resting HR was 62 for that day. Their HR_{max} from the VO2peak test was 206 bpm. The Soldier's $HRR_{maxtask}$ on the LEAP course would be 92% and their $HRR_{meantask}$ would be 72%.

At intervals during the testing sessions, participants were asked to rate their level of perceived exertion using the Rating of Perceived Exertion (RPE) Scale (Borg, 1970). The RPE Scale is a method for measuring perceived exertion and effort in physical work. The RPE is commonly determined in clinical diagnostics, therapy and rehabilitation, training of athletes and recreational sports, and in epidemiological evaluations of exercise intensity and daily physical activities. The RPE scale ranges from 6 to 20. A rating of 6 to 11 (very light) would essentially be the range for warm-up and cool-down. A rating of 12 to 13 (somewhat hard) is approximately 60% of maximum heart rate. A rating of 16 to 20 (between hard and very hard) is associated with approximately 90% of maximum heart rate.

Before the start of a session and after volunteers finish each test session, they also completed a rating of pain, soreness, or discomfort (RPSD) questionnaire (Corlett & Bishop, 1976) to indicate the level of discomfort experienced during the exercise.

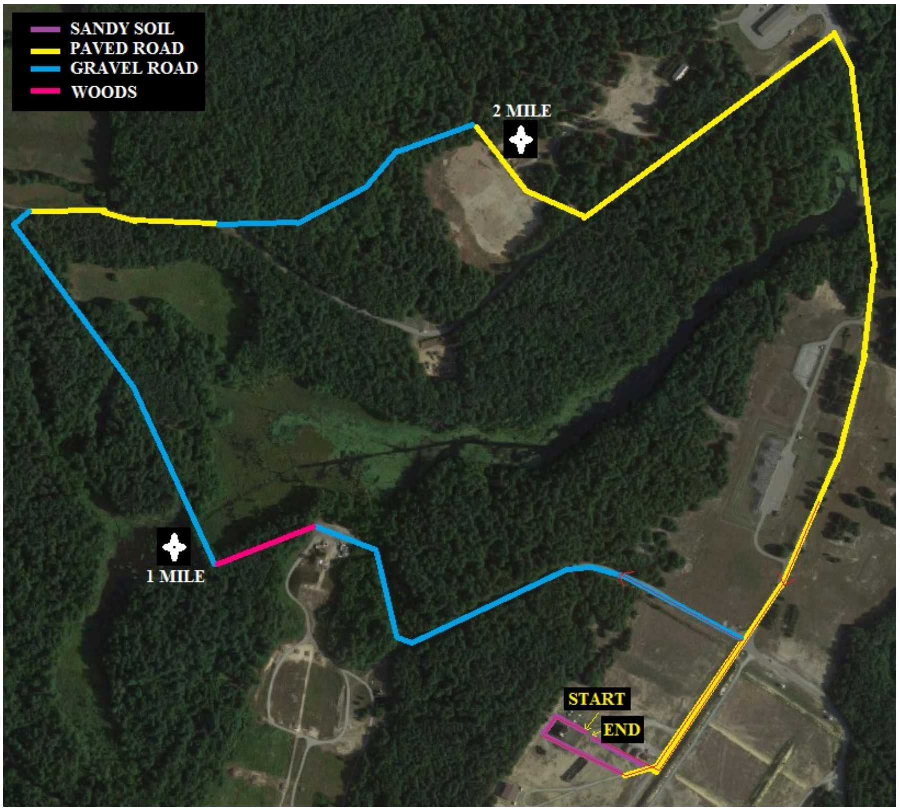
2.2.3. Dynamic Task Equipment

The equipment required for the dynamic marksmanship task includes the following: FN Expert weapon simulator, rifle, M68 close combat optical (CCO) sighting system, computer with NOS Pro software (associated with FN Expert weapon simulator) and Bluetooth, reflective scaled paper targets, target stands, and 30 ft by 20 ft open space.

The dynamic marksmanship event required the use of the FN Expert Weapon Simulator mounted on a demilitarized M4 carbine with an integrated CO2 recoil simulation system (LaserShot, Stafford, TX). The FN Expert Weapon Simulator utilizes an optical unit that is mounted on the barrel or Picatinny rail system of any weapon, and aligned with the weapon’s sighting system (in this case the M68 CCO). The unit emits an infrared (IR) light that is reflected off of specially designed reflective targets. The location of the beam hit on the target is processed by the NOS Pro software when the unit’s accelerometer detects the vibration of an operator pulling the trigger, providing x and y coordinates of hit location. The optical unit also provides a record of muzzle trace prior to shot, collecting data at .015 s intervals. These data provide insight on operator performance prior to shot execution during the acquisition and aiming phase. Additional equipment required for each marksmanship lane included four sets of paper targets with a diamond-graded reflective ring of 3” diameter with an embedded e-silhouette, scaled to simulate 75 m distance at an actual distance of 5 m. Each target was set on a stand at a height of 1.57 m.

2.2.4. Foot March, Biomechanics, Physiological, and Cognitive Task

The foot march route (Figure 1) was planned to require the participants to traverse over a variety of terrains and grades. This design perceptually challenged the participants while they were marching due to the varied terrain and grades. This was an important aspect of the march and enhanced the importance of the cognitive performance task. The terrain that the participants marched on consisted of paved, sand, dirt, gravel roads, and forest path. The varied grades of ascent and descent were no greater than +/-5% at any section of the course. The selected pace of 3 mph for the foot march with load was determined by the researchers to be a sufficient pace over the varied course terrain to elicit biomechanical and cognitive response differences in the participants across equipment conditions (Eddy et al., 2015).



Note: The start and end were located at the same point, and the 1-mile and 2-mile marks are displayed. The path terrain type is indicated by the path color.

Figure 1. Diagram of foot march route.

During the Foot march, participants performed a go/no-go task. For this task, participants were presented with AK-47 and M4 gunfire sounds through the headphones. The duration of each sound was 500 ms and the volume of both files was normalized. The task required participants to respond to AK-47 but not M4 gunfire using the response device. This task was performed for 5 min at a time, with short breaks in between. This go/no-go task had a frequent go stimulus (AK-47) that sets up a pre-potent response (i.e., one that is difficult to withhold) by having a large proportion of go trials and relatively few no-go trials (M4). The ratio of go to no-go tasks was 80% go and 20% no-go. During a given block of the task, there were 125 total stimuli (100 go trials, 25 no-go trials) for a total of 625 trials per road march (500 go trials, 125 no-go trials).

2.2.5. LEAP Obstacles

The LEAP system includes a variety of operationally relevant obstacles assembled by Human Systems, Inc. The obstacles in the course are designed to represent standard warfighter tasks, particularly in an urban environment. There are 10 obstacles in total, placed in a sequence with no rest breaks. The obstacles include the following in order of execution: hatch and tunnel, straight sprint, stair and ladder combination, zig-zag agility, casualty drag, two windows, five bounding rushes, angled balance beam with step-over obstacles, high crawl, and two walls. See Figure 2 for an illustration of the obstacles.

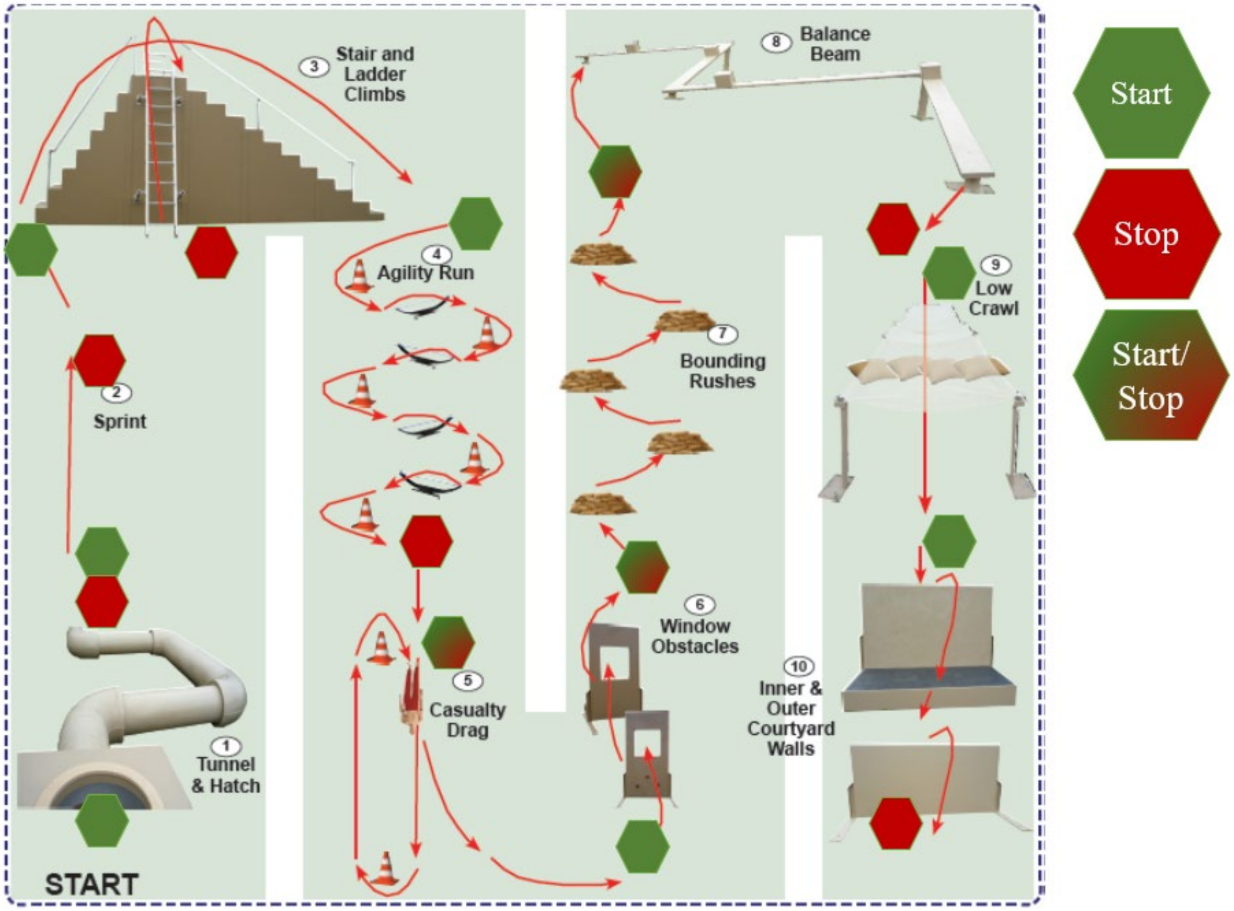


Figure 2. LEAP obstacle system layout and spacing distances (hexagons indicate start or stop points used for separation of obstacles).

2.2.6. MOUT task and targetry

The MOUT task utilized the FN Expert system, software, and demilitarized M4 as described in the dynamic marksmanship section above. However, the targets utilized for the MOUT task were different than the paper targets used in the dynamic task. The 14 targets in the MOUT were the NOPTEL NT-12 plywood target with NTM-10 hit indicator device consisting of prisms, hit indicator, and flash technology. These targets consist of a prism, target receiver, LED hit flash, and hit counter embedded on a wooden E-silhouette frame that is 152 x83 x 41 mm.

Each target also had an attached threatening or non-threating image for the go/no go engagement scenario. The pictures were selected based on their threatening nature (e.g. a weapon or device that could cause bodily harm, etc).

The MOUT task also required the use of a wrist-worn shot timer. This study used the Double Alpha Academy (DAA) SHOTMAXX timer. This device is a competition timer that detects the sound and vibration of a shot, and records the time at which it occurred. In addition, the researcher used a shot recording program on a tablet to record the number of shots fired at each target. These data were used to verify the timing data and capture shots that missed the targets but were correctly executed based on the threat/no-threat determination.

Additionally, a two-story building with multiple rooms and hallways was used for the building clearing task. This building was an empty facility made of concrete. The stands and targets were the only items placed at identified locations within the facility.

2.3. Procedure

2.3.1. IMU Set-Up

Prior to data collection and after donning the inertial measurement unit (IMU) data loggers (Opal V1, APDM, Portland OR, USA; 128 Hz sampling, ±6 g acceleration, ±2000 deg/s angular velocity) to the sternum, sacrum, and both feet, the participants were asked to individually complete a series of calibration motions. The calibration motions consisted of: 1) standing still for a period of 10 s, 2) performing four toe touches, and 3) walking straight for approximately 15 m.

2.3.2. Dynamic Marksmanship 1

Prior to data collection, the test participants were provided familiarization training on the FN Expert simulator and demilitarized M4 carbine. This training period was essential in order to reduce the occurrence of learning effect during the actual data collection period. Each participant fired 10 shots at the paper ring diamond graded (DG) target placed 5 m (simulating 75 m) in front of the shooter in the standing, kneeling, and prone unsupported firing positions. In the standing unsupported firing position, the participants were required to hit 7 of the 10 shots within the "6" ring (black area) of the target. For kneeling unsupported, the participant had to achieve 8 of the 10 shots within the "6" ring (black area) of the target, and 9 of the 10 shots for prone unsupported. The participant was considered qualified to participate in the marksmanship portion of the study when they met the minimum qualification standards for each of the firing positions as outlined above. If the shooter did not meet these minimum qualification standards, they were given additional practice until they were able to meet these standards. All participants met this standard and were not dropped from the study. In addition to familiarization training, the participants were required to complete two practice trials of the dynamic marksmanship task in its entirety, one in the baseline condition and one in an equipped condition, at 50-75% of maximal effort.

On the first day of data collection, the researchers mechanically zeroed the FN Expert simulator system. This requires the FN Expert sensor to be placed on the picatinny rail of the weapon and aligning it with the M68 CCO and shooting at a DG target at 5 m (simulated 75 m) from a gun vice level with the target center. The sensor provides feedback on the unit display to help determine when a zero is achieved. Once mechanical zero has been achieved, the NOS Pro software must be opened, FN Expert sensor connected via bluetooth, and the correct target on the application must be selected based on a simulated distance of 75 m, target type (ring), and weapon type (M4 or AR/RK).

The marksmanship event initiated the start of the entire testing scenario. Prior to starting, the participants were asked for their RPE rating, and their heart rate monitor was initiated (Trial 1 only). The participants were then given their random engagement order for the scenario day (standing, kneeling, or prone (all unsupported)) as seen in Table 11.

Table 11. Table of fires for the marksmanship event.

Scenario Section		Scenario	Firing Position	No. of Trials	No. Shots per Trial	Total No. Shots
I	A.	One Target	Standing Unsupported	5	5	25
	B.	One Target	Kneeling	5	5	25
	C.	One Target	Prone	5	5	25
II	A.	Dynamic	Standing Unsupported	1	8	8
	B.	Dynamic	Kneeling	1	8	8
	C.	Dynamic	Prone	1	8	8

For all participants, the first marksmanship task was the static 1-target event. Target 3 from Figure 2 was utilized for the static marksmanship event. The participant was asked to take the prone firing position at Firing Line 2 and shoot three shots at Target 3 for software (individual) zeroing purposes. Prone position was used to zero because it is the most stable of the unsupported positions. The application takes the cluster of three shots and adjusts them to be centered on the target center. Once the software zero was accomplished, the participant was instructed to take their first firing position and shoot five sets of five shots at the target. The participants were instructed to be deliberate with their shots, keeping accuracy as a priority over speed. The participants continued with five sets of five shots for each of the firing positions.

Next, the participants continued into the dynamic scenario as laid out in the diagram in Figure 3. The dynamic marksmanship scenario consists of four targets and two firing lines separated by 10 m. The participants start at Firing Line 2, facing away from the first set of targets. Upon cue by the researchers, the participant turns 180°, runs 10 m to Firing Line 1, assumes the first firing position assigned to them, shoulders and sights the weapon, acquires and engages Target 1 with a controlled pair of shots, and transitions across the 50° arc to engage Target 2 in the same manner. Next, the participant runs back to Firing Line 2 and assumes the same firing position while acquiring and engaging Target 3 and 4 each with a controlled pair of shots, totaling eight shots for the run. The participant then completes the scenario in the remaining firing positions with a 60-s rest between each run. This completes the dynamic scenario. The participant was instructed to assume the firing position, acquire the targets, and engage the targets as quickly as possible without sacrificing accuracy.

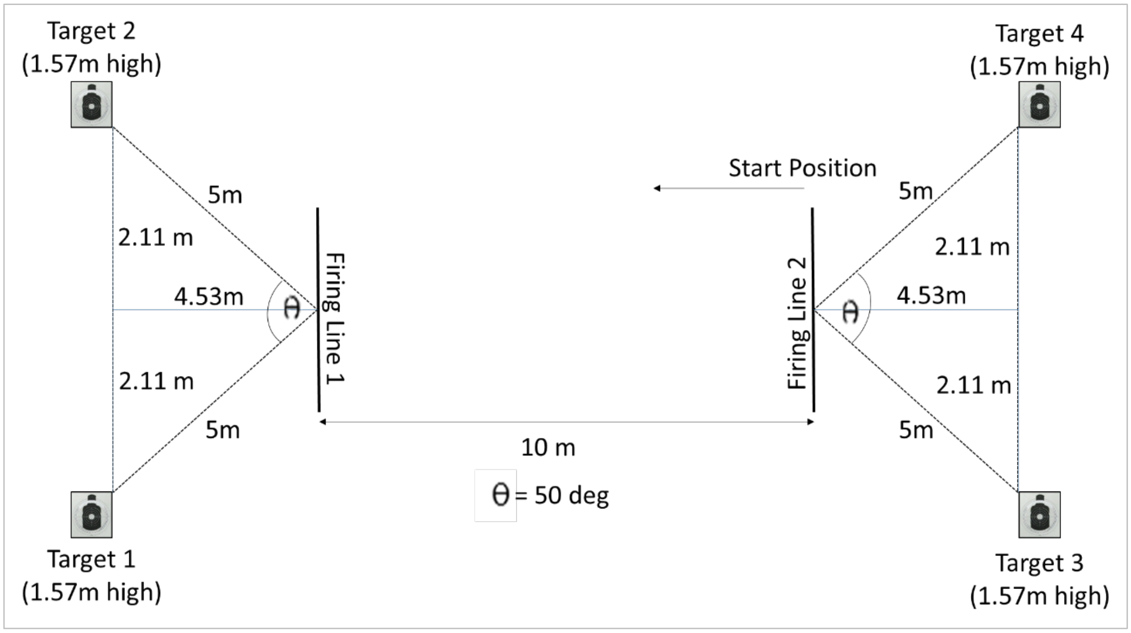


Figure 3. Diagram of the dynamic marksmanship event to include four targets and two firing lines separated by 10 m.

After completing all shots in a given firing position for each shooting event, the participant was asked to rate their level of interference or degradation from the equipment while performing that task using a 5-point rating scale, as seen in Table 12.

Table 12. Subjective interference rating scale.

No Interference	Slight Interference	Moderate Interference	Severe Interference	Extreme Interference
1	2	3	4	5

2.3.3. Foot March 1

After completing the Dynamic Marksmanship 1, the participant went to the foot march start station. The march was a 3-mile event at a controlled pace of 3 mph. Because of the 20-min staggering implemented to ensure Soldiers were walking independently, there was a brief pause at the foot march station to ensure the participant started at the correct time. During the pause, participants were equipped with either an assault pack loaded with 15.4 kg or a small backpack, in-ear headphones that were attached to the tablet carried in their pack, the hand-held USB response device, and a weighted mock M4. Prior to starting the foot march, participants provided an RPE. When participants began the foot march, they pressed the USB response device to start the task and the start button on the Heart Rate GPS watch. During the march, participants performed the go/no-go audio task approximately every 10 min starting at the beginning of walking. Throughout the march, there were signs that gave the participant feedback as to whether or not they were on pace (e.g., at 0.25 miles, the watch should read 5 min). In addition, at three points on the course, test staff were stationed to provide water, troubleshoot issues participants may have been having, and provide a safety check. Upon completion of the first foot march, participants doffed the assault pack, mock weapon, headphones, and response device, provided an RPE and Mission Performance Rating, and stopped the Heart Rate GPS watch.

2.3.4. LEAP

Participants went straight from the foot march station to the LEAP station. When they arrived, they gave an RPE. Prior to starting the obstacle course, they started the Heart Rate GPS watch. They completed the obstacles in the prescribed manner with a maximal effort. After completing the LEAP course, participants stopped the Heart Rate GPS watch, gave an RPE and Mission Performance Rating, and immediately proceeded to the MOUT.

2.3.5. MOUT

Training for the MOUT task consisted of a walkthrough of the facility and the course route, a practice room clearing session in a different portion of the facility, and practice on the threat determination task. The participants were not exposed to the actual threatening images during their practice session, just the FN Expert targetry and surrogate images.

When participants arrived at the MOUT for their trial of the actual task, they were given the demilitarized weapon with a mounted FN Expert optic and donned a Go-Pro camera on their helmet. In addition, they donned a Shotmaxx watch on their dominant shooting wrist with their sleeve rolled up to avoid any recordings of false shots. Prior to starting the MOUT task, participants gave an RPE and started the Heart Rate GPS watch. To initiate timing for the task, a Shotmaxx competition watch counted down 2 s and then beeped to indicate that the participant should engage the first target outside the MOUT facility door, marking the start of the sequence. The participant then completed room clearing and the shoot/don’t shoot task, assessing/engaging 12 targets within the facility. After completing the MOUT, participants gave their RPE and Mission Performance Rating, stopped the heart watch, and gave the tester the Go-Pro, Shotmaxx watch, and the weapon with mounted FN Expert optic.

2.3.6. Foot March 2

The same procedure described for Foot March 1 (2.3.3) was followed for Foot March 2, except participants came from the MOUT to the start of the foot march.

2.3.7. Dynamic Marksmanship 2

The same procedures were used for both pre- and post-dynamic marksmanship events (see Section 2.3.1 Dynamic Marksmanship 1). The only difference is that the post marksmanship event required the researchers to immediately commence the first marksmanship task (static) upon participant transition from the Road March 2, in order to capture any immediate fatigue effects from the previous event.

2.4. Data Analysis

2.4.1. IMUs

In order to calculate IMU metrics related to bodily position during post-processing, coordinate transformations were performed on each IMU using the calibration motions. Specifically, each IMU's sensor-fixed coordinate frame was transformed into a body-fixed (anatomical) coordinate frame. The period of quiet standing was used to define the direction of gravity of each IMU, which defined the first of three body-fixed coordinate axes. Since each IMU's axes were defined separately, depending upon the IMUs placement on the body, different calibration motions were used to define the second body-fixed axis (the sagittal rotation axis). For the sternum and sacrum IMUs, the toe touch angular velocity data (from the gyroscopes) were utilized as inputs within principal components analyses (PCA) to determine the sternum and sacrum sagittal rotation axes. For the purposes of this study, PCAs were utilized to determine axes that accounted for the greatest variation of a signal. During the toe touches, since the majority of the rotational motion of the sternum and sacrum-mounted IMUs occurred within the sagittal plane, the PCA determined a sagittal rotation axis for these two IMUs. Similarly, for the 15 m straight walk, the majority of the rotational motion of the feet-mounted IMUs occurred within the sagittal plane, allowing separate PCAs to determine sagittal rotation axes for each foot-mounted IMU. The last of the three axes was simply determined by taking the cross product of the two already defined axes of each IMU, finding an axis orthogonal to both already defined axes. Using these calculated body-fixed coordinate frames, activity-specific IMU metrics were outputted with the goal of distinguishing activity or obstacle performance between equipment configurations and march iterations. Statistical analysis sample sizes varied across activities due to several reasons including poor data (which was sometimes a result of IMUs that shifted from their original locations), loss of data, and sensor malfunctions. Developing a body-fixed coordinate frame was essential before conducting biomechanical analyses of any of the mission tasks. Specific IMU data analysis procedures for each mission task are presented in further detail in later sections of this report.

2.4.2. Timing with Watches

The timing of each participant was monitored during all testing sessions using the Garmin Forerunner 220. The Forerunner 220 measures essential data including distance, pace, and heart rate. In addition to using GPS to calculate distance and pace, the Garmin Forerunner 220 has a built-in accelerometer. The accelerometer can also track distance when GPS is unavailable.

For the timing of the Soldier's performance during each session of the scenario, the GPS watch was started at the beginning of the dynamic marksmanship tasks, both foot march tasks, LEAP, and MOUT and stopped at the completion of each of these tasks.

2.4.3. Dynamic Marksmanship

Human factors marksmanship measures were derived from the x, y coordinates and timing data produced by the NOS Pro software. These data were recorded per every .015 s of aiming data, as well as per shot fired. The marksmanship dependent variables are described in Table 13.

Table 13. Marksmanship dependent variables and descriptions.

Measure	*Description*
Lethality Measures	
Precision	Shot group dispersion, or cluster tightness
Accuracy	Distance of the shot to the target center
Probability of Hit (p(Hit))	Rate of shots that hit the target
Probability of Lethal Hit (p(LH))	Rate of shots that hit the more refined zone, or lethal zone at the center of mass
Mobility Measures	
Target Acquisition Time (TAT)	Time required to move, detect, and position prior to target engagement
Target Engagement Time (TET)	Total time spent at the target, to include aiming time for each shot, and time between each shot in the shot group
Aiming Time	Time required for aiming prior to shot
Weapon Handling/Stability:	
Trigger Control	Distance from the last .2 s of aiming to the final shot coordinates
Horizontal Stability	Barrel steadiness across the x-axis prior to shot, measured by the horizontal spread (range of aiming points across x-axis) during the last .6 to .2 s of aiming
Vertical Stability	Barrel steadiness across the y-axis prior to shot, measured by the vertical spread (range of aiming points across the y-axis) during the last .6 to .2 s of aiming
Barrel Rotation	Rotation of the barrel clockwise or counterclockwise from neutral position
Subjective Questionnaire:	
Interference Ratings	Rating of perceived interference on performance due to the worn CIE

Given that some of the data violated the assumption of normality, statistical analysis was based on parametric and non-parametric methods as appropriate. Within-subjects repeated measures analysis of variance (ANOVAs) and Friedman tests were performed, with the independent variables of condition (Condition I, Condition II, Condition III), firing position (prone unsupported, kneeling unsupported, standing unsupported), and state (pre-fatiguing events, post-fatiguing events). Tests of multiple comparisons were conducted using the Tukey Honestly Significant Differences (HSD) and Wilcoxon tests which reflects a Bonferroni adjustment.

Data are based on 54-62 participants. Due to technical issues with the mechanical zeroing on the FN Expert system for eight of the participants during one of the three sessions, the number of participants analyzed varied based on measure. Kacker-Harville correction was applied due to unbalanced data across test participants. The sample size included in each analysis will be described in the results section.

2.4.4. Foot March

2.4.4.1. Measures of Cognitive Performance (Go/No-Go Task)

Within-subjects repeated measures ANOVAs were performed with the independent variables of time block (Minutes 0-5, 15-20, 30-35, 45-50, 55-60), condition (Condition I, Condition II, Condition III), and foot march (Foot March 1, Foot March 2). The dependent variables were sensitivity (d'), calculated using the following formula: d' = z(hits) – z(false alarms), criterion (c) calculated as c = -.5*(z(hits)+z(false alarms)), the proportion of false alarms, the proportion of hits, reaction time for go trials in a go no/go block vs. reaction time for go trials in a go only block (additional variable of response time (RT) type), and reaction time for a go after a no-go. For criterion, note that negative values indicate a bias towards responding yes. Because some participants made no false alarms during some time blocks and load conditions, reaction times were not able to be calculated for no-go trials.

Data are based on 31 participants, due to technical issues such as headphone and/or tablet malfunction and hand paralysis in the other 31 participants.

2.4.4.2. Measures of Biomechanics Performance

For the foot march, a two-way repeated measure ANOVA was conducted within IBM SPSS Statistics 21 (IBM Corp., Armonk, NY, USA) to examine the main effects of any possible interactions between the equipment configuration variable (Conditions I, II, and III) and the march iteration variable (pre-march or post-march) for each dependent measure ($\alpha = 0.05$). In ANOVA analyses where sphericity was significant ($p<0.05$), the Greenhouse-Geisser adjustment was applied to the degrees of freedom. When statistically significant differences were observed ($p<0.05$), a Bonferroni correction was applied during the post-hoc analysis. When significant interaction effects were observed between equipment and march conditions ($p<0.05$), tests of simple effects were utilized to compare all pairs of equipment conditions for each march condition. Estimates of effect size (η_p^2) were also reported for each dependent variable.

2.4.4.2.1. Foot March Biomechanics Metric Calculations

The kinematics of 54 participants performing the two foot march iterations of the scenario were analyzed with IMUs mounted on the sternum, sacrum, and both feet. The following 11 derived kinematic metrics are defined in sections below: stride length, stride duration, stride width, foot yaw, PCA feet, PCA pelvis, PCA torso, mediolateral lean angle, standard deviation of mediolateral lean angle, anteroposterior lean angle, and standard deviation of anteroposterior lean angle.

In order to calculate several metrics for the foot march, a wavelet analysis was performed on the feet-mounted IMU acceleration signals to determine ground contact timings. Specifically, the wavelet analysis allowed identification of the periods of time in which there were relatively high frequency (>10Hz) constituents of the foot acceleration signal. Periods of time where the feet IMUs experienced high frequencies in a relatively short amount of time identified heel-strikes and toe-offs. If the foot angular velocity magnitude was decreasing while the acceleration was high, a heel-strike was identified. Conversely, if the foot angular velocity magnitude was increasing while the acceleration was high, a toe-off was identified. The period between heel-strikes and the toe-offs defined the ground contact timings (stance phase). A single value was calculated for each output metric between each consecutive ground contact of the same foot throughout the march. Each hour-long foot march was divided into five sections to match the sections examined in the cognitive analysis (i.e. time intervals: 0-5; 15-20; 30-35; 45-50; and 55-60 mins). The output metric values calculated between each consecutive ground contact of the same foot were then averaged within each of the five sections. For measures related to the feet, the left and right foot variants were also averaged.

2.4.4.2.2. Stride Length

Stride length was calculated by numerically integrating (using the trapezoidal rule) all three components of the feet acceleration signals between each ground contact which were assumed to be zero velocity points. By assuming the feet were stationary (zero velocity) during ground contacts, the resulting three components of linear velocity were drift corrected by assuming linear drift over time. The components of linear velocity were integrated again to obtain foot displacement. Stride length was calculated as the magnitude of the resulting displacement signal between ground contacts of the same foot (Figure 4).

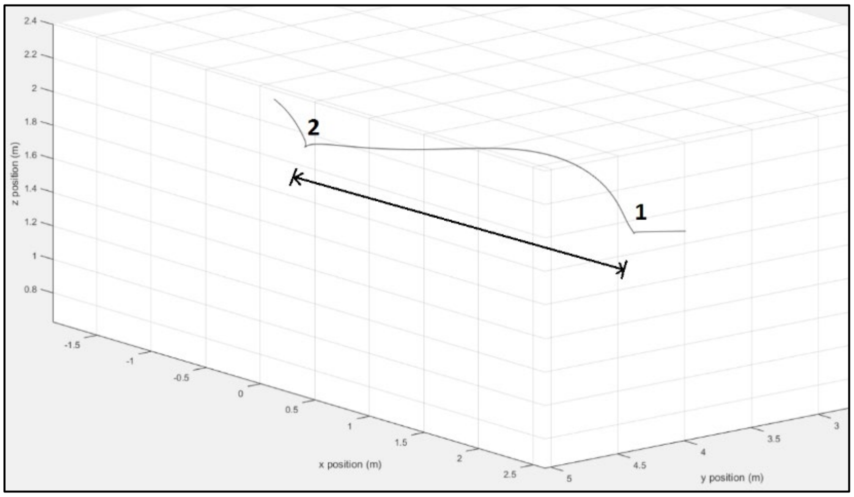


Figure 4. Stride foot trajectory with stride length identified between Foot-Falls 1 and 2

2.4.4.2.3. Stride Duration

Stride duration was calculated as the time between consecutive ground contacts of the same foot.

2.4.4.2.4. Stride Width

Stride width was calculated as the lateral deviation from the average stride direction of the same foot (Rebula, Ojeda, Adamczyk, & Kuo, 2013). A Kalman Filter estimated foot orientations for drift correction. Velocity was estimated as the integrated tilt-corrected accelerometer signal, and trajectories were calculated by integrating the velocity. The average stride direction was defined as the average of the three previous stride directions of that foot.

2.4.4.2.5. Foot Yaw

Foot yaw was calculated as the angular difference between the anteroposterior axis of the foot and the stride direction at heel-strike. Foot yaw represents the angle of the foot when stepping on the ground from a top-down perspective.

2.4.4.2.6. PCA Feet

PCA feet was defined as the percentage of variation in angular velocity data about the sagittal axis of the feet. The remaining variation in angular velocity data was accounted for by the other two axes. While walking, the majority of rotational foot motion is typically within the sagittal plane.

2.4.4.2.7. PCA Pelvis

PCA pelvis was defined as the percentage of variation in angular velocity data about the sagittal axis of the sacrum. The remaining variation in angular velocity data was accounted for by the other two axes.

2.4.4.2.8. PCA Torso

PCA torso was defined as the percentage of variation in angular velocity data about the sagittal axis of the sternum. The remaining variation in angular velocity data was accounted for by the other two axes.

2.4.4.2.9. Mediolateral Lean Angle

Mediolateral lean angle was calculated by finding the angular displacement of the sternum about the projection of the sagittal axis of the sternum onto the horizontal plane. This metric represents the amount of side-to-side bending of the torso. Mediolateral lean angle was averaged within each of the five sections, which distinguishes this from another metric: standard deviation of mediolateral lean angle.

2.4.4.2.10. Standard Deviation of Mediolateral Lean Angle

Mediolateral lean angle was calculated by finding the angular displacement of the sternum about the projection of the sagittal axis of the sternum onto the horizontal plane. This metric represents the amount of variation of side-to-side bending of the torso. Standard deviation of mediolateral lean angle was calculated by taking the standard deviation within each of the five sections.

2.4.4.2.11. Anteroposterior Lean Angle

Anteroposterior lean angle was calculated by finding the angular displacement of the sternum about the projection of the anteroposterior axis of the sternum onto the horizontal plane. This metric represents the amount of front and back bending of the torso. Anteroposterior lean angle was averaged within each of the five sections which distinguishes this from another metric, standard deviation of anteroposterior lean angle.

2.4.4.2.12. Standard Deviation of Anteroposterior Lean Angle

Anteroposterior lean angle was calculated by finding the angular displacement of the sternum about the projection of the anterior-posterior axis of the sternum onto the horizontal plane. This metric represents the amount of variation of front and back bending of the torso. Standard deviation of anteroposterior lean angle was calculated by taking the standard deviation within each of the five sections.

2.4.5. LEAP

2.4.5.1. Measures of Biomechanics Performance

One-way repeated measures ANOVAs were conducted for each obstacle individually to examine the main effects of the equipment configuration variable (Conditions I, II, and III) for each dependent measure ($\alpha = 0.05$). In ANOVA analyses where sphericity was significant ($p<0.05$), the Greenhouse-Geisser adjustment was applied to the degrees of freedom. When statistically significant differences were observed ($p<0.05$), a Bonferroni correction was applied during the post-hoc analysis. Estimates of effect size (η_p^2) were also analyzed for each dependent variable.

2.4.5.2. Sprint

The kinematics of 56 participants performing the sprint section of the LEAP obstacle course were analyzed with IMUs mounted on the sternum, sacrum, and both feet. The following 12 derived kinematic metrics are defined in sections below: speed, stride length, stride duration, stride width, foot yaw, PCA feet, PCA pelvis, PCA torso, mediolateral lean angle,standard deviation of mediolateral lean angle, anteroposterior lean angle, and standard deviation of anteroposterior lean angle. Only the main effect of equipment condition was examined for each metric.

All sprint metrics were identical to the foot march metrics except for the addition of the speed metric. Unlike the foot march, the sprint obstacle was also not divided into sections due to its short duration. All metrics were averaged across the duration of the sprint. Only the speed metric's definition is presented below, since the remaining metric definitions were presented in the foot march Sections 2.4.4.2.2-2.4.4.2.12.

Speed was calculated at each stride by dividing stride length by stride duration.

2.4.5.3. Agility Run

The kinematics of 56 participants performing the agility run section of the LEAP obstacle course were analyzed with IMUs mounted on the sternum, sacrum, and both feet. The following 17 derived kinematic metrics are defined in sections below: speed, stride length, stride duration, standard deviation of stride width, standard deviation of foot yaw, PCA feet, PCA pelvis, PCA torso, mediolateral lean angle, standard deviation of mediolateral lean angle, anteroposterior lean angle, standard deviation of anteroposterior lean angle, pelvis mediolateral acceleration at turn, pelvis anteroposterior acceleration at turn, pelvis mediolateral tilt at turn, pelvis anteroposterior tilt at turn, and pelvis angular velocity about a vertical axis at turn. Only the main effect of equipment condition was examined for each metric.

Before calculating individual metrics, direction cosine matrices were obtained by resolving the orientation of the sacrum-mounted IMU to define the orientation of the IMU axes relative to the course-fixed axes (Figure 5). The sacrum accelerometer data were then resolved along the course x, y, and z axes to allow integration to obtain estimated velocity and trajectory estimates about this course-fixed reference frame. The drift error introduced during integration was corrected via a least-squares minimization function that enforced the following constraints: 1) the participant started the agility run at zero velocity, 2) the sacrum IMU passed close to the five flags in between the starting and ending locations, and 3) the participant ended the agility run at zero velocity. The drift error correction function also utilized knowledge of the distance between flags of the agility course.

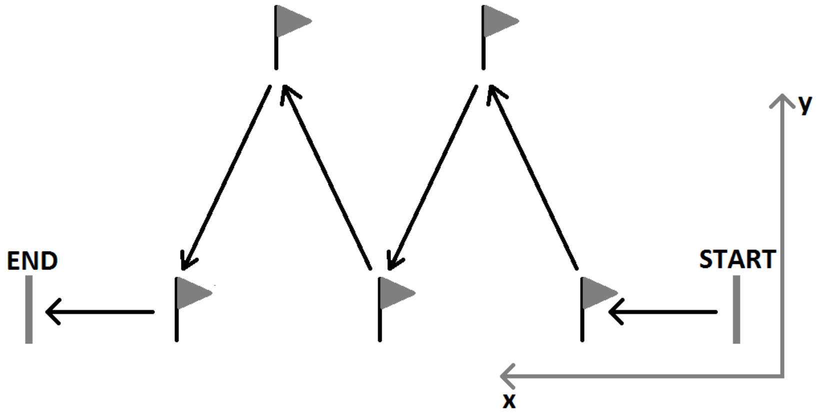


Figure 5. Agility diagram with example course-fixed axes

Once the trajectory estimate was drift corrected, several metrics could then be calculated at the apexes of the turns around each flag. However, since only the trajectory around the three central flags had sharp turning angles (the turn radius around the first and fifth flag was much larger), all the metrics that were calculated at the turn apexes were averaged across the middle three turns only. That being said, the first 12 agility run metrics were calculated across the duration of the entire agility run (between the starting and ending positions). These 12 metrics were calculated similarly to the methods described for the foot march and sprint obstacle and were not detailed below. The remaining metrics were all calculated as means across the three central turns and are described below.

2.4.5.3.1. Pelvis Mediolateral Acceleration at Turn

Pelvis mediolateral acceleration at turn was calculated as the sacrum acceleration in the mediolateral direction at the apex of the turn around the flag.
below.

2.4.5.3.2. Pelvis Anteroposterior Acceleration at Turn

Pelvis anteroposterior acceleration at turn was calculated as the sacrum acceleration in the anteroposterior direction at the apex of the turn around the flag.

2.4.5.3.3. Pelvis Mediolateral Tilt at Turn

Pelvis mediolateral tilt at turn was calculated as the sacrum angular tilt in the mediolateral direction at the apex of the turn around the flag. The sacrum IMU direction cosine matrix yielded the tilt of the pelvis from the vertical axis which was resolved into components of tilt in the mediolateral-vertical plane. This metric represents the orientation of the pelvis within the frontal plane (e.g. mediolateral pelvis tilt may indicate that one hip joint is hiked up relative to the other).

2.4.5.3.4. Pelvis Anteroposterior Tilt at Turn

Pelvis anteroposterior tilt at turn was calculated as the sacrum angular tilt in the anteroposterior direction at the apex of the turn around the flag. The sacrum IMU direction cosine matrix yielded the tilt of the pelvis from the vertical axis which was resolved into components of tilt in the anteroposterior-vertical plane. This metric represents the orientation of the pelvis within the sagittal plane (e.g. anteroposterior pelvis tilt may indicate pelvic thrust).

2.4.5.3.5. Pelvis Angular Velocity about a Vertical Axis at Turn

Pelvis angular velocity about a vertical axis at turn was calculated as the sacrum angular velocity about the course-fixed vertical axis (i.e. the z-axis) at the apex of the turn around the flag.

2.4.5.4. High Window

The kinematics of 54 participants performing the high window section of the LEAP obstacle course were analyzed with IMUs mounted on the sternum and sacrum. The following 10 derived kinematic metrics are defined in sections below: time, peak vertical velocity, horizontal mount velocity, horizontal dismount velocity, torso heading range of motion (ROM), pelvis heading ROM, torso anteroposterior ROM, pelvis anteroposterior ROM, torso mediolateral ROM, and pelvis mediolateral ROM. Only the main effect of equipment condition was examined for each metric.

The sacrum IMU provided kinematic data (acceleration and angular velocity) close to the participant's center of mass which was exploited to calculate participant velocity (horizontal and vertical), and to identify when the participant was climbing through the window opening. The data from the sacrum and sternum IMUs provided estimates of the orientation of the pelvis and torso, respectively, and therefore was used to understand participant window obstacle technique.

The first step required to analyze the window obstacle was to resolve the sacrum accelerations into an inertial frame and integrate the acceleration to obtain vertical velocity (i.e. the upward velocity needed to climb up or jump onto the window). Orientation of the IMU in an inertial frame was estimated using APDM's proprietary Kalman filter. When integrating to obtain velocity, zero-velocity points before and after the windows helped remove drift error from the estimated velocity with a linear correction. The peaks of the vertical velocity signal revealed the jump onto and off of the window obstacle which defined the window analysis time frame (Figure 6).

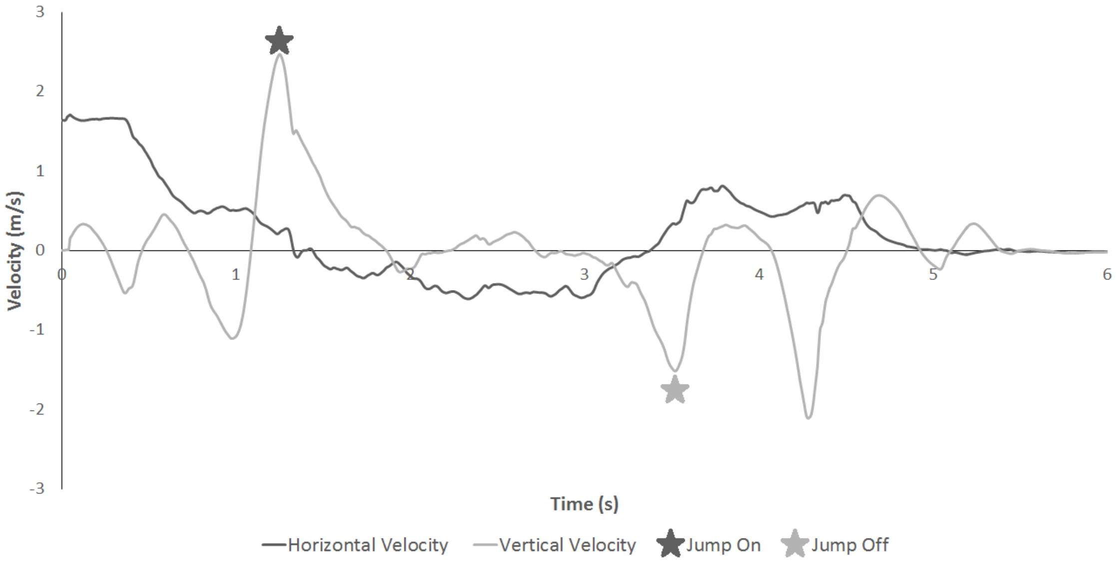


Figure 6. Example sacrum velocity during the window obstacle

By first defining the participant’s direction of travel based on the velocity data before the participant reached the window, the horizontal velocity was defined as the velocity along this axis of movement. The window obstacle was subsequently analyzed utilizing: 1) sacrum horizontal and vertical velocities, 2) anteroposterior, mediolateral, and heading angles of the sternum, and 3) anteroposterior, mediolateral, and heading angles of the sacrum. Heading angles of the torso and pelvis were set to zero at the beginning of the window obstacle, and therefore were aligned with the direction of travel (i.e. heading direction). Deviation from a zero-degree heading angle implied body segment rotation from a top-down view of the obstacle, indicating the body segment was no longer aligned with the direction of travel through the window.

These pelvis and torso orientation calculations revealed the strategy used to pass through the window opening. The proprietary Kalman filter employed by APDM provided estimates of the directions of gravity and magnetic north relative to the sensor-fixed axes. By combining the knowledge of the orientation of the sensors on the body segments (from the calibration process) with the estimates of gravity and magnetic north, the orientation of the torso and pelvis were determined. Tilt of the pelvis and torso were defined by calculating the angular displacement about the projection of the mediolateral or anteroposterior axis of the segment onto the horizontal plane. These calculations relied on the estimated gravity direction from the Kalman filter output, which was insensitive to magnetic disturbances.

2.4.5.4.1. Time

Time was defined as the total time to climb through the window. The start point was defined as the time when the participant began climbing or jumping onto the window (as determined by the maximum vertical velocity location). The end point was defined as the time when the participant landed on the platform after descending or jumping from the window (as determined by the minimum vertical velocity location).

2.4.5.4.2. Peak Vertical Velocity

Peak vertical velocity was calculated as the maximum vertical velocity of the sacrum-mounted IMU across the entire window traverse.

2.4.5.4.3. Horizontal Mount Velocity

Horizontal mount velocity was calculated as the horizontal velocity (the velocity acting along the direction of travel through the window) of the sacrum-mounted IMU as the participant climbed onto the window.

2.4.5.4.4. Horizontal Dismount Velocity

Horizontal dismount velocity was calculated as the horizontal velocity (the velocity acting along the direction of travel through the window) of the sacrum-mounted IMU as the participant descended from the window.

2.4.5.4.5. Torso Heading ROM

Torso heading ROM was defined as the sternum IMU heading angle ROM while climbing through the window. In this context, ROM implied the minimum value subtracted from the maximum.

2.4.5.4.6. Pelvis Heading ROM

Pelvis heading ROM was defined as the sacrum IMU heading angle ROM while climbing through the window. In this context, ROM implied the minimum value subtracted from the maximum.

2.4.5.4.7. Torso Anteroposterior ROM

Torso anteroposterior ROM was defined as the sternum IMU anteroposterior lean angle ROM while climbing through the window. In this context, ROM implied the minimum value subtracted from the maximum.

2.4.5.4.8. Pelvis Anteroposterior ROM

Pelvis anteroposterior ROM was defined as the sacrum IMU anteroposterior lean angle ROM while climbing through the window. In this context, ROM implied the minimum value subtracted from the maximum.

2.4.5.4.9. Torso Mediolateral ROM

Torso mediolateral ROM was defined as the sternum IMU mediolateral lean angle ROM while climbing through the window. In this context, ROM implied the minimum value subtracted from the maximum.

2.4.5.4.10. Pelvis Mediolateral ROM

Pelvis mediolateral ROM was defined as the sacrum IMU mediolateral lean angle ROM while climbing through the window. In this context, ROM implied the minimum value subtracted from the maximum.

2.4.5.5. Low Window

The kinematics of 55 participants performing the low window section of the LEAP obstacle course were analyzed with IMUs mounted on the sternum and sacrum. The 10 derived kinematic metrics included: time, peak vertical velocity, horizontal mount velocity, horizontal dismount velocity, torso heading ROM, pelvis heading ROM, torso anteroposterior ROM, pelvis anteroposterior ROM, torso mediolateral ROM, and pelvis mediolateral ROM. Only the main effect of equipment condition was examined for each metric.

All low window metrics were identical to the high window metrics.

2.4.5.6. Bounding Rush

The kinematics of 51 participants performing the bounding rush section of the LEAP obstacle course were analyzed with the IMU mounted on the sacrum. The following eight derived kinematic metrics are defined in sections below: time to complete each bounding rush, standard deviation of time to complete each bounding rush, time to stand from prone, standard deviation of time to stand from prone, sprinting velocity, standard deviation of sprinting velocity, vertical standing velocity, and standard deviation of vertical standing velocity. Participants got into the prone position on five sandbags, and the eight kinematic metrics were calculated and averaged over the four prone-to-prone transitions between bounds.

The sacrum-mounted IMU provided kinematic data (acceleration and angular velocity) close to the center of mass, which was exploited to calculate subject velocity (vertical and horizontal) and position (vertical) to identify when the subject was prone, standing up, sprinting, or getting down. The first step to obtain the bounding rush performance metrics was to resolve the sacrum acceleration into an inertial frame and integrate the acceleration to obtain vertical velocity of the sacrum. Orientation of the IMU in an inertial frame was estimated using the output from APDM's proprietary Kalman filter. The acceleration was integrated to obtain velocity and vertical position. Velocity drift and vertical position drift were estimated and corrected by exploiting the fact that the sacrum was approximately at rest and returned to approximately the same vertical position (i.e. low to the ground) each time the participant achieved a prone position.

After solving for velocity of the sacrum IMU, zero velocity points were identified at the beginning and end of each individual bound of the task. A bounding rush was defined as the time between the end of a prone position (followed by standing up) and the point where the participant assumed a prone position at the next sandbag location. Using the vertical position of the sacrum, each bounding rush was split into three distinct phases: standing, sprinting, and get-down (Figure 7).

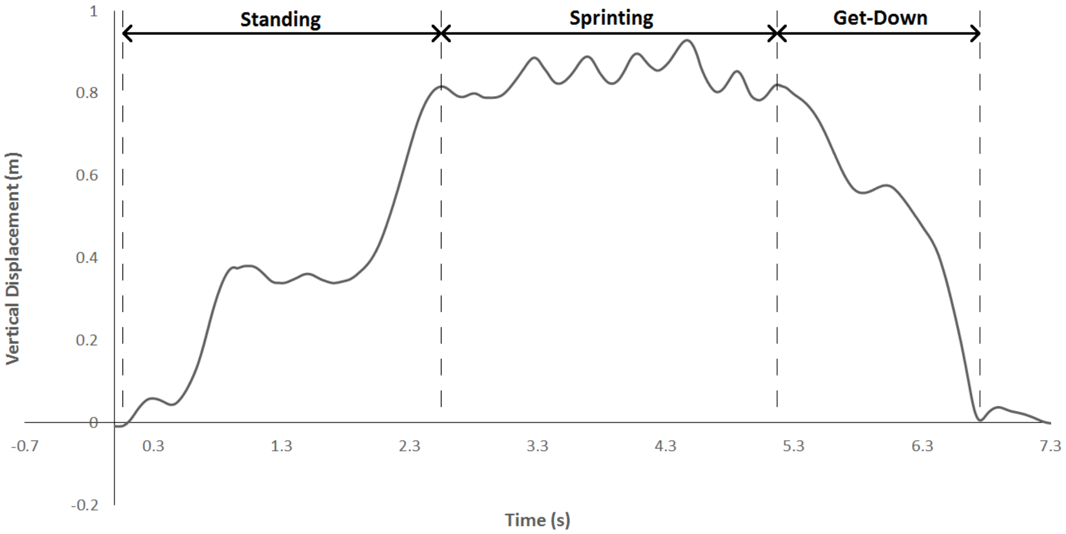


Figure 7. The three phases of a single bounding rush as distinguished by sacrum position

Analysis of the bounding rush task began by identifying the point at which the sacrum reached maximum vertical displacement. This was assumed to be the point at which the participant had stood up and reached optimal running height. A linear fit was then applied to the initial increase in the vertical displacement of the sacrum. The slope of this line represented the average vertical velocity achieved during the first portion of the standing phase while the x-intercept (i.e. the intercept of the time axis) of this line identified the time the participant began to move. The sprinting phase spanned the time between the end of the standing phase and the beginning of the get-down phase; the latter being defined when the vertical displacement of the sacrum began decreasing at a steady rate. Similar to the standing phase, a linear fit was applied to the decrease of the sacrum vertical displacement during the get-down phase. The get-down phase ended when the vertical displacement of the sacrum reached a minimum point relative to this second linear fit. Following the end of the get-down phase, the participant began the aiming phase, in which the participant stayed prone until a sight picture was obtained of a target down range.

2.4.5.6.1. Time to Complete Each Bounding Rush

Time to complete each bounding rush was defined as the average time taken to complete a bounding rush.

2.4.5.6.2. Standard Deviation of Time to Complete Each Bounding Rush

Standard deviation of time to complete each bounding rush was defined as the standard deviation of the time taken to complete a bounding rush.

2.4.5.6.3. Time to Stand from Prone

Time to stand from prone was calculated as the average time to reach maximum vertical displacement of the sacrum IMU.

2.4.5.6.4. Standard Deviation of Time to Stand from Prone

Standard deviation of time to stand from prone was calculated as the standard deviation of the time to reach maximum vertical displacement of the sacrum IMU.

2.4.5.6.5. Sprinting Velocity

Sprinting velocity was calculated as the average maximum horizontal velocity achieved between bounds.

2.4.5.6.6. Standard Deviation of Sprinting Velocity

Standard deviation of sprinting velocity was calculated as the standard deviation of the maximum horizontal velocity achieved between bounds.

2.4.5.6.7. Vertical Standing Velocity

Vertical standing velocity was calculated as the average maximum vertical velocity achieved during the standing phase.

2.4.5.6.8. Standard Deviation of Vertical Standing Velocity

Standard deviation of vertical standing velocity was calculated as the standard deviation of the maximum vertical velocity achieved during the standing phase.

2.4.5.7. Balance Beam

The kinematics of 53 participants performing the balance beam section of the LEAP obstacle course were analyzed with IMUs mounted on the sternum, sacrum, and both feet. The following 15 derived kinematic metrics are defined in sections below: time, step count, percent time double support, step frequency, stride duration, standard deviation of stride duration, standard deviation of foot yaw, sacrum mediolateral acceleration root-mean-square (RMS), sacrum anteroposterior acceleration RMS, sacrum acceleration RMS Ratio, torso mediolateral angular velocity RMS, Torso anteroposterior angular velocity RMS, torso angular velocity RMS ratio, torso angular velocity RMS magnitude, and torso mediolateral ROM.

To begin the analysis of the balance beam, sacrum accelerations were resolved in an inertial frame and integrated to obtain vertical velocity of the sacrum. Peaks in the sacrum vertical velocity signal revealed the steps onto and off of the beam, which defined the time required to traverse the beam (Figure 8). Orientation of the sternum IMU relative to gravity was used to calculate mediolateral tilt (i.e. left and right lateral flexion) of the torso. Foot-strikes and push-offs on the balance beam were identified via a wavelet analysis applied to foot segment angular velocities, allowing calculation of the duration of double support during each stride. Trials that involved the participant falling or stepping off the beam in the middle of the obstacle were eliminated from analysis.

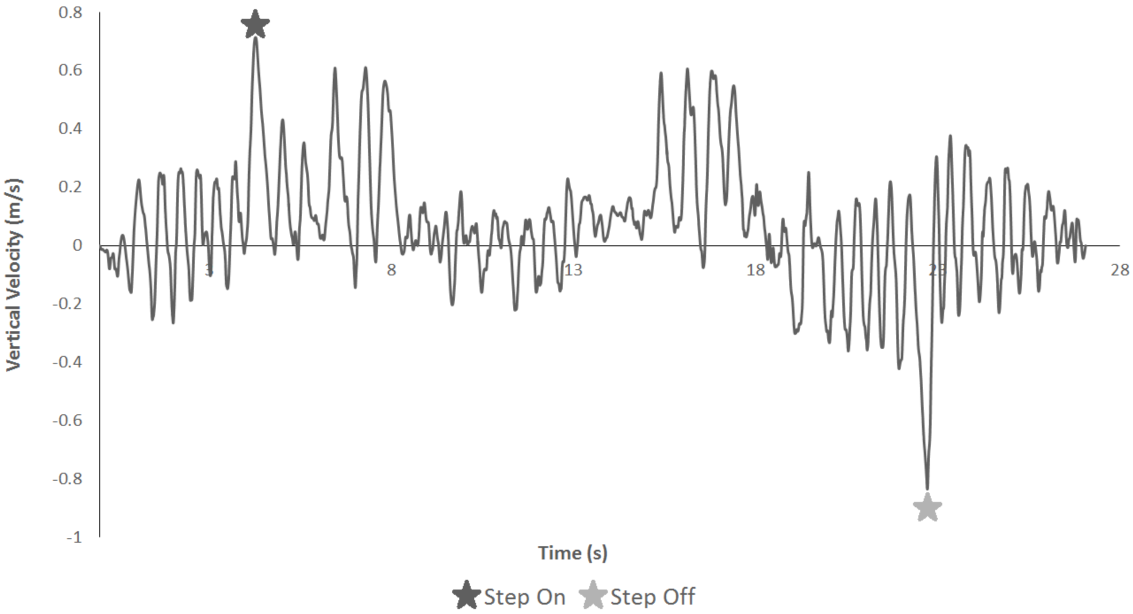


Figure 8. Example sacrum velocity during the balance beam obstacle

2.4.5.7.1. Time

Time was calculated as the total time the participant took to traverse the balance beam between the step on and the step off locations (as determined by the vertical velocity of the sacrum IMU).

2.4.5.7.2. Step Count

Step count was defined as the total number of steps (left and right) taken while crossing the beam.

2.4.5.7.3. Percent Time Double Support

Percent time double support was calculated as the percentage of time (out of the total time to cross the beam) that the subject spent in double support (i.e. two feet contacting the beam).

2.4.5.7.4. Step Frequency

Step frequency was defined as the average steps per second while traversing the beam.

2.4.5.7.5. Stride Duration

Stride duration was defined as the average time between a foot-strike and another foot-strike of the same foot.

2.4.5.7.6. Standard Deviation of Stride Duration

Standard deviation of stride duration was defined as the standard deviation of the time between a foot-strike and another foot-strike of same foot.

2.4.5.7.7. Standard Deviation of Foot Yaw

Standard deviation of foot yaw was defined as the standard deviation of the foot yaw angle while traversing the beam. Foot yaw was calculated as the angular difference between the anteroposterior axis of the foot and the stride direction at heel-strike. Foot yaw represents the angle of the foot when stepping along the beam from a top-down perspective.

2.4.5.7.8. Sacrum Mediolateral Acceleration RMS

Sacrum mediolateral acceleration RMS was calculated as the RMS of the mediolateral acceleration of the sacrum IMU. This metric represents side-to-side motion of the pelvis while traversing the beam.

2.4.5.7.9. Sacrum Anteroposterior Acceleration RMS

Sacrum anteroposterior acceleration RMS was calculated as the RMS of the anteroposterior acceleration of the sacrum IMU. This metric represents forward and backward motion of the pelvis while traversing the beam.

2.4.5.7.10. Sacrum Acceleration RMS Ratio

Sacrum acceleration RMS ratio was calculated by dividing the sacrum mediolateral acceleration RMS by the sacrum anteroposterior acceleration RMS. A lower ratio implies that there are less left and right balance correcting accelerations relative to forward and backward accelerations.

2.4.5.7.11. Torso Mediolateral Angular Velocity RMS

Torso mediolateral angular velocity RMS was calculated as the RMS of the mediolateral angular velocity of the sternum IMU. This metric represents side-to-side rotational speed of the torso while traversing the beam.

2.4.5.7.12. Torso Anteroposterior Angular Velocity RMS

Torso anteroposterior angular velocity RMS was calculated as the RMS of the anteroposterior angular velocity of the sternum IMU. This metric represents forward and backward rotational speed of the torso while traversing the beam.

2.4.5.7.13. Torso Angular Velocity RMS Ratio

Torso angular velocity RMS ratio was calculated by dividing the torso mediolateral angular velocity RMS by the torso anteroposterior angular velocity RMS. A lower ratio implies that there are less left and right balance correcting angular rates of motion relative to forward and backward angular rates of motion.

2.4.5.7.14. Torso Mediolateral Angular Velocity RMS

Torso mediolateral angular velocity RMS magnitude was calculated as the RMS of the angular velocity magnitude of the sternum IMU. This metric represents the overall (i.e. in all directions) rotational speed of the torso while traversing the beam.

2.4.5.7.15. Torso Mediolateral ROM

Torso mediolateral ROM was defined as the mediolateral range of motion of the sternum IMU while traversing the beam. This metric represents the amount of side-to-side motion of the torso while traversing the beam.

2.4.5.8. High Wall

The kinematics of 52 participants performing the high wall section of the LEAP obstacle course were analyzed with IMUs mounted on the sternum and sacrum. The 13 derived kinematic metrics included: time, peak vertical velocity, horizontal mount velocity, horizontal dismount velocity, mean horizontal velocity over wall, minimum horizontal velocity over wall, maximum horizontal velocity over wall, torso heading ROM, pelvis heading ROM, torso anteroposterior ROM, pelvis anteroposterior ROM, torso mediolateral ROM, and pelvis mediolateral ROM. Only the main effect of equipment condition was examined for each metric.

High and low wall metrics were mostly identical to the high and low window metrics. However, the three additional velocity metrics are detailed below.

2.4.5.8.1. Mean Horizontal Velocity over Wall

Mean horizontal velocity over wall was calculated as the mean horizontal velocity (the velocity acting along the direction of travel over the wall) of the sacrum-mounted IMU while climbing over the wall.

2.4.5.8.2. Minimum Horizontal Velocity over Wall

Minimum horizontal velocity over wall was calculated as the minimum horizontal velocity (the velocity acting along the direction of travel over the wall) of the sacrum-mounted IMU while climbing over the wall.

2.4.5.8.3. Maximum Horizontal Velocity over Wall

Maximum horizontal velocity over wall was calculated as the maximum horizontal velocity (the velocity acting along the direction of travel over the wall) of the sacrum-mounted IMU while climbing over the wall.

2.4.5.9. Low Wall

The kinematics of 55 participants performing the low wall section of the LEAP obstacle course were analyzed with IMUs mounted on the sternum and sacrum. The 13 derived kinematic metrics included: time, peak vertical velocity, horizontal mount velocity, horizontal dismount velocity, mean horizontal velocity over wall, minimum horizontal velocity over wall, maximum horizontal velocity over wall, torso heading ROM, pelvis heading ROM, torso anteroposterior ROM, pelvis anteroposterior ROM, torso mediolateral ROM, and pelvis mediolateral ROM. Only the main effect of equipment condition was examined for each metric.

All low wall metrics were identical to the high wall metrics.

2.4.6. MOUT

2.4.6.1. Human Factors Measures of Marksmanship Performance

Within-subjects repeated measures ANOVAs were performed with the independent variables of condition (Condition I, Condition II, Condition III) and threat order (Go after No-Go and Go after Go). Note that No-Go after Go was not assessed since no marksmanship data are recorded by the system when a target is not engaged. The dependent variables were probability of hit (p(Hit)), probability of lethal hit (p(LH)), accuracy, precision, aiming time, acquisition time, engagement time, and total trial time (for definitions of variables, refer to the Dynamic marksmanship section). Data are based on 60-62 participants. One participant had a corrupt file that was unreadable for the Condition III trial. The other participant's file was incorrectly saved and data were lost during the Condition II trial.

2.4.6.2. Measures of Cognitive Performance

Within-subjects repeated measures ANOVAs were performed with the independent variable of condition (Condition I, Condition II, Condition III). The dependent variables were sensitivity (d'), calculated using the following formula: d' = z(hits) – z(false alarms), criterion (c) calculated as c = -.5*(z(hits)+z(false alarms)), and the proportion of false alarms. Data are based on 60-62 participants. One participant had a corrupt file that was unreadable for the Condition III trial. The other participant's file was incorrectly saved and data were lost during the Condition II trial.

2.4.6.3. Measures of Physiological Performance

The participants' physiologic level of physical exertion (% Exertion) Pre- and Post-Foot March, Pre- and Post-Marksmanship, MOUT, and LEAP were measured by HRR analysis for each task.

A two-way repeated measures ANOVA was conducted within IBM SPSS Statistics 21 (IBM Corp., Armonk, NY, USA) to examine the main effects of and possible interactions between the equipment configuration variable (three equipment conditions) and the march, marksmanship iteration variable (pre-march or post-march, pre-marksmanship or post-marksmanship) for each dependent measure ($\alpha = 0.05$). In ANOVA analyses where sphericity was significant ($p<0.05$), the Greenhouse-Geisser adjustment was applied to the degrees of freedom. When statistically significant differences were observed ($p<0.05$), a Bonferroni correction was applied during the post-hoc analysis. When significant interaction effects were observed between equipment and march or marksmanship conditions ($p<0.05$), tests of simple effects were utilized to compare all pairs of equipment conditions for each march or marksmanship condition. Estimates of effect size (η_p^2) and observed power were also analyzed for each dependent variable.

One-way repeated measures ANOVAs were conducted for the LEAP and MOUT tasks to examine the main effects of the equipment configuration variable (three equipment conditions) for each dependent measure ($\alpha = 0.05$). In ANOVA analyses where sphericity was significant ($p<0.05$), the Greenhouse-Geisser adjustment was applied to the degrees of freedom. When statistically significant differences were observed ($p<0.05$), a Bonferroni correction was applied during the post-hoc analysis. Estimates of effect size (η_p^2) and observed power were also analyzed for each dependent variable.

3. Results

3.1. Dynamic Marksmanship

3.1.1. Marksmanship Performance

Test participants 1-8 had a malfunction in test equipment that affected accuracy, probability of hit, and probability of lethal hit between rested and fatigued states for one of the three CIE configurations and had to be removed from analysis for those dependent variables to prevent false positive results (accuracy, p(hit), and p(LH)). All other measures were analyzed using all 62 participants.

3.1.1.1. Static 1-Target Task

The static 1-Target task results are categorized into areas of lethality mobility, and stability. Tables 14-19 at the end of this section provide a summary of the mean, standard deviations, and medians for each dependent variable pre- and post-sessions.

Precision: Analysis indicated a main effect of CIE configuration, F(2,119.7)=9.55, p<.0001, Position, F(2, 118.8)=50.3, p<.0001, and State, F(1,58.4), p=.0012. Post hoc analysis using Tukey's HSD indicates that those wearing the most encumbered configuration, Condition III, had worse precision (M=93.2, SD=37.7), than the other two lighter loads, Condition II (M=87.4, SD=36.6) and Condition I (M=83.1, SD=34.1) as seen in Figure 9. In addition, all three positions were different than each other, with Prone having the best precision (M=72.3, SD=36.2), then Kneeling (M=87.5, SD=33.5), and Standing having the worst (M=103.8, SD=32.3). Finally, the participants were more precise with their shot groups in the rested state (M=85.1, SD=35.5) than the fatigued state (M=90.3, SD=37.0).

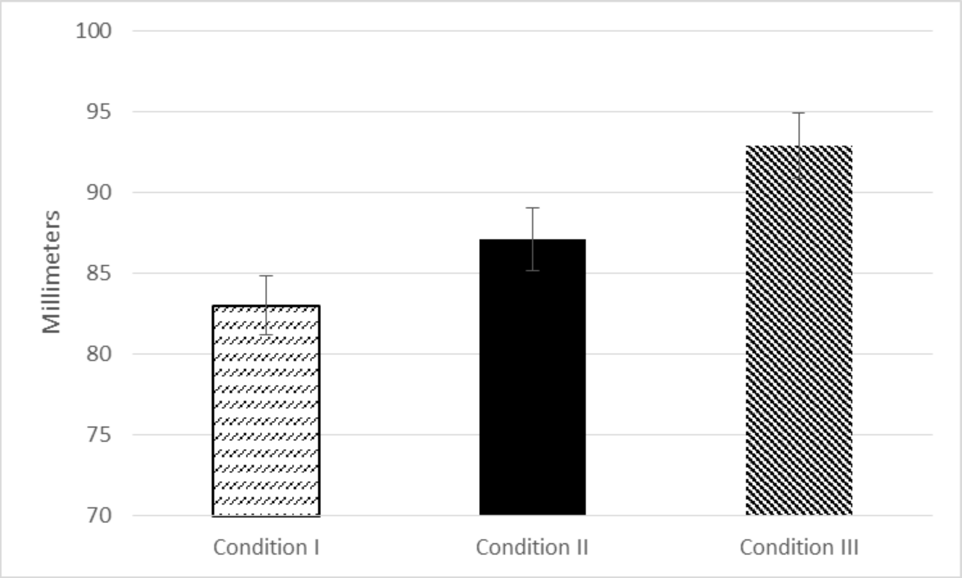


Figure 9. Shot group Precision across CIE encumbrance levels.

Accuracy: Analysis indicated a main effect of Position, F(2, 114.5)=21.4, p<.0001. Post hoc analysis using Tukey's HSD indicates that the standing position was different than that others, with Prone having the best accuracy (M=133.3, SD=59.6), then Kneeling (M=144.7, SD=55.8), and Standing having the worst (M=165.9, SD=68.6).

In addition, CIE configuration was trending towards significance. Post hoc analysis shows that encumbered Condition III (M=152.6, SD=61.5), was different than Condition I (M=142.6, SD=65.4), p=.05 as seen in Figure 10.

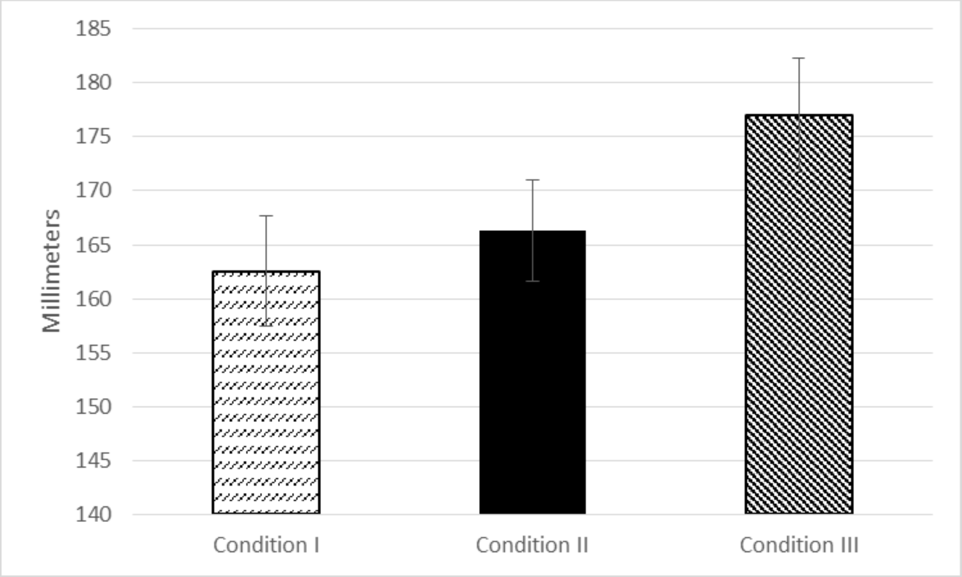


Figure 10. Differences in shot Accuracy across CIE encumbrance levels.

Probability of Hit: Freidman tests showed main effects of CIE configuration, χ^2 (2, N = 62) = 7.65, p = .022, and Position, χ^2 (2, N = 62) = 11.32, p = .003, indicating that there were differences among the three mean ranks for each independent variable. Post hoc analysis using Wilcoxon tests for each pair indicated that the contrasts between the most encumbered configuration, Condition III, (Median=.96), and the least encumbered configuration, Condition I (Median=.97), were statically significant, Z = -2.96, p=.003, r= -.38. In addition, the contrasts between the second most encumbered configuration, Condition II (Median=.96), and the least encumbered configuration, Condition I (Median=.97) were trending towards significance, Z = -1.85, p=.065, r= -.23, as seen in Figure 11.

In addition, post hoc analysis on position indicates that the contracts between Standing (Median=.95) and Prone (Median=.97) positions were statistically significant, Z = -2.99, p=.003, r=-.38; and the contrasts between Prone (Median=.97) and Kneeling (Median=.95) positions were statistically significant, Z = -2.75, p=.006, r=-.35; however, the probability of hit between Standing and Kneeling was not different.

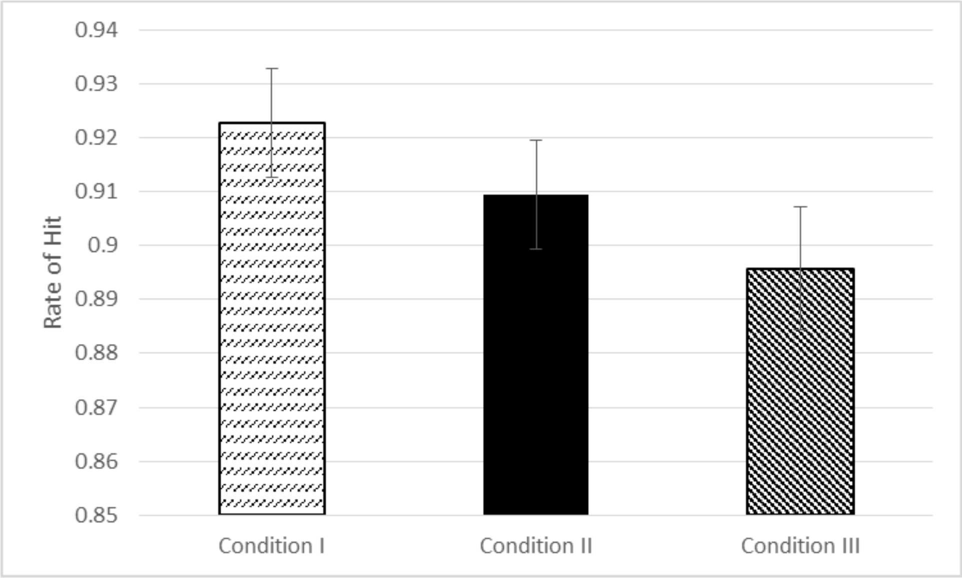


Figure 11. Differences in probability of hit across CIE encumbrance levels.

Probability of Lethal Hit: A Freidman test showed a main effect of Position, χ^2 (2, N = 62) = 22.96, p <.0001, indicating that there were differences among the three mean ranks. Post hoc analysis using Wilcoxon tests for each pair indicates that the contrasts between Standing (Median=.57) and Prone (Median=.63), positions were statistically significant, Z = -4.61, p<.0001, r=-.59; between Standing (Median=.57) and Kneeling (Median=.58), Z = -2.95, p=.003, r=-.37; and between Kneeling (Median=.58) and Prone (Median=.63), Z = -2.96, p=.003, r=-.38.

Aiming Time: Analysis indicated main effects of State, F(1, 57.5)=102.5, p<.0001 and Position, F(2,124.3)=23.5, p<.0001. The fatigued state showed shorter aiming time (M=1.3, SD=0.68) than the rested state (M=1.6, SD=0.69). Post hoc analysis using Tukey's HSD indicates that the Standing position was different than the other two positions, with Prone having the longest aiming time (M=1.59, SD=.77) and Standing having the shortest (M=1.32, SD=.56). CIE Configuration was also trending towards significance, F(2, 122.5)=2.9, p=.059. Post hoc analysis indicates that the greatest encumbered configuration, Condition III, (M=1.36, SD=.54) took less aiming time than Configuration I (M=1.55, SD=.83), as seen in Figure 12.

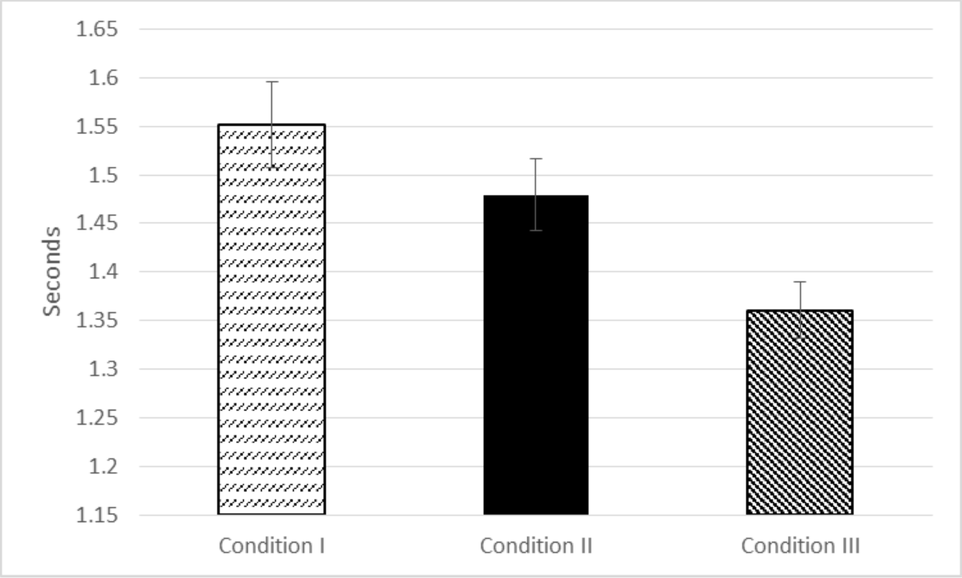


Figure 12. Differences in Aiming time across CIE encumbrance levels.

Time between Shots: Main effect of State, F(1, 44.82)=49.2, p<.0001 and Position, F(2,87.3)=7.38, p=.0011. The fatigued state produced quicker shots in succession (M=1.18, SD=.72) than the rested state (M=1.44, SD=.81). Post hoc analysis using Tukey's HSD indicates that all three positions were different, with Prone having the longest time between shots (M=1.38, SD=.88), then the Kneeling (M=1.32, SD=.88), and Standing having the shortest (M=1.19, SD=0.58).

In addition, there was an interaction between CIE Configuration and State, F(2, 443.9)=7.7, p=.0005. As encumbrance level was increased, the difference across rested to fatigued states became increasingly pronounced.

Trigger Control: Main effect of State, F(1, 55.62)=18.06, p<.0001, CIE configuration, F(2, 110.1)=9.1, p=.0002, and Position, F(2,118.6)=53.6, p<.0001. The fatigued state produced worse trigger control (M=133.1, SD=69.0) than the rested state (M=121.0, SD=61.9). Post hoc analysis using Tukey's HSD indicates that the most encumbered configuration, Condition III, affected the trigger control the greatest (M=135.3, SD=69.0), more than the least encumbered configuration, Condition I (M=120.4, SD=66.1) and trending towards more than Condition II (M=127.3, SD=66.8) as seen in Figure 13. Additionally, post hoc analysis showed that all three positions were different from each other (p<.0001 for each pair), with Prone having the best trigger control (M=97.1, SD=63.6), then Kneeling (M=126.2, SD=58.7) and Standing having the worst (M=159.0, SD=60.7).

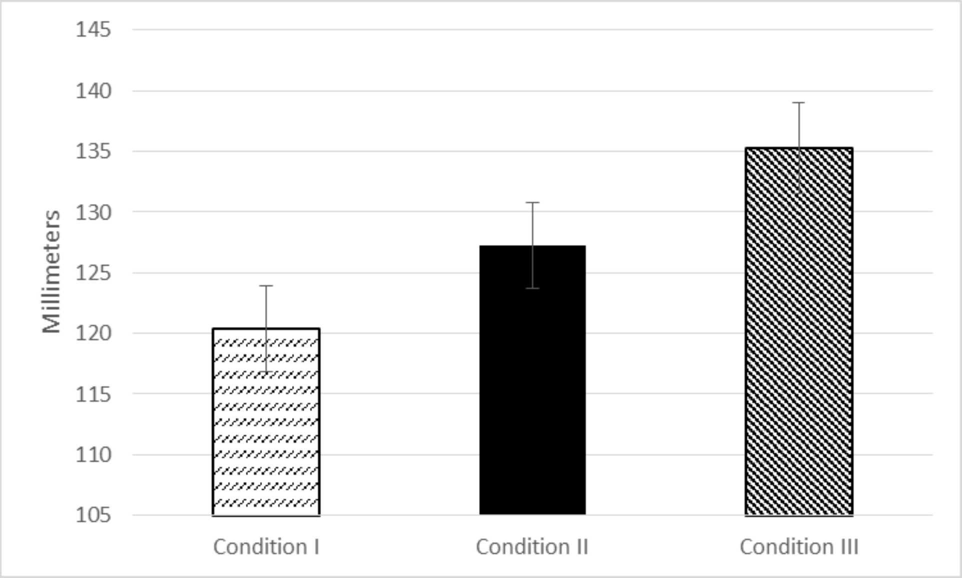


Figure 13. Differences in Trigger control across CIE encumbrance levels.

Horizontal Aiming Stability: Main effect of State, F(1, 58.9)=6.7, p=.012, CIE configuration, F(2, 118.3)=6.1, p=.003, and Position, F(2, 119.1)=36.9, p<.0001. The fatigued state produced less horizontal stability or greater horizontal aiming range (M=154.8, SD=68.4) than the rested state (M=146.3, SD=64.3). Post hoc analysis using Tukey's HSD indicates that the most encumbered configuration, Condition III, affected the horizontal stability the most (M=160.4, SD=71.3), more than the other two configurations, Condition I (M=144.0, SD=62.6) and Condition II (M=148.1, SD=64.8) (p<.05) as seen in Figure 14. Additionally, post hoc analysis showed that the Prone position was different from the other two positions, with Prone having the best horizontal stability (M=123.8, SD=67.5), then Kneeling (M=163.8, SD=67.3), and Standing having the worst (M=164.8, SD=56.2).

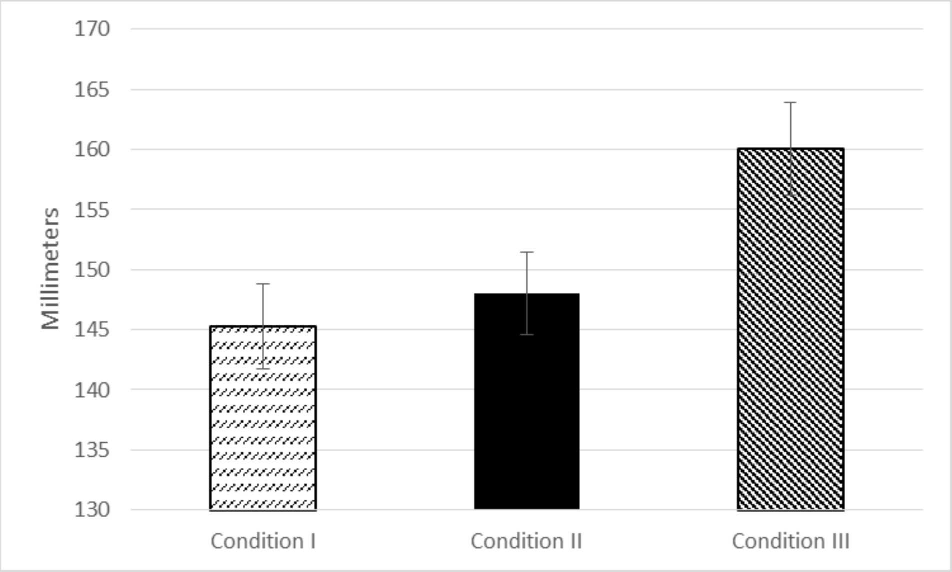


Figure 14. Differences in Horizontal Stability across CIE encumbrance levels.

Vertical Aiming Stability: Main effect of State, F(1, 57.33)=8.17, p=.006, CIE configuration, F(2, 118.2)=10.6, p<.0001, and Position, F(2,118.9)=45.8, p<.0001. The fatigued state produced less vertical stability or greater vertical aiming range (M=143.6, SD=89.5) than the rested state (M=133.8, SD=76.4). Post hoc analysis using Tukey's HSD indicates that the greatest encumbrance level, Condition III, affected the vertical stability the most (M=149.5, SD=79.1), more than the other two configurations, Condition I (M=135.3, SD=89.8) and Condition II (M=132.4, SD=81.2) (p<.001) as seen in Figure 15. Additionally, post hoc analysis showed that all three positions were different from each other (p<.001 each pair), with Prone having the best vertical stability (M=111.8, SD=82.3) and Standing having the worst (M=180.6, SD=83.3).

In addition, there was an interaction between CIE configuration and Position, F(4, 222.9)=8.2, p=.0018. The most encumbered configuration, Condition III, showed the most pronounced negative effect on vertical aiming stability in the kneeling and prone positions, but not in standing, as seen in Figure 16.

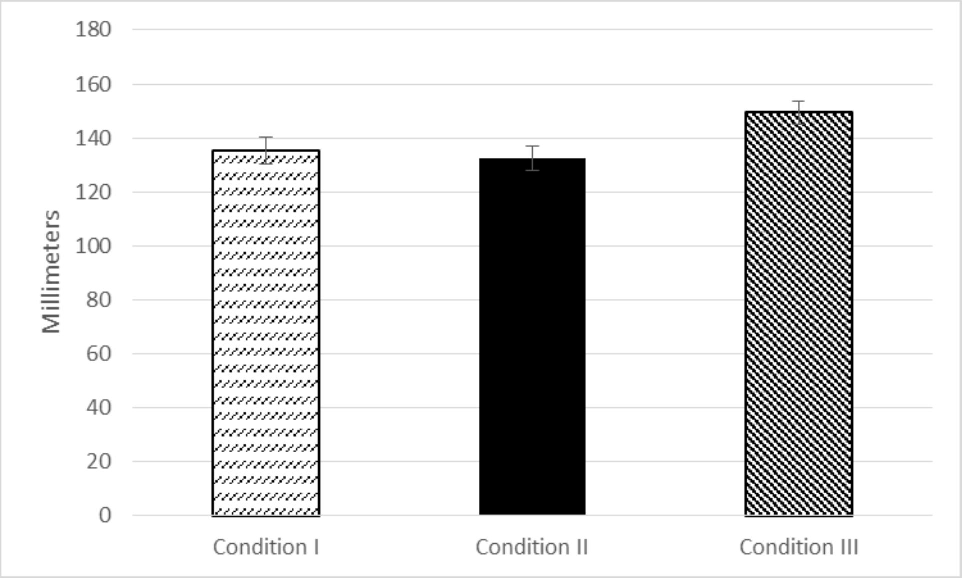


Figure 15. Differences in Vertical Stability across CIE encumbrance levels.

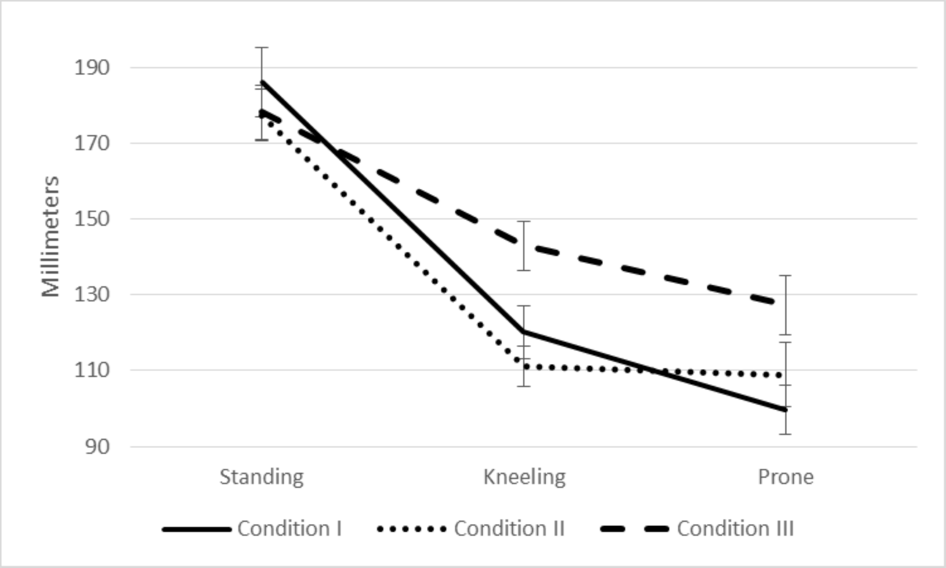


Figure 16. Interaction between CIE encumbrance and Firing position in Vertical Stability.

Overall Aiming Stability: Main effect of State, F(1, 58.8)=17.02, p=.0001, CIE encumbrance, F(2, 119.4)=9.5, p<.0001, and Position, F(2,119.3)=41.86, p<.0001. The fatigued state produced less overall stability with a greater aiming box area prior to engagement (M=32.51, SD=39.2) than the rested state (M=26.5, SD=26.2). Post hoc analysis using Tukey's HSD indicates that the greatest encumbrance, Condition III, affected the overall stability the most (M=32.98, SD=29.43), more than the other two CIE configurations, Condition I (M=27.72, SD=38.79) and Condition II (M=28.42, SD=32.41) (p<.01) as seen in Figure 17. Additionally, post hoc analysis showed that all three positions were different from each other (p<.001 each pair), with Prone having the best overall stability (M=21.96, SD=33.49) and Standing having the worst (M=39.21, SD=38.3). There was also an interaction between CIE encumbrance and Position, F(4,228.4)=2.6, p=.039.

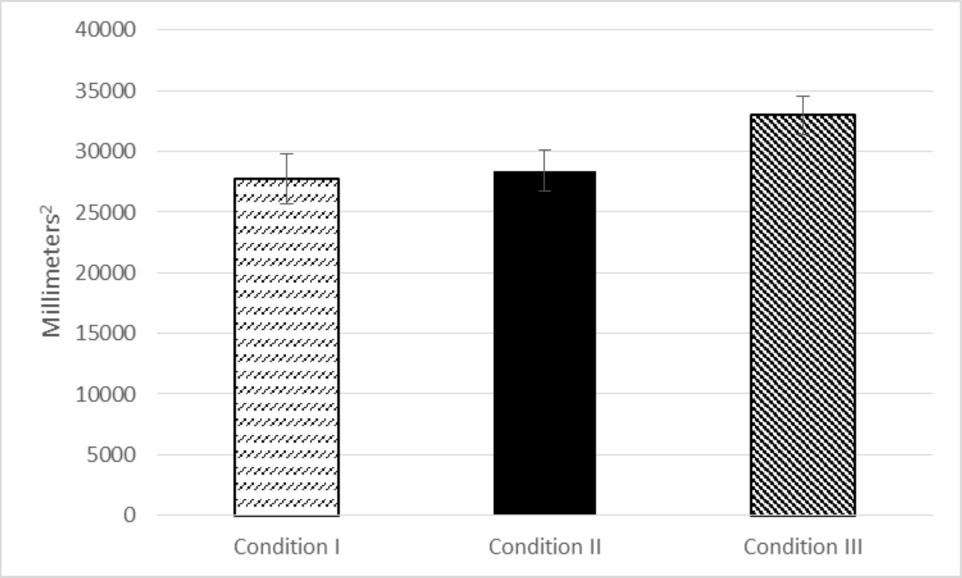


Figure 17. Differences in Overall Stability across CIE encumbrance levels.

Barrel Rotation: Main effect of Position, F(2,123.9)=6.88, p=.0015. Post hoc analysis showed that the Prone position was different from the other positions, with Prone having the greatest amount of rotation (M=.4, SD=5.5) and Kneeling and Standing having similar counterclockwise rotation (Kneeling: M=-.28, SD=5.6; Standing: M=-.29, SD=5.4). There was also an interaction between CIE configuration and Position, F(4,240.3)=3.6, p=.007, and CIE configuration and State F(2,113.9)=3.2, p=.04 as seen in Figures 18 and 19.

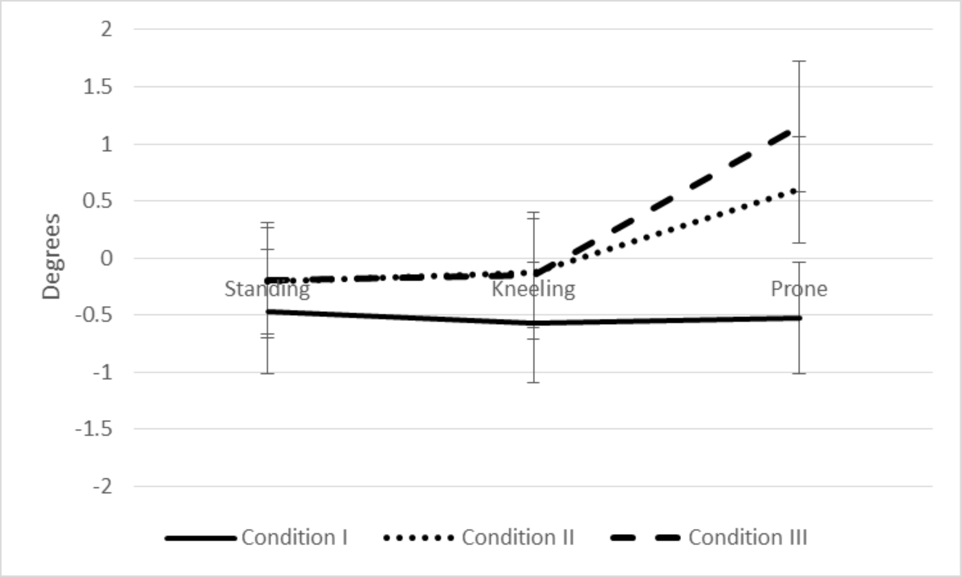


Figure 18. Interaction between CIE encumbrance and Firing position in Barrel Rotation.

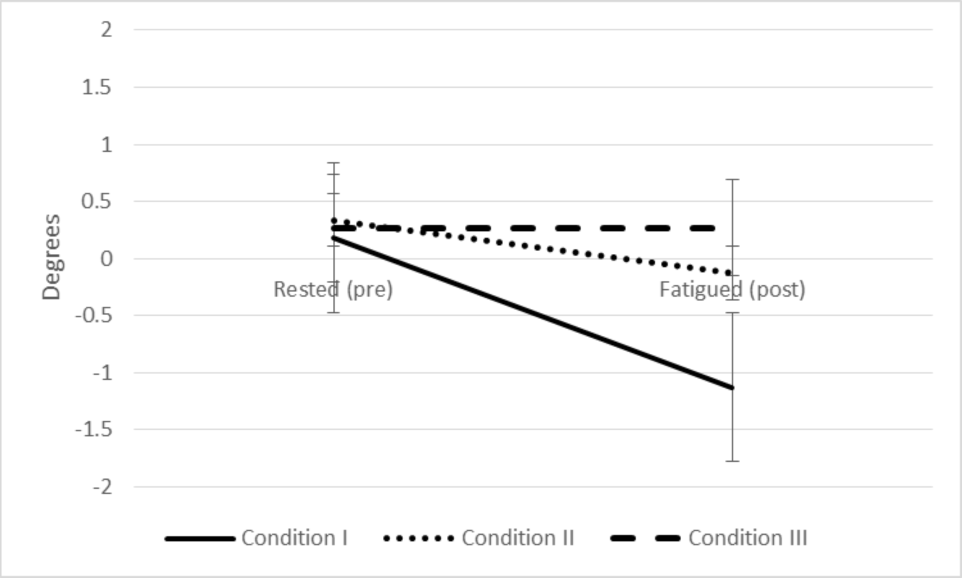


Figure 19. Interaction between CIE encumbrance and fatigue State in Barrel Rotation.

*Table 14***.** Mean Lethality performance measures for the Static 1-Target Marksmanship Task Rested (Pre) (n=62 for precision; n=66 for all other lethality measures)

		Condition I		Condition II		Condition III	
		Mean	Median	Mean	Median	Mean	Median
Precision (mm)	Standing	98.9 ±27.9	97	103 ±29.3	94.6	103.6 ±31.9	103
	Kneeling	83.3 ±35.9	76	81.8 ±31.7	75.2	91 ±37.3	84.5
	Prone	62.4 ±27.6	52.5	67.5 ±34.2	55.7	74.9 ±37.4	61.2
Accuracy (mm)	Standing	177.8 ±94.9	146.7	178.9 ±78.7	178.5	192.1 ±94.2	156.2
	Kneeling	154.3 ±76.5	132.2	164.8 ±98.4	129.6	184.1 ±99.4	160.2
	Prone	130.2 ±80.1	105.5	143.5 ±77.1	136.2	163.1 ±94.5	140.7
Probability of Hit	Standing	0.9 ±0.1	1	0.9 ±0.1	1	0.9 ±0.2	1
	Kneeling	0.9 ±0.1	1	0.9 ±0.2	1	0.9 ±0.2	1
	Prone	1 ±0.2	1	0.9 ±0.2	1	0.9 ±0.2	1
Probability of Lethal Hit	Standing	0.5 ±0.3	0.6	0.5 ±0.2	0.6	0.5 ±0.3	0.6
	Kneeling	0.6 ±0.2	0.6	0.6 ±0.3	0.7	0.5 ±0.3	0.6
	Prone	0.7 ±0.3	0.8	0.7 ±0.3	0.7	0.6 ±0.3	0.7

Table 15. Mean Lethality performance measures for the Static 1-Target Marksmanship Task Fatigued (Post) (n=62 for precision; n=66 for all other lethality measures)

		Condition I			Condition II			Condition III		
		Mean		Median	Mean		Median	Mean		Median
Precision (mm)	Standing	103.3	:32.5	99.6	105.7	±37.1	102.3	108	±34.2	105.1
	Kneeling	78.9	:27.2	73.5	92.7	±33.5	84.4	97	±32.6	94.6
	Prone	71.4	:34.4	57.7	72.5	±36.2	61.9	84	±42.8	67.8
Accuracy (mm)	Standing	191.3	:109.8	152.3	191.2	±91.1	158.5	183.9	±99.4	164.6
	Kneeling	164.9	:95.3	145.5	164.7	±82.3	139.7	169.6	±87.0	145.5
	Prone	152	:101.7	129.4	151.3	±90.2	127.2	166.5	±101.2	133.1
Probability of Hit	Standing	0.9	:0.2	1	0.9	±0.2	1	0.9	±0.2	1
	Kneeling	0.9	:0.2	1	0.9	±0.2	1	0.9	±0.2	1
	Prone	0.9	:0.2	1	0.9	±0.2	1	0.9	±0.2	1
Probability of Lethal Hit	Standing	0.6	:0.3	0.6	0.5	±0.3	0.5	0.5	±0.2	0.5
	Kneeling	0.6	:0.3	0.7	0.6	±0.3	0.6	0.6	±0.2	0.6
	Prone	0.7	:0.3	0.7	0.6	±0.3	0.7	0.6	±0.3	0.6

Table 16. Mean Mobility/Timing performance measures for the Static 1-Target Marksmanship Task Rested (Pre) (n=62)

		Condition I			Condition II			Condition III		
		Mean		Median	Mean		Median	Mean		Median
Aiming Time (s)	Standing	1.5	±0.6	1.3	1.4	±0.5	1.3	1.4	±0.5	1.4
	Kneeling	1.7	±0.9	1.4	1.6	±0.6	1.5	1.6	±0.6	1.3
	Prone	1.8	±0.9	1.6	1.8	±0.7	1.7	1.7	±0.7	1.5
Time between Shots (s)	Standing	1.4	±0.7	1.2	1.3	±0.6	1.1	1.3	±0.5	1.2
	Kneeling	1.7	±1.3	1.2	1.4	±0.7	1.2	1.4	±0.6	1.1
	Prone	1.6	±1.0	1.3	1.5	±0.8	1.3	1.5	±0.8	1.3

Table 17. Mean Mobility/Timing performance measures for the Static 1-Target Marksmanship Task Fatigued (Post) (n=62)

		Condition I		Condition II		Condition III	
		Mean	Median	Mean	Median	Mean	Median
Aiming Time (s)	Standing	1.3 ±0.6	1.1	1.2 ±0.6	1.1	1.1 ±0.4	1.1
	Kneeling	1.5 ±0.9	1.3	1.4 ±0.7	1.2	1.2 ±0.4	1.1
	Prone	1.6 ±0.9	1.4	1.5 ±0.7	1.2	1.3 ±0.4	1.2
Time between Shots (s)	Standing	1.2 ±0.7	1	1.1 ±0.5	1	1 ±0.4	0.9
	Kneeling	1.4 ±1.1	1.1	1.2 ±0.7	0.9	1 ±0.4	0.9
	Prone	1.4 ±1.0	1.1	1.2 ±0.8	1	1.1 ±0.4	1.1

Table 18. Mean Weapon Handling/Stability performance measures for the *Static 1-Target Marksmanship Task* Rested (Pre) (n=62)

		Condition I		Condition II		Condition III	
		Mean	Median	Mean	Median	Mean	Median
Trigger Control (mm)	Standing	148.4 ±54.4	151.7	157.8 ±47.9	149.9	154.9 ±56.9	153.8
	Kneeling	115.7 ±55.1	105.4	111.9 ±56.3	89.8	130.1 ±61.0	116.6
	Prone	79.8 ±49.2	60.2	92.9 ±65.1	69.5	93.2 ±56.7	74.3
Horizontal Stability (mm)	Standing	162.1 ±49.6	162.2	165.6 ±55.9	154.7	162.9 ±53.1	152.5
	Kneeling	159.6 ±64.2	152.8	154.3 ±59.5	136.8	167.3 ±65.2	160.4
	Prone	107.2 ±50.6	89.5	109.1 ±61.1	88.4	126.1 ±73.5	100.8
Vertical Stability (mm)	Standing	183.2 ±78.0	177.0	172.0 ±57.0	165.2	174.7 ±74.4	171.7
	Kneeling	120.3 ±80.6	94.1	105.9 ±56.4	91.3	135.7 ±68.3	120.3
	Prone	92.6 ±54.2	75.6	106.8 ±81.0	76.3	112.9 ±71.9	97.8
Overall Stability (mm)	Standing	35106.6 ±25392.1	29795.6	34473.8 ±22127.2	26985.5	34135.4 ±22298.0	28509.8
	Kneeling	26869.2 ±31233.5	14739.5	22342.5 ±22786.5	13419.4	29725.7 ±24843.1	18859.6
	Prone	13610.6 ±14703.2	9006.5	19194.2 ±27177.4	7941.6	23098.9 ±33369.3	12581.0
Barrel Rotation (deg)	Standing	0.2 ±5.6	0.0	0.2 ±5.1	0.0	-0.2 ±5.5	-0.1
	Kneeling	0.4 ±5.6	-0.4	0.0 ±5.5	-0.2	-0.2 ±6.2	-0.6
	Prone	0.0 ±5.5	-0.5	0.8 ±5.3	0.3	1.2 ±6.2	1.1

Table 19. Mean Weapon Handling/Stability performance measures for the *Static 1-Target Marksmanship Task* Fatigued (Post) (n=62)

		Condition I		Condition II		Condition III	
		Mean	Median	Mean	Median	Mean	Median
Trigger Control (mm)	Standing	166.7 ±78.9	159.9	167.0 ±75.1	168.4	164.3 ±66.5	168.5
	Kneeling	115.0 ±52.4	108.9	134.0 ±54.6	121.1	146.5 ±65.2	133.8
	Prone	94.6 ±59.0	68.5	97.9 ±61.1	77.6	119.9 ±80.6	92.7
Horizontal Stability (mm)	Standing	169.8 ±81.8	146.1	163.2 ±53.9	161.3	167.1 ±57.1	160.0
	Kneeling	153.1 ±65.3	145.0	170.8 ±61.1	154.2	179.3 ±83.3	151.6
	Prone	119.0 ±54.2	110.2	123.2 ±71.3	112.3	155.5 ±79.1	134.0
Vertical Stability (mm)	Standing	188.6 ±114.5	167.7	182.1 ±84.3	179.1	181.4 ±78.4	175.4
	Kneeling	119.9 ±70.5	97.4	115.6 ±57.7	99.8	149.4 ±69.5	136.7
	Prone	105.8 ±80.0	81.5	110.8 ±99.8	85.0	140.2 ±90.9	107.7
Overall Stability (mm)	Standing	46125.5 ±70575.2	25781.1	41167.2 ±30492.1	33898.8	42671.7 ±29912.9	36335.4
	Kneeling	26200.7 ±29872.3	15064.0	26722.1 ±20236.9	20909.3	35218.6 ±27406.7	22545.9
	Prone	17451.5 ±20323.7	9644.6	25586.8 ±53113.5	11176.1	31882.5 ±34005.4	17705.6
Barrel Rotation (deg)	Standing	-1.1 ±6.0	-0.6	-0.6 ±4.9	-0.8	-0.2 ±5.3	-0.3
	Kneeling	-1.4 ±5.6	-0.8	-0.3 ±4.9	-0.5	-0.1 ±5.6	-0.4
	Prone	-0.9 ±5.1	-0.2	0.5 ±4.8	-0.2	1.1 ±6.0	0.0

3.1.1.2. Dynamic 4-Target Task

The dynamic 4-Target task results are categorized into areas of lethality, mobility, and stability. Tables 20-25 at the end of this section provide a summary of the means, standard deviations, and medians for each dependent variable pre- and post-sessions.

Precision: Main effect of CIE Configuration, F(2,120.2)=3.25, p=.0424, and Position, F(2, 117.5)=121.7, p<.0001. Post hoc analysis using Tukey's HSD indicates that Condition I and III were different than each other, with the configuration with greatest encumbrance (Condition III) producing the worst precision (most shot dispersion) (M=135, SD=67.9), and the slick condition (Condition I) resulting in the best precision (M=124, SD=58.5) as seen in Figure 20. Post hoc analysis of the main effect of Position using Tukey's HSD indicates that all three positions were different than each other, with Prone having the best precision (M=104, SD=60.4) and Standing having the worst (M=153, SD=64.6).

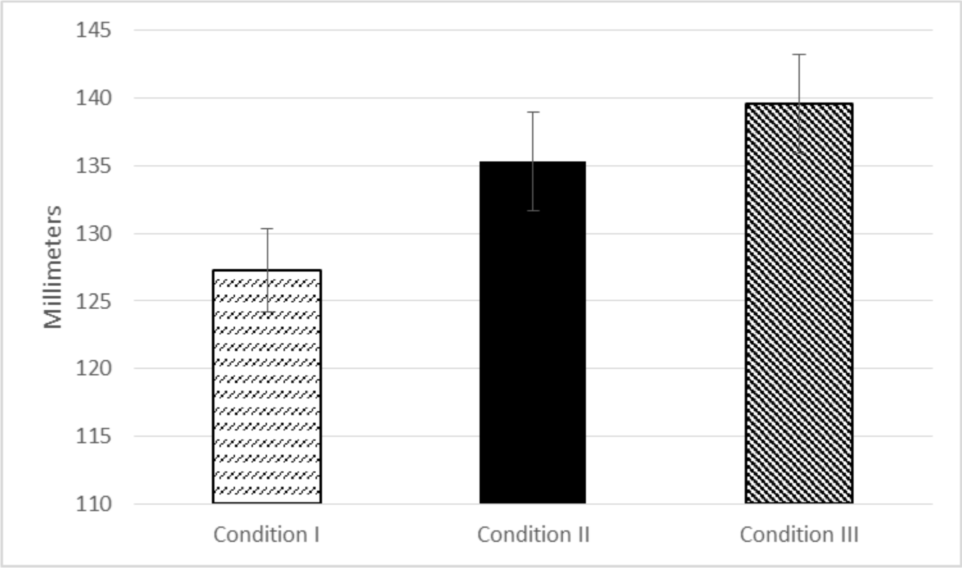


Figure 20. Differences in Precision across CIE encumbrance levels.

Accuracy: Main effect of Position, F(2, 115.7)=10.69, p<.0001, and State, F(1,61.16)=4.94, p=.03. Post hoc analysis using Tukey's HSD indicates that the Prone position was different than Kneeling and Standing, with Prone having the best accuracy (M=208.7, SD=81.6) and Standing having the worst (M=228.6, SD=68.0). Also, the fatigued state produced more accurate shots (M=216.4, SD=78.2) than the rested state (M=221.6, SD=74.3).

Probability of Hit: Freidman tests indicated main effects of Position, $\chi 2$ (2, N = 62) = 10.34, p =.006, and CIE Configuration, $\chi 2$ (2, N = 54) = 9.2, p = .01, indicating that there were differences among the three mean ranks.

Post hoc analysis using Wilcoxon tests for each pair indicated that the contrasts between Standing (Median =.65) and Prone (Median =.79) positions were statistically significant, Z = -3.09, p=.002, r=-.39, and Kneeling (Median =.74) and Prone (Median =.79), Z=-2.93, p=.003, r=-.37; however, Standing (Median=.65) and Kneeling (Median=.74) were not different, Z = -1.25, p=.21, r=-.16.

In addition, post hoc analysis on CIE configuration indicated that the contrasts between the most encumbered configuration, Condition III (Median =.65) and the least encumbered configuration, Condition I (Median=.73) were different, Z = -2.68, p=.007, r=-.36 as displayed in Figure 21.

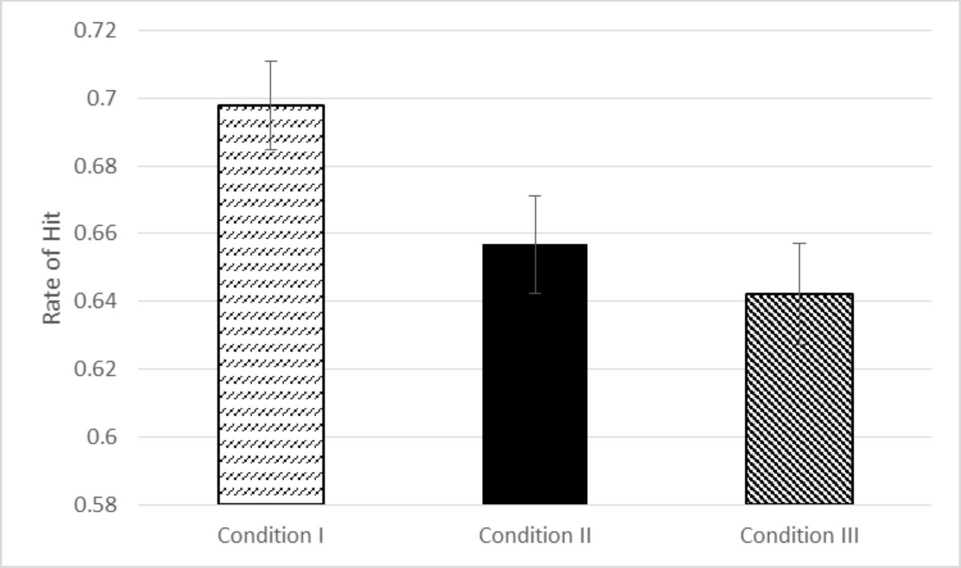


Figure 21. Differences in P(Hit) across CIE encumbrance levels.

Probability of Lethal Hit/Probability of Kill: Freidman tests indicated a main effect of Position, χ2 (2, N = 62) = 15.04, p =.001, indicating that there were differences among the three mean ranks.

Post hoc analysis using Wilcoxon tests for each pair indicated that the contrasts between Standing (Median=.23) and Prone (Median=.31) positions were statistically significant, Z = -4.45, p<.0001, r=.57; Kneeling (Median=.29) and Prone (Median=.23), Z=-3.63, p<.0001, r=-.46; and Kneeling (Median=.29) and Standing (Median=.23), Z=-2.35, p=.019, r=-.30.

In addition, a Wilcoxon test showed a main effect of State, Z = -2.73, p=.006, r=.35, indicating that the probability of lethal hit in the Fatigued state (Median=.29) was better than in the Rested state (Median=.28).

Mean Aiming Time per Target: Main effects of Position, F(2,121.8)=71.1, p<.0001, and State, F(1,60.5)=19.47, p<.0001. The Standing position produced the lowest mean aiming times (M=.79, SD=.30), lower than kneeling (M=.99, SD=.38) and prone (M=.99, SD=.31). The Fatigued state (M=.89,SD=.33) had significantly faster times for aiming than the rested state (M=.96,SD=.36).

There was also an interaction between position and state, F(2,122.5)=3.84, p=.024. The effect of fatigue on aiming time was more pronounced for the unstable positions of kneeling and standing, with little effect in the prone position.

Total Aiming Time per Trial: Main effects of Position, F(2,122.4)=63.2, p<.0001, and State, F(1,59.85)=7.6, p=.0077. The Standing position produced the lowest total aiming times (M=2.99, SD=1.2), lower than kneeling (M=3.76, SD=1.4) and prone (M=3.75, SD=1.3). The Fatigued state (M=3.4, SD=1.3) had faster total times for aiming than the Rested state (M=3.6, SD=1.4).

There was also an interaction between position and state, F(2,122.1)=6.9, p=.0014. The effect of fatigue on aiming time was more pronounced for the unstable positions of kneeling and standing, with little to no effect in the prone position.

Mean Target Acquisition Time per Target: Main effects of CIE configuration, F(2, 121.8)=35.0, p<.0001, Position, F(2,122.8)=531.04, p<.0001, and State, F(1,61.52)=6.31, p=.0146. Post hoc analysis using Tukey's HSD revealed that the most encumbered configuration, Condition III, resulted in the slowest movement times between targets (M=3.53, SD=1.29), slower than the least encumbered configuration, Condition I (M=3.03, SD=.88) as displayed in Figure 22. All of the positions were different from each other, with the Standing position producing the quickest movement times (M=2.63, SD=.6), and prone producing the slowest (M=4.23, SD=1.1). There were also interactions seen between CIE configuration and Position, F(4, 244.2)=12.31, p<.0001 as seen in Figure 23, and Position and State, F(2, 123)=4.71, p=.01.

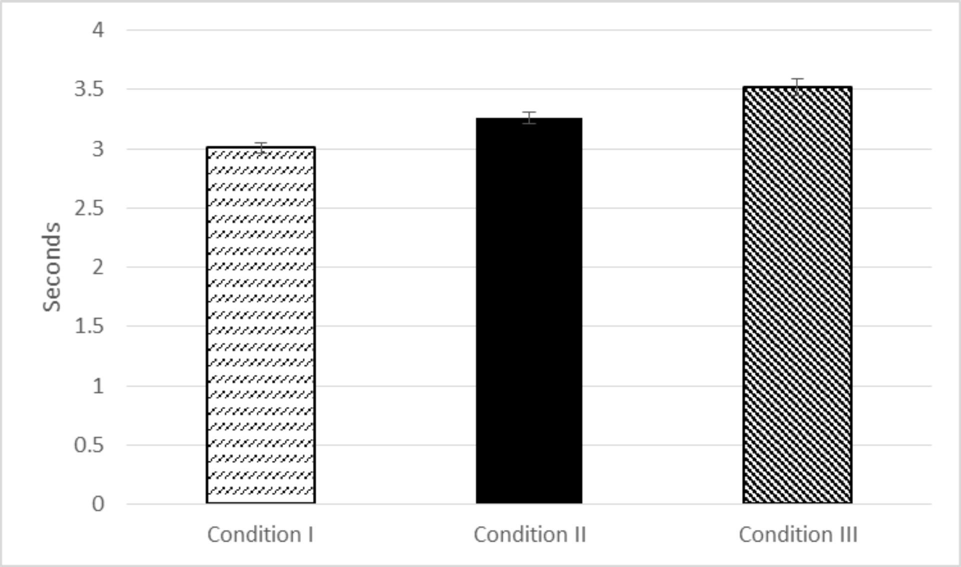


Figure 22. Differences in TAT across CIE encumbrance levels.

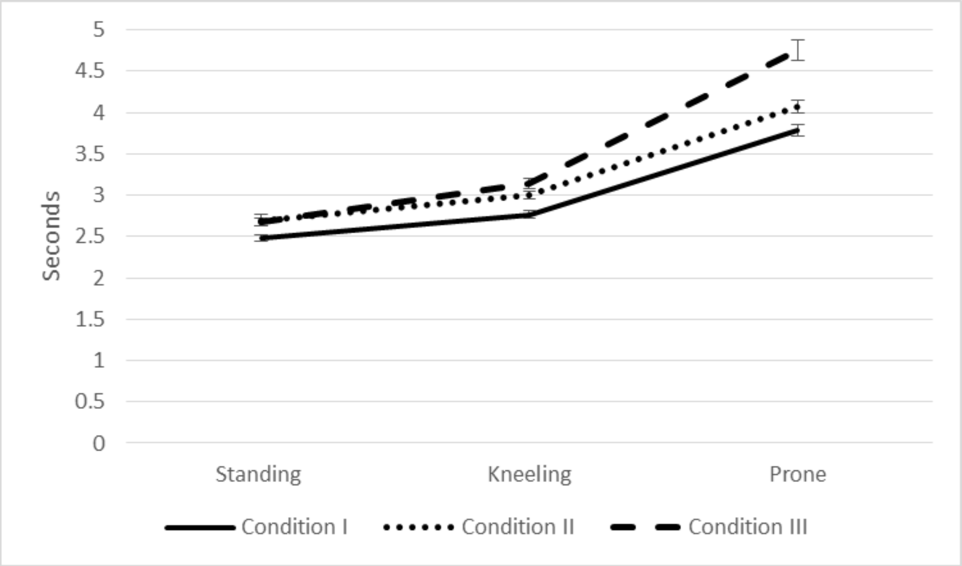


Figure 23. Interaction between CIE configuration and Position for TAT.

Mean Engagement Time per Target: Main effect seen for Position, F(2,122.3)=50.64, p<.0001, and State, F(1,60.36)=22.33, p<.0001. Less time was spent engaging the targets when shooting from the Standing position (M=1.47, SD=.54), as compared to the Kneeling (M=1.7, SD=.64) or Prone positions (M=1.73, SD=.57). More time was spent on average at targets when in the Rested state (M=1.7, SD=.63) than the Fatigued state (M=1.67, SD=.55).

Interaction found between CIE configuration and Position, F(4,244.9)=2.43, p=.0486, and CIE configuration, Position and State, F(4, 242.8)=3.00, p=.019. In the fatigued state, the time spent per target was less for kneeling and standing, but not affected in the prone position, as seen in Figure 24.

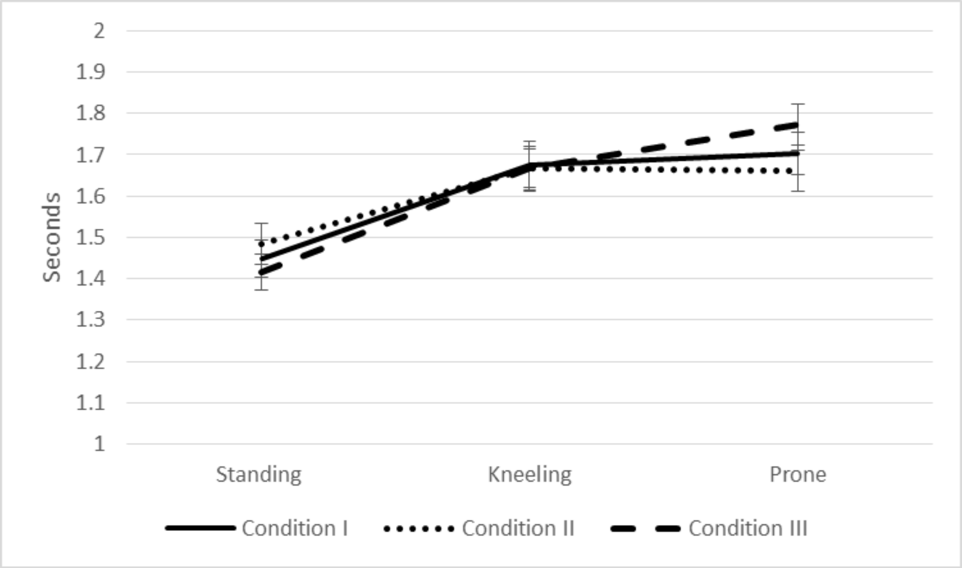


Figure 24. Interaction between CIE encumbrance levels and firing position for engagement time.

Total Engagement Time per Trial: Main effect seen for Position, F(2, 122.5)=45.96, p<.0001, and State, F(1,59.63)=7.75, p=.0072. Less time was spent at the targets when using the Standing position (M=5.5, SD=2.1), as compared to the Kneeling (M=6.4, SD=2.4) or Prone positions (M=6.5, SD=2.4). More time was spent on average at targets during the session when in the Rested state (M=6.4, SD=2.5) than the Fatigued state (M=6.0, SD=2.1).

There was also an interaction seen between Position and State, F(2,123.2)=3.87, p=.023. As participants became more fatigued, their time spent at the targets increased for positions that required more effort to achieve (i.e., kneeling and prone positions).

Total Trial Time: Main effect seen for CIE configuration, F(2,122.1)=14.21, p<.0001, Position, F(2, 122.4)=380.36, p<.0001, and State, F(1,60.09)=6.76, p=.0117. Post hoc analysis using Tukey's HSD revealed that the most encumbered configuration, Condition III, resulted in the slowest movement times between targets (M=15.6, SD=4.3), slower than the least encumbered configuration, Condition I (M=14.3, SD=3.5), as seen in Figure 25. The positions were all different than each other. There was less time spent in sessions utilizing the Standing position (M=12.7, SD=2.7) compared to the Kneeling (M=14.4, SD=3.2) or Prone positions (M=17.8, SD=3.8). Additionally, the task took more time when in the Rested state (M=15.2, SD=4.0) than the Fatigued state (M=14.8, SD=3.7). There was also an interaction between CIE configuration and position, F(4,245.7)=12.56, p<.0001, as seen in Figure 26. Total Trial Time increased significantly as the CIE encumbrance level increased (i.e., Condition I to Condition III) for firing positions that required more effort to achieve (i.e., kneeling and prone positions).

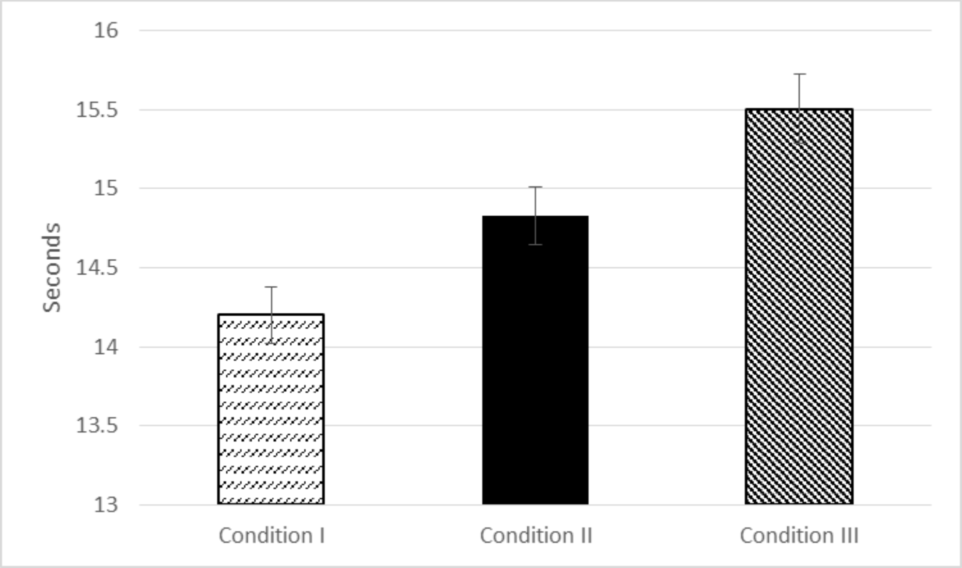


Figure 25. Differences in Total Trial Time across CIE encumbrance levels.

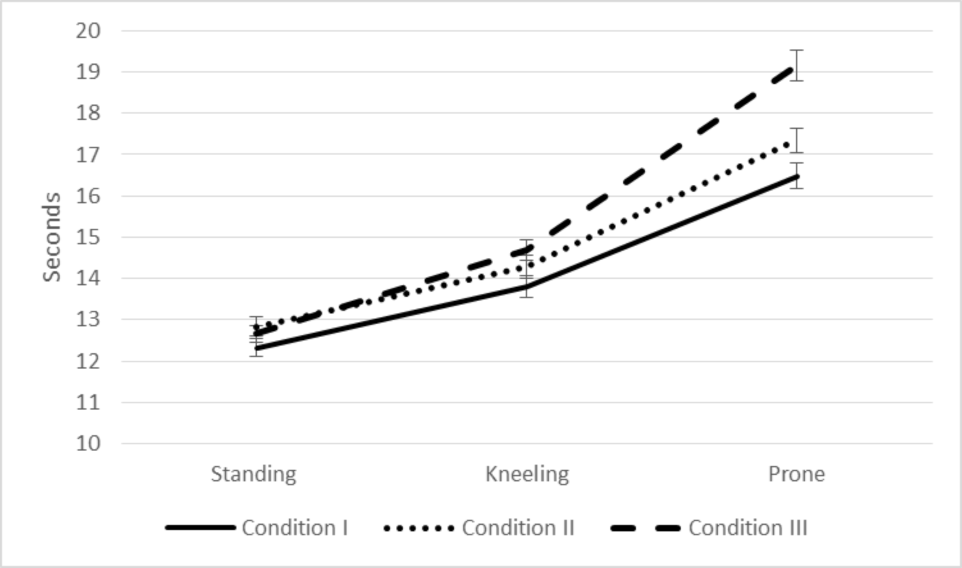


Figure 26. Interactions between CIE configuration and position for Total Trial Time.

Trigger Control: Main effect seen for Position, F(2, 121.7)=204.0, p<.0001. Post-hoc analysis using Tukey's HSD indicated that the positions were all different than each other. There was better control seen in the Prone position (M=206.0, SD=107.3), as compared to the Kneeling (M=315.2, SD=122.8) or Standing positions (M=385.7, SD=150.0).

Horizontal Aiming Stability: Main effect seen for Position, F(2, 122.2)=45.67, p<.0001, and State, F(1,61.07)=6.67, p=.012. Post-hoc analysis using Tukey's HSD indicated that the Prone position (M=407.4, SD=243.7) was more stable as compared to the Kneeling (M=487.8, SD=223.1) or Standing positions (M=493.9, SD=266.8). The participants were more stable during the Rested state (M=445.7, SD=232.6) than the Fatigued state (M=480.7, SD=261.9).

Vertical Aiming Stability: Main effect seen for Position, F(2, 122.2)=45.67, p<.0001, and State, F(1,61.42)=6.00, p=.017. Post-hoc analysis using Tukey's HSD indicated that all positions were different than each other, with the Prone position (M=376.6, SD=223.1) being the most vertically stable, followed by the Kneeling (M=418.5, SD=219.4) and the Standing positions (M=505.6, SD=249.0). The participants were more stable during the Rested state (M=420.9, SD=232.5) than the Fatigued state (M=446.4, SD=240.6).

Overall Aiming Stability: Main effect seen for Position, F(2, 122)=50.2, p<.0001, and State, F(1,61.55)=5.35, p=.024. Post-hoc analysis using Tukey's HSD indicated that all positions were different than each other, with the Prone position (M=230.4, SD=254.1) being the most stable overall, followed by the Kneeling (M=275.4, SD=240.7) and the Standing positions (M=341.7, SD=335.5). The participants were more stable during the Rested state (M=270.1, SD=269.6) than the Fatigued state (M=295.0, SD=296.4).

Barrel Rotation: Main effect seen for Position, F(2, 122.3)=30.3, p<.0001, and State, F(1,59.47)=6.6, p=.0126. The positions were all different than each other. There was more clockwise barrel rotation seen in the Prone position (M=1.18, SD=5.9), as compared to the Kneeling (M=-1.01, SD=5.5) or Standing positions (M=-1.00, SD=5.5). More counterclockwise rotation was seen in the Fatigued state (M=-.53, SD=5.59) than the Rested state (M=-.03, SD=5.87). There was also an interaction seen between CIE configuration and Position, F(4,244.5)=10.8, p<.0001. CIE configuration had a greater effect on barrel rotation in the prone position than the other two firing positions, as seen in Figure 27.

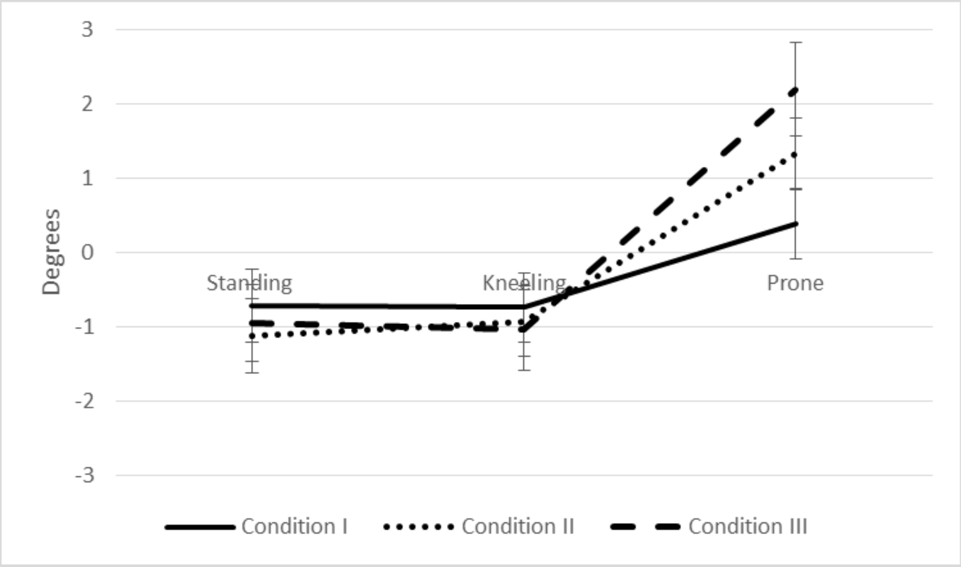


Figure 27. Interaction between CIE configuration and Position for Barrel Rotation.

Table 20. Mean Lethality performance measures for the Dynamic 4-Target Marksmanship Task Rested (Pre) (n=62 for precision; n=66 for all other lethality measures)

		Condition I		Condition II		Condition III	
		Mean	Median	Mean	Median	Mean	Median
Precision (mm)	Standing	153.2 ±57.0	148.2	155.5 ±68.9	139.8	157.4 ±65.0	147.3
	Kneeling	135.1 ±63.2	131.0	141.0 ±67.6	130.2	147.1 ±60.5	135.4
	Prone	101.5 ±50.5	90.3	108.5 ±69.8	92.3	115.5 ±70.3	100.3
Accuracy (mm)	Standing	309.8 ±99.4	296.4	320.2 ±115.2	303.7	336.3 ±103.8	334.6
	Kneeling	290.4 ±127.8	248.6	331.1 ±170.2	283.6	340.7 ±157.7	293.1
	Prone	281.6 ±141.6	249.4	297.7 ±139.7	257.4	296.5 ±157.3	259.0
Probability of Hit	Standing	0.7 ±0.2	0.8	0.6 ±0.3	0.6	0.6 ±0.2	0.6
	Kneeling	0.7 ±0.2	0.7	0.6 ±0.3	0.8	0.6 ±0.3	0.6
	Prone	0.7 ±0.3	0.8	0.7 ±0.3	0.8	0.6 ±0.3	0.8
Probability of Lethal Hit	Standing	0.2 ±0.1	0.3	0.2 ±0.2	0.3	0.2 ±0.2	0.1
	Kneeling	0.3 ±0.2	0.3	0.3 ±0.2	0.3	0.2 ±0.2	0.3
	Prone	0.3 ±0.3	0.3	0.3 ±0.3	0.3	0.3 ±0.3	0.3

Table 21. Mean Lethality performance measures for the Dynamic 4-Target Marksmanship Task Fatigued (Post) (n=62 for precision; n=66 for all other lethality measures)

		Condition I		Condition II		Condition III	
		Mean	Median	Mean	Median	Mean	Median
Precision (mm)	Standing	146.6 ±54.8	139.9	159.1 ±69.3	150.5	157.9 ±66.3	152.8
	Kneeling	124.3 ±57.5	111.8	138.7 ±72.7	121.2	138.5 ±56.2	129.3
	Prone	102.5 ±53.8	86.7	109.7 ±49.0	102.6	120.6 ±80.6	95.8
Accuracy (mm)	Standing	306.4 ±113.0	295.7	315.2 ±104.9	291.8	315.4 ±118.6	294.3
	Kneeling	285.8 ±115.6	254.2	292.8 ±129.3	247.7	308.1 ±137.2	259.7
	Prone	256.2 ±128.9	236.2	296.2 ±149.5	252.9	292.2 ±167.5	246.3
Probability of Hit	Standing	0.7 ±0.2	0.6	0.6 ±0.2	0.8	0.6 ±0.3	0.6
	Kneeling	0.7 ±0.2	0.8	0.7 ±0.3	0.7	0.7 ±0.3	0.8
	Prone	0.8 ±0.3	0.9	0.7 ±0.3	0.8	0.7 ±0.3	0.8
Probability of Lethal Hit	Standing	0.3 ±0.2	0.3	0.2 ±0.2	0.3	0.3 ±0.2	0.3
	Kneeling	0.3 ±0.2	0.3	0.3 ±0.2	0.3	0.3 ±0.2	0.3
	Prone	0.4 ±0.3	0.4	0.3 ±0.2	0.4	0.3 ±0.3	0.3

Table 22. Mean Mobility/Timing performance measures for the Dynamic 4-Target Marksmanship Task Rested (Pre) (n=62)

		Condition I		Condition II		Condition III	
		Mean	Median	Mean	Median	Mean	Median
Aiming Time (s)	Standing	0.8 ±0.3	0.8	0.9 ±0.3	0.8	0.8 ±0.3	0.8
	Kneeling	1.0 ±0.4	0.9	1.0 ±0.4	0.9	1.0 ±0.4	0.9
	Prone	1.0 ±0.3	1.0	1.0 ±0.3	0.9	1.1 ±0.3	1.0
Target Acquisition Time (s)	Standing	2.5 ±0.4	2.5	2.7 ±0.9	2.5	2.7 ±0.6	2.6
	Kneeling	2.8 ±0.5	2.7	3.0 ±0.5	3.0	3.1 ±0.8	3.0
	Prone	3.9 ±0.8	3.6	4.1 ±0.9	4.1	5.0 ±1.4	4.6
Target Engagement Time (s)	Standing	1.5 ±0.5	1.4	1.6 ±0.5	1.5	1.5 ±0.5	1.4
	Kneeling	1.8 ±0.7	1.6	1.7 ±0.7	1.6	1.7 ±0.6	1.7
	Prone	1.7 ±0.6	1.7	1.7 ±0.6	1.7	1.9 ±0.6	1.9
Total Trial Time (s)	Standing	12.5 ±2.8	12.2	13.2 ±2.9	12.6	12.9 ±2.6	12.4
	Kneeling	14.2 ±3.4	13.8	14.3 ±3.0	14.2	14.8 ±2.9	14.7
	Prone	16.5 ±3.6	15.8	17.5 ±3.2	17.3	19.4 ±4.4	18.9

Table 23. Mean Mobility/Timing performance measures for the Dynamic 4-Target Marksmanship Task Fatigued (Post) (n=62)

		Condition I		Condition II		Condition III	
		Mean	Median	Mean	Median	Mean	Median
Aiming Time (s)	Standing	0.7 ±0.3	0.7	0.7 ±0.3	0.7	0.7 ±0.2	0.7
	Kneeling	0.9 ±0.3	0.8	1.0 ±0.3	0.9	0.9 ±0.2	0.9
	Prone	1.0 ±0.3	0.9	0.9 ±0.3	0.9	0.9 ±0.3	0.9
Target Acquisition Time (s)	Standing	12.5 ±2.8	12.2	13.2 ±2.9	12.6	12.9 ±2.6	12.4
	Kneeling	14.2 ±3.4	13.8	14.3 ±3.0	14.2	14.8 ±2.9	14.7
	Prone	16.5 ±3.6	15.8	17.5 ±3.2	17.3	19.4 ±4.4	18.9
Target Engagement Time (s)	Standing	1.4 ±0.5	1.4	1.4 ±0.6	1.3	1.3 ±0.4	1.4
	Kneeling	1.6 ±0.5	1.4	1.6 ±0.5	1.6	1.6 ±0.4	1.7
	Prone	1.7 ±0.5	1.7	1.6 ±0.5	1.6	1.7 ±0.5	1.7
Total Trial Time (s)	Standing	12.2 ±2.3	11.9	12.5 ±2.3	12.2	12.4 ±2.1	12.3
	Kneeling	13.5 ±2.6	13.2	14.2 ±3.0	13.7	14.6 ±2.5	14.6
	Prone	16.5 ±3.0	16.2	17.1 ±3.2	16.7	18.9 ±3.8	17.9

Table 24. Mean Weapon Handling/Stability performance measures for the Dynamic 4 -Target Marksmanship Task Rested (Pre) (n=62)

		Condition I		Condition II		Condition III	
		Mean	Median	Mean	Median	Mean	Median
Trigger Control (mm)	Standing	358.8 108.1	332.1	381.3 146.7	361.4	406.2 174.9	389.2
	Kneeling	294.0 106.5	300.9	328.9 142.1	306.4	327.8 121.0	306.6
	Prone	202.5 96.6	192.6	209.2 118.4	187.2	205.0 108.5	175.4
Horizontal Stability (mm)	Standing	481.5 265.8	425.4	445.7 217.9	383.5	527.3 270.2	440.4
	Kneeling	463.3 214.3	437.1	495.6 230.1	472.8	485.8 228.4	429.9
	Prone	353.6 177.3	331.3	383.6 216.7	331.1	392.7 224.3	334.3
Vertical Stability (mm)	Standing	487.6 248.5	446.6	467.8 208.8	435.9	515.0 265.1	449.4
	Kneeling	407.2 228.9	360.7	410.0 231.9	370.6	431.0 239.4	356.4
	Prone	344.3 188.3	326.4	377.9 226.6	344.7	368.3 209.5	317.7
Overall Stability (mm)	Standing	344410.4 362904.6	226161.2	290184.9 266725.1	203027.7	357866.9 331489.2	257410.3
	Kneeling	259652.9 230357.7	185905.5	296934.4 292147.7	214357.7	282372.3 255342.5	196843.5
	Prone	187088.2 161351.4	154452.7	225558.3 249842.7	151355.9	210849.4 192160.4	154942.3
Barrel Rotation (deg)	Standing	-0.3 5.7	-1.0	-0.9 5.7	-0.8	-0.7 5.8	-1.0
	Kneeling	-0.4 5.3	-0.9	-0.6 5.4	-1.1	-0.9 6.0	-0.9
	Prone	0.9 5.3	-0.5	1.5 5.4	0.9	2.0 7.5	1.6

Table 25. Mean Weapon Handling/Stability performance measures for the Dynamic 4 -Target Marksmanship Task Fatigued (Post) (n=62)

		Condition I		Condition II		Condition III	
		Mean	Median	Mean	Median	Mean	Median
Trigger Control (mm)	Standing	376.9 139.9	360.5	411.7 188.8	356.1	389.2 131.5	365.9
	Kneeling	325.2 134.9	326.2	321.1 111.0	314.8	304.7 118.3	286.8
	Prone	181.5 88.8	155.8	228.3 115.5	226.5	215.4 115.2	192.6
Horizontal Stability (mm)	Standing	481.4 348.7	374.0	525.1 253.5	483.1	523.8 228.6	507.8
	Kneeling	484.9 223.4	427.5	508.6 231.0	472.1	506.7 220.6	448.4
	Prone	434.7 300.8	331.9	467.4 247.3	396.1	430.7 273.4	372.2
Vertical Stability (mm)	Standing	494.1 233.7	441.0	543.0 288.9	426.0	544.4 248.3	433.3
	Kneeling	399.3 220.0	366.9	412.6 171.3	418.3	468.1 221.8	415.0
	Prone	348.2 194.0	324.0	434.3 260.0	345.4	406.5 249.8	352.2
Overall Stability (mm)	Standing	343814.6 415787.1	195657.7	359488.2 323958.3	226606.0	377486.5 307060.7	276451.6
	Kneeling	259777.2 226222.3	187936.2	270223.5 189487.3	217746.6	302004.5 247845.0	220317.1
	Prone	226035.9 246312.7	122650.2	297905.4 294825.5	195916.5	254389.6 341497.8	145884.3
Barrel Rotation (deg)	Standing	-1.1 5.1	-1.0	-1.4 5.2	-1.8	-1.2 5.6	-1.8
	Kneeling	-1.1 4.9	-0.8	-1.2 5.2	-1.0	-1.2 5.9	-1.2
	Prone	-0.1 5.1	-0.9	1.1 5.3	0.3	2.4 6.6	1.9

3.1.2. Physiological Performance

The physiologic measures of 16 participants performing two marksmanship portions (Pre-, Post-sequence) of the scenario were analyzed with the wrist worn Forerunner 220 heart rate monitor. The derived physiologic metrics included: maximum attained heart rate (MaxHR), mean heart rate (MeanHR), maximum percent of heart rate reserve (%MaxHRR) and mean percent heart rate reserve (%MeanHRR). These metrics were derived for the pre- and post-marksmanship trials in three CIE conditions.

*Marksmanship Sequence * CIE interactions:* For maximum heart rate achieved, the repeated measures two-way ANOVA revealed interactions (p<.05) between marksmanship sequence and equipment conditions. Specifically, the statistical results for MeanHR were – F(2,18)=15.88, p <.001, ηp^2.638, power = .998. While wearing CIE Conditions I, II, or III the participants' MeanHR achieved post-marksmanship trial were higher by 9%, 18%, 22% respectively than during the pre-marksmanship trial sequence (p<.001). While wearing CIE Condition II, II, or III the participants' %MeanHRR - F(2,18)=17.13, p <.001, ηp^2.656, power = .999. The %MeanHRR achieved post-marksmanship sequence was higher by 21 %, 34 %, and 42% respectively, than pre-marksmanship sequence (p<.001). Figure 28 illustrates the change in the %MeanHRR by CIE condition relative interaction to pre- and post-marksmanship sequences.

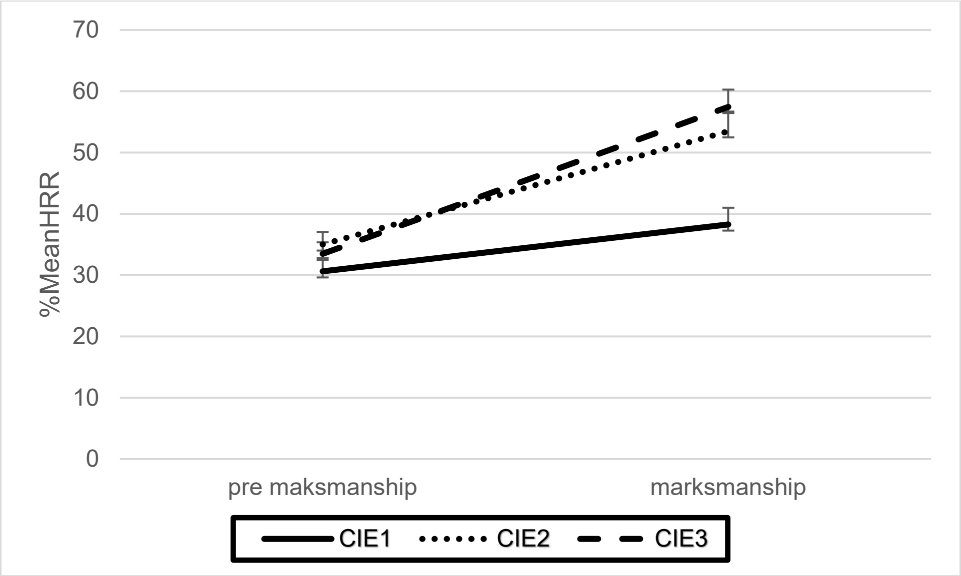


Figure 28. CIE Level Interaction by Marksmanship Sequence for %Mean HRR (SE).

Marksmanship Main Effects: Since interactions were observed between marksmanship sequence and CIE conditions for MeanHR and %MeanHRR (p<0.05), the main effects of marksmanship for these metrics were ignored. For MaxHR and MaxHRR the repeated measures two-way ANOVA did reveal main effects of sequence (p<.05). MaxHR - F(1,9)=36.05, p < .001, ηp^2.800, power = 1 and %MaxHRR - F(1,9)=42.56, p < .001, ηp^2.825, power = 1. The sequence post-marksmanship was higher as compared to the pre-marksmanship sequence for these HR measures. The post-marksmanship MaxHR and %MaxHRR were 6.8% and 33% higher respectively than the pre-marksmanship sequence (p<.001). Figure 29 represents the relationship of %HRR by marksmanship pre- and post-sequence.

For MaxHR and %MaxHRR the repeated measures two-way ANOVA did reveal main effects of CIE condition. MaxHR - $F(2,18)=16.06$, $p < .001$, $\eta p^2 .641$, power = .998 and %MaxHRR - $F(2,18)=14.88$, $p < .001$, $\eta p^2 .623$, power = .996. CIE Condition I was lower in MaxHR and %MaxHRR measures when compared to Conditions II and III. For Condition II compared to Condition III there were no differences in these same HR measures.

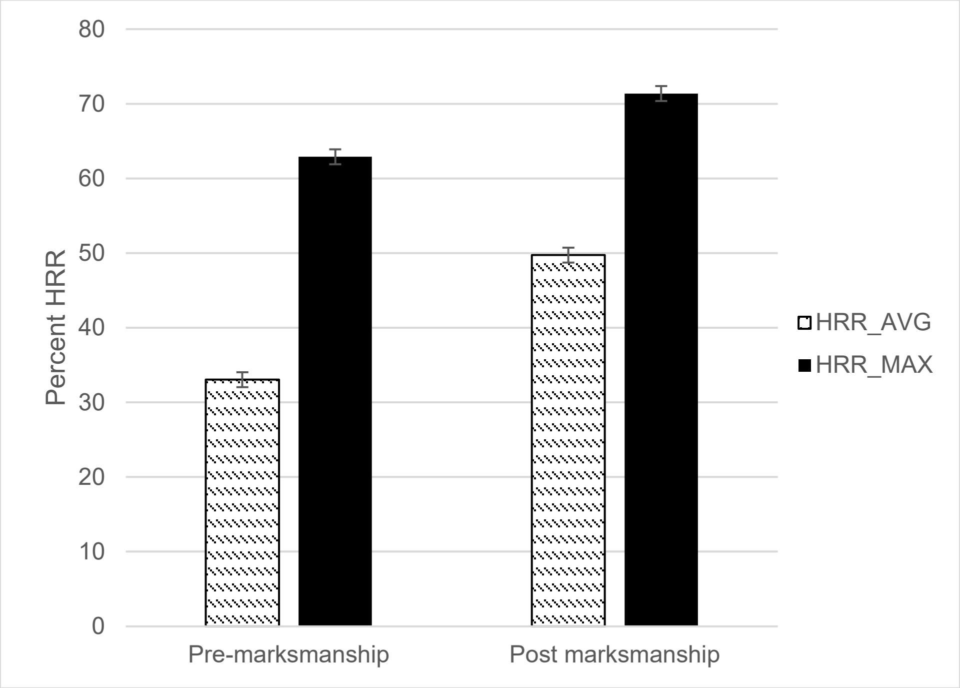


Figure 29. %MeanHRR (SE) and %MaxHRR (SE) by Marksmanship Sequence.

3.1.3. Subjective Opinions

Rested "Pre" State. Mean perceived exertion ratings before (RPE-pre) and after (RPE-post) completing the Marksmanship task in a Rested state increased with each consecutive condition level (Table 26). Conversely, the perceived mean mission performance ratings decreased with each consecutive condition. A series of Friedman tests revealed that the condition worn had an effect on the rating differences for RPE-pre, $\chi^2(2) = 21.66$, $p < .001$, RPE-post, $\chi^2(2) = 60.54$, $p < 0.001$, and mission performance, $\chi^2(2) = 66.98$, $p < 0.001$.

Table 26. Mean RPE and MP Ratings for the Marksmanship Rested State Run (n=62)

		Condition I	Condition II	Condition III
RPE	Pre	6.2 ± 0.49	6.4 ± 0.73	6.9 ± 1.69
	Post	7.5 ± 1.26	9.1 ± 1.81	10.2 ± 2.25
Mission Performance		6.1 ± 1.06	5.2 ± 1.20	4.2 ± 1.52

RPE Scale: No Exertion at all (6), Extremely Light (7), (8), Very Light (9), (10), Light (11), (12), Somewhat Hard (13), (14), Hard (Heavy) (15), (16), Very Hard (17), (18), Extremely Hard (19), Maximal Effort (20)
Mission Performance Scale: Very Poor (1), Moderately Poor (2), Slightly Poor (3), Neither Poor nor Good (4), Slightly Good (5), Moderately Good (6), Very Good (7)

Post-hoc analysis using paired Wilcoxon Signed-Ranks tests indicated that the most encumbered condition, Condition III, resulted in degraded perceived exertion and mission performance ratings compared to the less encumbered conditions. RPE-pre ratings were lower in Condition I (Median=6) than in Conditions II (Median=6), $Z = 2.47$, $p = 0.01$, $r = .31$, and III (Median=6), $Z = 3.85$, $p < 0.001$, $r = .49$. RPE-Post ratings were also lower in Condition I (Median=7) than in Conditions II (Median=9), $Z = 5.24$, $p < 0.001$, $r = .67$, and III (Median=10), $Z = 6.24$, $p < 0.001$, $r = .79$. Between the loaded conditions, ratings were significantly lower in Condition II than in Condition III for both RPE-pre, $Z = 3.12$, $p < 0.01$, $r = .40$, and RPE-post ratings, $Z = 3.80$, $p < 0.001$ $r = .48$. The participants' perceived mission performance rating was significantly lower in Condition III (Median=5) than in Conditions I (Median=6), $Z = 6.25$, $p < 0.001$, $r = .79$, and II (Median=5), $Z = 4.84$, $p < 0.001$, $r = .61$. The perceived performance rating was significantly higher in Condition I than in Condition II, $Z = 4.53$, $p < 0.001$, $r = .57$.

These results indicate that the participants felt more exertion after completing the Marksmanship task than before the task, and their experienced exertion was significantly higher with each consecutive condition. Additionally, after completing the task, the participants perceived their performance worsened with each consecutive condition.

Fatigued "Post" State. Like in the Rested state Marksmanship task run, mean mission performance ratings in the Fatigued state run also decreased with each consecutive condition.

A series of Friedman tests revealed that the condition worn had a significant effect on the participants' perceived exertion before the task (RPE-pre), $\chi^2(2) = 100.95$, $p < 0.01$, after completing the task (RPE-post), $\chi^2(2) = 90.81$, $p < 0.001$, and their mission performance, $\chi^2(2) = 61.28$, $p < 0.001$, see Table 27.

Table 27. Mean RPE and MP Ratings for the Marksmanship Fatigued State Run (n=62)

		Condition I	Condition II	Condition III
RPE	Pre	7.4 ± 1.57	12.5 ± 2.90	14.5 ± 3.19
	Post	8.6 ± 1.74	12.0 ± 2.50	13.8 ± 2.71
Mission Performance		6.0 ± 1.09	4.9 ± 1.23	4.1 ± 1.44

RPE Scale: No Exertion at all (6), Extremely Light (7), (8), Very Light (9), (10), Light (11), (12), Somewhat Hard (13), (14), Hard (Heavy) (15), (16), Very Hard (17), (18), Extremely Hard (19), Maximal Effort (20)
Mission Performance Scale: Very Poor (1), Moderately Poor (2), Slightly Poor (3), Neither Poor nor Good (4), Slightly Good (5), Moderately Good (6), Very Good (7)

Post-hoc analysis using paired Wilcoxon Signed-Ranks tests indicated that the most encumbered condition, Condition III, resulted in degraded perceived exertion and mission performance ratings compared to the less encumbered conditions. RPE-pre ratings were significantly lower in Condition I (Median=7) than in Conditions II (Median=13), $Z = 6.73$, $p < 0.001$, $r = .85$, and III (Median=14), $Z = 6.85$, $p < 0.001$, $r = .87$. RPE-Post ratings were also lower in Condition I (Median=8) than in Conditions II (Median=12), $Z = 6.14$, $p < 0.001$, $r = .79$, and III (Median=14), $Z = 6.63$, $p < 0.001$, $r = .86$. Between the loaded conditions, ratings were lower in Condition II than in Condition III for both RPE-pre, $Z = 4.29$, $p < 0.001$, $r = .54$, and RPE-post ratings, $Z = 4.55$, $p < 0.001$, $r = .59$. The participants' perceived mission performance rating was lower in Condition III (Median=4) than in Conditions I (Median=6), $Z = 5.77$, $p < 0.001$, $r = .75$, and II (Median=5), $Z = 4.03$, $p < 0.001$, $r = .52$. The perceived performance rating was higher in Condition I than in Condition II, $Z = 5.55$, $p < 0.001$, $r = .71$.

Like in the Rested state Marksmanship task run, these results indicate that RPE ratings were higher after completing the task and they also increased with each consecutive condition. Furthermore, the participants perceived that their performance deteriorated with each consecutive condition.

Rested vs Fatigued States. The RPE-pre and RPE-post ratings were considerably higher when completing the Marksmanship task in a Fatigued state than in a Rested state. Both ratings also increased with each consecutive condition (see Table 26 and Table 27).

A series of paired Wilcoxon Signed-Rank tests revealed that fatigue had an effect in the participants' RPE-pre ratings (Condition I, $Z = 5.05$, $p < 0.001$, $r = .64$; Condition II, $Z = 6.75$, $p < 0.001$, $r = .86$; Condition III, $Z = 6.78$, $p < 0.001$, $r = .86$) and RPE-post ratings (Condition I, $Z = 4.66$, $p < 0.001$, $r = .59$; Condition II, $Z = 5.74$, $p < 0.001$, $r = .73$; Condition III, $Z = 6.21$, $p < 0.001$, $r = .79$).

Fatigue also had an effect on the participants' perceived task performance. A paired Wilcoxon Signed-Rank test indicated that fatigue had an effect in Condition II, $Z = -2.62$, $p = 0.01$, $r = .33$, and a marginally effect in Condition I, $Z = -1.86$, $p = 0.06$, $r = .24$. In both cases, the participants perceived their performance to be better when in a Rested state (Condition I, Median=6; Condition II, Median=5) than when in a Fatigued state (Condition I, Median=6; Condition II, Median=5). Fatigue did not have an effect in Condition III, $Z = -0.83$, $p = 0.41$, $r = .11$. However, this is because the participants perceived their performance to be the worst in Condition III for both Rested (Median=5) and Fatigued (Median=4) states and their scores did not change.

Perceived Interference. The participants rated how much equipment interference they experienced after firing in each of the firing positions (unsupported standing, kneeling, and prone). As it was the case with RPE, mean interference ratings increased with each consecutive condition, in most cases by over a full interference point (Tables 28 and 29).

Table 28. Mean Interference Ratings for the Marksmanship Task Runs (Rested) (n=62)

		Condition I		Condition II		Condition III	
		Mean	Median	Mean	Median	Mean	Median
One Target	Standing	1.0 ± 0.00	1.0	2.2 ± 0.80	2.0	3.2 ± 1.16	3.0
	Kneeling	1.0 ± 0.28	1.0	2.2 ± 0.79	2.0	3.4 0.95	3.0
	Prone	1.0 ± 0.28	1.0	2.6 ± 0.90	2.5	3.7 ± 1.06	4.0
Dynamic	Standing	1.0 ± 0.00	1.0	2.0 ± 0.85	2.0	2.9 ± 1.19	3.0
	Kneeling	1.0 ± 0.00	1.0	2.2 ± 0.91	2.0	3.2 ± 1.06	3.0
	Prone	1.0 ± 0.00	1.0	2.6 ± 1.03	2.5	3.8 ± 0.99	4.0

Restriction Scale: No interference or degradation (1); Slight Interference, easily worked around (2); Moderate Interference, difficult but able to work around (3); Severe Interference, very difficult to work around, unacceptable (4); Extreme Interference, unable to work-around, unacceptable (5).

Table 29. Mean Interference Ratings for the Marksmanship Task Runs (Fatigued) (n=62)

		Condition I		Condition II		Condition III	
		Mean	Median	Mean	Median	Mean	Median
One Target	Standing	1.0 ± 0.00	1.0	2.0 ± 0.80	2.0	3.0 ± 1.21	3.0
	Kneeling	1.0 ± 0.00	1.0	2.2 ± 0.78	2.0	3.3 ± 1.02	3.0
	Prone	1.0 ± 0.00	1.0	2.6 ± 1.03	2.5	3.7 ± 1.13	4.0
Dynamic	Standing	1.0 ± 0.14	1.0	2.1 ± 0.87	2.0	3.1 ± 1.21	3.0
	Kneeling	1.0 ± 0.00	1.0	2.3 ± 0.90	2.0	3.2 ± 1.08	3.0
	Prone	1.0 ± 0.00	1.0	2.6 ± 1.02	2.5	3.8 ± 1.13	4.0

Restriction Scale: No interference or degradation (1); Slight Interference, easily worked around (2); Moderate Interference, difficult but able to work around (3); Severe Interference, very difficult to work around, unacceptable (4); Extreme Interference, unable to work-around, unacceptable (5).

A series of Friedman tests revealed that the condition worn had an effect on the restriction experienced for both of the sub-tasks in each firing position and in both Rested and Fatigued states (see statistical results in Table 30).

Table 30. Results of Friedman Test Statistical Comparisons of Interference Ratings between the Test Conditions

		Rested Marksmanship Run	Fatigued Marksmanship Run
One Target	Standing	$\chi^2(2) = 95.25$, $p < 0.001$	$\chi^2(2) = 95.80$, $p < 0.001$
	Kneeling	$\chi^2(2) = 105.12$, $p < 0.001$	$\chi^2(2) = 104.14$, $p < 0.001$
	Prone	$\chi^2(2) = 111.55$, $p < 0.001$	$\chi^2(2) = 104.84$, $p < 0.001$
Dynamic	Standing	$\chi^2(2) = 83.63$, $p < 0.001$	$\chi^2(2) = 90.58$, $p < 0.001$
	Kneeling	$\chi^2(2) = 97.72$, $p < 0.001$	$\chi^2(2) = 98.78$, $p < 0.001$
	Prone	$\chi^2(2) = 110.44$, $p < 0.001$	$\chi^2(2) = 104.93$, $p < 0.001$

Post-hoc analysis paired Wilcoxon Signed-Ranks tests revealed that restriction ratings increased significantly with each consecutive condition, with the less encumbered conditions having generated less restriction than the more encumbered conditions (see statistical results in Tables 31 and 32).

Table 31. Results of Wilcoxon Signed-Ranks Test Statistical Comparisons of Restriction Ratings between the Test Conditions (Rested – Pre)

		Conditions I vs II	Conditions I v III	Conditions II vs III
One Target	Standing	$Z = 6.45, p < 0.001, r = .82$	$Z = 6.63, p < 0.001, r = .84$	$Z = 5.30, p < 0.001, r = .67$
	Kneeling	$Z = 6.27, p < 0.001, r = .80$	$Z = 6.82, p < 0.001, r = .87$	$Z = 6.04, p < 0.001, r = .77$
	Prone	$Z = 6.63, p < 0.001, r = .84$	$Z = 6.86, p < 0.001, r = .87$	$Z = 5.81, p < 0.001, r = .74$
Dynamic	Standing	$Z = 6.17, p < 0.001, r = .78$	$Z = 6.34, p < 0.001, r = .81$	$Z = 5.09, p < 0.001, r = .65$
	Kneeling	$Z = 6.19, p < 0.001, r = .79$	$Z = 6.75, p < 0.001, r = .86$	$Z = 5.15, p < 0.001, r = .65$
	Prone	$Z = 6.43, p < 0.001, r = .82$	$Z = 6.87, p < 0.001, r = .87$	$Z = 5.97, p < 0.001, r = .76$

Table 32. Results of Wilcoxon Signed-Ranks Test Statistical Comparisons of Restriction Ratings between the Test Conditions (Fatigued - Post)

		Conditions I vs II	Conditions I v III	Conditions II vs III
One Target	Standing	$Z = 6.12, p < 0.001, r = .78$	$Z = 6.46, p < 0.001, r = .82$	$Z = 5.65, p < 0.001, r = .72$
	Kneeling	$Z = 6.57, p < 0.001, r = .83$	$Z = 6.82, p < 0.001, r = .87$	$Z = 5.50, p < 0.001, r = .70$
	Prone	$Z = 6.44, p < 0.001, r = .82$	$Z = 6.75, p < 0.001, r = .86$	$Z = 5.42, p < 0.001, r = .69$
Dynamic	Standing	$Z = 6.06, p < 0.001, r = .77$	$Z = 6.41, p < 0.001, r = .81$	$Z = 5.46, p < 0.001, r = .69$
	Kneeling	$Z = 6.33, p < 0.001, r = .80$	$Z = 6.75, p < 0.001, r = .86$	$Z = 5.26, p < 0.001, r = .67$
	Prone	$Z = 6.49, p < 0.001, r = .82$	$Z = 6.76, p < 0.001, r = .86$	$Z = 5.81, p < 0.001, r = .74$

In general, participant comments did not vary between the Rested and Fatigued Marksmanship task runs, with the exception of comments noting greater fatigue and lower back pain (due to exertion from the foot march) in the Fatigued state run. As would be expected, most participants did not experience any equipment restrictions when running the task in Condition I, other than issues with the helmet that were also reported for Condition II and Condition III. When in the prone position, the participants reported pressure on the back of the neck from the ACH strap and visual obstruction from the front rim of the ACH. A possible reason for these restrictions is that the participants likely had to strain their neck up to aim at the targets, which were set up at a higher altitude than what Soldiers would typically engage when in a prone position. Participants who were left-handed shooters reported that the ACH's chin strap buckle, which standardly snaps on the left side, caused their cheek to slide off the weapon's buttstock when sighting their weapon in the kneeling and prone firing positions.

The TAP was a common source of restriction for both of the loaded conditions (Conditions II and III) in all three of the firing positions. The participants noted that the combined bulk (armor and TAP) and the front-heavy setup led to instability, imbalance, reduced speed (particularly when going down to and getting up from a prone position), and restricted movement and transitioning between targets. The participants noted that these restrictions led to constant readjusting of their position and the need to re-aim at the target. When firing in a kneeling position, the added bulk from the TAP restricted the participants' ability to steady their elbow on the knee and squat low enough to achieve a stable position. However, some of the participants noted that they managed to use the TAP as a platform to support their elbows. When firing in a prone position, the participants noted that the extra bulk from the TAP raised their bodies off the ground, which made them less stable and placed them in an awkward position. Several participants added that, because of this restriction, they were not able to place their elbows on the ground while holding the weapon by the barrel hand guard and instead compensated by holding the weapon by the magazine.

Comments specific to Condition II focused on the restriction caused by the SPCS' shoulder strap. The participants noted that the shoulder strap obstructed their ability to securely hold the weapon's buttstock in their shoulder pocket in all three of the firing positions. Several participants noted that the buttstock slid off their shoulder while transitioning between targets and because of the weapon's recoil when firing. Even though the weapon recoil was minor (the weapon does not fire actual rounds), the participants reported difficulty managing it because of their inability to properly secure the weapon in their shoulder pocket. The participants also reported that the side plates dug into their sides and hips, particularly when in the kneeling position and when sprinting from one firing location to the next.

Most of the comments specific to Condition III focused on the restriction caused by the ancillary armor. The participants noted that the yoke collar in combination with the Deltoid and Auxiliary Protector System (DAPS) restricted their ability to get a proper sight picture when aiming in all three of the firing positions. The participants explained that this gear combination kept them from firmly placing their face on the weapon's buttstock. The participants compensated for this restriction by shortening the buttstock to increase stability and by straining their neck to reach the weapon. Furthermore, the restriction caused by the shoulder straps in Condition II was exacerbated in Condition III by the added bulk of the DAPS. The participants reported that the lack of a shoulder pocket increased the difficulty of transitioning between targets and stabilizing the weapon. They also noted restriction from the groin protector, which limited their positioning in all three firing positions and their stride by hitting the legs, twisting, and turning (particularly when sprinting between firing locations). Though visual obstruction from the ACH was commented on in all three of the conditions, this restriction was particularly more prominent in Condition III. The participants explained that the back of the ACH made contact with the IOTV's collar, which pushed the helmet forward and down into their face, which obstructed their sight picture. Finally, the participants noted that their breathing control, a fundamental marksmanship skill, was restricted by the tightness and bulk of the condition and was further exacerbated by exertion during the Fatigued state run of the Marksmanship task.

3.2. Foot March

3.2.1. Biomechanics Performance

The kinematics of 54 participants performing the two foot march portions of the scenario were analyzed with IMUs mounted on the sternum, sacrum, and both feet. The 11 derived kinematic metrics included: Stride length, Stride duration, Stride width, Foot yaw, PCA feet, PCA pelvis, PCA torso, Mediolateral lean angle, Standard deviation of mediolateral lean angle, Anteroposterior lean angle, and Standard deviation of anteroposterior lean angle. For the cognitive analysis, participants performed the go/no-go audio task approximately every 10 min. This meant that participants performed the audio task five times during each foot march at the following time intervals: 0-5; 15-20; 30-35; 45-50; and 55-60 min. In order to match the biomechanics results with the cognitive results, each hour-long foot march was divided into the same five sections, and each variable was examined in each section.

3.2.1.1. *Stride Length*

*March*Equipment Interactions:* For stride length, the repeated measures two-way ANOVA revealed interactions ($p<0.05$) between march iteration and equipment configurations of Sections 1, 3, and 4. Specifically, the statistical results for stride length of Section 1 were $F(2,106)=12.295$, $p=0.000$, $\eta_p^2=0.188$. The statistical results for stride length of Section 3 were $F(1.781,94.381)=9.314$, $p=0.000$, $\eta_p^2=0.149$ (Figure 30). The statistical results for stride length of Section 4 were $F(1.718,91.030)=5.653$, $p=0.007$, $\eta_p^2=0.096$.

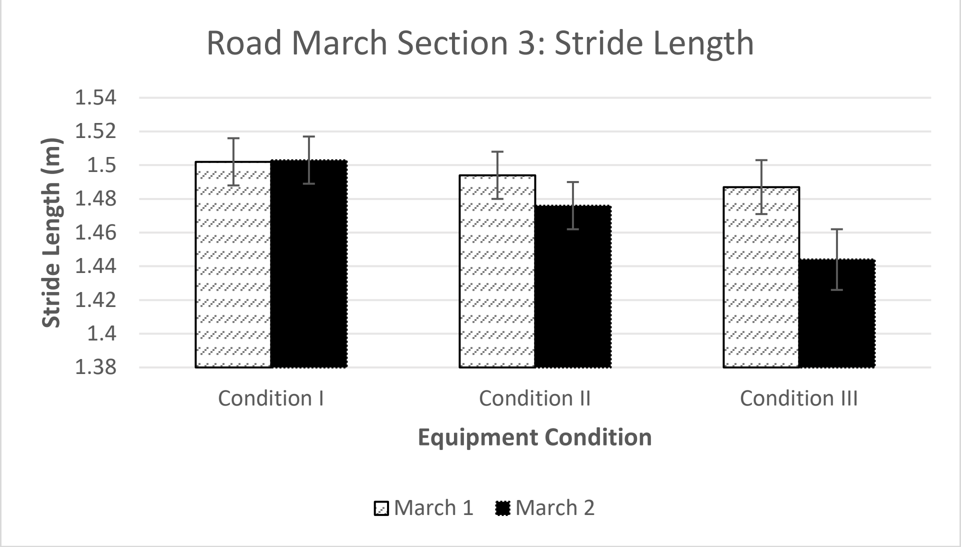


Figure 30. Cell means of stride length for each equipment condition and march iteration. Standard Error is displayed by the error bars.

While wearing equipment Condition I, stride length of Section 1 during March 1 was not different than during March 2 ($p=0.666$). While wearing Condition II, stride length of Section 1 during March 1 was 0.031 m greater than during March 2 ($p<0.000$). While wearing Condition III, stride length of Section 1 during March 1 was 0.036 m greater than during March 2 ($p<0.000$). Additionally, during March 1, stride length of Section 1 was not different across any equipment conditions ($p\geq0.05$). However, during March 2, stride length of Section 1 was 0.041 m greater while wearing Condition I than II ($p<0.000$) and 0.051 m greater while wearing Condition I than III ($p<0.000$). However, during March 2, stride length of Section 1 was not different between Conditions II and III ($p=0.988$).

While wearing Condition I, stride length of Section 3 during March 1 was not different than during March 2 ($p=0.911$). While wearing Condition II, stride length of Section 3 during March 1 was 0.018 m greater than during March 2 ($p=0.003$). While wearing Condition III, stride length of Section 3 during March 1 was 0.043 m greater than during March 2 ($p<0.000$). Additionally, during March 1, stride length of Section 3 was not different across any equipment conditions ($p\geq0.05$). However, during March 2, stride length of Section 3 was 0.027 m greater while wearing Condition I than II ($p=0.046$), 0.059 m greater while wearing Condition I than III ($p<0.000$), and 0.033 m greater while wearing Condition II than III ($p=0.011$).

While wearing Condition I, stride length of Section 4 during March 1 was not different than during March 2 ($p=0.540$). While wearing Condition II, stride length of Section 4 during March 1 was 0.020 m greater than during March 2 ($p=0.004$). While wearing Condition III, stride length of Section 4 during March 1 was 0.034 m greater than during March 2 ($p<0.000$). Additionally, during March 1 and March 2, stride length of Section 4 was not different across any equipment conditions ($p\geq0.05$).

Main Effect of March: Since interactions were observed between march and equipment conditions for stride length Sections 1, 3, and 4 ($p<0.05$), the main effect of march for these sections was ignored. For stride length of Sections 2 and 5, the repeated measures two-way ANOVA did not reveal main effects of march iteration ($p\geq0.05$).

Specifically, for stride length of Section 2, the repeated measures two-way ANOVA did not reveal a main effect for march iteration, $F(1,53)=0.950$, $p=0.334$, $\eta_p^2=0.018$. Similarly, for stride length of Section 5, the repeated measures two-way ANOVA did not reveal a significant main effect for march iteration, $F(1,53)=2.821$, $p=0.099$, $\eta_p^2=0.051$.

Main Effect of Equipment: Since interactions were observed between march and equipment conditions for stride length Sections 1, 3, and 4 ($p<0.05$), the main effect of equipment for these sections was ignored. For stride length of Sections 2 and 5, the repeated measures two-way ANOVA did not reveal main effects of equipment condition ($p\geq0.05$).

3.2.1.2. Stride Duration

*March*Equipment Interactions:* For stride duration, the repeated measures two-way ANOVA revealed interactions ($p<0.05$) between march iteration and equipment conditions of Sections 1 and 3. Specifically, the statistical results for stride duration of Section 1 were $F(2,106)=9.309$, $p=0.000$, $\eta_p^2=0.149$. The statistical results for stride duration of Section 3 were $F(1.675,88.780)=4.114$, $p=0.026$, $\eta_p^2=0.072$.

While wearing Condition I, stride duration of Section 1 during March 1 was 0.014 s greater than during March 2 ($p=0.001$). While wearing Condition II, stride duration of Section 1 during March 1 was not different than during March 2 ($p=0.551$). While wearing Condition III, stride duration of Section 1 during March 1 was 0.011 s less than during March 2 ($p<0.000$). Additionally, during March 1, stride duration of Section 1 was 0.028 s greater while wearing Condition I than III ($p=0.001$). However, during March 1, stride duration of Section 1 was not different between Conditions I and II ($p=0.073$) or Conditions II and III ($p=0.149$). During March 2, stride duration of Section 1 was not different across any equipment conditions ($p\geq0.05$).

While wearing Condition I, stride duration of Section 3 during March 1 was not different than during March 2 ($p=0.700$). While wearing Condition II, stride duration of Section 3 during March 1 was not different than during March 2 ($p=0.163$). While wearing Condition III, stride duration of Section 3 during March 1 was 0.026 s less than during March 2 ($p=0.013$). Additionally, during March 1 and March 2, stride duration of Section 3 was not different across any equipment conditions ($p\geq0.05$).

Main Effect of March: Since interactions were observed between march and equipment conditions for stride duration Sections 1 and 3 ($p<0.05$), the main effect of march for these sections was ignored. For stride duration of Sections 2, 4, and 5, the repeated measures two-way ANOVA did not reveal main effects of march iteration ($p \geq 0.05$).

Main Effect of Equipment: Since interactions were observed between march and equipment conditions for stride duration Sections 1 and 3 ($p<0.05$), the main effect of equipment for these sections was ignored. For stride duration of Sections 2, 4, and 5, the repeated measures two-way ANOVA did not reveal main effects of march iteration ($p \geq 0.05$).

3.2.1.3. Stride Width

*March*Equipment Interactions:* For stride width of every section, the repeated measures two-way ANOVA did not reveal interactions between march iteration and equipment conditions ($p \geq 0.05$).

Main Effect of March: For stride width of every section, the repeated measures two-way ANOVA did not reveal main effects of march iteration ($p \geq 0.05$).

Main Effect of Equipment: For stride width of every section, the repeated measures two-way ANOVA did not reveal main effects of equipment condition ($p \geq 0.05$).

3.2.1.4. Foot Yaw

*March*Equipment Interactions:* For foot yaw of every section, the repeated measures two-way ANOVA did not reveal interactions between march iteration and equipment conditions ($p \geq 0.05$).

Main Effect of March: For foot yaw of every section, the repeated measures two-way ANOVA did not reveal main effects of march iteration ($p \geq 0.05$).

Main Effect of Equipment: For foot yaw of every section, the repeated measures two-way ANOVA did not reveal main effects of equipment condition ($p \geq 0.05$).

3.2.1.5. PCA Feet

*March*Equipment Interactions:* For PCA feet, the repeated measures two-way ANOVA revealed interactions ($p<0.05$) between march iteration and equipment conditions of Sections 1 and 3. Specifically, the statistical results for PCA feet of Section 1 were $F(1.773,93.958)=8.717$, $p=0.001$, $\eta_p^2=0.141$. The statistical results for PCA feet of Section 3 were $F(2,106)=8.085$, $p=0.001$, $\eta_p^2=0.132$ (Figure 31).

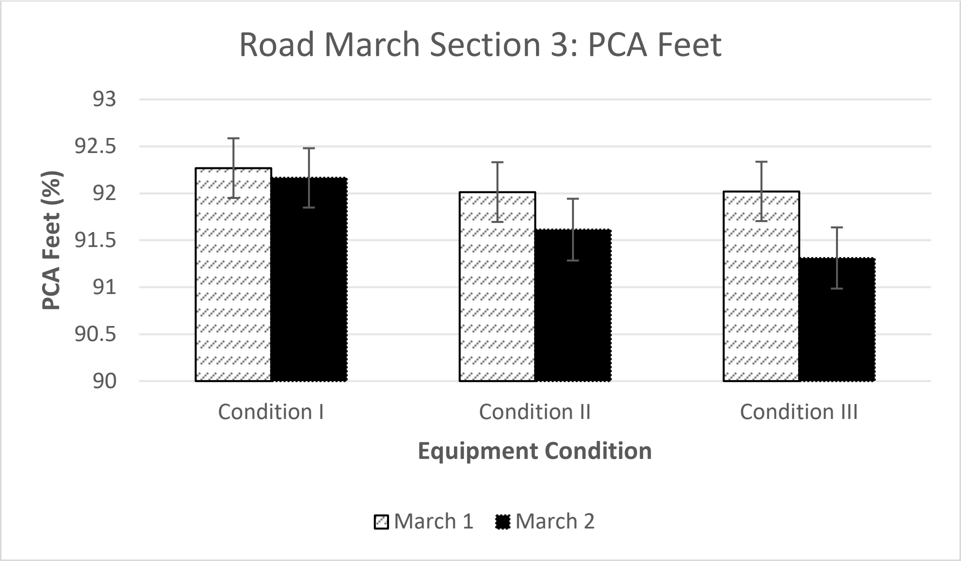


Figure 31. Cell means of PCA feet for each equipment condition and march iteration. Standard Error is displayed by the error bars.

While wearing Condition I, PCA feet of Section 1 during March 1 was not different than during March 2 ($p=0.076$). While wearing Condition II, PCA feet of Section 1 during March 1 was 0.479% greater than during March 2 ($p<0.000$). While wearing Condition III, PCA feet of Section 1 during March 1 was 0.722% greater than during March 2 ($p<0.000$). Additionally, during March 1, PCA feet of Section 1 was not different across any equipment conditions ($p\geq0.05$). During March 2, PCA feet of Section 1 was 0.670% greater while wearing Condition I than II ($p=0.001$) and 0.644% greater while wearing Condition I than III ($p=0.002$). However, during March 2, PCA feet of Section 1 was not different between Conditions II and III ($p=1.000$).

While wearing Condition I, PCA feet of Section 3 during March 1 was not different than during March 2 ($p=0.216$). While wearing Condition II, PCA feet of Section 3 during March 1 was 0.400% greater than during March 2 ($p=0.001$). While wearing Condition III, PCA feet of Section 3 during March 1 was 0.709% greater than during March 2 ($p<0.000$). Additionally, during March 1, PCA feet of Section 3 was not different across any equipment conditions ($p\geq0.05$). During March 2, PCA feet of Section 3 was 0.551% greater while wearing Condition I than II ($p=0.024$) and 0.853% greater while wearing Condition I than III ($p=0.002$). However, during March 2, PCA feet of Section 3 was not different between Conditions II and III ($p=0.246$).

Main Effect of March: Since interactions were observed between march and equipment conditions for PCA feet Sections 1 and 3 ($p<0.05$), the main effect of march for these sections was ignored. For PCA feet of Section 2, the repeated measures two-way ANOVA revealed a main effect for march iteration, $F(1,53)=6.660$, $p=0.013$, $\eta_p^2=0.112$. When averaging across equipment conditions, PCA feet of Section 2 was 0.405% greater for March 1 than March 2. For PCA feet of Section 4, the repeated measures two-way ANOVA revealed a main effect for march iteration, $F(1,53)=18.492$, $p=0.000$, $\eta_p^2=0.259$. When averaging across equipment conditions, PCA feet of Section 4 was 0.315% greater for March 1 than March 2. For PCA feet of Section 5, the repeated measures two-way ANOVA revealed a main effect for march iteration, F(1,53)=6.176, p=0.016, η_p^2=0.104. When averaging across equipment conditions, PCA feet of Section 5 was 0.275% greater for March 1than March 2.

Main Effect of Equipment: Since significant interactions were observed between march and equipment conditions for PCA feet Sections 1 and 3 (p<0.05), the main effect of equipment for these sections was ignored. For PCA feet of Section 2, the repeated measures two-way ANOVA did not reveal a significant main effect for equipment condition, F(1.459,77.312)=2.366, p=0.116, η_p^2=0.043. For PCA feet of Section 4, the repeated measures two-way ANOVA did not reveal a significant main effect for equipment condition, F(1.638,86.833)=2.128, p=0.134, η_p^2=0.039. For PCA feet of Section 5, the repeated measures two-way ANOVA revealed a significant main effect for equipment condition, F(2,106)=3.574, p=0.031, η_p^2=0.063. However, pairwise comparisons between equipment conditions did not reveal any significant differences.

3.2.1.6. PCA Pelvis

*March*Equipment Interactions:* For PCA pelvis of every section, the repeated measures two-way ANOVA did not reveal significant interactions between march iteration and equipment conditions (p≥0.05).

Main Effect of March: For PCA pelvis of Sections 1, 3, 4, and 5, the repeated measures two-way ANOVA did not reveal significant main effects of march iteration (p≥0.05).

For PCA pelvis of Section 2, the repeated measures two-way ANOVA revealed a significant main effect for march iteration, F(1,53)=5.019, p=0.029, η_p^2=0.087. When averaging across equipment conditions, PCA pelvis of Section 2 was 1.211% less for March 1 than March 2.

Main Effect of Equipment: For PCA pelvis of Section 1, the repeated measures two-way ANOVA revealed a significant main effect for equipment condition, F(2,106)=23.586, p=0.000, η_p^2=0.308. When averaging across march conditions, PCA pelvis of Section 1 was 6.161% less for Condition I than II (p<0.000), 3.552% less for Condition I than III (p<0.000), and 2.609% greater for Condition II than III (p=0.017). For PCA pelvis of Section 2, the repeated measures two-way ANOVA revealed a significant main effect for equipment condition, F(1.660,87.969)=18.726, p=0.000, η_p^2=0.261. When averaging across march conditions, PCA pelvis of Section 2 was 5.516% less for Condition I than II (p<0.000) and 4.033% less for Condition I than III (p<0.000). PCA pelvis of Section 2 was not different between Conditions II and III (p=0.223). For PCA pelvis of Section 3, the repeated measures two-way ANOVA revealed a significant main effect for equipment condition, F(1.598,84.696)=12.517, p=0.000, η_p^2=0.191 (Figure 32). When averaging across march conditions, PCA pelvis of Section 3 was 4.563% less for Condition I than II (p<0.000) and 4.033% less for Condition I than III (p=0.004). PCA pelvis of Section 3 was not different between Conditions II and III (p=0.140). For PCA pelvis of Section 4, the repeated measures two-way ANOVA revealed a significant main effect for equipment condition, F(1.711,90.695)=11.708, p=0.000, η_p^2=0.181. When averaging across march conditions, PCA pelvis of Section 4 was 4.862% less for Condition I than II (p<0.000) and 3.096% less for Condition I than III (p=0.009). PCA pelvis of Section 4 was not different between Conditions II and III (p=0.115). For PCA pelvis of Section 5, the repeated measures two-way ANOVA revealed a significant main effect for equipment condition, F(1.718,91.077)=9.900, p=0.000, η_p^2=0.157. When averaging across march conditions, PCA pelvis of Section 5 was 4.612% less for Condition I than II (p=0.001) and 2.747% less for Condition I than III (p=0.022). PCA pelvis of Section 5 was not different between Conditions II and III (p=0.118).

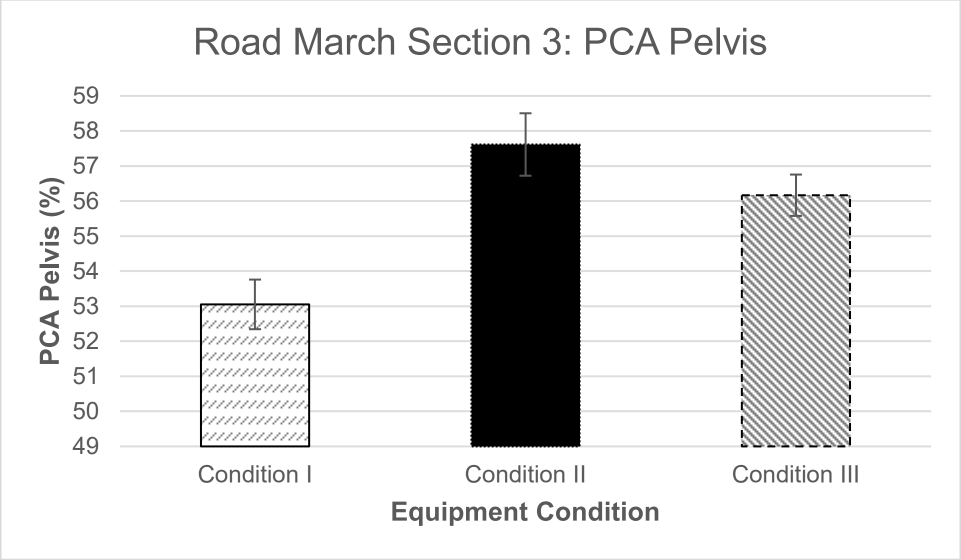


Figure 32. Marginal means of PCA Pelvis for each equipment condition collapsed over march iteration. Standard Error is displayed by the error bars.

3.2.1.7. PCA Torso

*March*Equipment Interactions:* For PCA torso of every section, the repeated measures two-way ANOVA did not reveal significant interactions between march iteration and equipment conditions ($p \geq 0.05$).

Main Effect of March: For PCA torso of Sections 1, 2, and 5, the repeated measures two-way ANOVA did not reveal significant main effects of march iteration ($p \geq 0.05$).

For PCA torso of Section 3, the repeated measures two-way ANOVA revealed a significant main effect for march iteration, F(1,53)=4.241, p=0.044, η_p^2=0.074. When averaging across equipment conditions, PCA torso of Section 3 was 0.733% less for March 1 than march 2. For PCA torso of Section 4, the repeated measures two-way ANOVA revealed a significant main effect for march iteration, F(1,53)=7.158, p=0.010, η_p^2=0.119. When averaging across equipment conditions, PCA torso of Section 4 was 0.719% less for March 1 than March 2.

Main Effect of Equipment: For PCA torso of Section 1, the repeated measures two-way ANOVA revealed a significant main effect for equipment condition, F(1.641,86.967)=19.409, p=0.000, η_p^2=0.268. When averaging across march conditions, PCA torso of Section 1 was 4.095% greater for Condition I than II ($p<0.000$) and 5.272% greater for Condition I than III ($p<0.000$). PCA torso of Section 1 was not different between Conditions II and III (p=0.225). For PCA torso of Section 2, the repeated measures two-way ANOVA revealed a significant main effect for equipment condition, F(1.764,93.508)=15.649, p=0.000, η_p^2=0.228. When averaging across march conditions, PCA torso of Section 2 was 3.331% greater for Condition I than II (p=0.005) and 4.936% greater for Condition I than III ($p<0.000$). PCA torso of Section 2 was not different between Conditions II and III (p=0.094). For PCA torso of Section 3, the repeated measures two-way ANOVA revealed a significant main effect for equipment condition, F(1.601,84.839)=8.983, p=0.001, η_p^2=0.145. When averaging across march conditions, PCA torso of Section 3 was 3.159% greater for Condition I than II (p=0.018) and 3.801% greater for Condition I than III (p=0.002). PCA torso of Section 3 was not different between Conditions II and III (p=1.000). For PCA torso of Section 4, the repeated measures two-way ANOVA revealed a significant main effect for equipment condition, F(1.659,87.913)=17.298, p=0.000, η_p^2=0.246. When averaging across march conditions, PCA torso of section 4 was 4.091% greater for Condition I than II (p=0.001) and 5.143% greater for Condition I than III (p<0.000). PCA torso of Section 4 was not different between Conditions II and III (p=0.395). For PCA torso of Section 5, the repeated measures two-way ANOVA revealed a significant main effect for equipment condition, F(1.592,84.352)=11.345, p=0.000, η_p^2=0.176. When averaging across march conditions, PCA torso of Section 5 was 3.704% greater for Condition I than II (p=0.005) and 4.514% greater for Condition I than III (p=0.001). PCA torso of Section 5 was not different between Conditions II and III (p=0.779).

3.2.1.8. Mediolateral Lean Angle

*March*Equipment Interactions*: For mediolateral lean angle of every section, the repeated measures two-way ANOVA did not reveal significant interactions between march iteration and equipment conditions (p≥0.05).

Main Effect of March: For mediolateral lean angle of every section, the repeated measures two-way ANOVA did not reveal significant main effects of march iteration (p≥0.05).

Main Effect of Equipment: For mediolateral lean angle of every section, the repeated measures two-way ANOVA did not reveal significant main effects of equipment condition (p≥0.05).

3.2.1.9. Standard Deviation of Mediolateral Lean Angle

*March*Equipment Interactions*: For standard deviation of mediolateral lean angle, the repeated measures two-way ANOVA revealed significant interactions (p<0.05) between march iteration and equipment conditions for every section. Specifically, the statistical results for standard deviation of mediolateral lean angle of Section 1 was F(2,106)=19.891, p<0.001, η_p^2=0.273. The statistical results for standard deviation of mediolateral lean angle of Section 2 was F(1.766,93.603)=5.197, p=0.010, η_p^2=0.089. The statistical results for standard deviation of mediolateral lean angle of Section 3 was F(1.649,87.376)=13.372, p=0.000, η_p^2=0.201 (Figure 33). The statistical results for standard deviation of mediolateral lean angle of Section 4 was F(1.527,80.935)=11.896, p=0.000, η_p^2=0.183. The statistical results for standard deviation of mediolateral lean angle of Section 5 was F(1.431,75.839)=8.081, p=0.002, η_p^2=0.132.

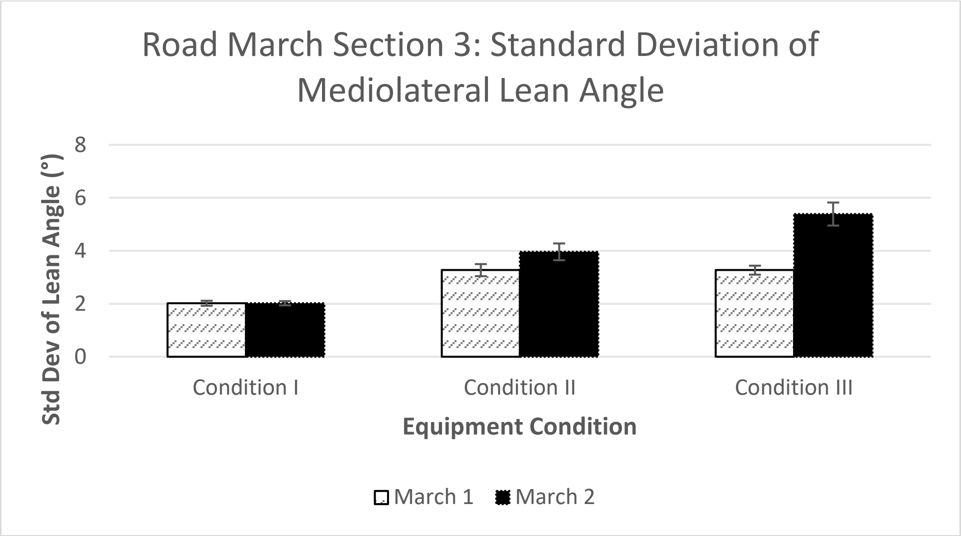


Figure 33. Cell means of the standard deviation of mediolateral lean angle for each equipment condition and march iteration. Standard Error is displayed by the error bars.

While wearing Condition I, standard deviation of mediolateral lean angle of Section 1 during March 1 was not different than during March 2 (p=0.566). While wearing Condition II, standard deviation of mediolateral lean angle of Section 1 during March 1 was 0.429° less than during March 2 (p<0.001). While wearing Condition III, standard deviation of mediolateral lean angle of Section 1 during March 1 was 0.552° less than during March 2 (p<0.000). Additionally, during March 1, standard deviation of mediolateral lean angle of Section 1 was not different across any equipment conditions (p≥0.05). During March 2, standard deviation of mediolateral lean angle of Section 1 was 0.419° less while wearing Condition I than II (p<0.000), 0.629° less while wearing Condition I than III (p<0.000), and 0.209° less while wearing Condition II than III (p=0.006).

While wearing Condition I, standard deviation of mediolateral lean angle of Section 2 during March 1 was not different than during March 2 (p=0.132). While wearing Condition II, standard deviation of mediolateral lean angle of Section 2 during March 1 was 0.860° less than during March 2 (p=0.003). While wearing Condition III, standard deviation of mediolateral lean angle of Section 2 during March 1 was 1.190° less than during March 2 (p=0.001). Additionally, during March 1, standard deviation of mediolateral lean angle of Section 2 was 0.906° less while wearing Condition I than II (p<0.000) and 1.133° less while wearing Condition I than III (p<0.000). However, during March 1, standard deviation of mediolateral lean angle of Section 2 displayed no significant differences between Conditions II and III (p=1.000). During March 2, standard deviation of mediolateral lean angle of Section 2 was 1.658° less while wearing Condition I than II (p<0.000) and 2.215° less while wearing Condition I than III (p<0.000). However, during March 2, standard deviation of mediolateral lean angle of Section 2 displayed no significant differences between Conditions II and III (p=0.429).

While wearing Condition I, standard deviation of mediolateral lean angle of Section 3 during March 1 was not different than during March 2 (p=0.986). While wearing Condition II, standard deviation of mediolateral lean angle of Section 3 during March 1 was 0.690° less than during March 2 (p=0.024). While wearing Condition III, standard deviation of mediolateral lean angle of Section 3 during March 1 was 2.12° less than during March 2 (p<0.000). Additionally, during March 1, standard deviation of mediolateral lean angle of Section 3 was 1.252° less while wearing Condition I than II (p<0.000) and 1.251° less while wearing Condition I than III (p<0.000). However, during March 1, standard deviation of mediolateral lean angle of Section 3 displayed no significant differences between Conditions II and III (p=1.000). During March 2, standard deviation of mediolateral lean angle of Section 3 was 1.940° less while wearing Condition I than II (p<0.000), 3.366° less while wearing Condition I than III (p<0.000), and 1.426° less while wearing Condition II than III (p=0.012).

While wearing Condition I, standard deviation of mediolateral lean angle of Section 4 during March 1 was not different than during March 2 (p=0.074). While wearing Condition II, standard deviation of mediolateral lean angle of Section 4 during March 1 was 1.084° less than during March 2 (p=0.001). While wearing Condition III, standard deviation of mediolateral lean angle of Section 4 during March 1 was 2.472° less than during March 2 (p<0.000). Additionally, during March 1, standard deviation of mediolateral lean angle of Section 4 was 1.560° less while wearing Condition I than II (p<0.000) and 1.771° less while wearing Condition I than III (p<0.000). However, during March 1, standard deviation of mediolateral lean angle of Section 4 displayed no significant differences between Conditions II and III (p=1.000). During March 2, standard deviation of mediolateral lean angle of Section 4 was 2.482° less while wearing Condition I than II (p<0.000), 4.080° less while wearing Condition I than III (p<0.000), and 1.598° less while wearing Condition II than III (p=0.012).

While wearing Condition I, standard deviation of mediolateral lean angle of Section 5 during March 1 was not different than during March 2 (p=0.190). While wearing Condition II, standard deviation of mediolateral lean angle of Section 5 during March 1 was 0.609° less than during March 2 (p=0.010). While wearing Condition III, standard deviation of mediolateral lean angle of Section 5 during March 1 was 1.873° less than during March 2 (p=0.001). Additionally, during March 1, standard deviation of mediolateral lean angle of Section 5 was 1.535° less while wearing Condition I than II (p<0.000) and 1.897° less while wearing Condition I than III (p<0.000). However, during March 1, standard deviation of mediolateral lean angle of Section 5 displayed no significant differences between Conditions II and III (p=0.628). During March 2, standard deviation of mediolateral lean angle of Section 5 was 1.986° less while wearing Condition I than II (p<0.000), 3.611° less while wearing Condition I than III (p<0.000), and 1.625° less while wearing Condition II than III (p=0.002).

Main Effect of March: Since significant interactions were observed between march and equipment conditions for standard deviation of mediolateral lean angle for every section (p<0.05), the main effect of march for every section was ignored.

Main Effect of Equipment: Since significant interactions were observed between march and equipment conditions for standard deviation of mediolateral lean angle for every section (p<0.05), the main effect of equipment for every section was ignored.

3.2.1.10. Anteroposterior Lean Angle

*March*Equipment Interactions:* For anteroposterior lean angle, the repeated measures two-way ANOVA revealed a significant interaction (p<0.05) between march iteration and equipment conditions for Section 3 (Figure 34). Specifically, the statistical results for anteroposterior lean angle of Section 3 were F(2,106)=3.525, p=0.033, η_p^2=0.062.

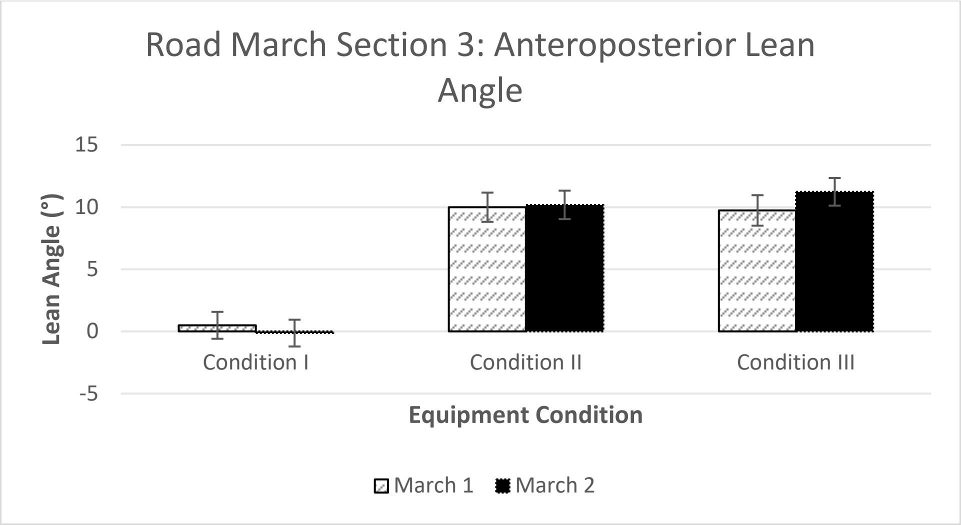


Figure 34. Cell means of anteroposterior lean angle for each equipment condition and march iteration. Standard Error is displayed by the error bars.

While wearing Condition I, anteroposterior lean angle of Section 3 during March 1 was not different than during March 2 (p=0.136). While wearing Condition II, anteroposterior lean angle of Section 3 during March 1 was also not different than during March 2 (p=0.776). While wearing Condition III, anteroposterior lean angle of Section 3 during March 1 was 1.497° less than during March 2 (p=0.036). Additionally, during March 1, anteroposterior lean angle of Section 3 was 9.498° less while wearing Condition I than II (p<0.000) and 9.241° less while wearing Condition I than III (p<0.000). However, during March 1, anteroposterior lean angle of Section 3 was different while wearing Condition II than III (p=1.000). Similarly, during March 2, anteroposterior lean angle of Section 3 was 10.31° less while wearing Condition I than II (p<0.000) and 11.36° less while wearing Condition I than III (p<0.000). However, during March 2, anteroposterior lean angle of Section 3 was different while wearing Condition II than III (p=0.905).

Main Effect of March: Since a significant interaction was observed between march and equipment conditions for anteroposterior lean angle Section 3 (p<0.05), the main effect of march for this section was ignored. The repeated measures two-way ANOVA did not reveal a significant main effect for march iteration for Sections 1, 2, 4, or 5 (p≥0.05).

Main Effect of Equipment: Since a significant interaction was observed between march and equipment conditions for anteroposterior lean angle Section 3 (p<0.05), the main effect of equipment for this section was ignored.

For anteroposterior lean angle of Section 1, the repeated measures two-way ANOVA revealed a significant main effect for equipment condition, F(2,106)=47.547, p=0.000, η_p^2=0.473. When averaging across march conditions, anteroposterior lean angle of Section 1 was 7.95° less for Condition I than II (p<0.000) and 8.39° less for Condition I than III (p<0.000). Anteroposterior lean angle of Section 1 was not different between Conditions II and III (p=1.000). For anteroposterior lean angle of Section 2, the repeated measures two-way ANOVA revealed a significant main effect for equipment condition, F(2,106)=54.536, p=0.000, η_p^2=0.507. When averaging across march conditions, anteroposterior lean angle of Section 2 was 9.54° less for Condition I than II (p<0.000) and 9.50° less for Condition I than III (p<0.000). Anteroposterior lean angle of Section 2 was not different between Conditions II and III (p=1.000). For anteroposterior lean angle of Section 4, the repeated measures two-way ANOVA revealed a significant main effect for equipment condition, F(2,106)=62.829, p=0.000, η_p^2=0.542. When averaging across march conditions, anteroposterior lean angle of Section 4 was 9.91° less for Condition I than II (p<0.000) and 10.20° less for Condition I than III (p<0.000). Anteroposterior lean angle of Section 4 was not different between Conditions II and III (p=1.000). For anteroposterior lean angle of Section 5, the repeated measures two-way ANOVA revealed a significant main effect for equipment condition, F(2,106)=63.164, p=0.000, η_p^2=0.544. When averaging across march conditions, anteroposterior lean angle of Section 5 was 10.41° less for Condition I than II (p<0.000) and 10.39° less for Condition I than III (p<0.000). Anteroposterior lean angle of Section 5 was not different between Conditions II and III (p=1.000).

3.2.1.11. Standard Deviation of Anteroposterior Lean Angle

*March*Equipment Interactions*: For standard deviation of anteroposterior lean angle, the repeated measures two-way ANOVA revealed significant interactions (p<0.05) between march iteration and equipment conditions for every section. Specifically, the statistical results for standard deviation of anteroposterior lean angle of Section 1 was F(1.774,94.013)=4.909, p=0.012, η_p^2=0.085. The statistical results for standard deviation of anteroposterior lean angle of Section 2 was F(1.754,92.986)=8.176, p=0.001, η_p^2=0.134. The statistical results for standard deviation of anteroposterior lean angle of Section 3 was F(1.688,89.484)=17.536, p=0.000, η_p^2=0.249 (Figure 35). The statistical results for standard deviation of anteroposterior lean angle of Section 4 was F(2,106)=12.772, p=0.000, η_p^2=0.194. The statistical results for standard deviation of anteroposterior lean angle of Section 5 was F(1.558,82.578)=7.986, p=0.002, η_p^2=0.131.

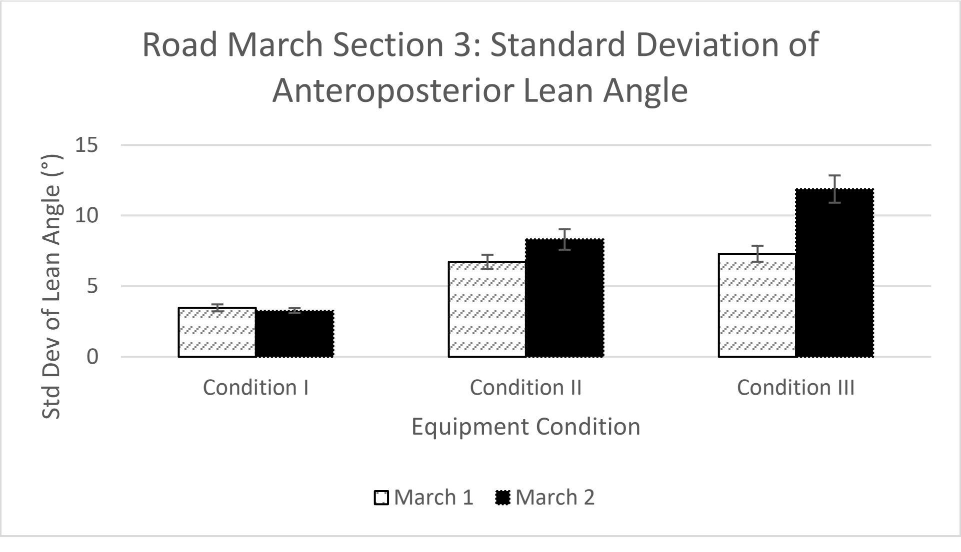


Figure 35. Cell means of the standard deviation of anteroposterior lean angle for each equipment condition and march iteration. Standard Error is displayed by the error bars.

While wearing Condition I, standard deviation of anteroposterior lean angle of Section 1 during March 1 was not different than during March 2 ($p=0.210$). While wearing Condition II, standard deviation of anteroposterior lean angle of Section 1 during March 1 was 0.524° less than during March 2 ($p<0.000$). While wearing Condition III, standard deviation of anteroposterior lean angle of Section 1 during March 1 was 0.835° less than during March 2 ($p<0.000$). Additionally, during March 1, standard deviation of anteroposterior lean angle of Section 1 was not different across any equipment conditions ($p\geq0.05$). However, during March 2, standard deviation of anteroposterior lean angle of Section 1 was 0.482° less while wearing Condition I than II ($p=0.027$) and 0.637° less while wearing Condition I than III ($p=0.023$). However, during March 2, standard deviation of anteroposterior lean angle of Section 1 was not different between Conditions II and III ($p=1.000$).

While wearing Condition I, standard deviation of anteroposterior lean angle of Section 2 during March 1 was not different than during March 2 ($p=0.080$). While wearing Condition II, standard deviation of anteroposterior lean angle of Section 2 during March 1 was 2.11° less than during March 2 ($p=0.001$). While wearing Condition III, standard deviation of anteroposterior lean angle of Section 2 during March 1 was 3.43° less than during March 2 ($p<0.000$). Additionally, during March 1, standard deviation of anteroposterior lean angle of Section 2 was 2.64° less while wearing Condition I than II ($p<0.000$) and 3.16° less while wearing Condition I than III ($p<0.000$). However, during March 1, standard deviation of anteroposterior lean angle of Section 2 displayed no significant differences between Conditions II and III ($p=1.000$). During March 2, standard deviation of anteroposterior lean angle of Section 2 was 4.22° less while wearing Condition I than II ($p<0.000$), 6.06° less while wearing Condition I than III ($p<0.000$), and 1.844° less while wearing Conditions 2 than 3 ($p=0.042$).

While wearing Condition I, standard deviation of anteroposterior lean angle of Section 3 during March 1 was not different than during March 2 ($p=0.448$). While wearing Condition II, standard deviation of anteroposterior lean angle of Section 3 during March 1 was 1.584° less than during March 2 ($p=0.009$). While wearing Condition III, standard deviation of anteroposterior lean angle of Section 3 during March 1 was 4.58° less than during March 2 ($p<0.000$). Additionally, during March 1, standard deviation of anteroposterior lean angle of Section 3 was 3.25° less while wearing Condition I than II ($p<0.000$) and 3.83° less while wearing Condition I than III ($p<0.000$). However, during March 1, standard deviation of anteroposterior lean angle of Section 3 displayed no significant differences between Conditions II and III ($p=1.000$). During March 2, standard deviation of anteroposterior lean angle of Section 3 was 5.04° less while wearing Condition I than II ($p<0.000$), 8.61° less while wearing Condition I than III ($p<0.000$), and 3.57° less while wearing Condition II than III ($p<0.000$).

While wearing Condition I, standard deviation of anteroposterior lean angle of Section 4 during March 1 was not different than during March 2 ($p=0.065$). While wearing Condition II, standard deviation of anteroposterior lean angle of Section 4 during March 1 was 2.45° less than during March 2 ($p<0.000$). While wearing Condition III, standard deviation of anteroposterior lean angle of Section 4 during March 1 was 4.97° less than during March 2 ($p<0.000$). Additionally, during March 1, standard deviation of anteroposterior lean angle of Section 4 was 4.23° less while wearing Condition I than II ($p<0.000$) and 5.94° less while wearing Condition I than III ($p<0.000$). However, during March 1, standard deviation of anteroposterior lean angle of Section 4 displayed no significant differences between Conditions II and III ($p=0.056$). During March 2, standard deviation of anteroposterior lean angle of Section 4 was 6.13° less while wearing Condition I than II (p<0.000), 10.37° less while wearing Condition I than III (p<0.000), and 4.24° less while wearing Condition II than III (p<0.000).

While wearing Condition I, standard deviation of anteroposterior lean angle of Section 5 during March 1 was not different than during March 2 (p=0.223). While wearing Condition II, standard deviation of anteroposterior lean angle of Section 5 during March 1 was 1.894° less than during March 2 (p<0.000). While wearing Condition III, standard deviation of anteroposterior lean angle of Section 5 during March 1 was 3.34° less than during March 2 (p<0.000). Additionally, during March 1, standard deviation of anteroposterior lean angle of Section 5 was 4.11° less while wearing Condition I than II (p<0.000), 6.57° less while wearing Condition I than III (p<0.000), and 2.46° less while wearing Condition II than III (p=0.006). During March 2, standard deviation of anteroposterior lean angle of Section 5 was 5.77° less while wearing Condition I than II (p<0.000), 9.68° less while wearing Condition I than III (p<0.000), and 3.91° less while wearing Condition II than III (p<0.000).

Main Effect of March: Since significant interactions were observed between march and equipment conditions for standard deviation of anteroposterior lean angle for every section (p<0.05), the main effect of march for every section was ignored.

Main Effect of Equipment: Since significant interactions were observed between march and equipment conditions for standard deviation of anteroposterior lean angle for every section (p<0.05), the main effect of equipment for every section was ignored.

3.2.2. Cognitive Performance – Go/No-Go Task

3.2.2.1. Hit Rate

There was a main effect of condition, $F(2, 60) = 14.82$, $p < .001$, $\eta^2 = .102$, and follow-up comparisons showed higher hit rates in Condition I compared to Condition II ($p = .001$), Condition I compared to Condition III ($p < .001$), and Condition II compared to Condition III ($p = .039$). In addition, there was a main effect of block, $F(4, 120) = 9.18$, $p < .001$, $\eta^2 = .032$, and follow-up comparisons showed higher hit rates in min 0-5 than all subsequent blocks (*p*s < .025) and min 15-20 than all subsequent blocks (*p* values < .012), but not between min 30-35, 45-50, or 55-60 (*p* values > .27), see Figure 36 and Table 33.

There was a condition by march number interaction, $F(2, 60) = 3.93$, $p < .05$, $\eta^2 = .008$, see Figure 36. During the first march, there was a main effect of condition, $F(2, 60) = 8.49$, $p = .001$, $\eta^2 = .088$, and follow-up comparisons showed that hit rate was higher in Condition I compared to Condition II ($p = .002$) and Condition I compared to Condition III ($p < .001$), but not Condition II compared to Condition III ($p = .476$). During the second march, there was a main effect of condition, $F(2,60) = 15.35$, $p < .001$, $\eta^2 = .125$, and follow-up comparisons showed that hit rate was higher in Condition I compared to Condition II ($p = .002$), Condition I compared to Condition III ($p < .001$), and Condition II compared to Condition III ($p = .006$). No main effect of march number or other interactions were found (*p* values > .07).

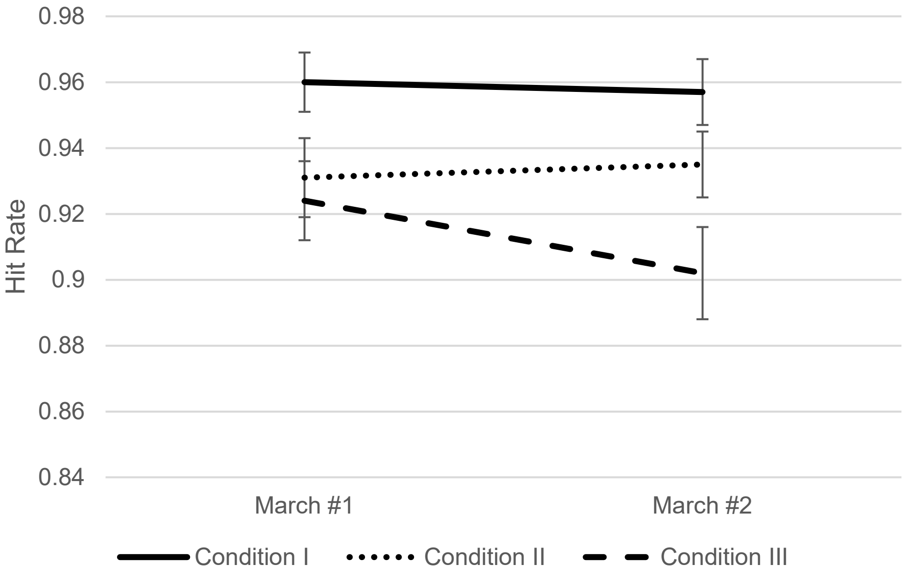


Figure 36. Hit rate means (SEM) for each condition and march, collapsed across block.

Table 33. Go/No-Go hit rate means ± SEM

		Condition I		Condition II		Condition III	
First March	Min 0-5	0.97	± 0.01	0.93	± 0.02	0.94	± 0.01
	Min 15-20	0.96	± 0.01	0.94	± 0.01	0.94	± 0.01
	Min 30-35	0.95	± 0.01	0.93	± 0.02	0.93	± 0.02
	Min 45-50	0.97	± 0.01	0.92	± 0.02	0.90	± 0.02
	Min 55-60	0.95	± 0.02	0.94	± 0.01	0.91	± 0.02
Second March	Min 0-5	0.97	± 0.01	0.95	± 0.01	0.94	± 0.01
	Min 15-20	0.96	± 0.01	0.94	± 0.01	0.91	± 0.02
	Min 30-35	0.96	± 0.01	0.92	± 0.01	0.88	± 0.02
	Min 45-50	0.93	± 0.02	0.92	± 0.02	0.89	± 0.02
	Min 55-60	0.96	± 0.01	0.94	± 0.01	0.89	± 0.02

3.2.2.2. False Alarm Rate

There was a main effect of condition, $F(2, 60) = 19.74$ $p < .001$, $\eta^2 = .131$, and follow-up comparisons showed higher false alarm rates in Condition II compared to Condition I ($p = .019$), Condition III compared to Condition I, ($p < .001$), and Condition III compared to Condition II ($p < .001$). In addition, there was a main effect of block, $F(4, 120) = 12.56$, $p < .001$, $\eta^2 = .039$, and follow-up comparisons showed higher false alarm rates in min 55-60 compared to all previous blocks (*p*s < .012), min 45-50 compared to min 0-5 and 15-20 (*p* values < .011), and min 30-35 compared to min 0-5 ($p < .001$). There was a main effect of march, $F(1, 30) = 20.81$, $p < .001$, $\eta^2 = .059$, in that false alarm rate was higher in the second than the first march, see Figure 37 and Table 34.

There was a condition by Block interaction, $F(8, 240) = 4.40$, $p < .001$, $\eta^2 = .020$, see Figure 37. During min 0-5, there was a main effect of condition, $F(2, 60) = 7.76$, $p = .001$, $\eta^2 = .081$, and follow-up comparisons showed that false alarm rate was higher in Condition III compared to Condition I (*p* < .001) and in Condition III compared to Condition II (*p* = .009), but not Condition II compared to Condition I (*p* = .804). During min 15-20, there was a main effect of condition, *F*(2, 60) = 3.72, *p* = .030, η^2 = .051, and follow-up comparisons showed that false alarm rate was higher in Condition III compared to Condition I (*p* = .012), but not Condition III compared to Condition II (*p* = .074) or Condition II compared to Condition I (*p* = .486). During min 30-35, there was a main effect of condition, *F*(2, 60) = 15.05, *p* < .001, η^2 = .208, and follow-up comparisons showed that false alarm rate was higher in Condition III compared to Condition I (*p* < .001), Condition III compared to Condition II (*p* = .002), and Condition II compared to Condition I (*p* = .036). During min 45-50, there was a main effect of condition, *F*(2, 60) = 12.37, *p* < .001, η^2 = .187, and follow-up comparisons showed that false alarm rate was higher in Condition III compared to Condition I (*p* < .001), Condition III compared to Condition II (*p* = .036), and Condition II compared to Condition I (*p* = .003). During min 55-60, there was a main effect of condition, *F*(2, 60) = 24.79, *p* < .001, η^2 = .260, and follow-up comparisons showed that false alarm rate was higher in Condition III compared to Condition I (*p* < .001), Condition III compared to Condition II (*p* < .001), and Condition II compared to Condition I (*p* < .001). No other interactions were found (*p*s > .57).

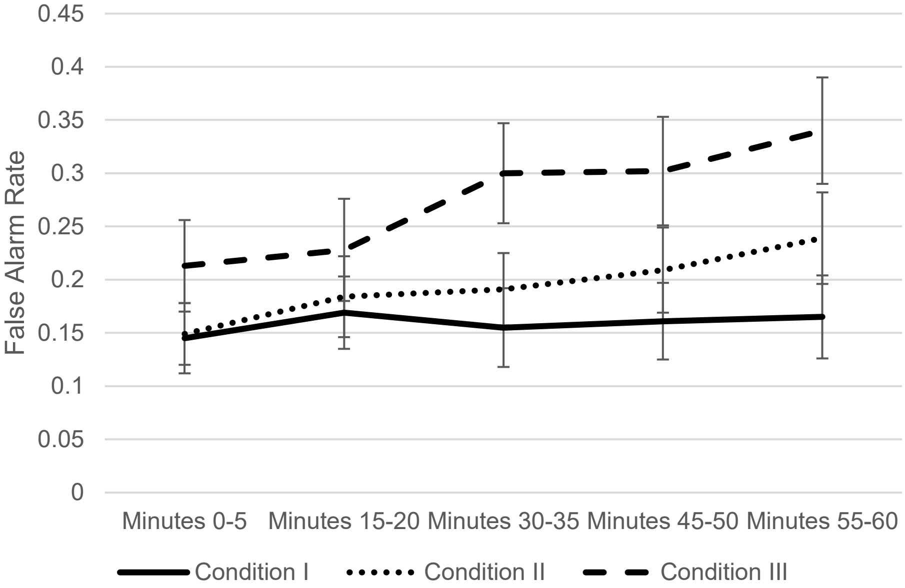


Figure 37. False alarm rate means (SEM) for each condition and block, collapsed across march.

Table 34. Go/No-Go false alarm rate means ± SEM

		Condition I		Condition II		Condition III	
First March	Min 0-5	0.12	± 0.03	0.12	± 0.02	0.19	± 0.04
	Min 15-20	0.14	± 0.03	0.14	± 0.03	0.19	± 0.04
	Min 30-35	0.11	± 0.03	0.17	± 0.03	0.25	± 0.04
	Min 45-50	0.15	± 0.03	0.19	± 0.04	0.26	± 0.05
	Min 55-60	0.14	± 0.04	0.20	± 0.04	0.29	± 0.05
Second March	Min 0-5	0.18	± 0.04	0.18	± 0.04	0.24	± 0.05
	Min 15-20	0.20	± 0.04	0.23	± 0.05	0.27	± 0.06
	Min 30-35	0.20	± 0.04	0.21	± 0.04	0.35	± 0.06
	Min 45-50	0.18	± 0.04	0.23	± 0.05	0.34	± 0.06
	Min 55-60	0.19	± 0.04	0.28	± 0.05	0.39	± 0.06

3.2.2.3. *Response Sensitivity (d')*

There was a main effect of Condition, $F(2, 60) = 34.33$, $p < .001$, $\eta^2 = .223$, and follow-up comparisons showed higher sensitivity in Condition I compared to Condition II ($p < .001$), Condition I compared to Condition III ($p < .001$), and Condition II compared to Condition III ($p < .001$). In addition, there was a main effect of block, $F(4, 120) = 15.74$, $p < .001$, $\eta^2 = .097$, and follow-up comparisons showed higher sensitivity in min 0-5 than all subsequent blocks (p values $< .014$) and min 15-20 than all subsequent blocks (p values $< .026$), but not between min 30-35, 45-50 or 55-60 (p values $> .07$). There was a main effect of march, $F(1, 30) = 30.94$, $p < .001$, $\eta^2 = .041$, in that sensitivity was higher in the first than second march, see Figure 38 and Table 35.

There was a condition by block interaction, $F(8, 240) = 3.46$, $p < .001$, $\eta^2 = .060$, see Figure 38. In min 0-5, there was a main effect of condition, $F(2, 60) = 11.36$, $p < .001$, $\eta^2 = .155$, and follow-up comparisons showed that sensitivity was higher in Condition I compared to Condition II ($p = .016$) and Condition I compared to Condition III ($p < .001$), but not Condition II compared to Condition III ($p = .056$). In min 15-20, there was a main effect of condition, $F(2, 60) = 10.57$, $p < .001$, $\eta^2 = .143$, and follow-up comparisons showed that sensitivity was higher in Condition I compared to Condition III ($p < .001$) and Condition II compared to Condition III ($p = .007$) but not Condition I compared to Condition II ($p = .065$). In min 30-35, there was a main effect of condition, $F(2, 60) = 27.08$, $p < .001$, $\eta^2 = .320$, and follow-up comparisons showed that sensitivity was higher in Condition I compared to Condition II ($p < .001$), Condition I compared to Condition III ($p < .001$) and Condition II compared to Condition III ($p = .002$). In min 45-50, there was a main effect of condition, $F(2, 60) = 20.27$, $p < .001$, $\eta^2 = .271$, and follow-up comparisons showed that sensitivity was higher in Condition I compared to Condition II ($p = .001$), Condition I compared to Condition III ($p < .001$) and Condition II compared to Condition III ($p = .007$). In min 55-60, there was a main effect of condition, $F(2, 60) = 29.70$, $p < .001$, $\eta^2 = .330$, and follow-up comparisons showed that sensitivity was higher in Condition I compared to Condition II ($p < .001$), Condition I compared to Condition III ($p < .001$) and Condition II compared to Condition III ($p = .001$). No other interactions were found (ps $> .21$).

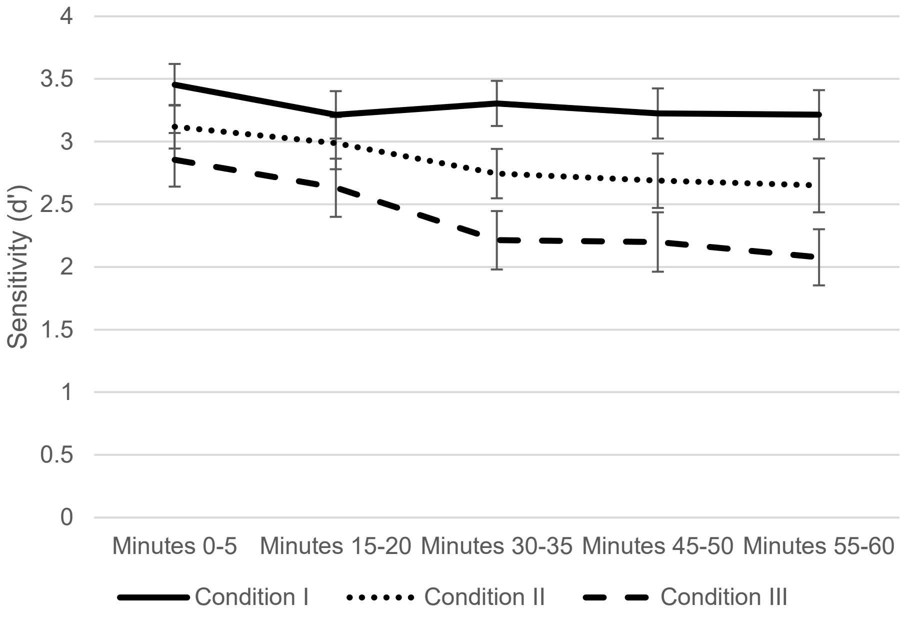


Figure 38. Sensitivity (d') (SEM) for each condition and block, collapsed across march.

Table 35. Go/No-Go sensitivity (d') means ± SEM

		Condition I	Condition II	Condition III
First March	Min 0-5	3.61 ± 0.16	3.16 ± 0.18	2.98 ± 0.20
	Min 15-20	3.35 ± 0.20	3.17 ± 0.20	2.86 ± 0.22
	Min 30-35	3.48 ± 0.19	2.93 ± 0.21	2.53 ± 0.22
	Min 45-50	3.36 ± 0.19	2.77 ± 0.21	2.39 ± 0.24
	Min 55-60	3.31 ± 0.18	2.85 ± 0.22	2.27 ± 0.22
Second March	Min 0-5	3.30 ± 0.19	3.08 ± 0.20	2.73 ± 0.25
	Min 15-20	3.08 ± 0.20	2.80 ± 0.23	2.41 ± 0.27
	Min 30-35	3.13 ± 0.20	2.56 ± 0.20	1.90 ± 0.27
	Min 45-50	3.09 ± 0.25	2.60 ± 0.24	2.01 ± 0.26
	Min 55-60	3.12 ± 0.22	2.45 ± 0.23	1.88 ± 0.27

3.2.2.4. Criterion (c)

There was a main effect of march, $F(1, 30) = 10.26$, $p = .003$, $\eta^2 = .027$ in which criterion was more negative (i.e. participants were more biased to respond) on the second than the first march, see Table 36. No main effects of condition or block or interactions were found (ps > .12).

3.2.2.5. Response Time

There was a main effect of march, $F(1, 30) = 19.26$, $p < .001$, $\eta^2 = .037$, in which response time (on correct Go trials) was slower on the first than second march, see Table 36. No main effects of condition or block or interactions were found (ps > .11).

Table 36. Go/No-Go response time (ms) means ± SEM

		Condition I		Condition II		Condition III	
First March	Min 0-5	607.00	± 22.29	633.51	± 22.20	602.35	± 20.24
	Min 15-20	611.26	± 23.52	618.90	± 20.80	596.24	± 22.24
	Min 30-35	604.86	± 22.33	615.58	± 19.95	604.52	± 22.59
	Min 45-50	614.25	± 22.47	623.84	± 20.69	608.41	± 25.42
	Min 55-60	630.31	± 27.46	619.60	± 21.06	607.82	± 26.28
Second March	Min 0-5	590.69	± 24.74	600.94	± 22.08	589.38	± 28.01
	Min 15-20	585.62	± 25.24	579.36	± 20.57	596.78	± 27.11
	Min 30-35	580.70	± 24.58	587.00	± 20.05	591.19	± 28.85
	Min 45-50	593.69	± 25.32	598.06	± 23.32	587.78	± 27.03
	Min 55-60	574.66	± 22.78	608.90	± 24.26	579.63	± 27.34

3.2.3. Ratings of Perceived Exertion

There was a main effect of condition, $F(2, 60) = 174.83$, $p < .001$, $\eta^2 = .397$, and follow-up comparisons showed lower ratings of perceived exertion in Condition I compared to Condition II ($p < .001$), Condition I compared to Condition III ($p < .001$) and in Condition II compared to Condition III ($p < .001$). In addition, there was a main effect of time, $F(1, 30) = 269.59$, $p < .001$, $\eta^2 = .284$, in which ratings of perceived exertion were lower before than after the marches. There was a main effect of march, $F(1, 30) = 26.78$, $p < .001$, $\eta^2 = .017$, in which perceived exertion was lower in the first than second march, see Table 37.

There was a condition by time interaction, $F(2, 60) = 38.64$, $p < .001$, $\eta^2 = .066$. Before the march, there was a main effect of condition, $F(2, 60) = 45.70$, $p < .001$, $\eta^2 = .400$, and follow-up comparisons showed that perceived exertion was lower in Condition I compared to Condition II ($p < .001$), Condition I compared to Condition III ($p < .001$), and Condition II compared to Condition III ($p < .001$). After the march, there was a main effect of condition, $F(2, 60) = 161.87$, $\eta^2 = .773$, and follow-up comparisons showed that perceived exertion was lower in Condition I compared to Condition II ($p < .001$), Condition I compared to Condition III ($p < .001$), and Condition II compared to Condition III ($p < .001$).

There was a condition by march interaction, $F(2, 60) = 13.64$, $p < .01$, $\eta^2 = .010$. During the first march, there was a main effect of condition, $F(2, 60) = 96.60$, $p < .001$, $\eta^2 = .316$, and follow-up tests showed that perceived exertion was lower in Condition I compared to Condition II ($p < .001$), Condition I compared to Condition III ($p < .001$), and Condition II compared to Condition III ($p < .001$). During the second march, there was a main effect of condition, $F(2, 60) = 172.18$, $p < .001$, $\eta^2 = .520$, and follow-up tests showed that perceived exertion was lower in Condition I compared to Condition II ($p < .001$), Condition I compared to Condition III ($p < .001$), and Condition II compared to Condition III ($p = .001$). No other interactions were found (ps > .05).

Table 37. Pre- and post-road march rated perceived exertion means ± SEM

		Condition I		Condition II		Condition III	
Pre-March	First March	6.61	± 0.36	8.13	± 0.37	9.29	± 0.43
	Second March	6.68	± 0.16	10.16	± 0.46	11.32	± 0.41
Post-March	First March	8.19	± 0.41	13.74	± 0.45	16.00	± 0.46
	Second March	7.97	± 0.32	15.23	± 0.47	17.07	± 0.48

3.2.4. Mission Performance

There was a main effect of condition, $F(2, 60) = 22.22$, $p < .001$, $\eta^2 = .322$, and follow-up comparisons showed participants rated their mission performance as better in Condition I compared to Condition II *(* $p < .001$), Condition I compared to Condition III ($p < .001$), and Condition II compared to Condition III ($p = .015$). No main effect of march or interaction was found (p values > .13), see Table 38.

Table 38. Post-roach march mission performance means ± SEM

	Condition I		Condition II		Condition III	
First March	6.39	± 0.22	5.13	± 0.30	4.16	± 0.48
Second March	6.45	± 0.14	4.77	± 0.30	3.58	± 0.38

3.2.5. Physiological Performance

The physiologic measures of 48 participants performing two foot march portions of the scenario were analyzed with the wrist worn Forerunner 220 heart rate monitor. The derived physiologic metrics included: maximum attained heart rate (MaxHR), mean heart rate (MeanHR), maximum percent of heart rate reserve (%MaxHRR) and mean percent heart rate reserve (%MeanHRR). These metrics were derived for the two sequenced 3 mile, 1 h paced foot marches in three CIE conditions.

*Foot March * CIE interactions:* For MaxHR achieved, the repeated measures two-way ANOVA revealed significant interactions ($p<.05$) between foot march sequence number and equipment conditions. Specifically, the statistical results for MaxHR was $F(2,94)=163.54$, $p = .041$, $\eta p^2 .066$. The statistical results for %MaxHRR were - $F(2,94)=98.62$, $p = .026$, $\eta p^2 .074$.

While wearing CIE Condition I, II, or III the participants MaxHR achieved during Foot March 2 were higher by 5.7%, 3.2%, 1.7% respectively, than during Foot March 1 (p<.001), (Figure 39).

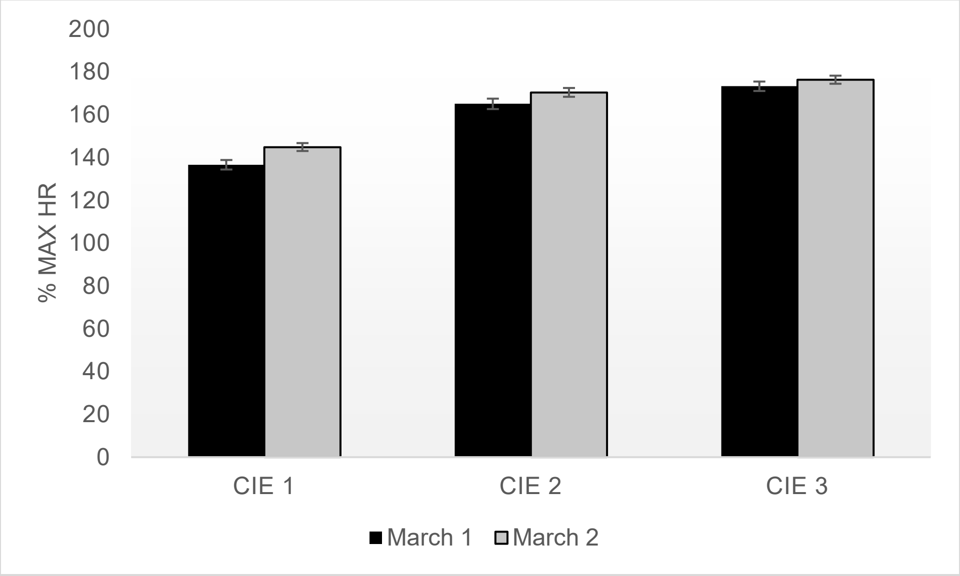


Figure 39. Maximum % HR (SE) by CIE Level and Foot March Sequence.

While wearing CIE Condition I, II, or III the participants %MaxHRR achieved during Foot March 2 of was higher by 6.5%, 4%, 2.4% respectively, than during Foot March 1 ($p<.001$), (Figure 40).

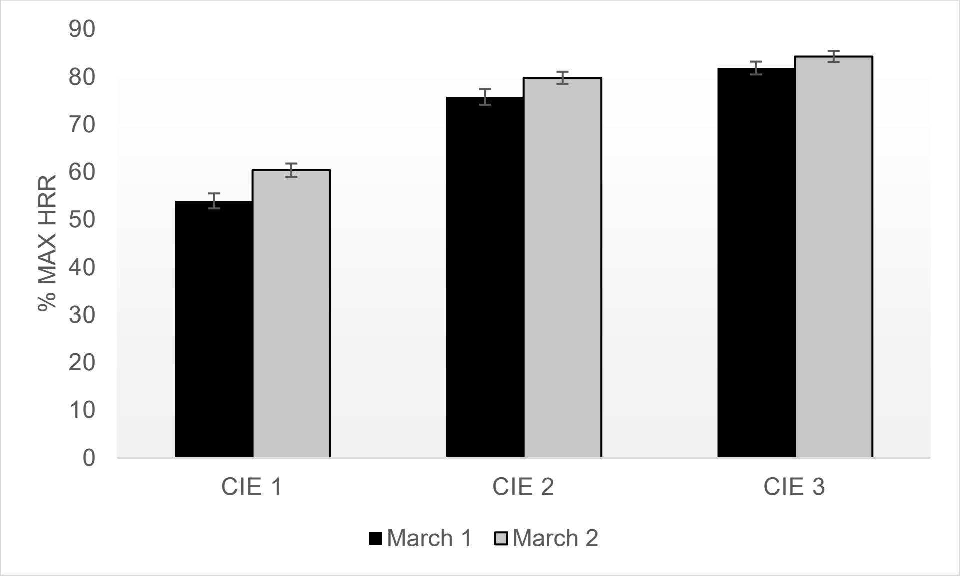


Figure 40. Maximum % HRR (SE) by CIE Level and Foot March Sequence.

Foot March Main Effects: Since significant interactions were observed between march and CIE conditions for MaxHR and %MaxHRR ($p<0.05$), the main effect of foot march for these metrics was ignored. For MeanHR and %MeanHRR the repeated measures two-way ANOVA did reveal significant main effects of foot march sequence number ($p\geq0.05$). MeanHR – $F(1,47)=172.58$, $p < .001$, $\eta p^2 .786$, and %MeanHRR - $F(1,47)=174.02$, $p < .001$, $\eta p^2 .787$. For MeanHR and %MeanHRR the repeated measures two-way ANOVA did reveal significant main effects of CIE condition ($p\geq0.05$). MeanHR – $F(1.71,80.38)=190.82$, $p < .001$, $\eta p^2 .802$, and

%MeanHRR - $F(1.75,82.24)=197.42$, $p < .001$, $\eta p^2 .808$. For MeanHR and %Mean HRR for Conditions I, II, and III, these heart rate measures were different from each other, with Condition III being the highest and Condition I being the lowest.

3.3. LEAP

3.3.1. Timing Performance

A limited number of IMU systems were available, and therefore, data were not collected for a small subset of the 62 participants. Additionally, even when IMUs were worn, there were cases when individual obstacle completion times were not captured. There were a total of 52 individuals for whom complete data sets were available; however, post hoc analysis may have had slightly larger numbers when those particular obstacles were missing less data.

A 3x13 repeated measures ANOVA was conducted with test conditions (3 levels) and obstacle (13 obstacles, including total obstacle time, total transition time and total time to complete the course). Main effects were found for condition ($F(1.62,82.53)=243.84$, $p \leq .001$) and obstacle ($F(1.16,59.08)=2051.83$, $p \leq .001$); because it was anticipated and designed so the different obstacles took different lengths of time to complete, no post hoc analysis was performed for the obstacle main effect. Post hoc analysis of the condition main effect found significant differences between all three conditions and each other ($p \leq .001$) (Figure 41).

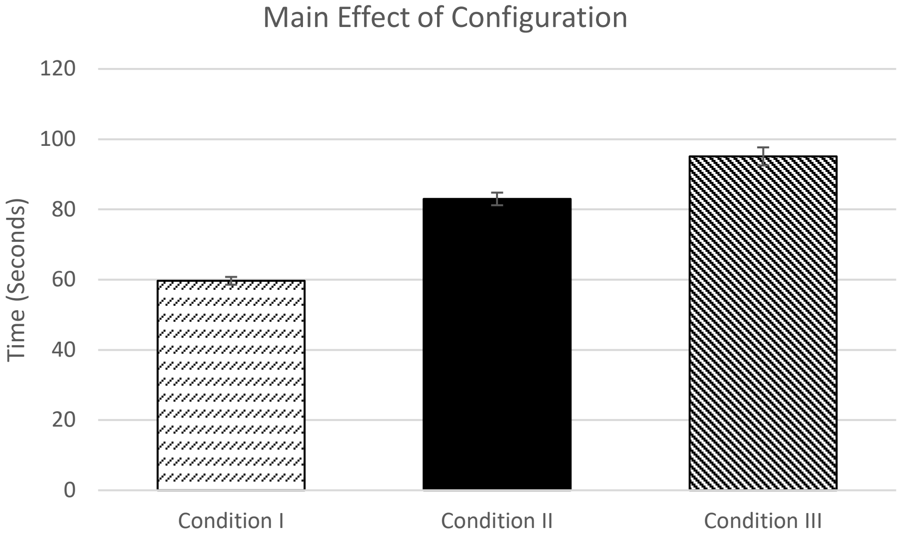


Figure 41. Summary of the means (± SE) across all obstacles by each condition (n=52).

A main interaction effect was also found for condition and obstacle ($F(2.00,101.81)=218.43$, $p \leq .001$). Post hoc analysis of the total course completion time, total obstacle time, and total transition time all found significant differences between each of the three conditions (see Figure 42).

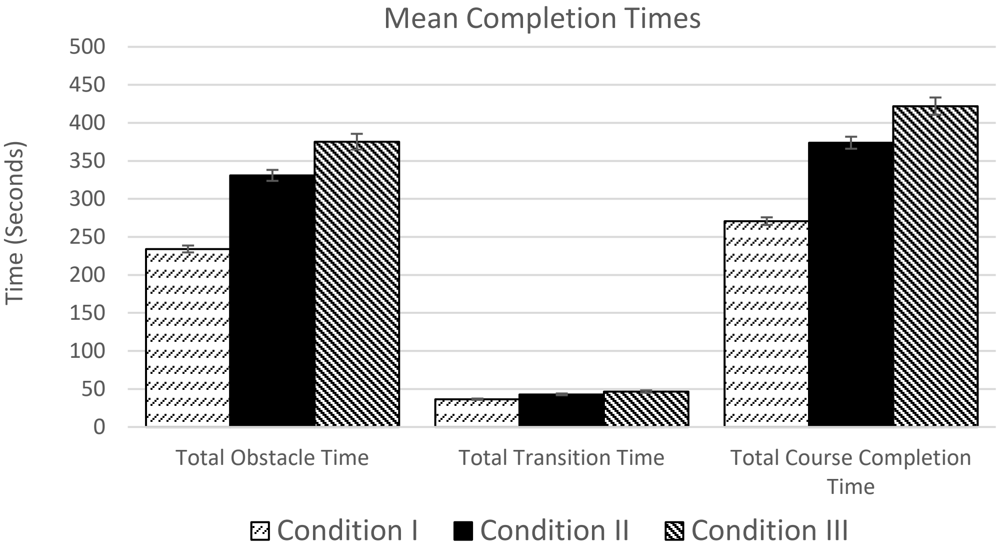


Figure 42. Summary of the mean times (± SE) for the obstacle portion, the transition portions, and the total time to complete the course by each condition (n=52).

Additionally, post hoc analysis of the interaction effect also found significant differences between the three conditions within each obstacle variable ($p \leq .05$, and in all but one case $p \leq .001$) (see Figure 43 and Table 39).

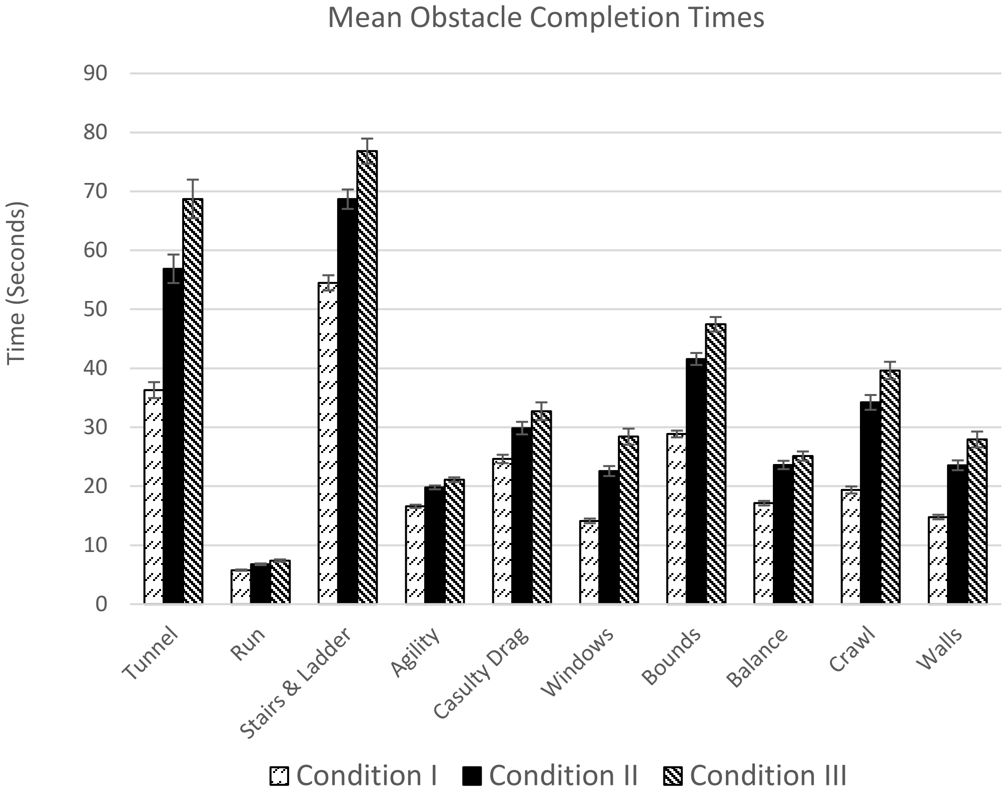


Figure 43. Summary of the mean times (± SE) for each individual obstacle by each condition.

Table 39. Summary of post hoc analysis for each of the individual obstacles and compared between the conditions.

Obstacle	Conditions I vs II	Conditions I vs III	Conditions II vs III
Tunnel	t(54)=-11.85, p≤ .001	t(54)=-13.06, p≤ .001	t(54)=-5.93, p≤ .001
Run	t(54)=-10.68, p≤ .001	t(54)=-12.31, p≤ .001	t(54)=-5.16, p≤ .001
Ladder & Stairs	t(53)=-13.59, p≤ .001	t(54)=-15.30, p≤ .001	t(53)=-6.97, p≤ .001
Agility Run	t(54)=-16.43, p≤ .001	t(54)=-17.15, p≤ .001	t(54)=-5.16, p≤ .001
Casualty Drag	t(52)=-6.34, p≤ .001	t(54)=-6.51, p≤ .001	t(52)=-2.48, p= .016
Windows	t(53)=-11.96, p≤ .001	t(54)=-12.11, p≤ .001	t(53)=-6.54, p≤ .001
Bounding Rushes	t(53)=-14.19, p≤ .001	t(54)=-18.27, p≤ .001	t(53)=-5.83, p≤ .001
Balance Beam	t(53)=-11.61, p≤ .001	t(54)=-13.32, p≤ .001	t(53)=-3.38, p=.001
Crawl	t(53)=-13.02, p≤ .001	t(54)=-14.98, p≤ .001	t(53)=-5.48, p≤ .001
Walls	t(53)=-11.76, p≤ .001	t(54)=-10.94, p≤ .001	t(53)=-4.36, p≤ .001
Total: Obstacles	t(51)=-17.14, p≤ .001	t(54)=-18.20, p≤ .001	t(51)=-7.86, p≤ .001
Total: Transitions	t(51)=-8.63, p≤ .001	t(54)=-10.61, p≤ .001	t(51)=-3.87, p≤ .001
Total: Course	t(51)=-8.63, p≤ .001	t(54)=-10.61, p≤ .001	t(51)=-3.87, p≤ .001

3.3.2. Biomechanics Performance

3.3.2.1. Sprint

The kinematics of 56 participants performing the sprint section of the LEAP obstacle course were analyzed with IMUs mounted on the sternum, sacrum, and both feet. The 12 derived kinematic metrics included: Speed, Stride length, Stride duration, Stride width, Foot yaw, PCA feet, PCA pelvis, PCA torso, Mediolateral lean angle, Standard deviation of mediolateral lean angle,) Anteroposterior lean angle, and Standard deviation of anteroposterior lean angle. Only the main effect of equipment condition was examined for each metric.

Speed: For speed, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(2,110)=70.639, p=0.000, η_p^2=0.562 (Figure 44). Pairwise comparisons revealed that speed was 0.442 m/s greater for Condition I than II (p<0.000), 0.604 m/s greater for Condition I than III (p<0.000), and 0.162 m/s greater for Condition II than III (p=0.002).

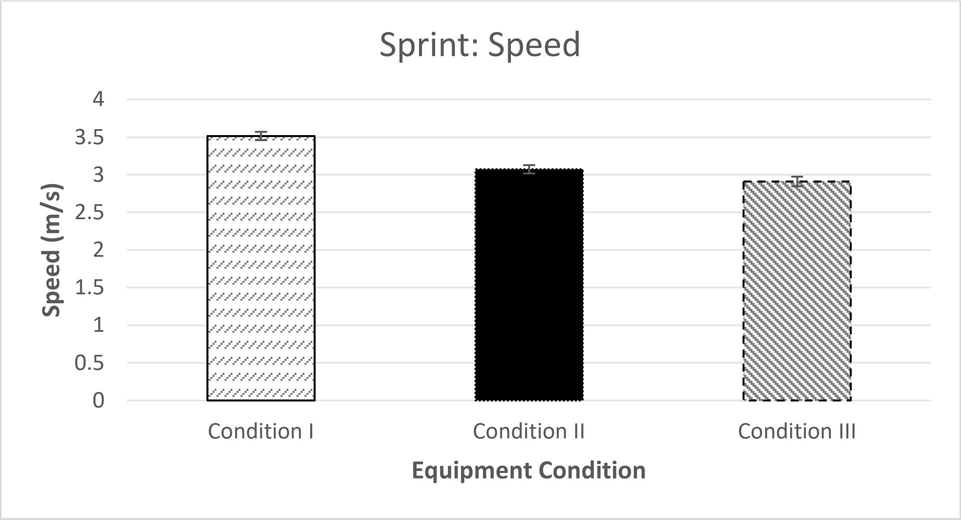


Figure 44. Cell means of speed during the sprint obstacle for each equipment condition. Standard Error is displayed by the error bars.

Stride Length: For stride length, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(1.659,91.266)=44.397, p=0.000, η_p^2=0.447 (Figure 45). Pairwise comparisons revealed that stride length was 0.240 m greater for Condition I than II (p<0.000), 0.318 m greater for Condition I than III (p<0.000), and 0.078 m greater for Condition II than III (p=0.030).

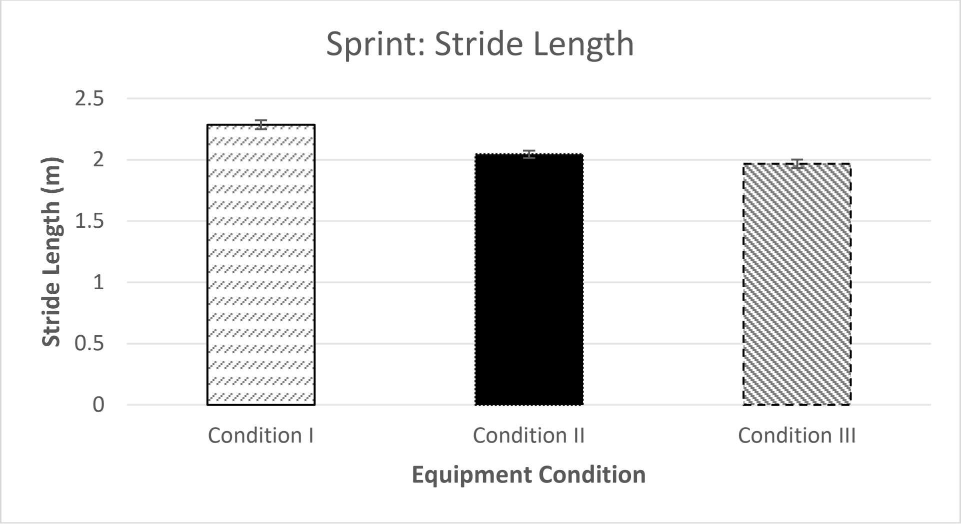


Figure 45. Cell means of stride length during the sprint obstacle for each equipment condition. Standard Error is displayed by the error bars.

Stride Duration: For stride duration, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(1.644,90.397)=8.631, p=0.001, η_p^2=0.136 (Figure 46). Pairwise comparisons revealed that stride duration was 0.019 s less for Condition I than II (p=0.044), 0.029s less for Condition I than III (p=0.002). However, stride duration was not different between Conditions II and III (p=0.180).

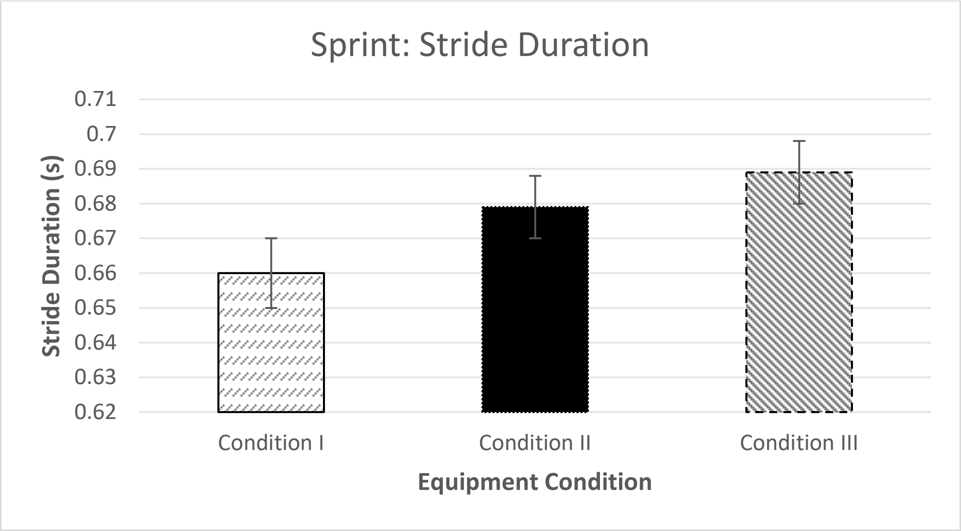


Figure 46. Cell means of stride duration during the sprint obstacle for each equipment condition. Standard Error is displayed by the error bars.

Stride Width: For stride width, the repeated measures one-way ANOVA did not reveal a significant main effect for equipment condition, F(2,110)=0.828, p=0.439, η_p^2=0.015.

Foot Yaw: For foot yaw, the repeated measures one-way ANOVA did not reveal a significant main effect for equipment condition, F(2,110)=2.233, p=0.112, η_p^2=0.039.

PCA Feet: For PCA feet, the repeated measures one-way ANOVA did not reveal a significant main effect for equipment condition, F(1.642,90.299)=0.057, p=0.915, η_p^2=0.001.

PCA Pelvis: For PCA pelvis, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(2,110)=4.705, p=0.011, η_p^2=0.079. Pairwise comparisons revealed that PCA pelvis was 2.99% less for Condition I than III (p=0.005). However, PCA foot was not different between Conditions I and II (p=0.380) or II and III (p=0.511).

PCA Torso: For PCA torso, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(2,110)=44.680, p=0.000, η_p^2=0.448 (Figure 47). Pairwise comparisons revealed that PCA torso was 8.77% greater for Condition I than II (p<0.000) and 8.33% greater for Condition I than III (p<0.000). However, PCA pelvis was not different between Conditions II and III (p=1.000).

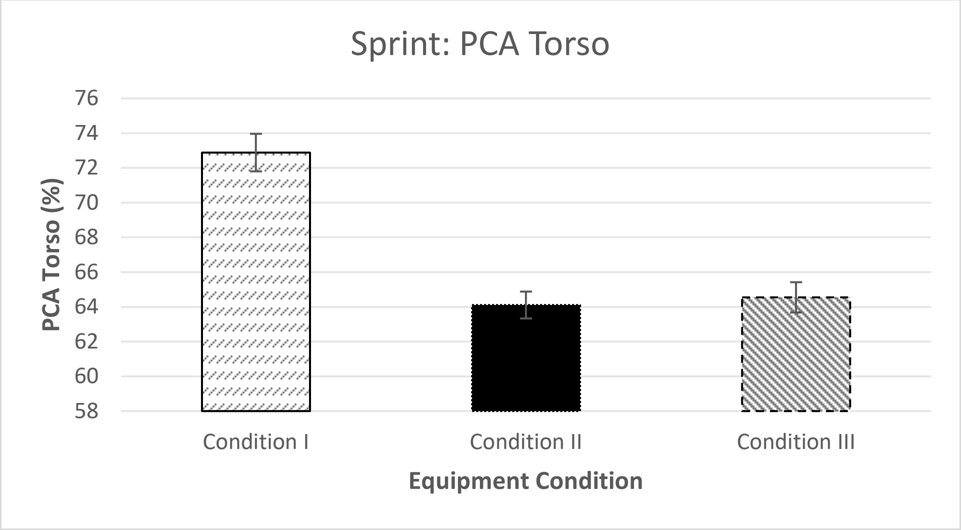


Figure 47. Cell means of PCA Torso during the sprint obstacle for each equipment condition. Standard Error is displayed by the error bars.

Mediolateral Lean Angle: For mediolateral lean angle, the repeated measures one-way ANOVA did not reveal a significant main effect for equipment condition, F(2,110)=0.604, p=0.548, η_p^2=0.011.

Standard Deviation of Mediolateral Lean Angle: For standard deviation of mediolateral lean angle, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(1.760, 96.792)=12.293, p=0.000, η_p^2=0.183 (Figure 48). Pairwise comparisons revealed that standard deviation of mediolateral lean angle was 0.493° greater for Condition I than II (p<0.000) and 0.493° greater for Condition I than III (p<0.000). However, standard deviation of mediolateral lean angle was not different between Conditions II and III (p=1.000).

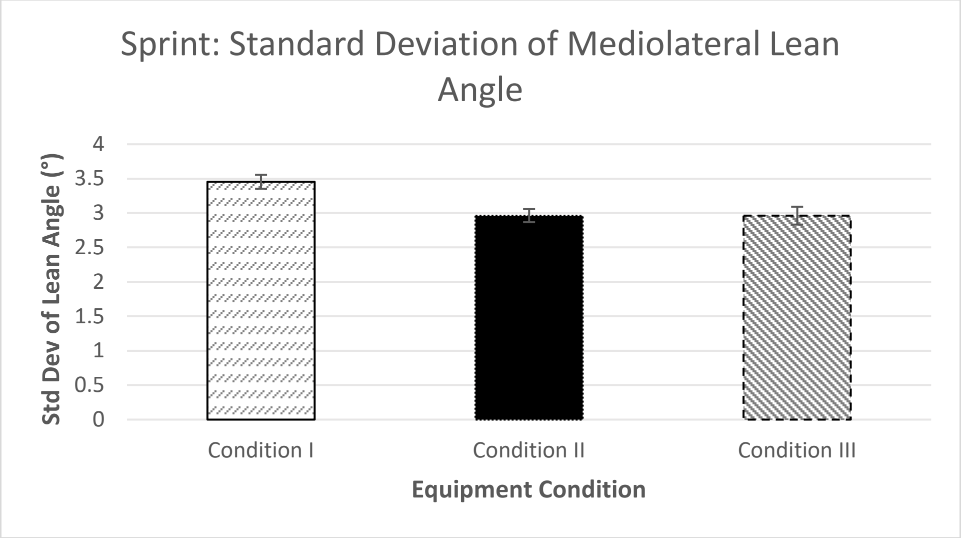


Figure 48. Cell means of the standard deviation of mediolateral lean angle during the sprint obstacle for each equipment condition. Standard Error is displayed by the error bars.

Anteroposterior Lean Angle: For anteroposterior lean angle, the repeated measures one-way ANOVA did not reveal a significant main effect for equipment condition, F(2,110)=2.392, p=0.096, η_p^2=0.042.

Standard Deviation of Anteroposterior Lean Angle: For standard deviation of anteroposterior lean angle, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(2,110)=84.081, p=0.000, η_p^2=0.605 (Figure 49). Pairwise comparisons revealed that standard deviation of anteroposterior lean angle was 3.10° greater for Condition I than II (p<0.000), 4.73° greater for Condition I than III (p<0.000), and 1.629° greater for Condition II than III (p<0.000).

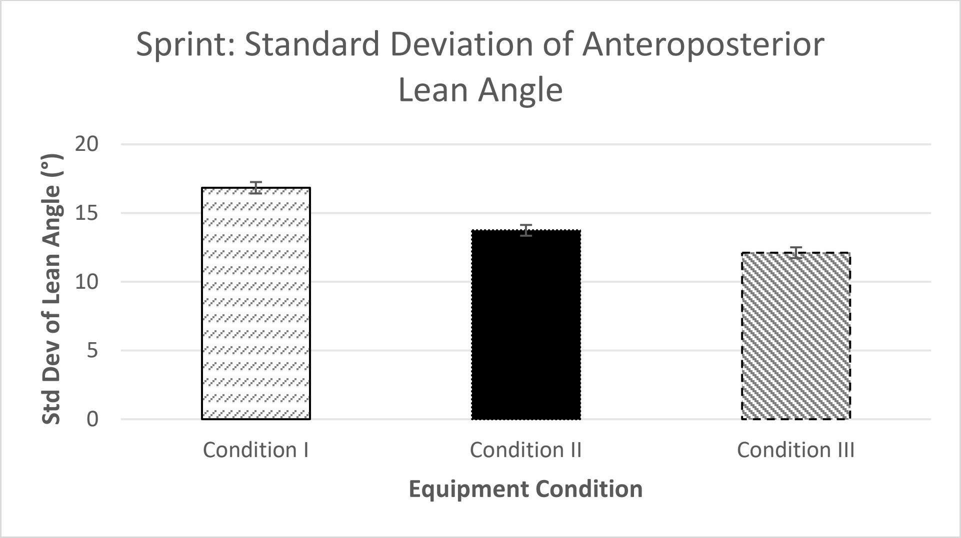


Figure 49. Cell means of the standard deviation of anteroposterior lean angle during the sprint obstacle for each equipment condition. Standard Error is displayed by the error bars.

3.3.2.2. Agility Run

The kinematics of 56 participants performing the agility run section of the LEAP obstacle course were analyzed with IMUs mounted on the sternum, sacrum, and both feet. The 17 derived kinematic metrics included: Speed, Stride length, Stride duration, Standard deviation of stride width, Standard deviation of foot yaw, PCA feet, PCA pelvis, PCA torso, Mediolateral lean angle, Standard deviation of mediolateral lean angle, Anteroposterior lean angle, Standard deviation of anteroposterior lean angle, Pelvis mediolateral acceleration at turn, Pelvis anteroposterior acceleration at turn, Pelvis mediolateral tilt at turn, Pelvis anteroposterior tilt at turn, Pelvis angular velocity about a vertical axis at turn. Only the main effect of equipment condition was examined for each metric.

Speed: For speed, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(2,110)=277.626, p=0.000, η_p^2=0.835 (Figure 50). Pairwise comparisons revealed that speed was 0.394 m/s greater for Condition I than II (p<0.000), 0.522m/s greater for Condition I than III (p<0.000), and 0.128 m/s greater for Condition II than III (p<0.000).

Figure 50. Cell means of speed during the agility run obstacle for each equipment condition. Standard Error is displayed by the error bars.

Stride Length: For stride length, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(2,110)=227.060, p=0.000, η_p^2=0.805. Pairwise comparisons revealed that stride length was 0.235 m greater for Condition I than II (p<0.000), 0.309 m greater for Condition I than III (p<0.000), and 0.075 m greater for Condition II than III (p<0.000).

Stride Duration: For stride duration, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(2,110)=27.596, p=0.000, η_p^2=0.334. Pairwise comparisons revealed that stride duration was 0.026 s less for Condition I than II (p<0.000) and 0.037 s less for Condition I than III (p<0.000). However, stride duration was not different between Conditions II and III (p=0.114).

Standard Deviation of Stride Width: For standard deviation of stride width, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(2,110)=186.287, p=0.000, η_p^2=0.772 (Figure 51). Pairwise comparisons revealed that standard deviation of stride width was 0.212 m greater for Condition I than II (p<0.000), 0.273 m greater for Condition I than III (p<0.000), and 0.061 m greater for Condition II than III (p<0.000).

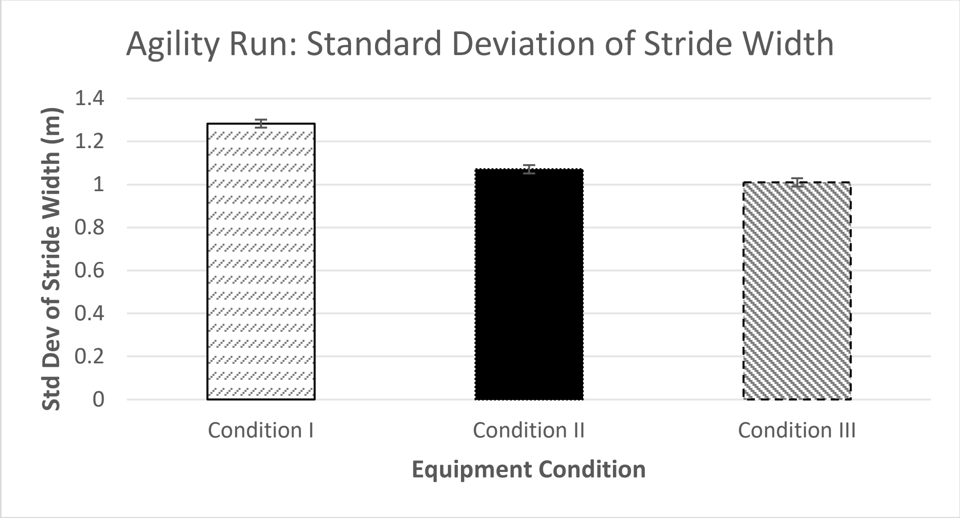


Figure 51. Cell means of the standard deviation of stride width during the agility run obstacle for each equipment condition. Standard Error is displayed by the error bars.

Standard Deviation of Foot Yaw: For standard deviation of foot yaw, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(1.549,85.211)=59.473, p=0.000, η_p^2=0.520 (Figure 52). Pairwise comparisons revealed that standard deviation of foot yaw was 3.08° greater for Condition I than II (p<0.000), 4.08° greater for Condition I than III (p<0.000), and 0.998° greater for Condition II than III (p=0.001).

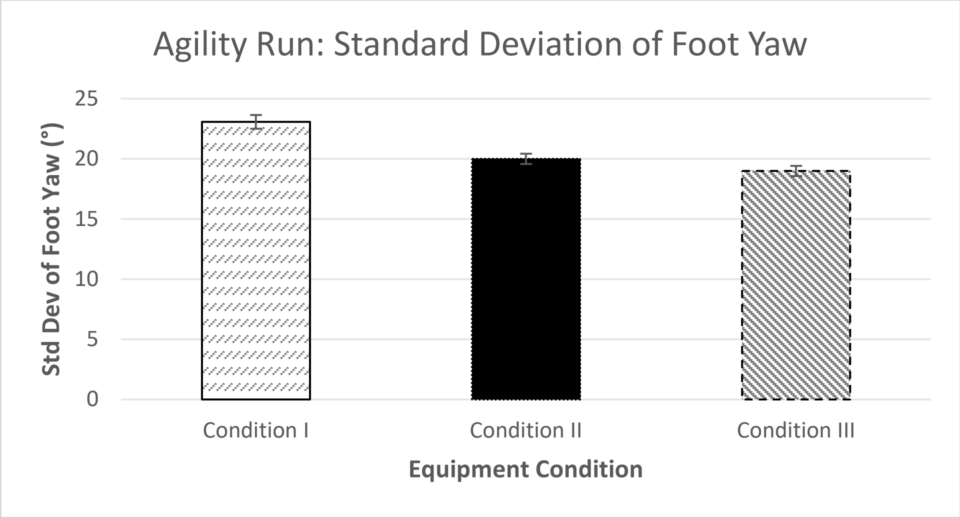


Figure 52. Cell means of the standard deviation of foot yaw during the agility run obstacle for each equipment condition. Standard Error is displayed by the error bars.

PCA Feet: For PCA feet, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(1.728,95.044)=32.160, p=0.000, η_p^2=0.369 (Figure 53). Pairwise comparisons revealed that PCA feet was 1.601% less for Condition I than II (p<0.000) and 1.928% less for Condition I than III (p<0.000). However, PCA feet was not different between Conditions II and III (p=0.338).

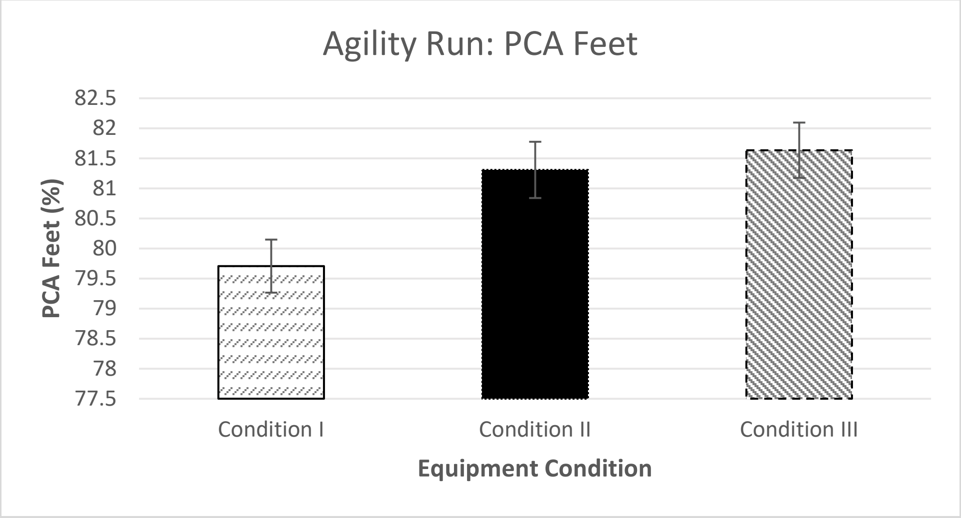


Figure 53. Cell means of PCA Feet during the agility run obstacle for each equipment condition. Standard Error is displayed by the error bars.

PCA Pelvis: For PCA pelvis, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(1.797,98.816)=58.657, p=0.000, η_p^2=0.516. Pairwise comparisons revealed that PCA pelvis was 4.63% less for Condition I than II (p<0.000), 7.26% less for Condition I than III (p<0.000), and 2.63% less for Condition II than III (p<0.000).

PCA Torso: For PCA torso, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(1.725,94.853)=69.389, p=0.000, η_p^2=0.558 (Figure 54). Pairwise comparisons revealed that PCA torso was 7.10% greater for Condition I than II (p<0.000) and 6.44% greater for Condition I than III (p<0.000). However, PCA torso was not different between Conditions II and III (p=0.637).

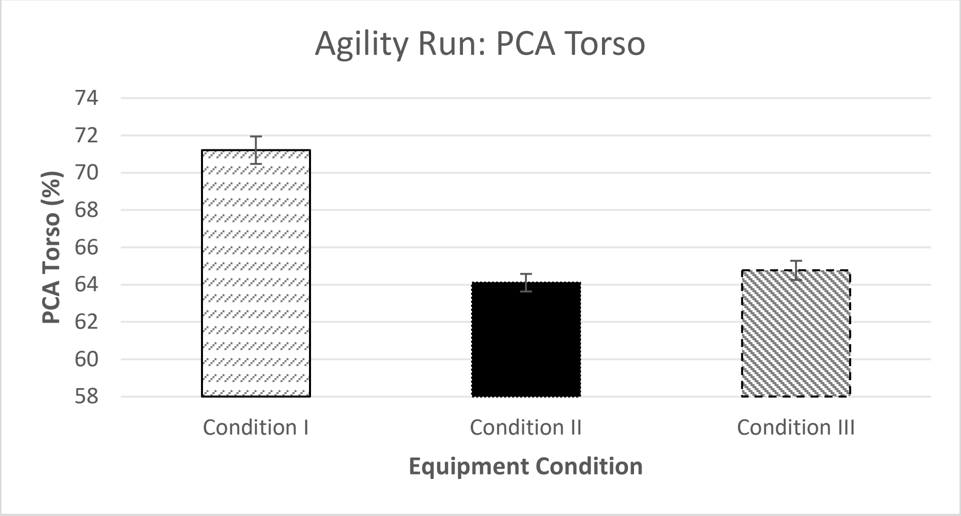


Figure 54. Cell means of PCA Torso during the agility run obstacle for each equipment condition. Standard Error is displayed by the error bars.

Mediolateral Lean Angle: For mediolateral lean angle, the repeated measures one-way ANOVA did not reveal a significant main effect for equipment condition, F(2,110)=0.750, p=0.475, η_p^2=0.013.

Standard Deviation of Mediolateral Lean Angle: For standard deviation of mediolateral lean angle, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(2,110)=17.039, p=0.000, η_p^2=0.237 (Figure 55). Pairwise comparisons revealed that standard deviation of mediolateral lean angle was 0.738° greater for Condition I than II (p<0.000) and 1.162° greater for Condition I than III (p<0.000). However, standard deviation of mediolateral lean angle was not different between Conditions II and III (p=0.102).

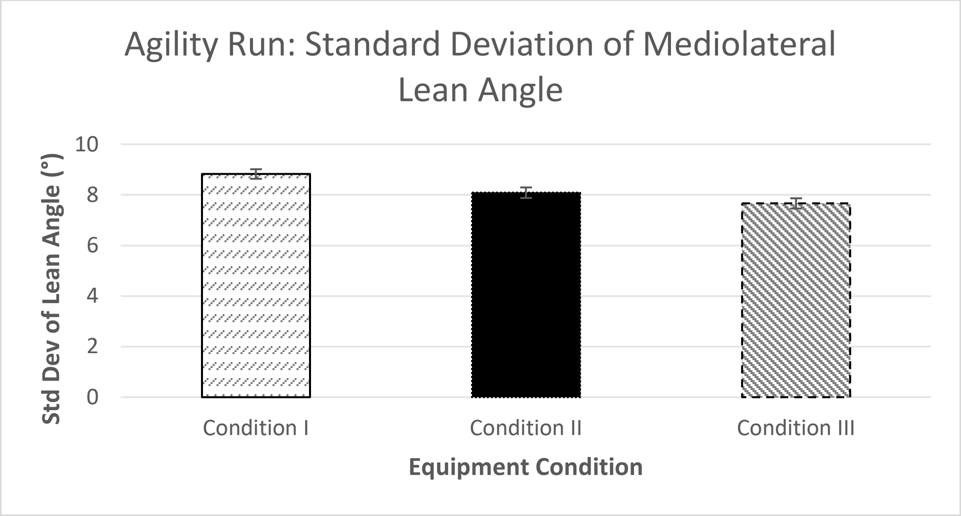


Figure 55. Cell means of the standard deviation of mediolateral lean angle during the agility run obstacle for each equipment condition. Standard Error is displayed by the error bars.

Anteroposterior Lean Angle: For anteroposterior lean angle, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(2,110)=29.208, p=0.000, η_p^2=0.347 (Figure 56). Pairwise comparisons revealed that anteroposterior lean angle was 4.83° greater for Condition I than II (p<0.000) and 5.64° greater for Condition I than III (p<0.000). However, anteroposterior lean angle was not different between Conditions II and III (p=0.867).

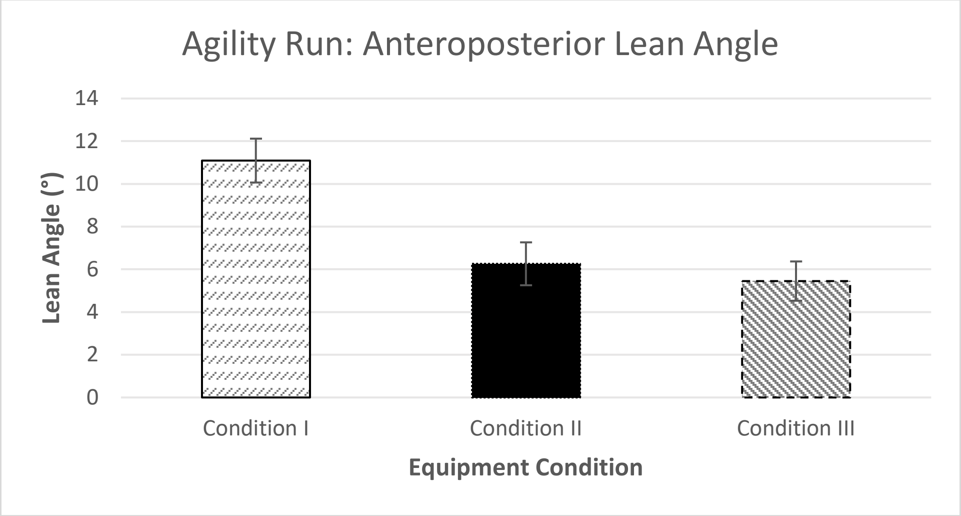


Figure 56. Cell means of anteroposterior lean angle during the agility run obstacle for each equipment condition. Standard Error is displayed by the error bars.

Standard Deviation of Anteroposterior Lean Angle: For standard deviation of anteroposterior lean angle, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(1.766,97.139)=92.812, p=0.000, η_p^2=0.628 (Figure 57). Pairwise comparisons revealed that standard deviation of anteroposterior lean angle was 1.946° greater for Condition I than II (p<0.000), 2.48° greater for Condition I than III (p<0.000), and 0.538° greater for Condition II than III (p<0.000).

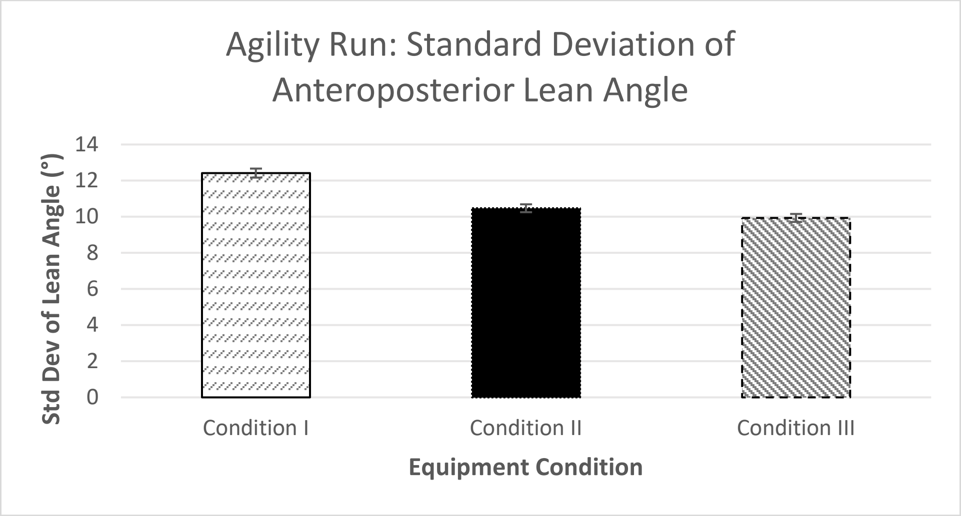


Figure 57. Cell means of the standard deviation of anteroposterior lean angle during the agility run obstacle for each equipment condition. Standard Error is displayed by the error bars.

Pelvis Mediolateral Acceleration at Turn: For pelvis mediolateral acceleration at turn, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(1.597,87.811)=43.505, p=0.000, η_p^2=0.442 (Figure 58). Pairwise comparisons revealed that pelvis mediolateral acceleration at turn was 0.585m/s^2 greater for Condition I than II (p<0.000), 0.882m/s^2 greater for Condition I than III ($p<0.000$), and 0.297m/s^2 greater for Condition II than III ($p<0.000$).

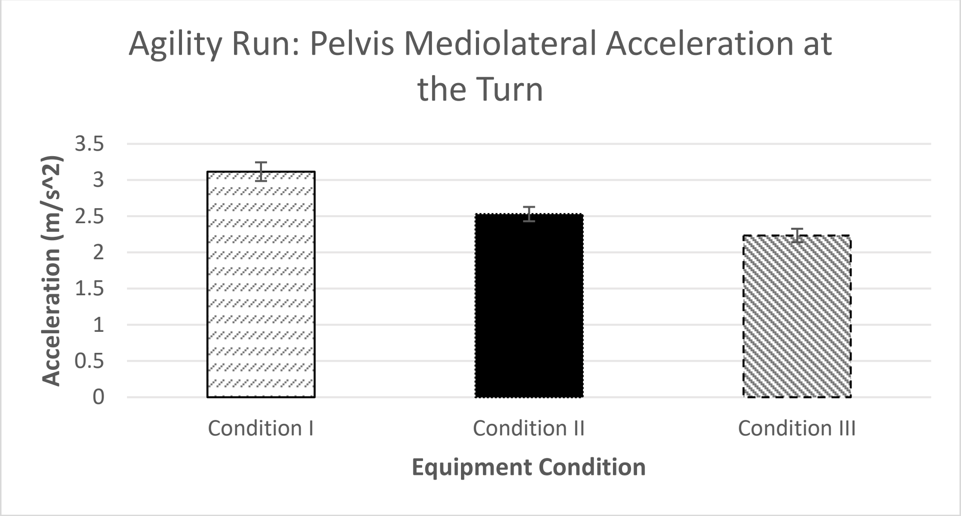


Figure 58. Cell means of pelvis mediolateral acceleration at turn during the agility run obstacle for each equipment condition. Standard Error is displayed by the error bars.

Pelvis Anteroposterior Acceleration at Turn: For pelvis anteroposterior acceleration at turn, the repeated measures one-way ANOVA did not reveal a significant main effect for equipment condition, $F(1.477,81.243)=3.335$, $p=0.055$, $\eta_p^2=0.057$.

Pelvis Mediolateral Tilt at Turn: For pelvis mediolateral tilt at turn, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, $F(1.793,98.637)=14.429$, $p=0.000$, $\eta_p^2=0.208$ (Figure 59). Pairwise comparisons revealed that pelvis mediolateral tilt at turn was not different between Conditions I and II ($p=0.163$). However, pelvis mediolateral tilt at turn was 3.48° greater for Condition I than III ($p<0.000$) and 2.10° greater for Condition II than III ($p=0.001$).

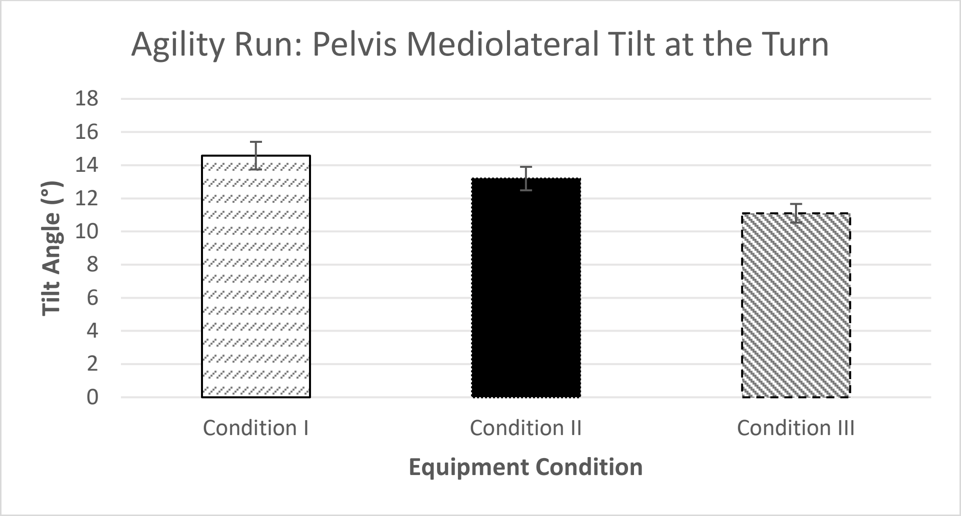


Figure 59. Cell means of pelvis mediolateral tilt at turn during the agility run obstacle for each equipment condition. Standard Error is displayed by the error bars.

Pelvis Anteroposterior Tilt at Turn: For pelvis anteroposterior tilt at turn, the repeated measures one-way ANOVA did not reveal a significant main effect for equipment condition, F(1.769,97.309)=2.443, p=0.099, η_p^2=0.043.

Pelvis Angular Velocity about a Vertical Axis at Turn: For pelvis angular velocity about a vertical axis at turn, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(1.701,93.555)=30.189, p=0.000, η_p^2=0.354. Pairwise comparisons revealed that pelvis angular velocity about a vertical axis at turn was 0.141°/s greater for Condition I than II (p<0.000) and 0.184°/s greater for Condition I than III (p=0.001). However, pelvis angular velocity about a vertical axis at turn was not different between Conditions II and III (p=0.084).

3.3.2.3. High Window

The kinematics of 54 participants performing the high window section of the LEAP obstacle course were analyzed with IMUs mounted on the sternum and sacrum. The 10 derived kinematic metrics included: Time,II) Peak Vertical Velocity, Horizontal Mount Velocity, Horizontal Dismount Velocity, Torso Heading ROM, Pelvis Heading ROM, Torso AP ROM, Pelvis AP ROM, Torso ML ROM, and Pelvis ML ROM. Only the main effect of equipment condition was examined for each metric.

Time: For time, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(1.540,81.632)=59.940, p=0.000, η_p^2=0.531. Pairwise comparisons revealed that time was 2.18 s less for Condition I than II (p<0.000), 3.30 s less for Condition I than III (p<0.000), and 1.127 s less for Condition II than III (p<0.000).

Peak Vertical Velocity: For peak vertical velocity, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(2,106)=10.774, p=0.000, η_p^2=0.169 (Figure 60). Pairwise comparisons revealed that peak vertical velocity was 0.163 m/s greater for Condition I than II (p=0.001) and 0.206 m/s greater for Condition I than III (p=0.001). However, peak vertical velocity was not different between Conditions II and III (p=0.979).

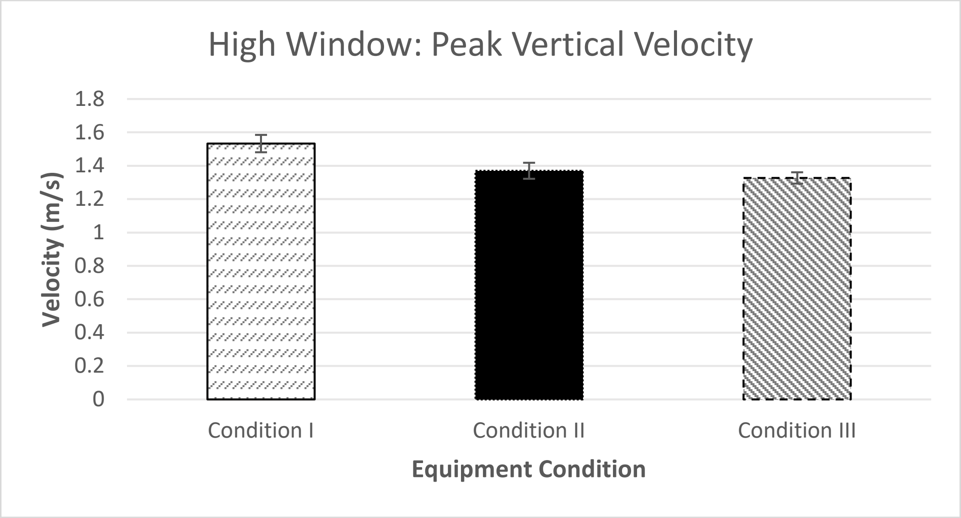


Figure 60. Cell means of peak vertical velocity during the high window obstacle for each equipment condition. Standard Error is displayed by the error bars.

Horizontal Mount Velocity: For horizontal mount velocity, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(2,106)=7.393, p=0.001, η_p^2=0.122. Pairwise comparisons revealed that horizontal mount velocity was 0.536 m/s greater for Condition I than II (p=0.006) and 0.653 m/s greater for Condition I than III (p=0.001). However, horizontal mount velocity was not different between Conditions II and III (p=1.000).

Horizontal Dismount Velocity: For horizontal dismount velocity, the repeated measures one-way ANOVA did not reveal a significant main effect for equipment condition, F(2,106)=1.006, p=0.363, η_p^2=0.019.

Torso Heading ROM: For torso heading ROM, the repeated measures one-way ANOVA did not reveal a significant main effect for equipment condition, F(2,106)=0.669, p=0.514, η_p^2=0.012.

Pelvis Heading ROM: For pelvis heading ROM, the repeated measures one-way ANOVA did not reveal a significant main effect for equipment condition, F(1.760,93.285)=0.256, p=0.775, η_p^2=0.005.

Torso AP ROM: For torso AP ROM, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(2,106)=3.271, p=0.042, η_p^2=0.058 (Figure 61). Pairwise comparisons revealed that torso AP ROM was not different between Conditions I and II (p=0.192) or II and III (p=1.000). However, torso AP ROM was 15.61° less for Condition I than III (p=0.048).

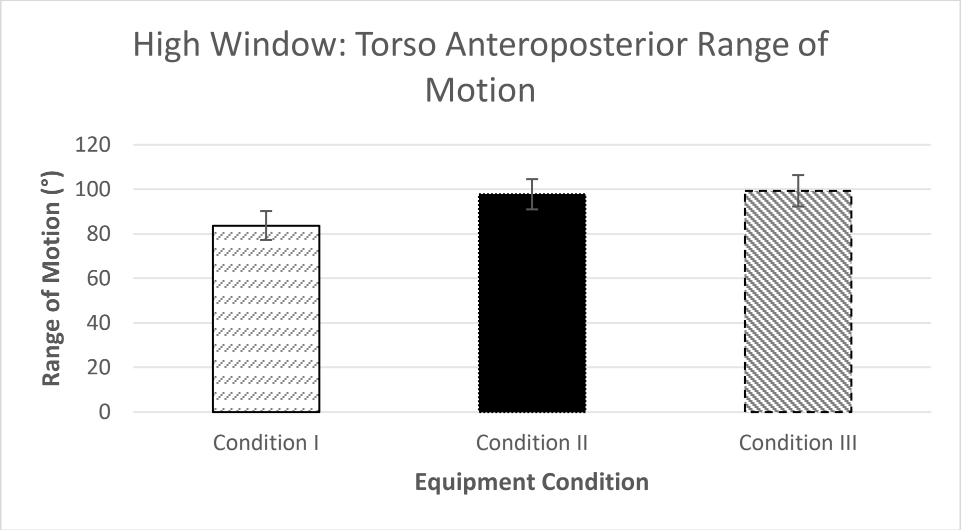


Figure 61. Cell means of torso anteroposterior range of motion during the high window obstacle for each equipment condition. Standard Error is displayed by the error bars.

Pelvis AP ROM: For pelvis AP ROM, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(2,106)=11.293, p=0.000, η_p^2=0.176 (Figure 62). Pairwise comparisons revealed that pelvis AP ROM was 9.12° less for Condition I than II (p=0.008) and 13.27° less for Condition I than III (p<0.000). However, pelvis AP ROM was not different between Conditions II and III (p=0.335).

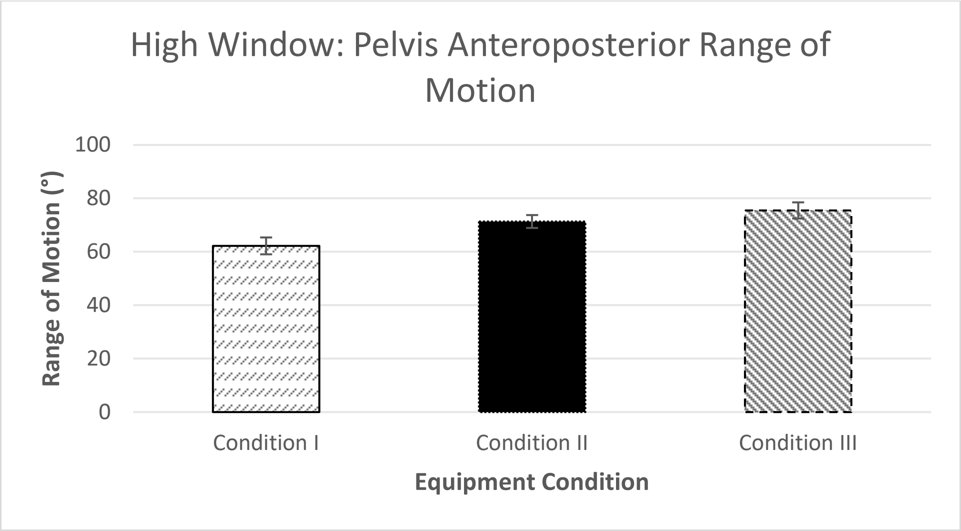


Figure 62. Cell means of pelvis anteroposterior range of motion during the high window obstacle for each equipment condition. Standard Error is displayed by the error bars.

Torso ML ROM: For torso ML ROM, the repeated measures one-way ANOVA did not reveal a significant main effect for equipment condition, F(2,106)=1.495, p=0.229, η_p^2=0.027.

Pelvis ML ROM: For pelvis ML ROM, the repeated measures one-way ANOVA did not reveal a significant main effect for equipment condition, F(1.592,84.379)=0.719, p=0.460, η_p^2=0.013.

3.3.2.4. Low Window

The kinematics of 55 participants performing the low window section of the LEAP obstacle course were analyzed with IMUs mounted on the sternum and sacrum. The 10 derived kinematic metrics includedTime, Peak Vertical Velocity, Horizontal Mount Velocity, Horizontal Dismount Velocity, Torso Heading ROM, Pelvis Heading ROM, Torso AP ROM, Pelvis AP ROM, Torso ML ROM, and Pelvis ML ROM. Only the main effect of equipment condition was examined for each metric.

Time: For time, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(1.236,66.740)=25.574, p=0.000, η_p^2=0.321. Pairwise comparisons revealed that time was 1.585 s less for Condition I than II (p<0.000), 2.98 s less for Condition I than III (p<0.000), and 1.395 s less for Condition II than III (p=0.017).

Peak Vertical Velocity: For peak vertical velocity, the repeated measures one-way ANOVA did not reveal a significant main effect for equipment condition, F(2,108)=2.359, p=0.099, η_p^2=0.042 (Figure 63).

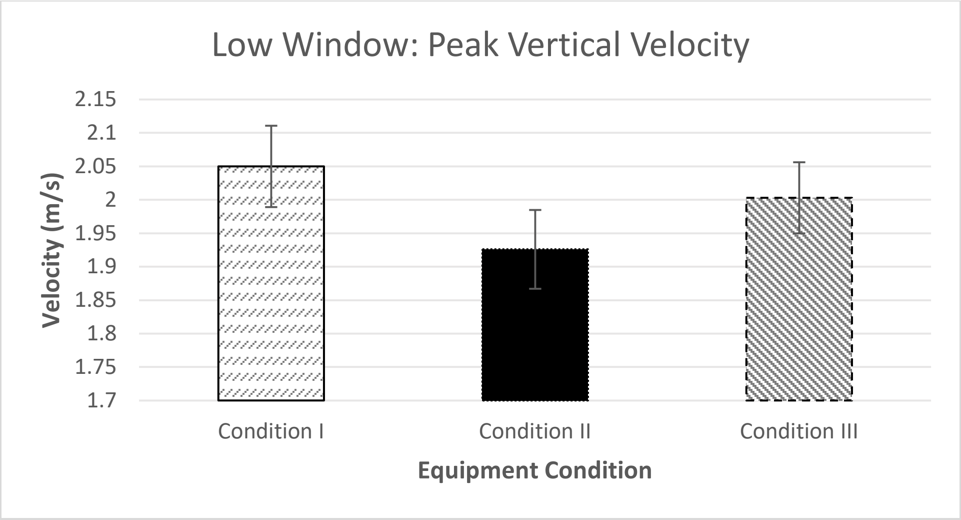


Figure 63. Cell means of peak vertical velocity during the low window obstacle for each equipment condition. Standard Error is displayed by the error bars.

Horizontal Mount Velocity: For horizontal mount velocity, the repeated measures one-way ANOVA did not reveal a significant main effect for equipment condition, F(2,108)=0.010, p=0.990, η_p^2=0.000.

Horizontal Dismount Velocity: For horizontal dismount velocity, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(2,108)=9.372, p=0.000, η_p^2=0.148. Pairwise comparisons revealed that horizontal dismount velocity was 0.416 m/s greater for Condition I than II (p=0.013) and 0.550 m/s greater for Condition I than III (p<0.000). However, horizontal dismount velocity was not different between Conditions II and III (p=0.823).

Torso Heading ROM: For torso heading ROM, the repeated measures one-way ANOVA did not reveal a significant main effect for equipment condition, F(2,108)=2.134, p=0.123, η_p^2=0.038.

Pelvis Heading ROM: For pelvis heading ROM, the repeated measures one-way ANOVA did not reveal a significant main effect for equipment condition, F(1.762,95.145)=0.358, p=0.673, η_p^2=0.007.

Torso AP ROM: For torso AP ROM, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(2,108)=9.482, p=0.000, η_p^2=0.149 (Figure 64). Pairwise comparisons revealed that torso AP ROM was 29.4° less for Condition I than II (p=0.001) and 27.4° less for Condition I than III (p=0.002). However, torso AP ROM was not different between Conditions II and III (p=1.000).

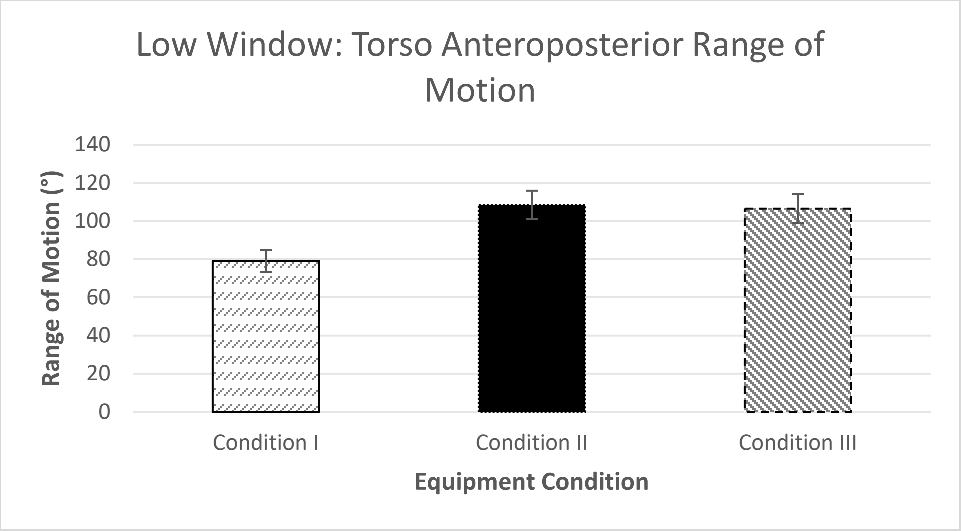


Figure 64. Cell means of torso anteroposterior range of motion during the low window obstacle for each equipment condition. Standard Error is displayed by the error bars.

Pelvis AP ROM: For pelvis AP ROM, the repeated measures one-way ANOVA did not reveal a significant main effect for equipment condition, F(1.738,93.827)=1.978, p=0.143, η_p^2=0.035.

Torso ML ROM: For torso ML ROM, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(2,108)=11.823, p=0.000, η_p^2=0.180 (Figure 65). Pairwise comparisons revealed that torso ML ROM was 36.5° less for Condition I than II (p<0.000) and 30.8° less for Condition I than III (p=0.001). However, torso ML ROM was not different between Conditions II and III (p=1.000).

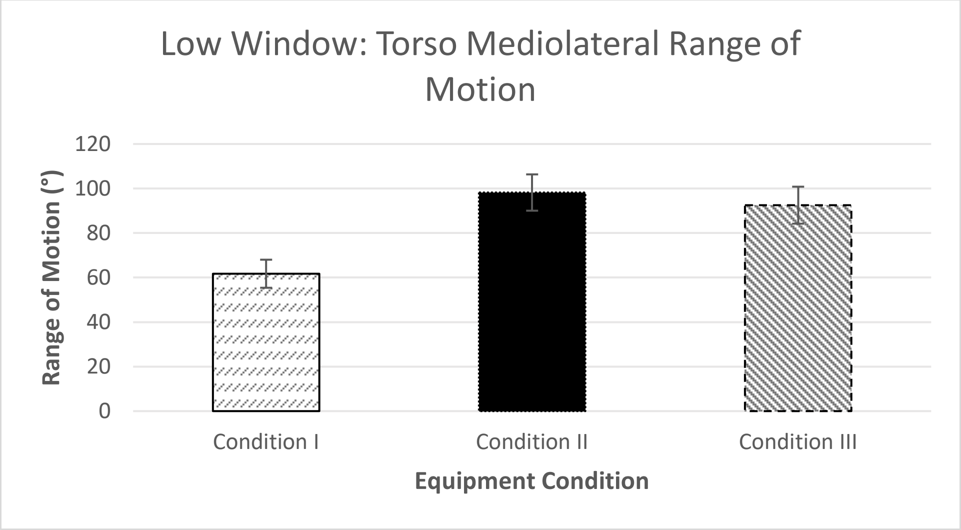


Figure 65. Cell means of torso mediolateral range of motion during the low window obstacle for each equipment condition. Standard Error is displayed by the error bars.

Pelvis ML ROM: For pelvis ML ROM, the repeated measures one-way ANOVA did not reveal a significant main effect for equipment condition, F(1.637,88.392)=0.695, p=0.474, η_p^2=0.013.

3.3.2.5. Bounding Rush

The kinematics of 51 participants performing the bounding rush section of the LEAP obstacle course were analyzed with the IMU mounted on the sacrum. The eight derived kinematic metrics included: Time to complete each bounding rush, Standard deviation of time to complete each bounding rush, Time to stand from prone, Standard deviation of time to stand from prone, Sprinting velocity, Standard deviation of sprinting velocity, Vertical standing velocity, and Standard deviation of vertical standing velocity.

Time to Complete Each Bounding Rush: For time (time to complete each bounding rush), the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(2,100)=187.593, p=0.000, η_p^2=0.790 (Figure 66). Pairwise comparisons revealed that time was 2.07 s less for Condition I than II (p<0.000), 2.97 s less for Condition I than III (p<0.000), and 0.901 s less for Condition II than III (p<0.000).

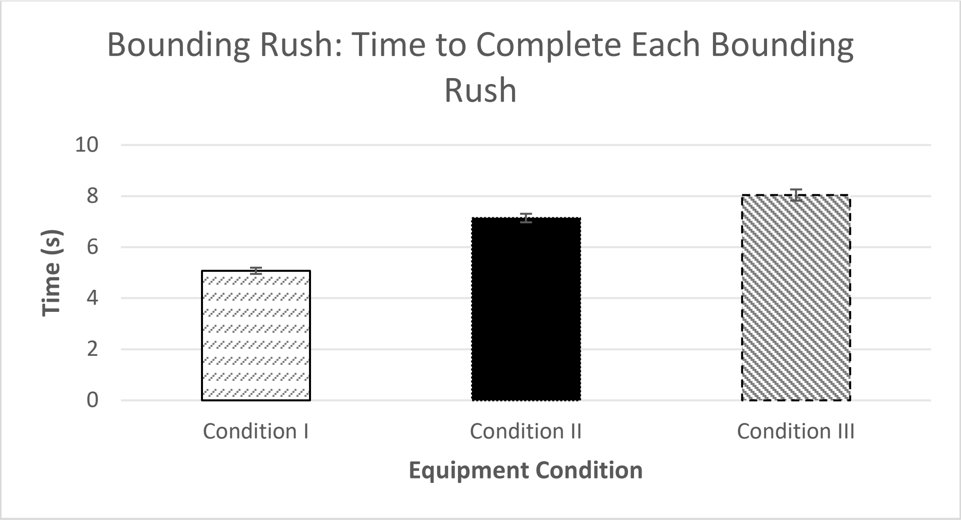


Figure 66. Cell means of time to complete each bounding rush during the bounding rush obstacle for each equipment condition. Standard Error is displayed by the error bars.

Standard Deviation of Time to Complete each Bounding Rush: For standard deviation of time (standard deviation of time to complete each bounding rush), the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(1.775,88.762)=16.662, p=0.000, η_p^2=0.250 (Figure 67). Pairwise comparisons revealed that standard deviation of time was 0.198 s less for Condition I than II (p<0.000) and 0.333 s less for Condition I than III (p<0.000). However, standard deviation of time was not different between Conditions II and III (p=0.072).

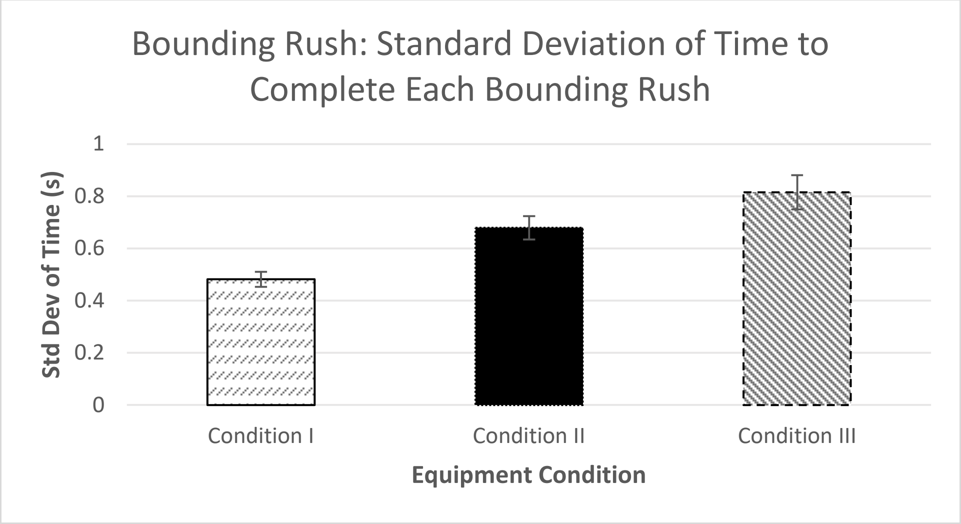


Figure 67. Cell means of the standard deviation of time to complete each bounding rush during the bounding rush obstacle for each equipment condition. Standard Error is displayed by the error bars.

Time to Stand from Prone: For time to stand from prone, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(1.749, 87.446)=37.551, p=0.000, η_p^2=0.429 (Figure 68). Pairwise comparisons revealed that time to stand from prone was 0.971 s less for Condition I than II (p<0.000) and 1.350 s less for Condition I than III (p<0.000). However, time to stand from prone was not different between Conditions II and III (p=0.130).

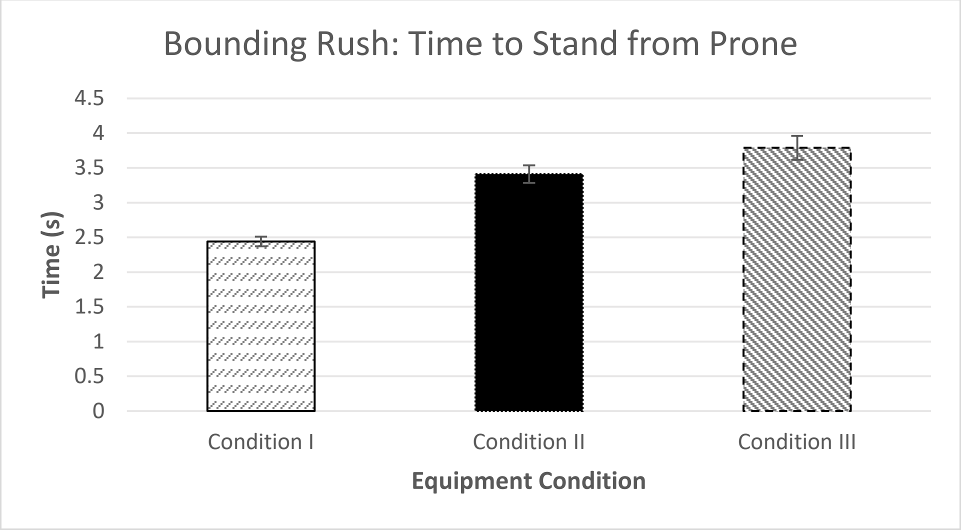


Figure 68. Cell means of time to stand from prone during the bounding rush obstacle for each equipment condition. Standard Error is displayed by the error bars.

Standard Deviation of Time to Stand from Prone: For standard deviation of time to stand from prone, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(2, 100)=7.336, p=0.001, η_p^2=0.128. Pairwise comparisons revealed that standard deviation of time to stand from prone was not different between Conditions I and II (p=0.884). However, standard deviation of time to stand from prone was 0.324 s less for Condition I than III (p=0.005) and 0.246 s less for Condition II than III (p=0.032).

Sprinting Velocity: For sprinting velocity, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(2,100)=58.099, p=0.000, η_p^2=0.537 (Figure 69). Pairwise comparisons revealed that sprinting velocity was 0.493 m/s greater for Condition I than II (p<0.000) and 0.589 m/s greater for Condition I than III (p<0.000). However, sprinting velocity was not different between Conditions II and III (p=0.156).

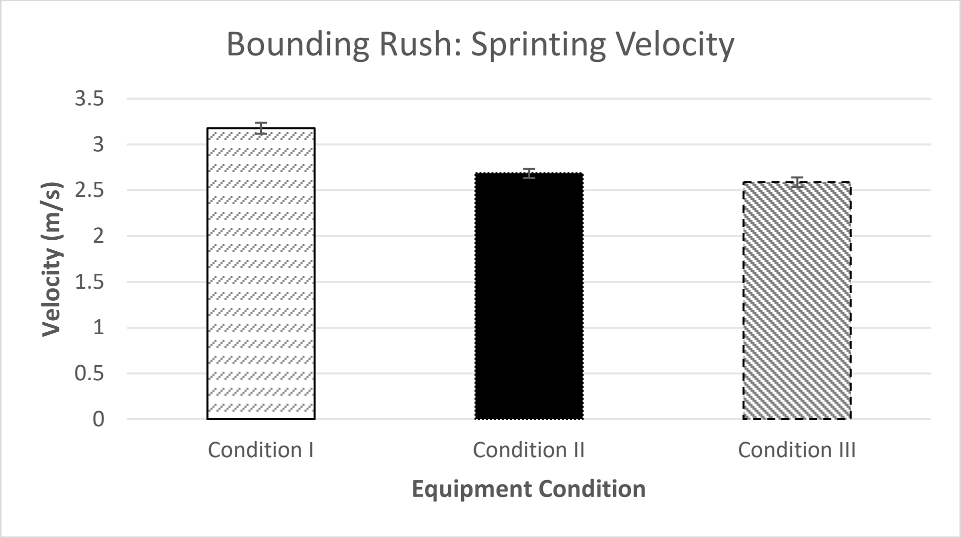


Figure 69. Cell means of sprinting velocity during the bounding rush obstacle for each equipment condition. Standard Error is displayed by the error bars.

Standard Deviation of Sprinting Velocity: For standard deviation of sprinting velocity, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(2,100)=25.989, p=0.000, η_p^2=0.342. Pairwise comparisons revealed that standard deviation of sprinting velocity was 0.181 m/s greater for Condition I than II (p<0.000) and 0.217 m/s greater for Condition I than III (p<0.000). However, standard deviation of sprinting velocity was not different between Conditions II and III (p=0.699).

Vertical Standing Velocity: For vertical standing velocity, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(1.438,71.905)=24.290, p=0.000, η_p^2=0.327 (Figure 70). Pairwise comparisons revealed that vertical standing velocity was 0.136 m/s greater for Condition I than II (p<0.000), 0.195 m/s greater for Condition I than III (p<0.000), and 0.058 m/s greater for Condition II than III (p=0.007).

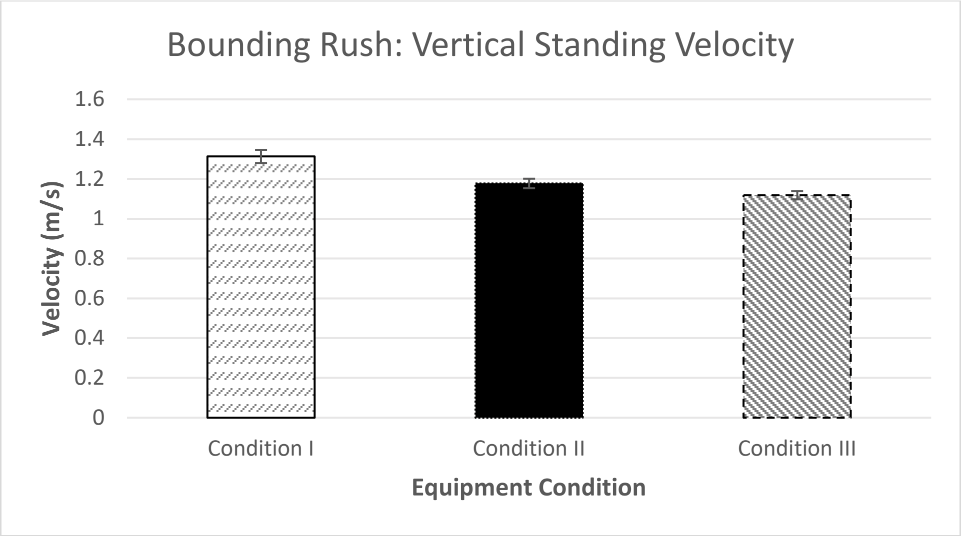


Figure 70. Cell means of vertical standing velocity during the bounding rush obstacle for each equipment condition. Standard Error is displayed by the error bars.

Standard Deviation of Vertical Standing Velocity: For standard deviation of vertical standing velocity, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(2,100)=6.250, p=0.003, η_p^2=0.111. Pairwise comparisons revealed that standard deviation of vertical standing velocity was not different between Conditions I and II (p=0.095) or II and III (p=0.891). However, standard deviation of vertical standing velocity was 0.047 m/s greater for Condition I than III (p=0.002).

3.3.2.6. Balance Beam

The kinematics of 53 participants performing the balance beam section of the LEAP obstacle course were analyzed with the IMU mounted on the sternum, sacrum, and both feet. The 15 derived kinematic metrics included: Time, Step count, Percent time double support, Step frequency, Stride duration, Standard deviation of stride duration, Standard deviation of foot yaw, Sacrum ML acceleration RMS, Sacrum AP acceleration RMS, Sacrum acceleration RMS Ratio, Torso ML angular velocity RMS, Torso AP angular velocity RMS, Torso angular velocity RMS ratio, Torso angular velocity RMS magnitude, and Torso ML ROM.

Time: For time, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(2,104)=89.531, p=0.000, η_p^2=0.633. Pairwise comparisons revealed that time was 3.97 s less for Condition I than II (p<0.000), 5.13 s less for Condition I than III (p<0.000), and 1.151 s less for Condition II than III (p=0.015).

Step Count: For step count, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(2,104)=42.375, p=0.000, η_p^2=0.449 (Figure 71). Pairwise comparisons revealed that step count was 3.36 steps less for Condition I than II (p<0.000) and 3.87 steps less for Condition I than III (p<0.000). However, step count was not different between Conditions II and III (p=0.834).

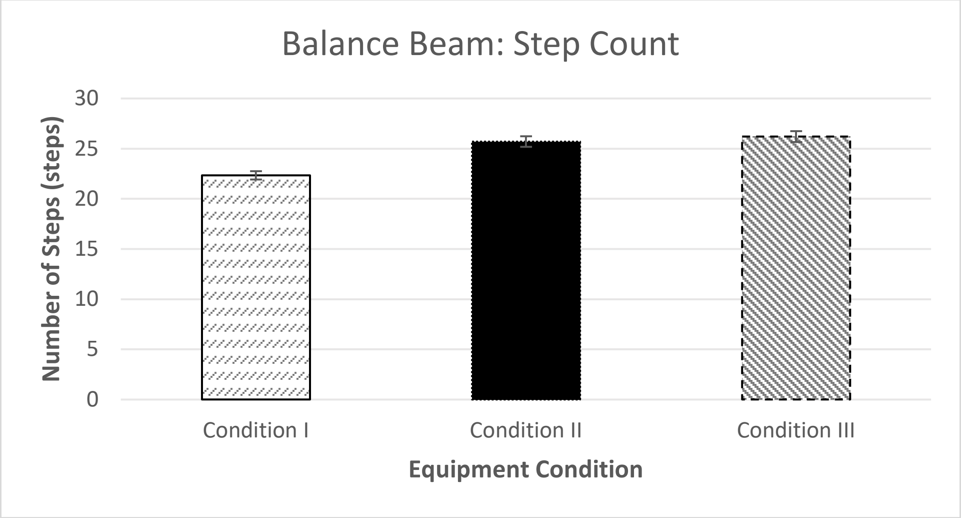


Figure 71. Cell means of step count during the balance beam obstacle for each equipment condition. Standard Error is displayed by the error bars.

Percent Time Double Support: For percent time double support, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(2,104)=32.437, p=0.000, η_p^2=0.384 (Figure 72). Pairwise comparisons revealed that percent time double support was 5.05% less for Condition I than II (p<0.000) and 7.09% less for Condition I than III (p<0.000). However, percent time double support was not different between Conditions II and III (p=0.170).

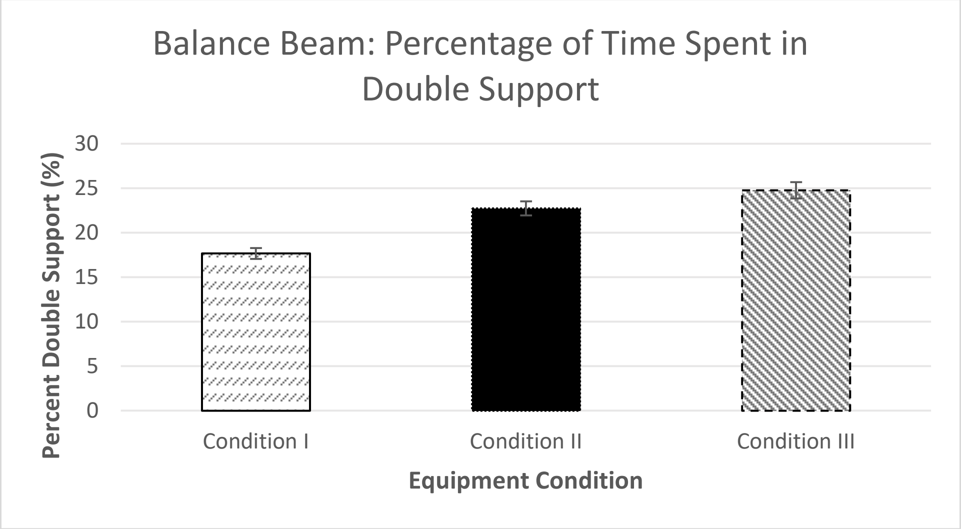


Figure 72. Cell means of percentage of time spent in double support during the balance beam obstacle for each equipment condition. Standard Error is displayed by the error bars.

Step Frequency: For step frequency, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(1.794,93.274)=92.978, p=0.000, η_p^2=0.641 (Figure 73). Pairwise comparisons revealed that step frequency was 0.320 steps/s greater for

Condition I than II (p<0.000), 0.411 steps/s greater for Condition I than III (p<0.000), and 0.092 steps/s greater for Condition II than III (p=0.003).

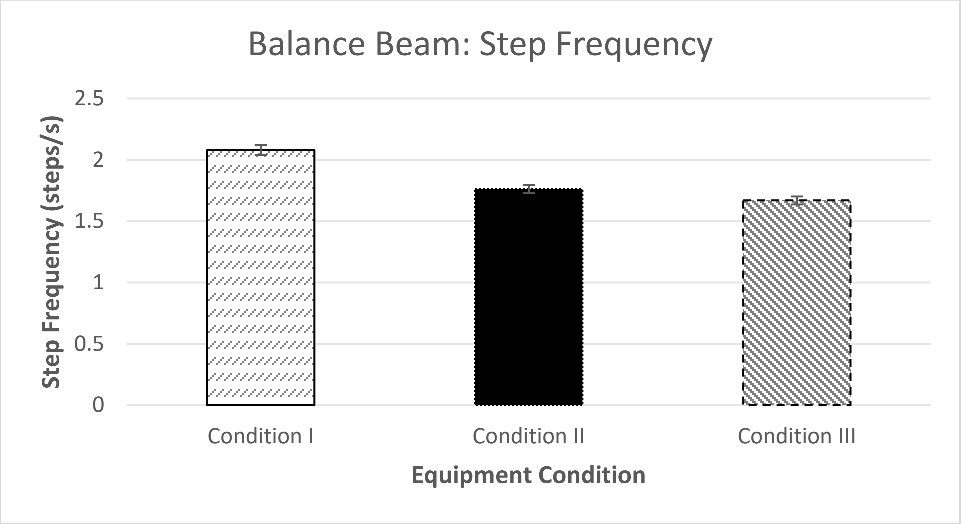


Figure 73. Cell means of step frequency during the balance beam obstacle for each equipment condition. Standard Error is displayed by the error bars.

Stride Duration: For stride duration, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(2,104)=79.525, p=0.000, η_p^2=0.605 (Figure 74). Pairwise comparisons revealed that stride duration was 0.180 s less for Condition I than II (p<0.000), 0.252 s less for Condition I than III (p<0.000), and 0.072 s for Condition II than III (p=0.003).

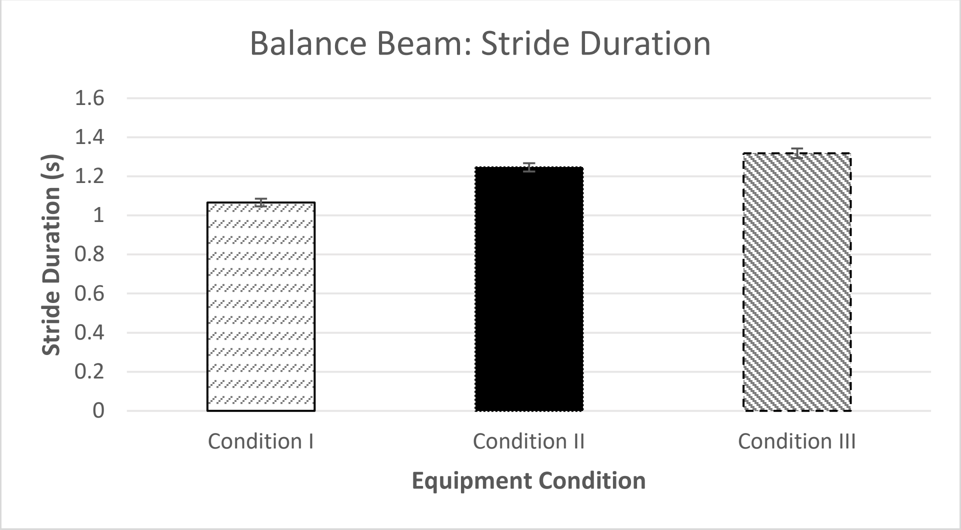


Figure 74. Cell means of stride duration during the balance beam obstacle for each equipment condition. Standard Error is displayed by the error bars.

Standard Deviation Stride Duration: For standard deviation stride duration, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition,

$F(2,104)=45.975$, $p=0.000$, $\eta_p^2=0.469$. Pairwise comparisons revealed that standard deviation stride duration was 0.114 s less for Condition I than II ($p<0.000$) and 0.153 s less for Condition I than III ($p<0.000$). However, standard deviation stride duration was not different between Conditions II and III ($p=0.099$).

Standard Deviation of Foot Yaw: For standard deviation of foot yaw, the repeated measures one-way ANOVA did not reveal a significant main effect for equipment condition, $F(2,104)=3.003$, $p=0.054$, $\eta_p^2=0.055$.

Sacrum ML Acceleration RMS: For sacrum ML acceleration RMS, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, $F(1.412,73.419)=141.687$, $p=0.000$, $\eta_p^2=0.732$ (Figure 75). Pairwise comparisons revealed that sacrum ML acceleration RMS was 0.911 m/s^2 greater for Condition I than II ($p<0.000$), 1.134 m/s^2 greater for Condition I than III ($p<0.000$), and 0.223 m/s^2 greater for Condition II than III ($p<0.000$).

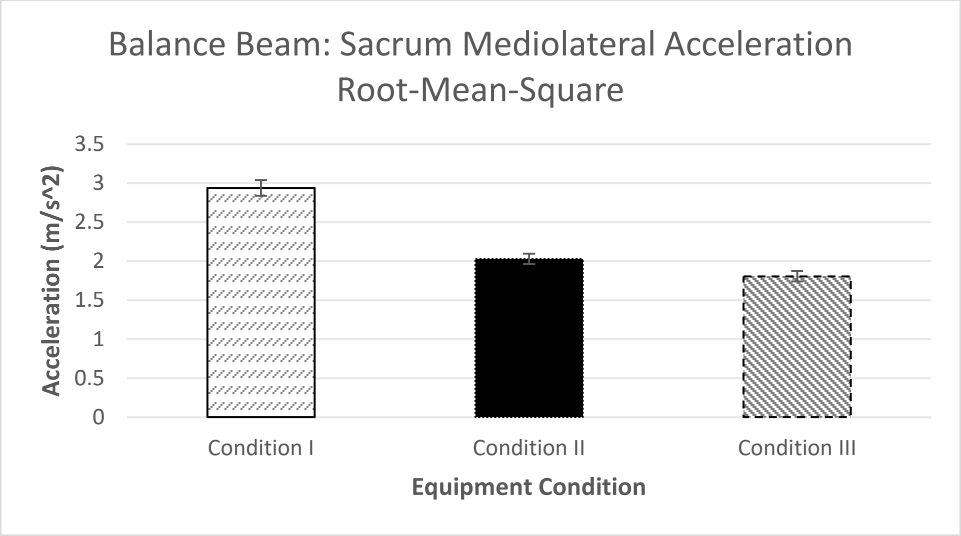


Figure 75. Cell means of sacrum mediolateral acceleration RMS during the balance beam obstacle for each equipment condition. Standard Error is displayed by the error bars.

Sacrum AP Acceleration RMS: For sacrum AP acceleration RMS, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, $F(1.245,64.725)=109.245$, $p=0.000$, $\eta_p^2=0.678$ (Figure 76). Pairwise comparisons revealed that sacrum AP acceleration RMS was 0.863 m/s^2 greater for Condition I than II ($p<0.000$), 0.997 m/s^2 greater for Condition I than III ($p<0.000$), and 0.135 m/s^2 greater for Condition II than III ($p=0.001$).

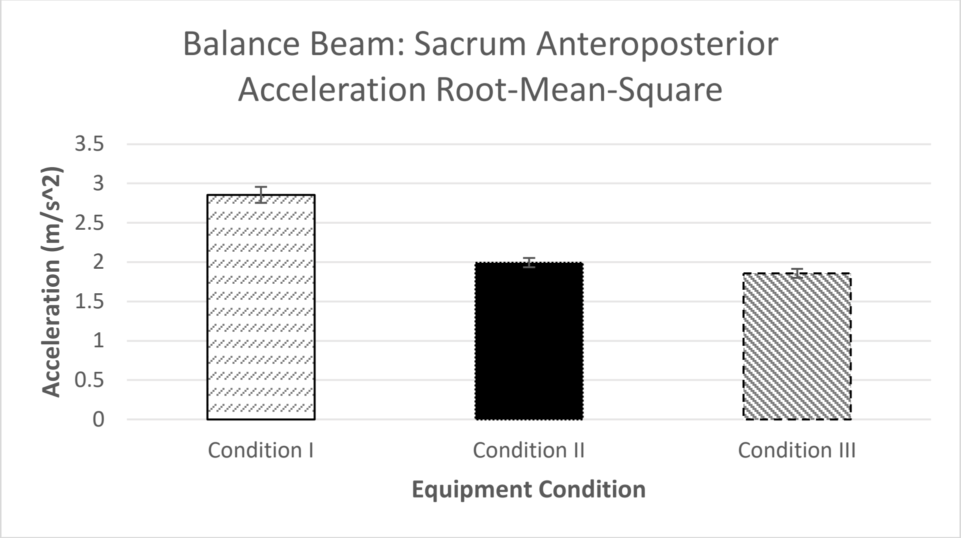


Figure 76. Cell means of sacrum anteroposterior acceleration RMS during the balance beam obstacle for each equipment condition. Standard Error is displayed by the error bars.

Sacrum Acceleration RMS Ratio: For sacrum acceleration RMS ratio, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(1.703,88.565)=6.575, p=0.004, η_p^2=0.112 (Figure 77). Pairwise comparisons revealed that sacrum acceleration RMS ratio was not significantly different between Conditions I and II (p=1.000). However, sacrum acceleration RMS ratio was 0.063 less for Condition I than III (p=0.008) and 0.049 less for Condition II than III (p=0.003).

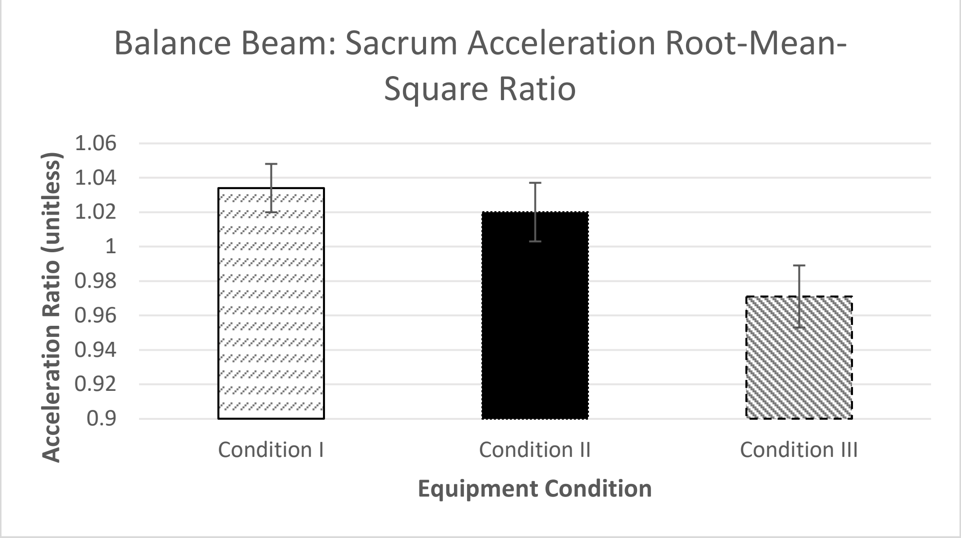


Figure 77. Cell means of sacrum acceleration RMS ratio during the balance beam obstacle for each equipment condition. Standard Error is displayed by the error bars.

Torso ML Angular Velocity RMS: For torso ML angular velocity RMS, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(1.526,79.360)=18.586, p=0.000, η_p^2=0.263 (Figure 78). Pairwise comparisons revealed that torso ML angular velocity RMS was 5.60°/s greater for Condition I than II (p=0.001) and 6.60°/s greater for Condition I than III (p<0.000). However, torso ML angular velocity RMS was not different between Conditions II and III (p=0.714).

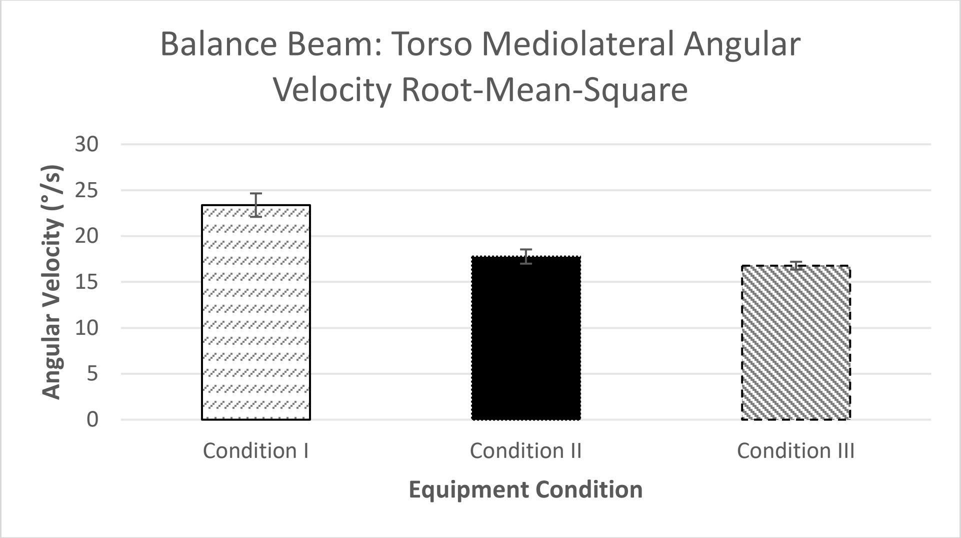


Figure 78. Cell means of torso mediolateral angular velocity RMS during the balance beam obstacle for each equipment condition. Standard Error is displayed by the error bars.

Torso AP Angular Velocity RMS: For torso AP angular velocity RMS, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(1.397,72.645)=27.585, p=0.000, η_p^2=0.347 (Figure 79). Pairwise comparisons revealed that torso AP angular velocity RMS was 7.86°/s greater for Condition I than II (p<0.000), 10.48°/s greater for Condition I than III (p<0.000), and 2.63°/s greater for Condition II than III (p=0.014).

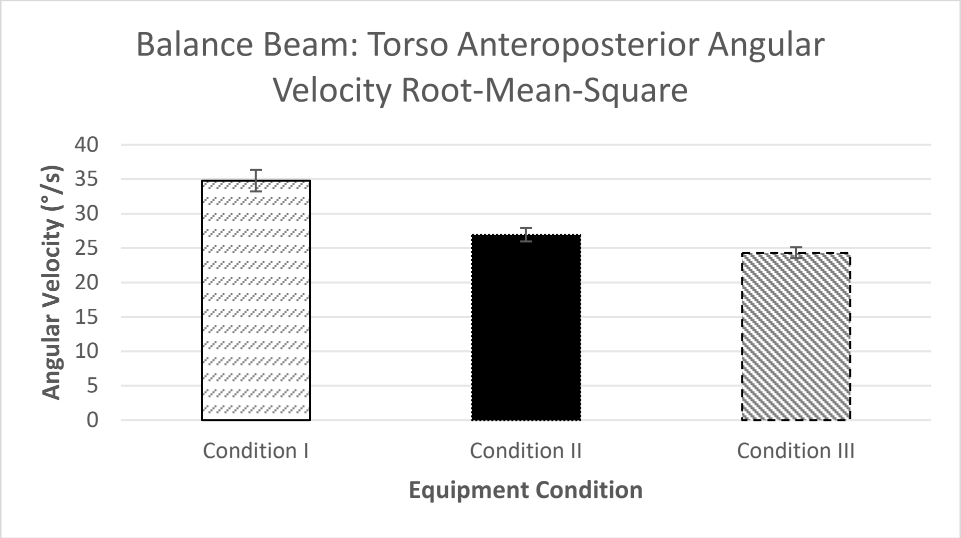


Figure 79. Cell means of torso anteroposterior angular velocity RMS during the balance beam obstacle for each equipment condition. Standard Error is displayed by the error bars.

Torso Angular Velocity RMS Ratio: For torso angular velocity RMS ratio, the repeated measures one-way ANOVA did not reveal a significant main effect for equipment condition, F(2,104)=2.428, p=0.093, η_p^2=0.045.

Torso ML ROM: For torso ML ROM, the repeated measures one-way ANOVA did not reveal a significant main effect for equipment condition, F(2,104)=0.098, p=0.907, η_p^2=0.002.

Torso Angular Velocity RMS Magnitude: For torso angular velocity RMS magnitude, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(1.319,68.572)=78.787, p=0.000, η_p^2=602. Pairwise comparisons revealed that torso angular velocity RMS magnitude was 20.3°/s greater for Condition I than II (p<0.000) and 23.0°/s greater for Condition I than III (p<0.000). However, torso angular velocity RMS magnitude was not different between Conditions II and III (p=0.055).

3.3.2.7. High Wall

The kinematics of 52 participants performing the high wall section of the LEAP obstacle course were analyzed with IMUs mounted on the sternum and sacrum. The 13 derived kinematic metrics included: Time, Peak Vertical Velocity, Horizontal Mount Velocity, Horizontal Dismount Velocity V) Mean Horizontal Velocity Over Wall, Minimum Horizontal Velocity Over Wall, Maximum Horizontal Velocity Over Wall, Torso Heading ROM, Pelvis Heading ROM, Torso AP ROM, Pelvis AP ROM, Torso ML ROM, and Pelvis ML ROM. Only the main effect of equipment condition was examined for each metric.

Time: For time, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(2,102)=41.410, p=0.000, η_p^2=0.448. Pairwise comparisons revealed that time was 1.910 s less for Condition I than II (p<0.000), 2.93 s less for Condition I than III (p<0.000), and 1.022 s less for Condition II than III (p=0.012).

Peak Vertical Velocity: For peak vertical velocity, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(2,102)=4.516, p=0.013, η_p^2=0.081 (Figure 80). Pairwise comparisons revealed that peak vertical velocity was 0.168 m/s greater for Condition I than II (p=0.026) and 0.170 m/s greater for Condition I than III (p=0.041). However, peak vertical velocity was not different between Conditions II and III (p=1.000).

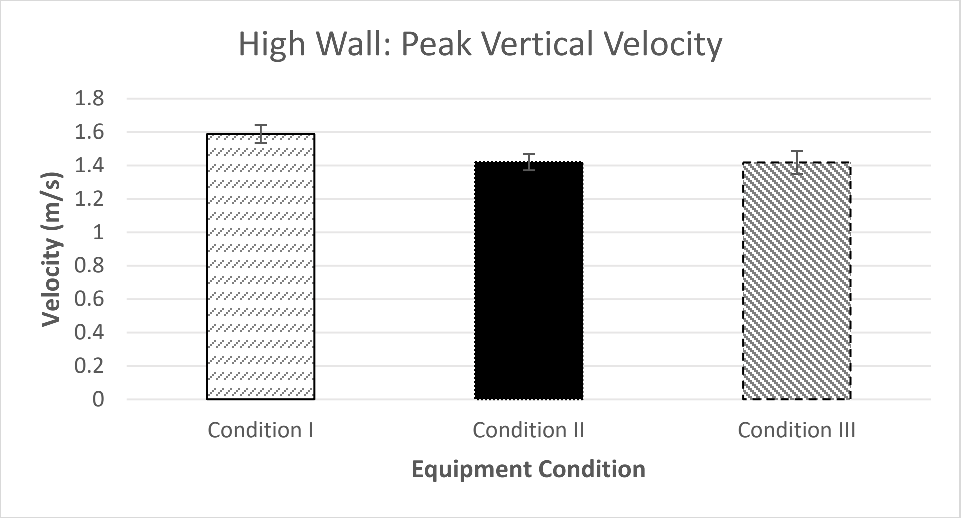


Figure 80. Cell means of peak vertical velocity during the high wall obstacle for each equipment condition. Standard Error is displayed by the error bars.

Horizontal Mount Velocity: For horizontal mount velocity, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(2,102)=9.643, p=0.000, η_p^2=0.159. Pairwise comparisons revealed that horizontal mount velocity was 0.616 m/s greater for Condition I than II (p=0.008) and 0.850 m/s greater for Condition I than III (p=0.001). However, horizontal mount velocity was not different between Conditions II and III (p=0.621).

Horizontal Dismount Velocity: For horizontal dismount velocity, the repeated measures one-way ANOVA did not reveal a significant main effect for equipment condition, F(2,102)=0.454, p=0.636, η_p^2=0.009.

Mean Horizontal Velocity Over Wall: For mean horizontal velocity over wall, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(2,102)=12.134, p=0.000, η_p^2=0.192. Pairwise comparisons revealed that mean horizontal velocity over wall was 0.729 m/s greater for Condition I than II (p=0.001) and 0.934 m/s greater for Condition I than III (p<0.000). However, horizontal mount velocity was not different between Conditions II and III (p=0.908).

Minimum Horizontal Velocity Over Wall: For minimum horizontal velocity over wall, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(2,102)=9.561, p=0.000, η_p^2=0.158. Pairwise comparisons revealed that minimum horizontal velocity over wall was 0.539 m/s greater for Condition I than II (p=0.013) and 0.768 m/s greater for Condition I than III (p<0.000). However, horizontal mount velocity was not different between Conditions II and III (p=0.683).

Maximum Horizontal Velocity Over Wall: For maximum horizontal velocity over wall, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(2,102)=3.283, p=0.042, η_p^2=0.060. However, pairwise comparisons did not reveal any significant differences across any equipment conditions (p≥0.05).

Torso Heading ROM: For torso heading ROM, the repeated measures one-way ANOVA did not reveal a significant main effect for equipment condition, F(2,102)=1.071, p=0.346, η_p^2=0.021.

Pelvis Heading ROM: For pelvis heading ROM, the repeated measures one-way ANOVA did not reveal a significant main effect for equipment condition, F(2,102)=0.948, p=0.391, η_p^2=0.018.

Torso AP ROM: For torso AP ROM, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(2,102)=4.795, p=0.011, η_p^2=0.086 (Figure 81). Pairwise comparisons revealed that torso AP ROM was not different between Conditions I and II (p=0.559) or II and III (p=0.229). However, torso AP ROM was 25.8° less for Condition I than III (p=0.015).

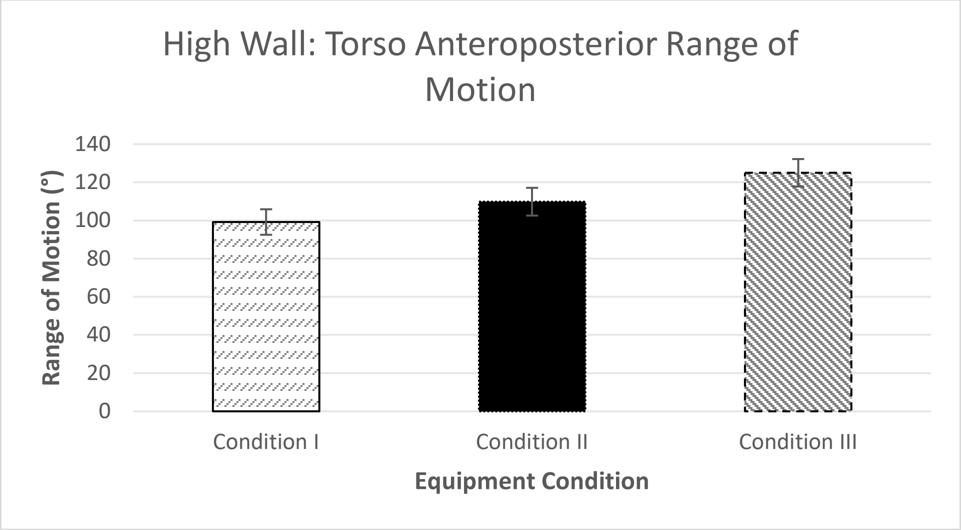


Figure 81. Cell means of torso anteroposterior ROM during the high wall obstacle for each equipment condition. Standard Error is displayed by the error bars.

Pelvis AP ROM: For pelvis AP ROM, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(2,102)=4.190, p=0.019, η_p^2=0.076. Pairwise comparisons revealed that pelvis AP ROM was 19.94° less for Condition I than II (p=0.014). However, pelvis AP ROM was not different between Conditions I and III (p=1.000) or II and III (p=0.177).

Torso ML ROM: For torso ML ROM, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(2,102)=5.527, p=0.006, η_p^2=0.098 (Figure 82). Pairwise comparisons revealed that torso ML ROM was not different between Conditions I and II (p=0.754) or II and III (p=0.089). However, torso ML ROM was 28.9° less for Condition I than III (p=0.013).

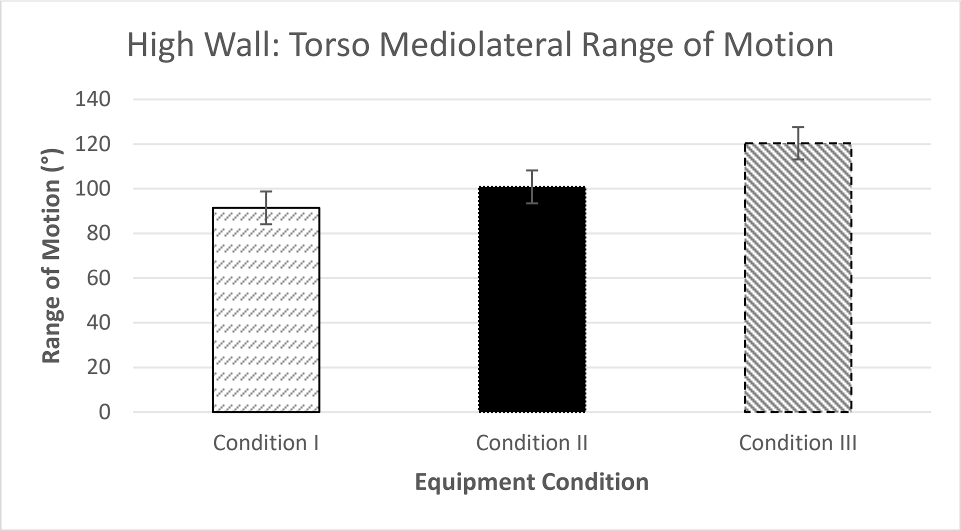


Figure 82. Cell means of torso mediolateral ROM during the high wall obstacle for each equipment condition. Standard Error is displayed by the error bars.

Pelvis ML ROM: For pelvis ML ROM, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(2,102)=4.933, p=0.009, η_p^2=0.088. Pairwise comparisons revealed that pelvis ML ROM was 26.0° less for Condition I than II (p=0.007). However, pelvis ML ROM was not different between Conditions I and III (p=0.451) or II and III (p=0.302).

3.3.2.8. Low Wall

The kinematics of 55 participants performing the low wall section of the LEAP obstacle course were analyzed with IMUs mounted on the sternum and sacrum. The 13 derived kinematic metrics included: Time, Peak Vertical Velocity, Horizontal Mount Velocity, Horizontal Dismount Velocity, Mean Horizontal Velocity Over Wall, Minimum Horizontal Velocity Over Wall, Maximum Horizontal Velocity Over Wall, Torso Heading ROM, Pelvis Heading ROM, Torso AP ROM, Pelvis AP ROM, Torso ML ROM, and Pelvis ML ROM. Only the main effect of equipment condition was examined for each metric.

Time: For time, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(2,108)=51.706, p=0.000, η_p^2=0.489. Pairwise comparisons revealed that time was 1.042 s less for Condition I than II (p<0.000) and 1.217 s less for Condition I than III (p<0.000). However, time was not different between Conditions II and III (p=0.419).

Peak Vertical Velocity: For peak vertical velocity, the repeated measures one-way ANOVA did not reveal a significant main effect for equipment condition, F(1.523,82.226)=1.255, p=0.283, η_p^2=0.023 (Figure 83).

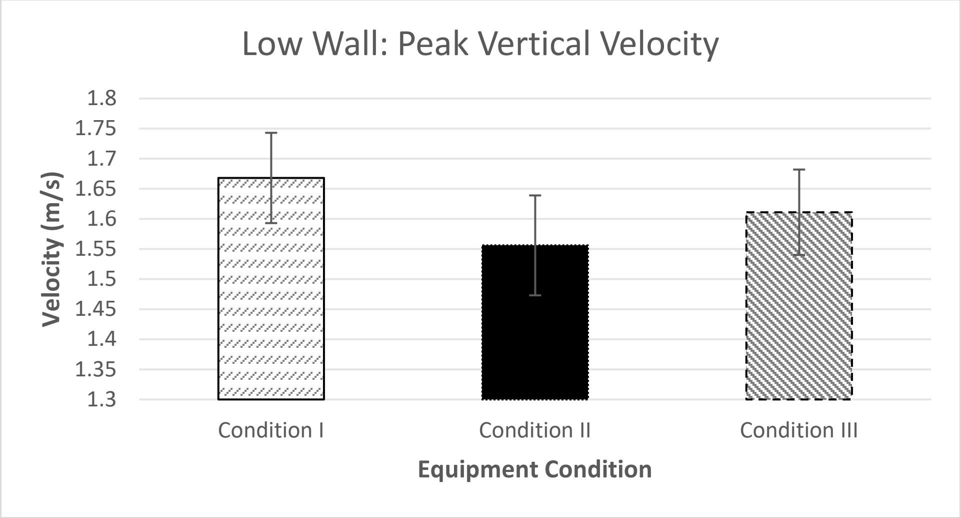


Figure 83. Cell means of peak vertical velocity during the low wall obstacle for each equipment condition. Standard Error is displayed by the error bars.

Horizontal Mount Velocity: For horizontal mount velocity, the repeated measures one-way ANOVA did not reveal a significant main effect for equipment condition, F(2,108)=3.075, p=0.050, η_p^2=0.054.

Horizontal Dismount Velocity: For horizontal dismount velocity, the repeated measures one-way ANOVA did not reveal a significant main effect for equipment condition, F(2,108)=0.972, p=0.382, η_p^2=0.018.

Mean Horizontal Velocity Over Wall: For mean horizontal velocity over wall, the repeated measures one-way ANOVA did not reveal a significant main effect for equipment condition, F(2,108)=0.117, p=0.890, η_p^2=0.002.

Minimum Horizontal Velocity Over Wall: For minimum horizontal velocity over wall, the repeated measures one-way ANOVA did not reveal a significant main effect for equipment condition, F(2,108)=0.330, p=0.720, η_p^2=0.006.

Maximum Horizontal Velocity Over Wall: For maximum horizontal velocity over wall, the repeated measures one-way ANOVA did not reveal a significant main effect for equipment condition, F(2,108)=0.228, p=0.797, η_p^2=0.004.

Torso Heading ROM: For torso heading ROM, the repeated measures one-way ANOVA did not reveal a significant main effect for equipment condition, F(1.324,71.508)=3.210, p=0.066, η_p^2=0.056.

Pelvis Heading ROM: For pelvis heading ROM, the repeated measures one-way ANOVA did not reveal a significant main effect for equipment condition, F(1.573,84.93)=5.151, p=0.013, η_p^2=0.087 (Figure 84). Pairwise comparisons revealed that pelvis heading ROM was not different between Conditions I and II (p=0.347) or II and III (p=0.129). However, pelvis heading ROM was 27.4° less for Condition I than III (p=0.020).

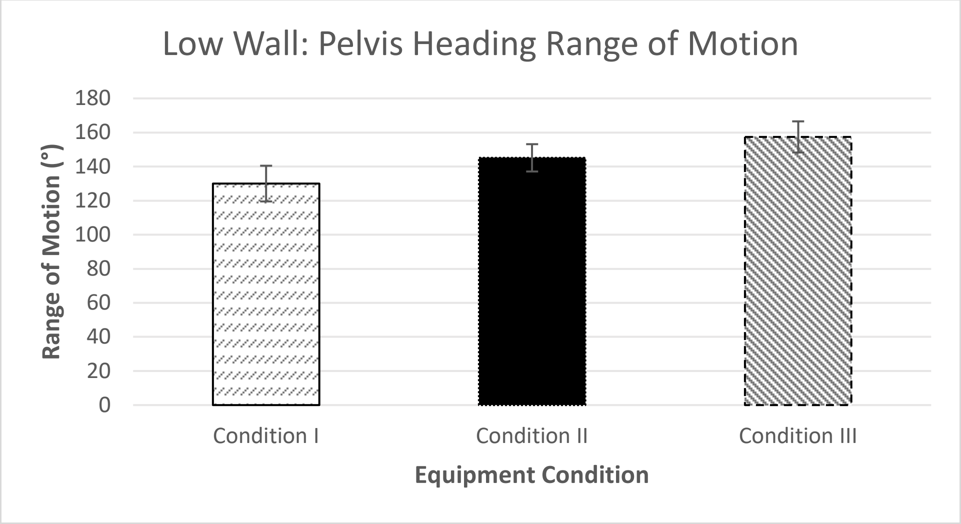


Figure 84. Cell means of pelvis heading ROM during the low wall obstacle for each equipment condition. Standard Error is displayed by the error bars.

Torso AP ROM: For torso AP ROM, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(2,108)=6.944, p=0.001, η_p^2=0.114 (Figure 85). Pairwise comparisons revealed that torso AP ROM was not different between Conditions I and II (p=0.107) or II and III (p=0.332). However, torso AP ROM was 27.4° less for Condition I than III (p=0.020).

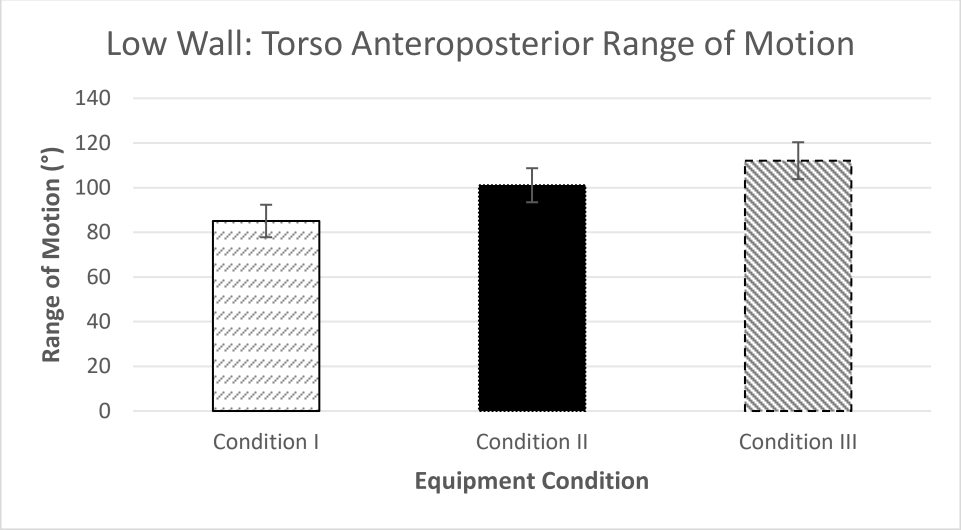


Figure 85. Cell means of torso anteroposterior ROM during the low wall obstacle for each equipment condition. Standard Error is displayed by the error bars.

Pelvis AP ROM: For pelvis AP ROM, the repeated measures one-way ANOVA did not reveal a significant main effect for equipment condition, F(1.750,94.508)=0.464, p=0.605, η_p^2=0.009.

Torso ML ROM: For torso ML ROM, the repeated measures one-way ANOVA revealed a significant main effect for equipment condition, F(2,108)=9.536, p=0.000, η_p^2=0.150 (Figure

86). Pairwise comparisons revealed that torso ML ROM was 22.0° less for Conditions I than II (p=0.018) and 31.7° less for Conditions I than III (p<0.000). However, torso ML ROM was not different between Conditions II and III (p=0.535).

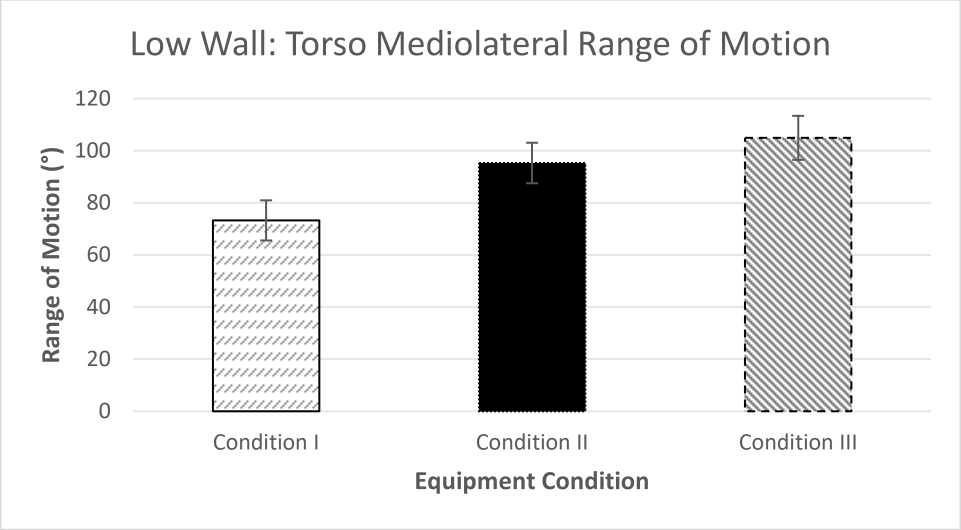


Figure 86. Cell means of torso mediolateral ROM during the low wall obstacle for each equipment condition. Standard Error is displayed by the error bars.

Pelvis ML ROM: For pelvis ML ROM, the repeated measures one-way ANOVA did not reveal a significant main effect for equipment condition, F(1.764,95.276)=0.171, p=0.816, η_p^2=0.003.

3.3.3. Physiological Performance

The physiologic measures of 44 participants performing the LEAP_A obstacle course portion of the scenario were analyzed with the wrist worn Forerunner 220 heart rate monitor. The derived physiologic metrics included: maximum attained heart rate (MaxHR), mean heart rate (MeanHR), maximum percent of heart rate reserve (%MaxHRR), mean percent heart rate reserve (%MeanHRR).

LEAP-A Obstacles Main Effects: For MaxHR, %MaxHRR, MeanHR and %MeanHRR the repeated measures two-way ANOVA did not reveal any significant main effects of CIE conditions (p≥0.05). MeanHR – $F(2,86)=2.13$, p =.125, ηp^2.047, , MaxHR - $F(2,86)=.15$, p =.861, ηp^2.003, , %MaxHRR - $F(2,86)=.12$, p =.884, ηp^2.003, % Mean HRR - $F(2,86)=2.06$, p =.133, ηp^2.046.

3.3.4. Subjective Opinions

Mean RPE (pre- and post-execution of the LEAP course) and mission performance ratings degraded with each consecutive condition (Table 40). A series of Friedman tests revealed that the rating differences between the conditions were significant for the RPE-pre ratings, $\chi^2(2) = 94.18$, $p < 0.001$, RPE-post ratings, $\chi^2(2) = 91.84$, $p < 0.001$, and mission performance ratings, $\chi^2(2) = 98.87$, $p < 0.001$.

Table 40. *Mean RPE and MP Ratings for LEAP Mission Runs (n=62)*

		Condition I		Condition II		Condition III	
RPE	Pre	7.3	± 1.19	11.3	± 2.49	12.7	± 2.94
	Post	13.8	± 2.43	16.8	± 1.98	17.9	± 2.05
Mission Performance		6.3	± 0.88	4.0	± 1.41	2.9	± 1.44

RPE Scale: No Exertion at all (6), Extremely Light (7), (8), Very Light (9), (10), Light (11), (12), Somewhat Hard (13), (14), Hard (Heavy) (15), (16), Very Hard (17), (18), Extremely Hard (19), Maximal Effort (20)
Mission Performance Scale: Very Poor (1), Moderately Poor (2), Slightly Poor (3), Neither Poor nor Good (4), Slightly Good (5), Moderately Good (6), Very Good (7)

Post-hoc analysis using paired Wilcoxon Signed-Ranks tests indicated that the most encumbered condition, Condition III, resulted in degraded perceived exertion and mission performance ratings compared to the less encumbered conditions. RPE-pre ratings were lower in Condition I (Median=7) than in Conditions II (Median=11), $Z = -6.78$, $p < 0.001$, $r = .86$, and III (Median=12), $Z = -6.76$, $p < 0.001$, $r = .86$. RPE-post ratings were also lower in Condition I (Median=13) than in Conditions II (Median=17), $Z = -6.42$, $p < 0.001$, $r = .82$, and III (Median=18), $Z = -6.53$, $p < 0.001$, $r = .83$. Between the loaded conditions, ratings were lower in Condition II than in Condition III for both RPE-pre, $Z = -3.45$, $p < 0.01$, $r = .44$, and RPE-post ratings, $Z = -4.79$, $p < 0.001$, $r = .61$. The participants' perceived mission performance rating was lower in Condition III (Median=3) than in Conditions I (Median=6.5, $Z = -6.82$, $p < 0.001$, $r = .87$, and II (Median=4), $Z = -4.81$, $p < 0.001$, $r = .61$. The perceived performance rating was higher in Condition I than in Condition II, $Z = -6.44$, $p < 0.001$, $r = .82$.

Like in the Marksmanship task, these results indicate the participants felt more exertion after completing the LEAP course and their experienced exertion was higher with each consecutive condition. Additionally, after completing the LEAP, the participants perceived their performance to deteriorate with each consecutive condition. Indeed, mission performance mean ratings moved from positive (in Condition I), to neutral (in Condition II), to negative (in Condition III).

When in Condition I, the majority of the participants did not report any problems while completing the LEAP course. The exception was interference from the weapon's sling, which participants noted got caught in the stairs and ladders. One participant added that while the weapon was shouldered, the sling slipped down his body and it almost tripped him during the casualty drag section. He noted this issue not just in Condition I, but also in Conditions II and III.

The participants reported several other equipment-related issues for both of the loaded conditions. The majority of the comments focused on the interference and restriction caused by the mass and bulk from the combination of the armor and the TAP. The participants reported that the TAP (and radio) easily got caught in the tunnel (particularly the narrow section), ladders, windows, and walls. Furthermore, the added bulk restricted the participants' ability to position themselves and maneuver over the windows and walls, which led to multiple failed attempts before successfully clearing the obstacles. The participants noted that the TAP was cumbersome, as it hung low, bumped their legs, dragged on the ground while crawling, and was difficult to adjust and keep adjusted.

The participants added that their performance was further hindered by the loaded conditions' combined mass (armor plates, TAP) and front-heavy setup. They reported feeling more fatigued because of the mass, adding that they had a difficult time building momentum (particularly during the casualty drag), maneuvering obstacles (i.e., ladder, walls, windows), keeping balance, and going prone and getting up during the bounding rushes. The participants also reported that prior exertion from the ruck march affected their performance. Several participants noted that their shoulders, arms, and hands were still in pain/numb from the pressure caused by the rucksack shoulder straps. This discomfort was aggravated by the DAPS in Condition III, in which two participants specifically noted this pain/numbness affected their ability to grab the ladders.

Participant comments specific to Condition II pointed to discomfort caused by the side plates digging into the sides, hips, and ribs. Comments specific to Condition III focused on the restriction caused by the DAPS, which the participants reported hindered their arm and shoulder mobility during all LEAP activities, but particularly when crawling, going through windows, and climbing the ladders. Two participants noted restriction caused by the groin protector. One stated that the groin protector restricted his leg stride and the other noted that it got caught on the ladder rungs.

3.4. MOUT

3.4.1. Marksmanship Performance

The marksmanship performance results from the MOUT scenario are summarized for each dependent variable in Table 41.

Table 41. Means of Marksmanship Performance measures during the MOUT task

	Condition I			Condition II			Condition III		
	Mean		Median	Mean		Median	Mean		Median
Precision	15.30	±11.57	14.19	15.61	±9.54	13.96	16.50	±9.36	14.33
Accuracy	24.12	±9.04	23.48	24.89	±9.18	23.73	26.38	±12.43	27.11
P(Hit)	0.94	±0.12	1.00	0.96	±0.06	1.00	0.95	±0.09	1.00
P(LH)	0.94	±0.12	1.00	0.96	±0.06	1.00	0.95	±0.09	1.00
Aiming Time	0.21	±0.12	0.18	0.20	±0.15	0.18	0.20	±0.13	0.17
TAT	7.55	±1.72	7.59	7.90	±1.90	7.65	8.17	±2.07	8.02
TET	0.52	±0.20	0.48	0.51	±0.23	0.46	0.50	±0.18	0.47
TTT	71.16	±14.74	70.77	75.64	±19.28	73.65	75.90	±18.70	73.95

3.4.1.1. Accuracy

Main effect of Threat Order was found, F(1, 60.55) = 4.54, p=.037. Engagements of threats after non-threats (Go after No-Go: *M* = 24.7, *SD*= 15.3) were more accurate than engagements of sequential threats (Go after Go: *M* = 25.3, *SD*= 11.6). No main effect of condition was found, *p*>.1.

However, a main effect of sequence was also found, *F*(2,115.6) = 5.56, *p*=.0049. Sequence 3 (*M* = 23.25, *SD* = 10.42) was more accurate than Sequence 2 (*M* = 27.01, *SD* = 9.63).

3.4.1.2. Precision

No main effect of condition or threat order was found, $p>.1$.

3.4.1.3. Probability of Hit

Main effect of threat order was found, $Z = 3.34$, $p = .0008$. Engagements of threats after non-threats (Go after No-Go) had greater rate of hit than engagements of sequential threats (Go after Go). No main effect of condition was found, $p>.1$.

However, a main effect of sequence was found, $\chi^2(2) = 49.42$, $p < 0.001$. Post-hoc analysis using paired Wilcoxon Signed-Ranks tests indicated that Sequence 3 had lower rates of hit than Sequence 1 or 2, $p < .0001$.

3.4.1.4. Probability of Lethal Hit

Main effect of threat order was found, $Z = 3.43$, $p = .0006$. Engagements of threats after non-threats (Go after No-Go) had greater rate of lethal hit than engagements of sequential threats (Go after Go). No main effect of condition was found, $p>.1$.

However, a main effect of sequence was found, $\chi^2(2) = 51.8$, $p < 0.001$. Post-hoc analysis using paired Wilcoxon Signed-Ranks tests indicated that Sequence 3 had lower rates of hit in the center of mass than Sequence 1 or 2, $p < .0001$.

3.4.1.5. Aiming Time

A main effect of threat order was found, $F(1,59.93)=53.5$, $p<.0001$. Engagements of threats after non-threats (Go after No-Go: $M = .15$, $SD=.13$) had less aiming time prior to shot than engagements of sequential threats (Go after Go: $M = .20$, $SD=.14$). No main effect of condition was found for mean aiming time, $p>.1$.

However, a main effect of sequence was also found, $F(2,115.4) = 3.21$, $p=.044$. Sequence 2 ($M = .53$, $SD = .2$) had greater aiming times than Sequence 1 ($M = .49$, $SD = .2$).

3.4.1.6. Target Acquisition Time

A main effect of condition was found, $F(2,118) = 3.93$, $p = .022$. The condition with the greatest encumbrance, Condition III ($M = 8.2$, $SD = 2.1$), was significantly slower to acquire the targets than Condition I ($M = 7.6$, $SD = 1.7$), $p = .02$, as seen in Figure 87.

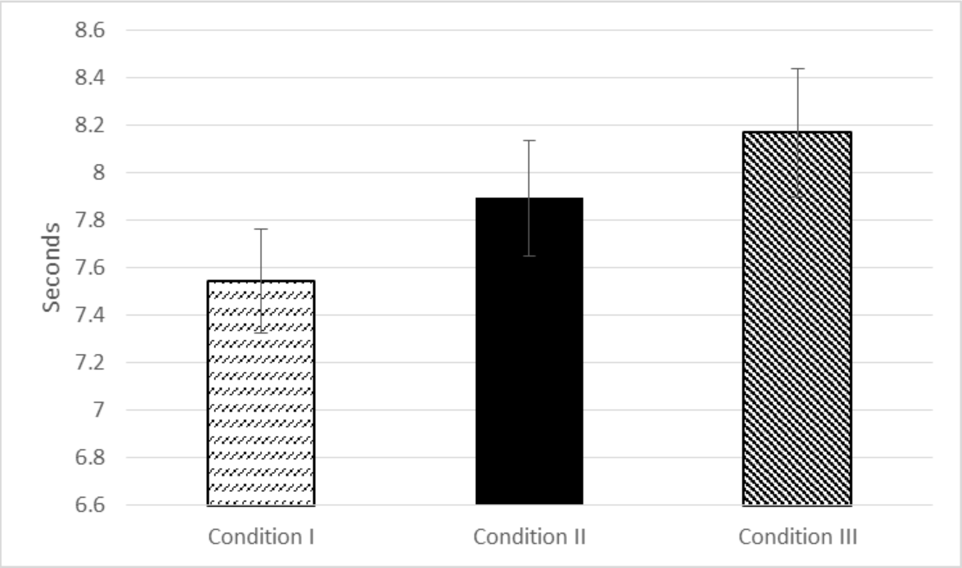


Figure 87. Differences in Target Acquisition Time across CIE condition.

Additionally, a main effect of Iteration was found, *F(*2,118) = 36.04, *p* < .0001. Post hoc comparisons indicated that target acquisition for each iteration was faster than the previous (*p*<.001 all pairs), with Iteration 1 having the slowest acquisition times (*M* =8.6, *SD* = 1.9) and Iteration 3 (*M* =7.3, *SD* = 1.8) being the fastest. This indicates a course learning effect, even though the target positions were slightly different and the threat/non-threat images were changed per exposure.

3.4.1.7. Target Engagement Time

A main effect of threat order was found, *F*(1,63.4) = 91.15, *p*<.0001. Engagements of threatening targets after non-threatening targets (Go after No-Go: *M* = .45, *SD* = .25) took less time than engagements of sequential threatening targets (Go after Go: *M* = .55 , *SD* = .26). No main effect of condition was found, *p*>.1.

3.4.1.8. Total Trial Time

A main effect of condition was found, *F(*2,118.3) = 4.12, *p* = .019. Condition III (*M*=75.9, *SD*=18.7) was slower to clear the facility than Condition I (*M*=71.2, *SD*=14.7), *p*=.028 as seen in Figure 88.

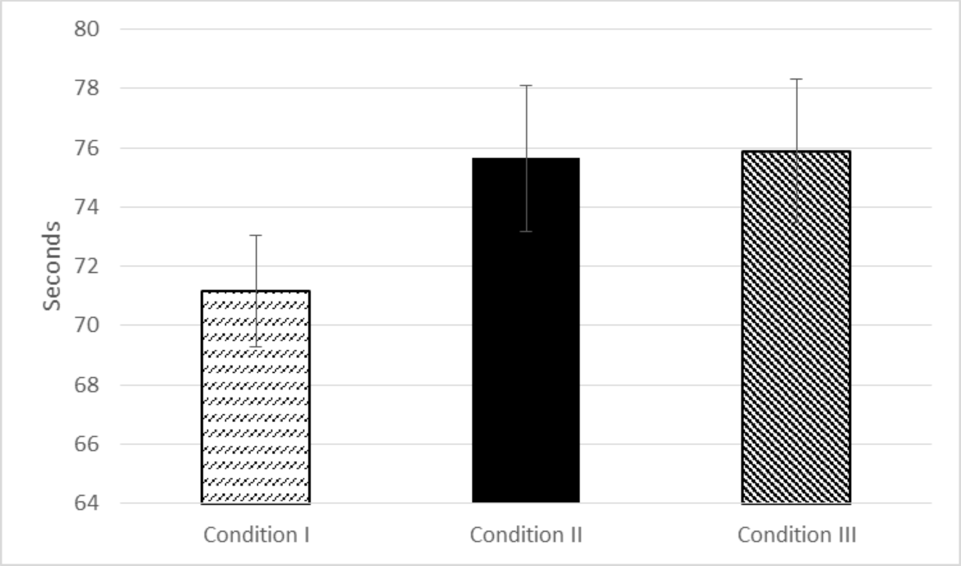


Figure 88. Differences in Total Trial Time across CIE condition.

Additionally, a main effect of sequence, *F(*2,118.1) = 6.08, *p* = .003, and iteration, *F(*2, 118.1) = 20.42, *p*<.0001, were found. Post hoc comparisons indicated that Sequence 3 (*M*=71.6, *SD*=16.9) was faster than Sequence 1(*M*=76.9, *SD*=16.6) or Sequence 2 (*M*=74.0, *SD*=19.4), (*p*<.0001). Additionally, Trial 1 (*M*=79.4, *SD*=18.1) or exposure to the clearing task was slower than Trial 2 (*M*=72.8, *SD*=16.3) or 3 (*M*=70.5, *SD*=17.8), (*p*<.001), indicating that there was a significant learning effect present.

3.4.2. Cognitive Performance- Go/No go task

The cognitive performance results from the MOUT scenario are summarized in Table 42 at the end of this section.

Table 42. Means of cognitive performance measures during the MOUT task

	Condition I		Condition II		Condition III	
	Mean	Median	Mean	Median	Mean	Median
Hit Rate	0.94 ±0.05	0.96	0.94 ±0.04	0.96	0.94 ±0.04	0.96
False Alarm	0.08 ±0.12	0.04	0.08 ±0.11	0.04	0.07 ±0.10	0.04
Sensitivity (d’)	3.19 ±0.63	3.46	3.15 ±0.58	3.46	3.22 ±0.49	3.46
Criterion	0.00 ±0.02	0.00	0.00 ±0.02	0.00	0.00 ±0.02	0.00

3.4.2.1. Hit Rate

No main effect of condition was found, *p*>.1. However, a main effect of sequence was found, *F(*2,116.6)=43.87, *p*<.0001. Post hoc comparisons indicated that Sequence 3 was different than Sequence 1 (*p*<.0001) or Sequence 2 (*p*<.0001).

3.4.2.2. False Alarm Rate

No main effect of condition was found, $p>.1$.

3.4.2.3. Response Sensitivity (d')

No main effect of condition was found, $p>.1$. However, again a main effect of sequence was found, $F(2,116.6)=17.2$, $p<.0001$. Post hoc comparisons indicated that Sequence 3 was different than Sequence 1 ($p<.0001$) or Sequence 2 ($p<.0001$).

3.4.2.4. Criterion (c)

No main effect of condition was found, $p>.1$.

3.4.3. Physiological Performance

The physiologic measures of 46 participants performing the MOUT portion of the scenario were analyzed with the wrist worn Forerunner 220 heart rate monitor. The derived physiologic metrics included: maximum attained heart rate (MaxHR), mean heart rate (MeanHR), maximum percent of heart rate reserve (%MaxHRR), mean percent heart rate reserve (%MeanHRR).

For MaxHR, %MaxHRR, MeanHR and %MeanHRR the repeated measures two-way ANOVA did reveal significant main effects of CIE conditions ($p \geq 0.05$). Mean HR – $F(1.65,74.41)=22.16$, $p<.001$, $\eta p^2 .33$, MaxHR - $F(1.49,67.08)=23.65$, $p<.001$, $\eta p^2 .34$, %MaxHRR - $F(1.52,68.46)=23.27$, $p<.001$, $\eta p^2 .34$, %MeanHRR - $F(1.62,72.87)=22.39$, $p<.001$, $\eta p^2 .33$. CIE Condition I was higher in MeanHR and MaxHR heart rate measures when compared to Conditions II and III. With respect to Condition II as compared to Condition III there were no significant differences. For %MaxHRR and %MeanHRR for Conditions I, II, and III all heart rate measures were different from each other, with Condition III being the highest and Condition I being the lowest. Figure 89 and 90 represent heart rate physiologic data during the MOUT task.

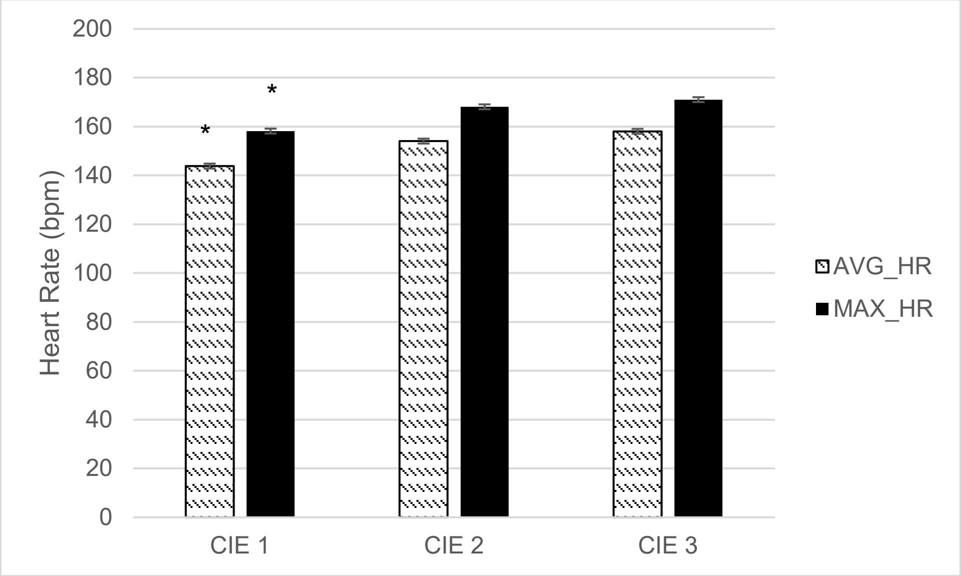


Figure 89. Differences in maximum and mean heart across CIE conditions during the MOUT task (* p<.05)

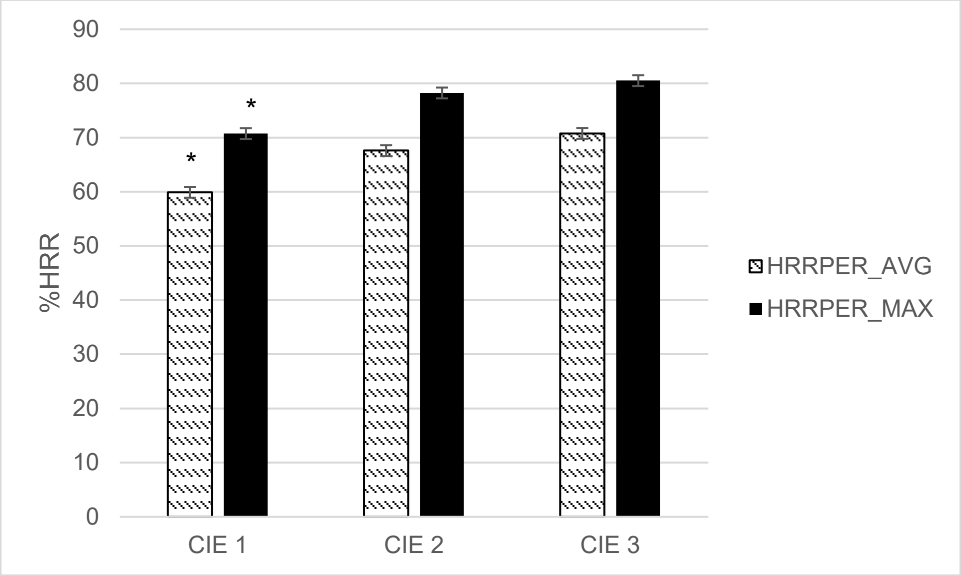


Figure 90. Differences in maximum and mean heart across CIE conditions during the MOUT task.

3.4.4. Subjective Opinions

Mean RPE (pre and post execution) and mission performance ratings degraded with each consecutive condition level for the MOUT task (Table 43). A series of Friedman tests revealed that the rating differences between the conditions were significant for the RPE-pre ratings, $\chi2(2) = 52.76$, $p < 0.001$, RPE-post ratings, $\chi2(2) = 75.76$, $p < 0.001$, and mission performance ratings, $\chi2(2) = 48.27$, $p < 0.001$.

Table 43. Mean RPE and Mission Performance Ratings for MOUT (n=62)

		Condition I	Condition II	Condition III
RPE	Pre	10.9 ± 2.52	13.5 ± 2.63	14.4 ± 2.76
	Post	10.5 ± 2.38	13.2 ± 2.20	14.2 ± 2.70
Mission Performance		6.0 ± 1.11	5.3 ± 1.14	4.6 ± 1.57

RPE Scale: No Exertion at all (6), Extremely Light (7), (8), Very Light (9), (10), Light (11), (12), Somewhat Hard (13), (14), Hard (Heavy) (15), (16), Very Hard (17), (18), Extremely Hard (19), Maximal Effort (20)
Mission Performance Scale: Very Poor (1), Moderately Poor (2), Slightly Poor (3), Neither Poor nor Good (4), Slightly Good (5), Moderately Good (6), Very Good (7)

Post-hoc analysis using paired Wilcoxon Signed-Ranks tests indicated that the most encumbered condition, Condition III, resulted in degraded perceived exertion and mission performance ratings compared to the less encumbered conditions. RPE-pre ratings were lower in Condition I (Median=11) than in Conditions II (Median=13), $Z = -5.76$, $p < 0.001$, $r = .73$, and III (Median=15), $Z = -6.04$, $p < 0.001$, $r = .77$. RPE-post ratings were also lower in Condition I (Median=11) than in Conditions II (Median=13), $Z = -6.01$, $r = .76$, $p < 0.001$, and III (Median=14), $Z = -6.24$, $p < 0.001$, $r = .79$. Between the loaded conditions, ratings were lower in Condition II than in Condition III for both RPE-pre, $Z = -2.49$, $p = 0.01$, $r = .32$, and RPE-post ratings, $Z = -2.91$, $p < 0.01$, $r = .37$. The participants' perceived mission performance rating was lower in Condition III (Median=5) than in Conditions I (Median=6), $Z = -5.54$, $p < 0.001$, $r = .70$, and II (Median=5), $Z = -3.54$, $p < 0.001$, $r = .45$. The perceived performance rating was higher in Condition I than in Condition II, $Z = -4.73$, $p < 0.001$, $r = .60$.

Like in the previous tasks, these results indicate that the participants experienced higher exertion in each consecutive condition. Additionally, after completing the activity, the participants perceived that their performance deteriorated with each consecutive condition. However, unlike the previous tasks, mean RPE-post ratings were lower than mean RPE-pre ratings, indicating that the participants experienced less exertion after than before completing the activity. It is possible that the participants were able to recover from previous fatigue while completing the MOUT task, which focused on accuracy rather than completion speed. Furthermore, the participants were not instructed to go at their fastest pace through the course, and therefore they could take their time, leaving room to initiate recovery.

3.5. Overarching Subjective Opinions

3.5.1. Condition Questionnaire

After completing all of the test activities for each session, the participants answered the *End of Daily Activities Questionnaire*. This questionnaire asked the participants about their experiences with the condition they had worn that day. They rated their experiences using the following scale: (1) Very Poor, (2) Moderately Poor, (3) Slightly Poor, (4) Neither Poor nor Good, (5) Slightly Good, (6) Moderately Good, (7) Very Good, and (X) N/A. If a rating of 4 or lower (at or below neutral) was given, they were asked to provide an explanation. The results of this questionnaire are presented in Table 44. The participant comments explaining neutral or poor ratings are summarized in the subsections below.

Table 44. Mean Experience Ratings for the End of Daily Activities Questionnaire (n=62)

Topic Area	Condition I		Condition II		Condition III	
Ease of Donning						
a. Body Armor Vest	n/a	n/a	5.7	± 1.22	4.1	± 1.81
b. Ancillary Armor	n/a	n/a	5.7	± 1.21	4.3	± 1.56
c. Other Mission Gear	6.9	± 0.32	6.1	± 1.06	5.1	± 1.48
Fit	6.7	± 0.91	4.5	± 1.67	3.3	± 1.94
Physical Comfort	6.6	± 1.28	3.7	± 1.64	2.3	± 1.58
Mission Performance						
a. Overall ability to accomplish Mission Critical tasks and movements effectively	6.9	± 0.42	5.2	± 1.15	3.5	± 1.84
b. Ability to freely move head/neck	6.8	± 0.52	5.5	± 1.22	4.5	± 1.76
c. Ability to freely move arms	6.9	± 0.41	5.5	± 1.30	3.0	± 1.68
d. Ability to freely bend/turn at the waist	6.9	± 0.39	5.4	± 1.22	4.3	± 1.50
e. Ability to freely move legs	6.9	± 0.41	6.0	± 0.98	5.2	± 1.40
f. Ability to aim/sight weapon - Standing Unsupported	6.8	± 0.56	5.4	± 1.35	3.9	± 1.79
g. Ability to aim/sight weapon - Kneeling Unsupported	6.9	± 0.40	5.2	± 1.41	3.8	± 1.81
h. Ability to aim/sight weapon - Prone Unsupported	6.8	± 0.71	4.3	± 1.73	2.9	± 1.77
Compatibility						
a. Body armor and helmet	6.1	± 1.49	5.7	± 0.98	4.8	± 1.75
b. Body armor and load carriage Equipment	n/a	n/a	4.2	± 1.71	3.2	± 1.89
c. Body armor and other Items	6.5	± 1.00	4.3	± 1.76	3.0	± 1.85
Acceptability/Sustainability for Mission Use*						
a. Overall Acceptability of condition for use in a combat environment	5.8	± 2.06	4.6	± 1.72	2.4	± 1.66

Scale: 1=Very Poor, 2=Moderately Poor, 3=Slightly Poor, 4=Neither Poor nor Good, 5=Slightly Good, 6=Moderately Good, 7=Very Good.
*Rating scale used Unacceptable/Acceptable instead of Poor/Good.

3.5.1.1. Donning and Fit

While participants rated donning for Condition I, there were limited items to don, and therefore ratings were very high. In some cases, responses have been greyed out if not applicable even if the participants provided a rating. Regarding the loaded conditions, the participants favored Condition II over III for the tasks of donning the armor vest and ancillary armor. For both of the loaded conditions, they noted the need for assistance donning the armor vests and the TAP, a process which they added required awkward movements (e.g., uncomfortably bending the arms) to attach the buckles. Comments specific to Condition III described the donning process as taking too long. The participants explained that the donning process was hindered by the DAPS, which restricted their range of motion, particularly when donning the rucksack.

The participants preferred the overall fit of Condition I over Condition II, which was preferred over Condition III. When explaining neutral or poor ratings, they noted that the side plates sat low and dug into their sides and hips. Regarding Condition III, the participants noted that they were unable to achieve a proper interface between the IOTV's DAPS and the rucksack. They explained that the improper fit led to pain (see Physical Comfort section below) and poor arm range of motion due to the bulk and the tightness of this gear combination.

3.5.1.2. Physical Comfort

The participants rated their physical comfort (resulting from pressure points, skin irritation, bulkiness, etc.). They favored Condition I over Condition II, followed by Condition III. One participant gave a rating of 1 (Very Poor) when wearing Condition I, explaining that the ACH trapped heat and reduced his audio situational awareness.

Regarding Condition II, the participants noted shoulders and back pain (pressure, pinching, numbness) caused by the combination of the SPCS and the rucksack. Additionally, the participants reported that the side plates were difficult to adjust and that they hit, chafed, dug into, and pinched their hips and sides. For Condition III, the participants offered similar, but more fervent reasons for the discomfort they experienced. They stated they were unable to adjust the IOTV to improve their comfort. Additionally, they noted back pain from the rucksack-IOTV combination. The participants also reported problems breathing and chafing on their collar bones and upper chest area, emphasizing pressure and pinching around their necks.

It should be noted that when major discomfort was brought to the attention of the test team, the participants were assessed by the on-site medic before being allowed to continue. In all cases, once the packs and armor were removed, the discomfort reported was alleviated.

3.5.1.3. Mission Performance and Mobility

The participants preferred Condition I over Condition II, followed by Condition III. All of the participants rated their ability to accomplish their mission positively (5, 6 or 7) when in Condition I. However, ratings were not as positive when in Conditions II and III. Those who rated Condition II neutral or poor explained that the SPCS slowed them down due to its overall bulk and heavy mass. One participant experienced discomfort from hand numbness during the foot march that continued on to the marksmanship task. This participant added that the pain was distracting and negatively affected his ability to shoot. Regarding Condition III, those who gave neutral or poor ratings reported that their mission performance was negatively affected by the IOTV's heavy mass, bulkiness, and poor mobility, all of which led them to feel fatigued and unfocused.

Regarding their mobility, the participants were asked to rate their ability to freely move their head/neck, arms, waist, and legs. All of the participants rated head, arm, torso, and leg mobility positively (5, 6 or 7) when in Condition I. Mean ratings indicated worse mobility for Condition III than Condition II in all areas of the body. In Condition II, the participants noted restriction in head movement due to the interface of the SPCS and ACH, discomfort in the arms/shoulders from the rucksack straps, and encumbrance at the hips/waist from the SPCS' overall bulk and mass of the condition. For Condition III, the participants noted the IOTV's yoke/collar and the interface between the IOTV and ACH (especially in the prone) hindered their ability to turn their heads and affected their vision. Additionally, the participants noted that the DAPS caused extensive restriction of the shoulders and the groin protector restricted their leg mobility (reducing the length of their stride). Finally, they described the overall set up of the condition as bulky, heavy, and restrictive.

3.5.1.4. Marksmanship Ability

Regarding their mission performance, the participants were asked to rate their ability to aim/sight their weapon in three firing positions (standing unsupported, kneeling unsupported, and prone unsupported). For all three firing positions, the participants favored Condition I over Condition II, followed by Condition III. When explaining neutral or poor ratings, one participant commented that the ACH partially obstructed his view in Condition I. Regarding the loaded conditions, the participants noted that the armor vests' shoulder straps and overall bulk kept them from being able to properly shoulder the weapon's buttstock. When kneeling, the participants explained that the TAP negatively affected stability and positioning ability. When lying prone, they noted problems with attaining and maintaining a low, tight, and stable profile on the ground because of the overall bulkiness of the conditions, the TAP raising their bodies off the ground, and the ACH obstructing their view.

Comments specific to Condition III noted that the DAPS in combination with the yoke/collar assembly kept them from properly placing their weapon in the shoulder pocket for stability. Several participants stated that their weapon slipped off their shoulder, which kept them from achieving an accurate sight picture when firing. The participants added that this gear combination kept them from easily transferring from one target to the next.

3.5.1.5. Compatibility

The participants rated the test conditions' compatibility with the equipment they wore, focusing on their ability to wear/use items together as intended, with no/minimal negative impacts.

Compatibility with helmet: The participants favored Condition I over Condition II, followed by Condition III. Comments explaining neutral and poor ratings for all conditions noted that the ACH negatively affected the participants' marksmanship ability, adding that the chin strap blocked their cheeks from the weapon's buttstock. The participants added that the ear covers of the ACH diminished their view. Comments specific to Condition III explained that the IOTV-ACH combination was bulky, heavy, and caused poor head mobility. They emphasized that the back of the IOTV pushed the ACH forward down into their face when in the prone position, which prevented them from achieving a proper sight picture. One participant added that the bulk from the IOTV's neck protector further hindered head mobility.

Compatibility with load carriage equipment (worn only in Conditions II and III): The participants preferred Condition II over Condition III. When explaining neutral and poor ratings for both conditions, the participants pointed to compatibility issues with the rucksack. They noted that the rucksack's shoulder straps were loose and did not keep the rucksack fitted properly on the body, even after adjusting. The participants expressed that the rucksack sat low on their back, which caused mobility issues and back pain. Another compatibility issue was the TAP system, which participants described as front-heavy, bulky, loose, and sitting low on the vest. They added that the TAP obstructed movement during test activities, particularly in the marksmanship task (see Marksmanship Ability section above). Regarding Condition III specifically, the participants noted that the DAPS worsened the restriction from the rucksack, citing pinching in the shoulder and neck area and decreased overall arm mobility and flexibility.

Compatibility with other gear items: The participants rated the compatibility of the test conditions with other gear items. They had the opportunity to write in a specific item and provide a compatibility rating. The most common write-in items were the rucksack (23) and TAP (10), both of which were covered in the previous subsection.

3.5.1.6. Combat Acceptability/Suitability

The participants rated the overall acceptability of each test condition for use in a combat environment. They again favored Condition I over Condition II, followed by Condition III. After providing a rating, the participants were asked to comment and provide improvement recommendations/modifications for the conditions' overall combat suitability.

The participants brought up two common needed improvements for all three of the test conditions. First, they recommended the use of the Army Combat Shirt instead of the ACU top to improve comfort. Another common recommendation was the suggestion of improving the ACH design by implementing better fitting chinstraps and helmet pads, reducing the mass, and developing an overall better design (i.e., cut) to improve visibility.

Regarding the loaded conditions, the participants suggested the need to reduce the bulk and mass of the gear. More detailed comments focused on the need to improve the unbalanced mass distribution between the TAP and the rucksack. They also noted the need for improved compatibility between the gear systems they wore. They specifically mentioned the compatibility issues between the rucksack, the TAP, and the armor vests. Another common suggestion was the redesign or discontinued use of the TAP. Several comments expressed extreme discontent for it, noting that the TAP was obtrusive, movement restrictive, and unnecessary. Lastly, the participants requested a design improvement of the side plate holders to increase support of the plates' mass. The participants reported chafing on their hips and suggested the need for a design that keeps the side plates in place.

Comments specific to Condition I focused on its practicality but also its lack of protection in a real combat environment. The participants enjoyed the liberty of movement and ease of achieving a proper sight picture when firing their weapon. However, they acknowledged the need for armor protection against shrapnel and rounds.

Regarding Condition II, participant comments focused on the need to improve the shoulder strap interaction between the SPCS and the rucksack. They noted the need for better padding on either the vest or the rucksack straps because of the pressure and pinching generated from the heavy mass carried on their shoulders.

The participants were more vocal when commenting on the combat acceptability of Condition III. Many expressed strong dislike for the IOTV, as they felt the protection offered by the condition's added armor did not compensate for the loss of marksmanship ability, proper breathability/ventilation, maneuverability, speed, and agility. Some noted these restrictions made them a liability to their team rather than an asset. The participants pointed to an ill-padded shoulder area, shoulder strap buckles, DAPS, and the yoke/collar assembly as the main causes of restrictions. However, not all comments were negative. Some participants noted that the IOTV's design and added armor was useful for certain positions and situations outside of dismounted combat missions or patrols (e.g., HMMWV gunners, tower guards, and convoy travel).

3.5.1.7. Questionnaire Summary

After completing the study activities in each test condition, the participants provided subjective information on what they experienced by answering the *End of Daily Activities Questionnaire*. Overall results demonstrated a strong preference for Condition I over Conditions II and III. Condition I was best rated followed by Condition II and then III predominantly for donning, fit, comfort, mission performance, mobility, marksmanship, compatibility, and acceptability. However, the participants did note the tactical disadvantages of Condition I in combat scenarios, stating that the loaded conditions would be more appropriate in these cases.

Most reported issues with the loaded conditions regarded compatibility of the ancillary armor attachments with the SPCS and IOTV armor vests. A majority of the comments explaining poor ratings (104 in total) pointed to the TAP as one of the main issues, particularly during the marksmanship task, as the participants noted that it prevented them from achieving proper firing positions. Specific to Condition III, the DAPS was another main issue, which the participants noted caused the most discomfort, particularly in combination with the rucksack shoulder straps.

3.5.2. Focus Group

At the end of each test cycle, focus group interview sessions were conducted with the test participants. During these sessions, a number of items were discussed. These included the test procedure/methodology, the equipment and conditions worn, the tests conducted, and suggestions for improvements or changes from the Soldiers' perspective.

3.5.2.1. Test Conditions and Equipment

Conditions: The participants stated that they definitely noticed differences between the equipment conditions, especially between Conditions II and III. The differences were in mass and in task performance. They said that performance in Condition III was affected by the bulk of the DAPS and TAP and the range of motion restriction that resulted from the bulk. The mass differences were most noticeable in transitions to/from the standing position (such as while executing tasks/obstacles such as bounding rushes).

Condition II was most similar to the mass and load they carried in the field; in contrast, for many, Condition III was "too much weight." They also felt that Condition III required more cognitive effort to maintain performance and avoid injury than the other conditions.

Body Armor: Nearly all of the participants used plate carriers (SPCS) in the field rather than IOTVs. Those few who used IOTVs did not use the groin protector, DAPS, or yoke. The participants said that the side plates caused discomfort/rubbing. They do not experience rubbing with their own side plates because they raise and secure them off/above the hips with 550 cord. They also noted that the IOTV retained much more heat than the plate carrier. They further stated that the IOTV made it difficult to shoulder the weapon properly, and sighting was also more difficult. The IOTV made it difficult to bring the arms together to hold the rifle barrel as far forward as desired.

They also reported that they do not use DAPS in the field. They noted DAPS affects the weapon sight picture because it affects the ability to shoulder the weapon. They disliked how the DAPS snagged on many things. Snagging affected obstacle clearance and at times caught the rifle sling.

TAP: The participants noted that they do not use the TAP on missions by choice. Many participants reported mounting their equipment on the plate carrier. They said they would have configured the items differently on the TAP, though they acknowledged there is no ‘standard’ condition. They also noted that if they used a TAP, they would not carry as much mass on it—the test conditions had more items than they use/carry and were heavier (e.g., they do not use grenades). If they did need all of the items, they would have mounted some on the IOTV rather than mounting everything on the TAP.

The participants also noted that the TAP was bulky and affected their task performance. They also said that the pouch condition restricted their motion and caught on things. The TAP made using the prone firing position especially difficult—they could not lay flat and had difficulty sighting the weapon. The low crawl was difficult and fatiguing due to the TAP. It also made the tunnel passage tight due to its girth.

Rucksack: The participants do not use the medium MOLLE rucksack in the field. They disliked it in the study because the load dropped to the bottom, and it also did not have enough adjustments to secure the load high and against the back where they wanted it. The large MOLLE has multiple adjustments to do this. They also noted instances of rucksack paralysis and shoulder pain during the study. They do experience shoulder pain on their missions, but the pain was worse with the medium MOLLE than with the large MOLLE. Participants with this issue suggested using the large MOLLE rucksack’s shoulder straps on the medium MOLLE. The large MOLLE’s straps are wider and spread the load on the shoulders better. They also suggested using the assault pack for this study instead of the medium MOLLE (the large MOLLE would be used for longer marches).

3.5.2.2. Test Scenarios/Procedures

Instructions/Procedure: The participants agreed that the instructions received were clear and easily followed. They stated that the test day pace was fine, and the time between tasks was acceptable, though not always similar to mission timing.

LEAP: The participants felt the LEAP course was safe. Some felt that the width between the ladder and the hand rails was a bit tight, and some caught the rifle muzzle in this area at times.

They found that the LEAP tasks were broadly representative of mission tasks. They said that the LEAP’s climbing walls were shorter than what was typical on missions. The LEAP’s bounding rushes were closer together than their 3-5 s training rushes. They made a few suggestions for potential additional tasks. These included adding a rope climb (pulling oneself up a wall with a rope, then up onto a roof or through a window), though they climbed less frequently on their missions than they performed other tasks similar to LEAP tasks. They also suggested adding a marksmanship task during LEAP (or moving that task into LEAP), which would simulate a mission where their adrenaline levels would be high.

The groups noted that stopping after each obstacle did not have a large effect on performance. It did cause a loss of forward momentum (that could be used for example in continuing forward to go through windows). Some found the stop annoying but others said it helped them to catch their breath or was similar to a tactical pause.

The participants indicated that LEAP was the most fatiguing activity in the entire study, specifically the dummy drag, accessing windows, low crawl, and bounding rushes tasks.

Foot March: The participants noted a few issues with the foot march. The terrain was 'easier' than typical mission marches. They felt that the terrain in the construction area behind the MOUT building was more typical of what they saw on missions. Also, wooded areas were more typical for marches on deployments than roads.

The main issue with the foot march for the participants was the pace. Many participants found it slow or very slow, although they found the watches helpful to maintain the proper pace. Those who complained of the slow pace said that an 18 min per mile pace would be better, as it would be closer to their usual pace (15 min per mile) and would still be easy to maintain with the equipment/mass they wore. Some felt that maintaining a slower pace than what they would naturally choose affected their stride and the ability to make their typical gait/stride/speed adjustments during the march.

The participants had several suggestions for improving the foot march. One was to march fully in wooded terrain (both for realism and to help with the speed/pace). They also suggested including a variable such as 'react to fire' so they would need to adjust their speed to get back on pace after reacting. Another suggestion was to break the foot march into segments for mission realism—for example, three 1.5-mile marches, one each before conducting LEAP, MOUT, and marksmanship.

The participants noted issues with the shot stimuli used in the cognitive task. Some participants could not hear any difference between the shot types. Many said that shot type is irrelevant—they are trained to react to any audible fire, whether friendly or enemy. Also, most contact on deployments was from RPGs or machine gun rounds (from an enemy version of an M240), so those sounds were what they most expected. They also said that the response could be made more realistic than just pressing a button. For realism, they suggested creating a "react to contact" or call for MEDEVAC drill to gauge fatigue—they must complete these tasks successfully even while fatigued.

Marksmanship: The participants had one main complaint. They said the targets were unrealistically high when prone. They said they probably would stop firing prone if the objective ended up that high.

Otherwise, the participants found the dynamic scenario realistic enough, although they said it included kneeling firing, which they never used on missions. The participants made some suggestions for greater realism. Some suggested using two lanes per participant, zig-zagging across lanes and assuming different positions at different points in the same run. Also, they suggested including a time limit for assuming (or attempting) a proper firing position before firing. They suggested using a wall for firing while kneeling and standing, using a C grip to hold the weapon, then running to the next station. Further, sandbags would be helpful to support the weapon while prone (especially because the TAP prevents lying flat).

MOUT: The participants noted two main issues with MOUT. One issue was that the photos were mostly unrealistic. They were unsure of what some objects in the photos were and whether many of them were threats. They suggested using e-type silhouettes or actual people with/without hostile intent (e.g., holding coffee cup vs. weapon, etc.). The other issue was that building clearing would not be an individual activity; a building that size would be cleared by a platoon, broken into fire teams/squads per floor. The participants also noted that using controlled shot pairs might not be realistic, since they are trained to fire until target is neutralized. However, they felt that target placement was good (not always directly ahead or in the direction of travel). A further suggestion would be to add kicking in a door—they occasionally had to do that on deployments.

4. Discussion

4.1. Discussion of Biomechanics Performance

The primary objective of this study was to establish a test methodology utilizing an operational scenario to assess the effects of CIE on Soldier physical and cognitive performance. The scenario was designed to have Soldiers perform an operationally relevant and fatiguing set of tasks that could distinguish physical and cognitive performance between equipment configurations of varying masses. In terms of biomechanical performance, the equipment conditions were assessed during the foot march and LEAP portions of the scenario with IMUs. Repetition of the foot marches allowed examination of Soldier biomechanics between a rested and a more fatigued state. For the foot march, the effect of equipment configuration and march iteration on the dependent variables were analyzed. For the LEAP obstacles, only the effect of equipment on the obstacle-specific dependent measures were analyzed.

4.1.1. Foot March Biomechanics

Biomechanical performance during gait is affected by many parameters including movement speed, grade, terrain, temperature, and carried load. During this study, the study staff attempted to eliminate the confounding effect of gait speed by having test participants self-monitor their speed with GPS watches. Additionally, study staff, located at each mile of the 3 mile march, checked that participants were arriving each 20 min to ensure the 3 mph march pace was reasonably controlled. Grade and terrain, while variable throughout the march, were consistent across test participants and trial iterations since the same path was taken during each trial. The varying grade and terrain allowed a more operationally realistic excursion that a Soldier may take during an actual mission. The general conclusions for the foot march biomechanical analysis with IMUs were:

1) Anterior lean angle increased for the two heavier equipment conditions (as compared to the lightest condition) during both marches, which allowed participants to keep their center of mass as close above the stance leg as possible to improve stability.
2) When comparing the same sections of the two marches, anterior lean angle was not different in four of five sections, indicating that fatigue seemingly only affected average lean angle in one section. Specifically, lean angle was greater in the second march during Section 3 (of 5) while wearing the heaviest equipment condition.
3) Lean angle variation increased mediolaterally and anteroposteriorly as equipment load increased during the second foot march but not the first, possibly indicating the presence of torso and pelvis muscle fatigue during the second march.
4) During the second foot march, but not the first, participants exhibited shortened stride lengths while wearing the two heavier load conditions, which likely helped maintain stability and control.
5) As determined by a PCA, motion of the feet within the sagittal plane decreased between the marches, resulting in increased frontal and transverse motion of the feet for the two heavier equipment conditions, possibly due to fatigued ankle plantar flexors.
6) The metrics: PCA pelvis, stride length, standard deviation of mediolateral lean, and standard deviation of anteroposterior lean may be the most sensitive to relatively small changes in body-borne load since they sometimes (depending upon the section of the

march and the march iteration) revealed significant differences between the two heaviest equipment conditions.

Effect of Equipment on IMU Dependent Variables during the Foot March: Several key spatiotemporal and kinematic differences were identified between equipment conditions. With the majority of the biomechanical variables, the significant differences between equipment conditions were seen primarily during the second march. For example, participant stride lengths were not different between equipment conditions during the first march, but for the majority of the examined sections of the second march, stride lengths were shorter for the two heavier equipment conditions as compared to the lightest condition. Stride length is often shown to shorten as carried load increases during fixed speed walking experiments (Harman et al., 1992; Kinoshita, 1985; Martin & Nelson, 1986; Tilbury-Davis & Hooper, 1999). In addition, decreased leg swing time, coupled with increased step frequency and double support time are common responses to increased load during walking (Birrell & Haslam, 2009; Martin & Nelson, 1986; Seay, 2015). In the present study, the duration of time spent in each individual stance phase (i.e. single support, double support, and swing phase) was not examined. Stride duration, which is the reciprocal of stride frequency, was analyzed, but there were no conclusive differences for stride duration between equipment conditions. The fact that participants travelled at a fixed pace for all equipment conditions likely contributed to this apparent disagreement with previous load carriage literature. However, this result seemed counterintuitive since in order to maintain the same movement speed, if stride length decreased, the stride frequency must have increased. Since stride frequency (strides per second) is the reciprocal of stride duration (seconds per stride), if stride frequency increases, stride duration must decrease. Consequently, a simple explanation remains elusive and may likely be a combination of several kinematic and spatiotemporal alterations. Regardless, shorter stride lengths likely allowed the feet to remain under the body's center of mass for a higher percentage of the stance phase, which helped increase stability while carrying the heavier loads. In addition to increased stability, decreased stride lengths may have helped limit energy expenditure by decreasing the moments about the joints of the stance leg.

Similarly to the stride length finding, the variation about the mean mediolateral and anteroposterior lean angles increased as equipment mass increased, but this was primarily only evident during the second march. However, the motion of the pelvis within the sagittal plane increased during both marches, resulting in decreased frontal and transverse motion, as equipment condition mass increased. Similarly, mean anterior lean angle increased when comparing the lightest to the two heavier conditions during both marches, but the difference between the two heavier conditions was not significant. These results align with previous literature suggesting that forward trunk lean increases with added torso-borne load, allowing the center of mass to remain close to the base of support of the stance leg to improve stability (Seay, 2015). Increased trunk lean causes greater bending at the hip, requiring increased muscle activity around the lower back and pelvis, which likely increases fatigue in those regions (Harman, Hoon, Frykman, & Pandorf, 2000; Seay, 2015). Increased forward lean also lowers the vertical center of mass position, which may help control the potentially destabilizing effect of the carried load by reducing the moment about the feet (Harman et al., 2000). The combined effect of the biomechanical differences exhibited between load conditions resulted in altered gait that demonstrated the participants' adaptations to equipment load and increased fatigue. The adaptations to the heavier equipment loads appeared to create additional stability during the marches.

As demonstrated, most of the examined metrics were only different when comparing the lightest to the two heavier equipment conditions. Only four of the examined metrics (PCA pelvis, stride length, standard deviation of mediolateral torso lean, and standard deviation of anteroposterior torso lean) yielded significant differences between the two heaviest equipment conditions. However, for each metric, these differences were not consistent for each section of the foot march. These metrics were generally only different between the two heaviest equipment conditions during the second foot march, with the exception of standard deviation of torso anteroposterior lean in the last section (Section 5 of 5) of the first march. Therefore, these four IMU-derived metrics of human performance during a fixed-speed foot march seem to be the most sensitive of the examined metrics to relatively small changes in body-borne load.

Additional IMUs attached to the shank and thigh segments could have revealed other important load adaptations. For instance, computing the angular difference between the shank and thigh IMU could allow the analysis of knee range of motion which could increase (Knapik et al., 1996; Seay, 2015), decrease (Harman et al., 2000; Polcyn, Bensel, Harman, Obusek, & Pandorf, 2002; Seay, 2015), or not change (Polcyn et al., 2002; Seay, 2015) as equipment load increases depending on the distribution of the load under examination. The effect of load on ankle angle, which could be calculated as the angular difference between foot and shank IMUs, also has conflicting findings in literature (Birrell, Hooper, & Haslam, 2007; Ghori & Luckwill, 1985; Harman et al., 2000; Rice, Fallowfield, Allsopp, & Dixon, 2017; Silder, Delp, & Besier, 2013) which were likely influenced by differences in experimental protocols across studies (e.g. speed, terrain, duration, footwear, distribution of the carried load, carrying or not carrying a weapon, etc.). Regardless, as demonstrated in the current study, several of the gait alterations were not evident during the first foot march, but the heavier equipment conditions, in particular, appeared to tire the participants throughout the course of the mission scenario, resulting in the participants exhibiting biomechanical deviations throughout the second foot march.

Effect of March Iteration on IMU Dependent Variables during the Foot March: Several key spatiotemporal and kinematic differences were identified between march iterations. In general, the heavier equipment loads seemingly fatigued participants more between marches, as a result of completing the LEAP and MOUT portions of the scenario, resulting in spatiotemporal and kinematic changes that were not necessarily evident with the lightest load condition. For instance, as detailed above, participants took shorter strides during the second march than the first for the two heavier equipment conditions, but not the lightest. The shorter strides exhibited during the second march were likely a result of fatigue, particularly of the knee extensors, which have been shown to constitute a relatively large proportion of the burden during load carriage (Seay, 2015). Similarly, as determined by a PCA, the motion of the feet within the sagittal plane decreased between the two marches, implying that there was increased frontal and transverse motion of the feet for the two heavier equipment conditions as compared to the lightest. The decreased sagittal plane motion of the feet could be a result of fatigued ankle plantar flexors which have increased activity whilst carrying load that may have affected postural stability (Rice et al., 2017).

Mean anterior lean was only greater in one of the five examined sections of the second march as compared to the first march. In order to maintain stability over the stance leg's base of support, increased trunk lean may have been accompanied by increased knee flexion (in the single section) in order to counteract the more anterior center of mass. While lean angle was not generally different between marches (in four out of the five sections), the variation of the mediolateral and anteroposterior torso angles increased between marches for the two heavier conditions, but not the lightest. Similarly, the motion of the torso within the sagittal plane (as determined by a PCA) increased between marches in three of the five examined time intervals. In the remaining two intervals, sagittal plane motion was not different. The musculature of the torso and pelvis likely had to generate greater moments while wearing heavier equipment in order to damp the motion of the trunk during each stride. Assuming this was the case, these muscles likely fatigued between the two marches and their force generation may not have been equivalent during the second march, resulting in less trunk control and greater motion variability.

Following the completion of prolonged load carriage, reduced knee extensor moments, increased ankle dorsiflexion, and increased knee flexion have been reported (Quesada, Mengelkoch, Hale, & Simon, 2000). The reduced knee extensor moments are likely a result of fatigued quadriceps muscles, which may influence the more distal lower extremity, reducing the ability to maintain the pre-fatigued gait pattern (Rice et al., 2017). While lower extremity joint moments and angles were not calculated in the present study, participants may have exhibited these load carriage and fatigue related symptoms which could have caused, or at least influenced, several of the aforementioned findings.

4.1.2. LEAP: Sprint Obstacle Biomechanics

As mentioned previously for the foot march, biomechanical performance during gait is affected by many parameters including movement speed, grade, terrain, temperature, and carried load. During the mission scenario, the study staff utilized the standardized LEAP course, which eliminated the confounding effects of grade and terrain since all participants completed the same course at the same location. The sprint was the second obstacle of the course, but there were no algorithms currently designed to analyze the biomechanical performance of individuals completing the first obstacle (the hatch and tunnel). The general conclusions for the LEAP sprint obstacle biomechanical analysis with IMUs were:

1) Speed decreased as condition load increased.
2) Stride length decreased as condition load increased.
3) Stride duration increased when comparing the lightest to the two heavier equipment conditions.
4) As determined by a PCA, motion of the torso within the sagittal plane decreased when comparing the lightest to the two heavier equipment conditions.
5) Condition load had no effect on anteroposterior or mediolateral lean angle.
6) Variation of anteroposterior lean angle decreased as condition load increased.
7) Variation of mediolateral lean angle decreased when comparing the lightest to the two heavier equipment conditions.

Effect of Equipment on IMU Dependent Variables during the LEAP Sprint Obstacle: Unlike the fixed-pace foot march section of the mission scenario, participants were instructed to complete each obstacle as quickly as possible within the LEAP. However, due to constraints of the IMU algorithms, the participants were asked to come to a complete halt before and after each obstacle. For the sprint obstacle, the average movement speed decreased as condition load increased, which was likely a result of decreased acceleration to peak speed. The added mass of the heavier conditions made overcoming inertia a much more challenging task. Participants wearing the heavier conditions were also likely more fatigued by the start of the sprint obstacle as a result of carrying the heavier loads during the first foot march, which occurred directly prior to the LEAP. In addition to moving at slower speeds while wearing heavier equipment, participants exhibited decreased stride length. Decreased stride length, decreased time in swing, increases in step frequency, and increased time in double support are common responses to increased load while walking (Birrell & Haslam, 2009; Martin & Nelson, 1986; Seay, 2015). Unlike while walking, as the participants approached sprint speeds during the obstacle, participants eliminated any double support time because neither feet were in contact with the ground at the same time. Additionally, stride frequency was actually lower for the heavier conditions, since stride duration increased when comparing the lightest to the two heaviest equipment conditions. The longer ground contact durations allowed increased time for internal loading of lower limb structures, yet the longer durations may have lowered the loading rate on these structures to help reduce the negative effects of the increased load (Arndt, Ekenman, Westblad, & Lundberg, 2002; Rice et al., 2017). Regardless, the combination of decreased stride length and increased stride duration for the heavier conditions explain the observed decrease in speed.

Unlike the foot march, lean angle (anteroposterior and mediolateral) was not different between equipment conditions. The sprint obstacle possibly was simply not long enough to allow participants time to settle into a leaning posture (sprint length was a relatively short ~18.3 m), and also since participants started and ended the sprint standing upright. Participants typically only took around seven or eight strides during the sprint. Perhaps with a longer duration sprint, forward lean may have increased with heavier equipment conditions. However, increased forward lean would have moved the center of mass anteriorly which could have potentially led to destabilizing moments that would have made forward falls more likely. With a slower velocity, participants were more easily able to keep their center of masses above their bases of support, effectively increasing their stability with the heavier loads.

Similarly, to the foot march results, the motion of the pelvis within the sagittal plane increased when comparing the lightest to the heaviest equipment condition. However, unlike the foot march results, the variation about the mean mediolateral and anteroposterior torso lean angles decreased as equipment mass increased. The motion of the torso within the sagittal plane also decreased when comparing the lightest to the two heaviest conditions. The general decrease in torso motion as load increased, particularly in the sagittal plane, likely allowed participants to maintain greater stability by keeping the body center of mass closer above the base of support. In order to maintain stability while standing, the vertical projection of the body center of mass should remain within the base of support (Hof, Gazendam, & Sinke, 2005; Shumway-Cook & Woollacott, 1995; Winter, 1995). During sprinting, a relatively high center of mass velocity is directed towards the movement direction, which must be accounted for during each subsequent step, in addition to the center of mass location, in order to prevent a fall. With the greater mass of the heavier load conditions, the momentum (mass*velocity) increased, which caused additional difficulty for the participants attempting to maintain stability. However, the decreased movement speed (decreased magnitude of velocity) exhibited by participants as equipment condition mass increased limited this increase in momentum, allowing better control and stability during the sprint despite increased mass.

As previously mentioned for the foot march, most of the examined metrics were only different when comparing the lightest to the two heavier equipment conditions. Only four of the examined metrics (PCA pelvis, stride length, standard deviation of mediolateral torso lean, and standard deviation of anteroposterior torso lean) yielded significant differences between the two heaviest equipment conditions during the foot march. Similarly, for the sprint obstacle, only three of the examined metrics (stride length, speed, and standard deviation of anteroposterior torso lean) yielded significant differences between the two heaviest conditions. Average speed did not yield significant differences between any equipment conditions during the foot march since speed was fixed. Stride length and standard deviation of anteroposterior torso lean metrics were consistent with the foot march, and seem to be the most sensitive of the examined metrics to relatively small changes in body-borne load for this obstacle.

Similarly to the foot march, additional IMUs attached to the shank and thigh segments could have revealed other important load adaptations. Regardless, additional analysis of lower extremity segments, as well as arm swing and head motion, could reveal further biomechanical adaptations to load during a sprint.

4.1.3. LEAP: Agility Run Obstacle Biomechanics

Biomechanical performance during an agility run is often determined by an individual's ability to quickly and efficiently change direction. Agility courses often require multiple instances of braking in the direction of forward progression and reorientation in a new direction without stopping locomotion (Hase & Stein, 1999; Havens & Sigward, 2015). The agility run was the fourth obstacle of the course, but there were no algorithms currently designed to analyze the biomechanical performance of individuals completing the third obstacle (stairs and ladder). The general conclusions for the LEAP agility run obstacle biomechanical analysis with IMUs were:

1) Movement speed decreased as equipment condition load increased, which was likely a result of shorter stride lengths and longer stride durations.
2) The variation in foot yaw and stride width decreased as equipment condition load increased.
3) As determined by PCAs, within the sagittal plane, motion of the feet increased and motion of the torso decreased when comparing the lightest to the two heavier equipment conditions.
4) The variation of mediolateral lean decreased when comparing the lightest to the two heaviest equipment conditions.
5) The variation of anteroposterior lean decreased as equipment condition load increased.
6) Anteroposterior lean decreased when comparing the lightest to the two heaviest equipment conditions.
7) Pelvis acceleration in the mediolateral direction at each turn decreased as equipment condition load increased.
8) Pelvis tilt angle in the mediolateral direction at each turn decreased between the two lightest and the heaviest equipment condition.
9) Pelvis angular velocity about a vertical axis at each turn decreased between the lightest and the two heaviest equipment conditions.

Effect of Equipment on IMU Dependent Variables during the LEAP Agility Run Obstacle: The agility run obstacle could be divided up into sections that involve purely translation (i.e. the straightaways between turns) and sections that involve a combination of rotation and translation (i.e. the turning phases around the flags). Some metrics were calculated at the apex of each turn phase, but most were averaged across the entire agility run, encompassing both the straightaway and turning phases. Similar to the results evident during the sprint obstacle, overall participant movement speed decreased as equipment condition mass increased. The decreased movement speed was accompanied by decreased stride length and increased stride duration. The shorter stride length and slower stride frequency unsurprisingly resulted in decreased movement speed. In order to decelerate the body before a turn phase, the body must generate posteriorly-directed ground reaction forces and position their center of mass posteriorly to their center of pressure (Havens & Sigward, 2015). With greater body-borne loads, the participants had a more difficult time decelerating the increased mass before each turn. By incorrectly assuming the participants moved at the same speed during the straightaways for each equipment condition, the participants would have required much greater posteriorly-directed ground reaction forces to decelerate the increased mass in the same amount of time. In actuality, the participants moved slower during the straightaways, lowering the ground reaction force and deceleration magnitudes required to slow before each turning phase.

A previous study that utilized a similar agility course to quantify agility performance determined that high performers generated larger horizontal ground reaction forces at turns, had shorter duration footfalls, larger changes in movement speed between straightaways and turn phases, and executed sharper turns (Zaferiou et al., 2017). The low performers maintained a medium body speed throughout and took wider turns that required more steps. Comparing these results to the present study reveals that the high performers are synonymous with participants wearing the lightest equipment condition while the low performers are most comparable to the participants wearing the heaviest equipment condition. The heaviest condition resulted in participants generating smaller horizontal foot accelerations at the turns, which likely implied lower horizontal ground reaction forces due to Newton's Second Law (F=m*a) despite increased mass. The heaviest condition also resulted in longer duration footfalls, smaller changes in movement speed (due to the slower overall movement speed), and likely wider turns. While turn radius was not computed in the present study, angular velocity of a sacrum-mounted IMU (close to the body center of mass) about a vertical axis was less for participants wearing heavier equipment. Since a smaller turn radius is likely associated with greater angular velocity about a vertical axis, participants wearing the heavier equipment conditions likely exhibited greater turn radii due to the smaller angular velocity magnitudes.

A separate previous study that also utilized a similar agility course determined that high performers (as determined by a k-means cluster analysis incorporating acceleration, velocity, and angle estimates from a sacrum-mounted IMU) generated high tangential acceleration at the apex of each turn, and that they aligned their hips to the new direction of travel at each turn (McGinnis et al., 2017). In the present study, the pelvis was tilted the most in the mediolateral-vertical plane during each turn when participants wore the lightest equipment condition. Additionally, the sacrum acceleration in the mediolateral direction at each turn was the greatest for participants wearing the lightest equipment condition. Therefore, when the participants wore the lightest equipment condition, they were most similar to the high performers from the study by McGinnis et al. Participants wearing the lightest equipment condition decreased their agility run time and had higher speeds throughout by better aligning their hips with the direction of travel at the apex of each turn, which allowed them to increase their speed more quickly when coming out of each turn.

While partially a result of slower movement speeds, participants completed the agility run with a more upright torso that exhibited less motion while wearing the heavier equipment conditions. The more stable upright torso allowed participants to keep their center of mass better positioned above their base of support to maintain better stability and control while moving. Similarly, participant's feet moved more within the sagittal pane, had less foot yaw variation, and had less variable stride widths for the heavier equipment conditions. This more restricted foot motion was likely a result of the decreased movement speed and shorter stride lengths but may have been a compensatory mechanism for the increased load to allow better stability. Consequently, participants completed the agility course more conservatively while wearing heavier loads, which likely helped prevent slips and falls around the turns and reduced stress on the lower extremity but at the expense of time.

4.1.4. LEAP: High and Low Window Obstacle Biomechanics

IMUs mounted on the sacrum and torso allowed the analysis of participant technique and performance while climbing through the window obstacles. The sacrum-mounted IMU provided kinematic data (acceleration and angular velocity) close to the center of mass, which was exploited to calculate vertical and horizontal movement velocity and to identify when the participant was climbing through the window opening. The high and low windows were the sixth and seventh obstacles of the course, respectively, but there were no algorithms currently designed to analyze the biomechanical performance of individuals completing the fifth obstacle (casualty drag). The general conclusions for the LEAP high and low window obstacle biomechanical analyses with IMUs were:

High Window

1) Peak vertical velocity decreased when comparing the lightest to the two heaviest equipment conditions.
2) Mount horizontal velocity decreased when comparing the lightest to the two heaviest conditions.
3) Torso and pelvis anteroposterior range of motion increased when comparing the lightest to the two heaviest equipment conditions.

Low Window

1) Peak vertical velocity was not different between equipment conditions.
2) Dismount horizontal velocity decreased when comparing the lightest to the two heaviest conditions.
3) Torso anteroposterior and mediolateral range of motion increased when comparing the lightest to the two heaviest conditions.

Effect of Equipment on IMU Dependent Variables during the LEAP High and Low Window Obstacles: While the general strategies utilized to complete the two window obstacles were similar, the sacrum and torso IMU derived metrics revealed differences because of the differing window heights. For both windows, participant horizontal velocity started near zero, increased as they approached the window, decreased as they climbed through the window, and increased as they ran from the window. The jump onto either window created a large peak in vertical velocity, and the dismount from the window created a large negative peak in vertical velocity. When considering vertical jump performance, which is related to the initial jump onto the window, particularly for the high window, jump height is dependent on flight time and take-off velocity (McGinnis et al., 2015). The participants in the present study demonstrated decreased peak vertical take-off velocity on the high window when comparing the lightest to the two heaviest conditions. Despite the decreased velocity because of the heavier loads, the participants were still able to successfully jump onto the high window, although the time to do so was longer due to the slower vertical motion. The horizontal velocity, at the point in time of greatest vertical velocity, was also greater for the lightest equipment condition for the high window as compared to the two heavier conditions. This implies that participants were moving forward (horizontally) through the window at a quicker rate when jumping upwards, which resulted in improved movement efficiency. In addition to the velocity analysis, the torso and pelvis anteroposterior range of motion increased when comparing the lightest to the two heaviest conditions. This implies that participants exhibited increased forward and backward lean as they attempted to fit through the high window while wearing the heavier equipment. The greater bulk of the heavier equipment conditions caused participants more difficulty in passing through the high window opening, which resulted in greater trunk and pelvic motion.

The low window was lower in height, which placed less emphasis on the initial vertical jump. In fact, taller participants often barely needed to jump onto the low window at all. Consequently, there were no significant differences in peak vertical velocity for the low window between equipment conditions. On the other hand, the horizontal velocity while dismounting the window decreased when comparing the lightest to the two heaviest conditions. Similar to the high window, the torso anteroposterior lean range of motion was greater for the heavier equipment conditions. Additionally, the torso mediolateral lean range of motion was greater for the heavier equipment conditions. For the heavy conditions, this implies that participants contorted their torsos more in order to squeeze through the window opening. The extra torso twisting and bending, combined with the slower dismount velocity, caused worse completion times, which was primarily due to the added bulk and mass.

Additional IMUs attached to the upper extremity could have provided additional insight into the different window traversing techniques utilized by participants under load. Similarly, analysis and examination of the raw data associated with the already attached feet IMUs could have proved beneficial. However, at the time of this report, the algorithms for the window obstacles were primarily designed to understand the general motion of the body by examining the data of an IMU attached near the body center of mass (i.e. the sacrum IMU) and the torso. This was viewed as a positive, since window traversing performance could be analyzed with the use of only two IMUs. For the purposes of this study, the IMU placed on the sacrum and the torso provided sufficient information about participant window traversing technique. In fact, as demonstrated above, the metrics were adequately able to distinguish different techniques across the three examined equipment conditions. However, analysis of IMU data from monitors placed on both the upper and lower extremities would allow a more complete understanding of window obstacle strategy.

4.1.5. LEAP: Bounding Rush Obstacle Biomechanics

The sacrum IMU provided kinematic data near the center of mass to allow calculation of body velocity and to identify when participants were prone, standing, or running. Bounding rush performance metrics were calculated within these phases to differentiate performance between the equipment conditions. The bounding rush obstacle was the eighth obstacle of the course and occurred directly after the high and low window obstacles. The general conclusions for the LEAP bounding rush obstacle biomechanical analysis with IMUs were:

1) Time to complete each bounding rush increased with equipment mass.
2) There was greater variation in the time to complete each bounding rush for the two heavier equipment conditions as compared to the lightest.
3) Time to stand from the prone position was longer for the two heavier equipment conditions primarily due to a decrease in vertical standing velocity.
4) There was greater variation in the time to stand from the prone position for the two heavier equipment conditions as compared to the lightest.
5) Vertical standing velocity and sprinting velocity decreased with equipment mass.
6) There was less variation in vertical standing velocity and sprinting velocity for the two heavier equipment conditions as compared to the lightest.

Effect of Equipment on IMU Dependent Variables during the LEAP Bounding Rush Obstacle: A single bounding rush was defined as the initial prone position, followed by the remaining sections: standing, sprinting, and getting down into the next prone position. As equipment condition mass increased, the time to complete each bounding rush increased. While the time spent in each section of the bounding rush was not computed, the time spent standing up from the prone position to an upright position was shortest for the lightest condition as compared to the two heavier equipment conditions. This result was unsurprising since participants had to generate greater force to lift themselves while wearing heavier equipment. The added mass of the heavier conditions made overcoming inertia a much more challenging task. Consequently, the sacrum vertical velocity also decreased as equipment mass increased. The added mass also likely fatigued participants to a greater extent during the previous obstacles and the initial foot march, which also decreased participant performance during the rushes.

During the sprinting portion of each bounding rush, similar to the results of the sprint obstacle, sprint velocity was greater for the lightest as compared to the two heaviest equipment conditions. Standard deviation of sprint velocities (where a high standard deviation implies a less consistent velocity across the sprint duration) was also greatest for the lightest as compared to the two heavier equipment conditions. When wearing the lightest equipment condition, participants tended to sprint the quickest during the first few sprints between prone positions. Near the end of the bounding rush obstacle, participants often slowed due to fatigue, hence the standard deviation of sprint velocities grew. While wearing the heavier equipment conditions, participants tended to have more similar speeds across each sprint section, reducing the standard deviation in sprint speed. Similarly, participants wearing the heavier equipment conditions had lower standard deviation of vertical velocity when standing up. Perhaps the already fatigued participants decided to exert less than maximal energy during each rush in order to ensure they would get through the obstacle without tiring out. However, the standard deviation of the time to stand and the time to complete a single bounding rush was greater for the two heavier equipment conditions as compared to the lightest. Therefore, participants wearing the lightest equipment condition, despite exhibiting greater velocity variation, completed each bounding rush in more similar (and shorter) durations than the two heavier equipment conditions.

If comparing the heaviest to the lightest equipment condition, the participants would have spent 3 fewer seconds (5 compared to 8 s, or a 37.5% decrease in time) attempting to reach the next prone position if wearing the lightest condition. In an actual combat situation, assuming a single AK-47 rifle with a cyclic rate of fire of 600 rounds per minute was firing upon a Soldier as they were moving to a new prone position (completing a single bounding rush), 3 s could correspond to approximately 30 extra rounds fired at the Soldier. Hence, the seemingly small differences in bounding rush completion times between the equipment conditions seem much more relevant when put into a more realistic context.

4.1.6. LEAP: Balance Beam Obstacle Biomechanics

While traversing a balance beam, dynamic instability is constantly combatted in order to maintain balance. Maintaining balance requires specific coordination of the entire body to control the position and velocity of the body center of mass relative to the base of support (Cain et al., 2016; Hof et al., 2005; Winter, 1995). Despite some passive dynamic properties of the limbs that help maintain balance, participants likely generated significant active control in order to remain stable to avoid falling from the beam (Bauby & Kuo, 2000). The balance beam obstacle was the ninth obstacle of the course and occurred directly after the bounding rush obstacle. The general conclusions for the LEAP balance beam obstacle biomechanical analysis with IMUs were:

1) Time to traverse the balance beam increased with equipment condition load due to an increased step count, a lower step frequency, a higher stride duration, and a higher percentage of time spent in double support.
2) Participants used a more conservative and slower approach under load, which entailed a larger movement safety margin and less reliance on large lateral torso motion to achieve balance correction.

Effect of Equipment on IMU Dependent Variables during the LEAP Balance Beam Obstacle: While wearing heavier equipment conditions, participants generally traversed the beam more conservatively in order to avoid falls. The more conservative approach resulted in an increased amount of time to cross the beam due to an increase in the number of steps, a lower step frequency, a higher stride duration, and a higher percentage of time spent in double support. These findings are identical to the results of a study performed by Cain et al. in which they analyzed the effect of load on balance beam traversal performance (Cain et al., 2016). The increased amount of time spent with two feet touching the beam demonstrated the more cautious approach used by participants while carrying a load, which revealed the participant's trade-off between speed and stability. Additionally, sacrum and torso mediolateral and anteroposterior accelerations decreased while carrying a load, indicating a more stable upper body while traversing the beam. Torso angular velocity magnitude was also greatest for the lightest equipment condition, implying the angular rate of torso motion was slower when participants wore heavier loads. A decreased sacrum acceleration ratio between mediolateral and anteroposterior acceleration indicated that participants had fewer lateral balance corrections (i.e. increased stability) while carrying a load. The lower ratio implied that there were fewer left and right balance correcting accelerations relative to forward and backward accelerations. A lower ratio could be considered favorable since it suggests increased balance control and stability, but the more cautious approach was simply a result of the added torso-borne load, which led to increased beam traversal time.

While traversing the balance beam, participants needed to generate sufficient moments at the shoulder, the neck, the hip joint of the swing leg, and particularly the hip joint of the stance leg in order to limit the angular acceleration of the head-arms-trunk complex (Otten, 1999). For the heavier equipment conditions in particular, since the carried load was primarily torso-borne, the increased mass caused a larger moment about the feet. Generally speaking, increases in body lean cause the moment about the feet, generated by the more superior (closer to the head) and greater magnitude center of mass, to grow more rapidly. Consequently, greater joint moment production from across the body, working in union, is necessary in order to prevent loss of balance. Due to these reasons, if participants had not traversed the beam more cautiously while wearing the heavier equipment, preventing mediolateral or anteroposterior falls would have been much more challenging as a result of the increased moment about the feet. Instead, participants took a more conservative approach while carrying load, relied less on large lateral torso motion to achieve balance correction, and exhibited a larger movement safety margin (Cain et al., 2016).

4.1.7. LEAP: High and Low Wall Obstacle Biomechanics

Participants had to navigate through relatively small openings during the window obstacles, but for the wall obstacles, participant motion was not as limited. Nonetheless, the general motion of climbing and dismounting the walls was similar enough to the motion used during the window obstacles which allowed the use of nearly identical algorithms. IMUs mounted on the sacrum and torso allowed the analysis of participant technique and performance while climbing over the wall obstacles. The sacrum-mounted IMU provided kinematic data (acceleration and angular velocity) close to the center of mass, which was exploited to calculate vertical and horizontal movement velocity and to identify when the participant was climbing over the wall. The high and low walls were the 11th and 12th obstacles of the course, respectively, but there were no algorithms currently designed to analyze the biomechanical performance of individuals completing the 10th obstacle (crawl). The low wall was the final obstacle of the LEAP course. The general conclusions for the LEAP high and low wall obstacle biomechanical analyses with IMUs were:

High Wall

1) Peak vertical velocity decreased when comparing the lightest to the two heaviest equipment conditions.
2) Mount horizontal velocity decreased when comparing the lightest to the two heaviest equipment conditions.
3) Horizontal velocity over the wall (mean and minimum) decreased when comparing the lightest to the two heaviest equipment conditions.
4) Torso anteroposterior and mediolateral range of motion increased when comparing the lightest to the two heaviest equipment conditions.

Low Wall

1) Peak vertical velocity was not different between equipment conditions.
2) Pelvis heading range of motion increased between the lightest and heaviest equipment condition.

3) Torso anteroposterior and mediolateral range of motion increased when comparing the lightest to the two heaviest equipment conditions

Effect of Equipment on IMU Dependent Variables during the LEAP High and Low Wall Obstacles: It's important to note that while participants were ultimately successful at climbing the high wall, participants often had multiple failed attempts while climbing due to the height and depth of the wall, particularly while wearing increased torso-borne load. The load added bulk, particularly around the abdomen and chest, which made it more difficult for participants to climb and grip over the top of the wall. Due to these failed attempts, the overall time to complete the high wall was often inflated. In order to allow a more reasonable biomechanical performance comparison across equipment conditions, only the successful climbs and the time required to complete those successful climbs were compared across equipment conditions.

While the strategies utilized to complete the two wall obstacles were similar, the sacrum IMU derived metrics revealed differences because of the differing wall heights. For both walls, participant horizontal velocity started near zero, increased as they approached the wall, decreased as they climbed over the wall, and increased as they ran from the wall. One of the primary differences between the two walls, besides height, was that the high wall had footholds which the participants climbed before boosting themselves atop the wall. This boost created a large peak in vertical velocity and the dismount from the wall created a large negative peak in vertical velocity. The participants demonstrated decreased peak vertical take-off velocity on the high wall when comparing the lightest to the two heaviest conditions. Despite the decreased velocity because of the heavier loads, the participants were still able to successfully jump onto the high wall, although the time to do so was longer due to the slower vertical motion. The time it took to climb the footholds before boosting atop the wall was also generally longer for the heavier conditions. Similarly to the high window finding, the horizontal velocity, at the point in time of greatest vertical velocity, was greatest for the lightest equipment condition for the high wall. This implies that participants were moving forward (horizontally) over the wall at a quicker rate when jumping upwards which resulted in improved movement efficiency. Participants also exhibited increased horizontal velocity with the lighter loads while moving across the top of the high wall (note: this metric was not calculated for the window obstacles). In addition to the velocity analysis, similar to the high window, the torso anteroposterior range of motion increased when comparing the lightest to the two heaviest conditions. This implies that participants exhibited increased forward and backward lean as they attempted to climb over the high wall while wearing heavier equipment. Unlike the high window, participant torso mediolateral range of motion also increased when comparing the lightest to the two heaviest conditions. This difference was likely not evident during the high window since participant motion was constrained by the small window opening. During the high wall, participants were able to turn their bodies and lay atop the wall, which resulted in the increased torso anteroposterior and mediolateral ranges of motion with load. The greater bulk of the heavier equipment conditions caused participants more difficulty when climbing onto the high wall, which resulted in the increased trunk and pelvic motion.

Similarly to the low window, peak vertical velocity was not different between load conditions for the low wall. Horizontal movement velocity was also not different while mounting, climbing over, or dismounting the low wall. Despite moving at the same speeds, the motion of the torso and pelvis were different when comparing the lightest to the two heavier equipment conditions. For instance, the pelvis heading range of motion increased with load. The most extreme values occurred when participants were jumping onto and off of the wall. Participants wearing load generally tilted their pelvis more away from the direction of travel over the wall. By keeping their pelvis more aligned and square with the direction of travel (as demonstrated with the lightest equipment condition), participants were in a more ideal position to jump onto the low wall and to absorb the landing simultaneously with both legs while dismounting. Additionally, similarly to the high wall, torso anteroposterior and mediolateral range of motion was greater for the heavier equipment conditions. For the heavy conditions, this implies that participants bent their torsos more forward and backward and side to side in order to climb over the low wall. This result was not surprising since, similarly to both windows and high wall, the participants had to find a way to lift the added torso-borne mass and bulk above and around the wall obstacle.

Similarly to the window obstacles, additional IMUs attached to the upper extremity could have provided additional insight into the different wall traversing techniques utilized by participants under load. Likewise, analysis and examination of the raw data associated with the already attached feet IMUs could have proved beneficial. However, at the time of this report, the algorithms for the wall obstacles were primarily designed to understand the general motion of the body by examining the data of an IMU attached near the body center of mass (i.e. the sacrum IMU) and the torso. This was viewed as a positive, since wall traversing performance could be analyzed with the use of only two IMUs. For the purposes of this study, the IMU placed on the sacrum and the torso provided sufficient information about participant wall traversing technique. In fact, as demonstrated above, the metrics were adequately able to distinguish different techniques across the three examined equipment conditions. However, analysis of IMU data from monitors placed on both the upper and lower extremities would allow a more complete understanding of wall obstacle strategy.

4.2. Discussion of Cognitive Performance

The present research evaluated the influence of CIE and sustained physical exertion on response inhibition, a key component of cognitive control. Soldiers completed a go/no-go task of response inhibition throughout each of two 3-mile foot marches, while wearing one of three CIE configurations, totaling approximately 9.5, 46, and 51 kg. Findings suggest that CIE and sustained physical exertion impaired response inhibition performance, as evidenced by a lower proportion of correct responses, higher proportion of false alarms, and lower response sensitivity between all three conditions, particularly upon successive foot marches and blocks within each foot march. Increasing loads of CIE and successive foot marches also elevated perceived rated exertion and reduced subjective mission performance.

The results support and extend previous laboratory work showing that CIE configurations totaling approximately 40 kg increased the proportion of false alarms, particularly beginning 45 minutes into the 120 minute march (Eddy et al., 2015). Similarly, the present findings suggest that although performance was degraded in Condition III (approximately 51 kg) relative to I (approximately 9.5 kg) from the outset of the march, degradations between Conditions III and II (approximately 46.2 kg) and between Conditions II and I began approximately 30 minutes into the march. Notably, effect sizes for the main effects of CIE, across marches and times, are quite large (Cohen, 1992). Notable also are the significant effects between Conditions III and II, given that the difference in load was approximately 10 lb, and substantially less than the difference between Conditions II and I. It is possible that at such heavy loads, each extra pound measurably detracts from cognitive control function. It is also possible that the equipment configuration on the body, rather than or in addition to the load itself can influence cognition, as load distribution has been shown to influence foot march physical and cognitive performance (Knapik et al., 1997). Recall that the biomechanical findings of the foot march only showed significant differences between the two heaviest load conditions for four of the calculated IMU metrics (PCA pelvis, stride length, standard deviation of mediolateral torso lean, and standard deviation of anteroposterior torso lean). Consequently, these biomechanical metrics and false alarm rate appear to be relatively sensitive to small changes in body-borne load.

The results also support previous work on sustained physical exertion and cognitive control, as the proportion of hits and sensitivity were higher during the first 5 min of marching than all subsequent times, and the proportion of false alarms was higher during the final 5 min of marching than all previous times. The intensity of physical exertion, particularly in Condition III where Soldiers' heart rates averaged 83% maximum heart rate, was akin to previous studies finding impaired cognitive control during cycling and running exercise (Davranche & McMorris, 2009; Del Giorno et al., 2010; Dietrich & Sparling, 2004). The intensity of physical exertion in Condition II (average 74% maximum heart rate) was more akin to a moderate intensity (Garber et al., 2011), which has generally not affected or improved cognitive control (Davranche & McMorris, 2009; Sibley & Beilock, 2007). However, unlike participants in previous studies, Soldiers in the present research had the added task of traversing variable terrain across the 3-mile, outdoor foot march, including overstepping tree roots and other natural debris, navigating changing incline, and monitoring their pace to maintain a 3 mph speed. Similar dual-task interferences, such as crossing obstacles, have been shown to impair vigilance (Mahoney et al., 2007), and load carriage itself has been shown to impair task switching performance (May, Tomporowski, & Ferrara, 2009)

Although response criterion and response time did not differ as functions of CIE, they changed between the first and second march. Soldiers were more biased towards responding yes and responded more rapidly in the second than first march. These findings, along with those showing degraded response inhibition across CIE and time, support the reticular-activating hypofrontality (RAH) model of acute exercise, which posits that heightened arousal during exercise enhances implicit processes, such as response time, but this comes at the expense of explicit, cognitive control processes, which tend to degrade during high-intensity exercise (Dietrich & Audiffren, 2011).

4.3. Discussion of Physiology

As a recap, the scenario was loosely designed as a mission scenario, where first the Soldier baselines their marksmanship performance, then a sustained a high level of aerobic effort during a foot march is performed to reach a location where a maximal exertion effort over obstacles is required, which then leads to a MOUT room clearing task and then a foot march back to home base and another marksmanship follow-on task. Physical performance intensity is an important measure of exertion during Soldier physical performance tasks. Measures of heart rate or percentage of maximum heart rate used by themselves as a measure of exercise intensity has limited application. The ACSM has established more reliable methods for calculating exercise intensity that could be applied in field settings (American College of Sports Medicine, 2010). One method recommended by the ACSM is a measure of the range of heart rate from rest to maximum: a percentage of this range is typically used to establish target heart rates in training as %HRR provides similar intensities as equivalent values of $\%VO_{2max}$ and $\%VO_2R$. However, collection of VO_2 measurements requires technical expertise and portable oxygen sampling equipment that interferes with situational awareness during tasks rendering this type of data collection impractical for multiple subjects in a field environment. The use of %HRR is a practical measure for the field environment due to the fact that the calculation only requires readily available heart rate during rest, maximum heart rate during maximal exertion and heart rate during the relevant exercise activity. The accuracy of a participant's maximal heart rate was enhanced in this study through the use of measured maximal HRs attained during the VO_{2peak} testing for each participant during baseline testing. An alternative but less accurate acceptable method is to calculate the maximal HRs from age-based formulas for participants. Relationships between percentages of heart rate reserve (%HRR), maximal oxygen uptake $\%VO_{2max}$, and oxygen uptake reserve (% VO_2R) have been proposed as being effective for exercise intensity prescription. In a review of experimental studies that investigated these relationships, it was reported that the %HRR was closer to the $\%VO_2R$ than % VO_{2max} (Cunha, Farinatti, & Midgley, 2011).

The %HRR is typically used by exercise physiologists to calculate a range of exercise intensities to improve aerobic fitness during the development of individualized exercise prescription programs. In this study, the %HRR was used to identify the physical performance intensity when the Soldier was completing a set task (i.e. marksmanship, foot march, LEAP obstacles, and MOUT). This allowed for the measurement of the level of exertion that the Soldier was working at and what residual physical capacity the Soldier has available when the task was completed. Practically speaking, for a Soldier the %HRR is a measure of energy reserve left in the tank that then could be used for unexpected demands (i.e. enemy contact). It also afforded the researchers a measure of the exertion level that the Soldier was working at as they completed cognitive tasks which were overlayed on the physical tasks, specific performance tasks of marksmanship, and changes found in biomechanical measures during the foot march. This allows for the analysis of the interaction effects of physical exertion on task performance (March 1 vs March 2, pre-post marksmanship).

4.3.1. Dynamic Marksmanship Physiologic Performance Data

The physiologic measure of %HRR during the marksmanships tasks demonstrated that the goals of this methodology to cause a high level of exertion or fatigue during the 4 h scenario were met and that the Soldier was shown to respond differently to the physical demands while fresh at the start of the scenario and while physically fatigued at the end of the scenario. The results showed a higher %HRR during the post marksmanship task. There were also significant differences with respect to %HRR and CIE condition level. Not surprisingly, the higher the mass the higher the %HRR. However, there was a significant interaction for %HRR response that demonstrated that the Soldier's exertion level during the post-marksmanship testing for the CIE Condition II and III were higher than during the pre-marksmanship for the same CIE conditions relative to CIE Condition I. During the pre- and post-marksmanship tasks, the Soldiers were performing at a mean of 63% and 71% respectively of their %HRR. This indicates that at the end of the 4-h scenario, during the post marksmanship task when encumbered with CIE, the Soldiers only had approximately 29% energy capacity available for additional tasks. The full effect of CIE on a Soldier's energy capacity and ability to conserve energy for other tasks was only demonstrated through the use of the 4-h taxing scenario and a pre-and post-marksmanship task. If the marksmanship task were completed independently when "fresh", then these important interactions and effects of CIE on Soldier performance would be omitted. As shown in the specific results of pre- vs post-Marksmanship dependent measures of shooting performance and the interaction effects of exertion and fatigue level are important considerations when considering the effects of CIE on performance.

4.3.2. Foot March Physiologic Performance Data

Based upon previous research findings for the detection of cognitive effects due to exertion levels, certain criteria for exertion during a foot march were followed (Eddy et al., 2015). These methodological considerations for the foot marches in the scenario were as follows, 1) The distance needed to be long enough to complete the cognitive task requirements, 2) The terrain needed to be challenging enough to tax the situational awareness of the task, and 3) The pace and CIE mass combination needed to raise the level of exertion above 50% of the Soldiers %HRR. Previous laboratory research had shown that exertion above 50% $VO_{2\ peak}$ is needed to elicit cognitive response changes to a go/no go auditory task. All of these design goals were met with this methodology (Eddy et al., 2015).

Overall, during the foot marches the physiologic responses of the Soldiers were not unexpected. As CIE condition's mass increased, the %HRR was increased. However, the designed sequence of foot marches and additional Soldier tasks demonstrated the unique utility of the methodology design. By having the Soldiers' foot march pace controlled and identical between Foot March 1 and 2, the physiological response could be easily evaluated. Specifically, the Soldiers' physiological response while carrying CIE Condition III during Foot March 1 and Foot March 2 was 81% and 83% respectively. This indicates that at the end of Foot Marches 1 and 2 with CIE Condition III, the Soldiers had ~20% physiological capacity in reserve for additional tasks. In addition, during Foot March 1 relative to Foot March 2, the Soldier responded differently to the conditions presented. The CIE Condition I physiologic responses during Foot March 2 were much higher as compared to CIE Condition II, %HRR 53% and %HRR 60%, respectively. This indicated a significant increase in %HRR in the second foot march for CIE Condition I. The Soldiers' physiologic responses during Foot Marches 1 and 2 were different. During Foot March 1, CIE for Conditions II and III the %HRR responses were 76% and 79% respectively. During Foot March 2 for CIE Conditions II and III, the physiologic responses were 82% and 84% respectively. As shown, there was a small charge of HRR response for the higher CIE conditions (Conditions II and III) and this may be due to topping out of physical capacity of the Soldier during the foot march tasks. The Soldier was essentially maxed out and performing close to a physiological level that approached exhaustion. These CIE conditions only left ~20% -30% HRR available for additional tasks. In contrast to this, during the foot march with CIE Condition I, the Soldiers' physiologic response interaction was greater between Foot March 1 and Foot March 2. This may be due to the fact that the light mass of Condition I elicited only an approximate 50% HRR response and the Soldiers had a larger physiologic capacity to adjust to the exertion during Foot March 2.

The design of the team's methodology approach of controlling the foot march pace and mass carried enabled the physiologic responses of the Soldiers to be controlled in a fashion that elicited measurable cognitive changes over time. This approach allows the team to use this foot march design in future research as a tool to measure cognitive responses during a dynamic physical task. Additionally, it is important to note that these foot march loads, terrain, and pace are well within the norms of what is currently required of infantry Soldiers conducting field operations. The measured exertion levels in this study demonstrate that there is a measured detrimental effect on both the physical capacity to do follow on tasks and the required cognitive capability to accomplish required operational tasks.

4.3.3. LEAP Physiologic Performance Data

The LEAP obstacle course in the methodological sequence was used to require the Soldier to physically use a maximal effort mid-way through the scenario. The goal of having the Soldiers perform a maximal effort task over obstacles was achieved. Unlike the %HRR which distinguished among external loads carried on the experimenter-paced task foot march, the %HRR did not vary with load on the self-paced maximal effort LEAP obstacle task. However, in conjunction with completion times, the %HRR provided critical data on soldiers' physical exertion during both tasks. The Soldiers were asked to perform at a maximal level of exertion for all CIE conditions and the study results demonstrated that when properly instructed to do the task they responded with consistent maximal efforts. The %HRR for each CIE condition saw no significant difference between conditions and achieved 91% of HRR. The time of completion of the task was different for all conditions. Thus, the Soldiers in this study were asked and demonstrated performance at a high level of exertion for a longer period of time with the heavier CIE conditions. As indicated earlier in this report, the fighting loads used in this study for CIE Condition II and III are typical of infantry Soldiers. Prolonged physical exertion at 91% HRR (Astrand, 1986) cannot be sustained for extended periods of time and when follow-on Soldier tasks of cognition and marksmanship are required and as this study demonstrates that there is significant degradation of a Soldiers mental, physiologic and performance capacity when completing required follow-on tasks.

4.3.4. MOUT Physiologic Performance Data

The MOUT task Soldiers were required to clear the MOUT building, using short-range marksmanship skills to eliminate threatening targets throughout the facility. Participants were asked to move through the course in an efficient, self-paced manner. The MOUT task focused on accuracy, however. Speed was not emphasized as an important metric. The participants arrived at the MOUT task after completing the maximal effort on the LEAP obstacle course. They were asked to start the MOUT course as soon as possible after the LEAP course. The Maximum %HRR and Mean %HRR for the MOUT course indicated that the Soldiers continued to perform the task at a relatively high percentage of their HRR. This is shown by the max %HRR being 71%, 78% and 81% maximally for CIE Conditions I, II, and III respectively. Their Mean %HRR over the course of the task was 60%, 68%, and 71% for CIE Conditions I, II, and III respectively. There was a significant difference between CIE Condition I when compared to Condition II or III for Maximum and Mean %HRR. There was no significant difference found between CIE Condition II and III for these dependent measures. The levels of exertion demonstrated by the Soldiers indicated an aerobic level of work and that demonstrated they had recovered from the maximal anaerobic level of exertion recorded during the LEAP task. However, CIE Conditions II and III did not allow the Soldier to recover at the same rate as CIE Condition I. On average the Soldiers were performing at an exertion level that allowed for approximately 30-40% HRR capacity to be available. By adjusting their level of exertion, the Soldiers may have afforded themselves the capability to sufficiently complete the level of marksmanship and cognitive tasks without detrimental effects. Cognitive differences were not found during this task and marksmanship metric differences were found to be minimal.

4.4. Discussion of Human Factors Performance

This study's primary objective was to establish a test methodology utilizing an operational scenario to assess the effects of CIE on Soldier performance. Human factors performance was assessed during the simulated marksmanship, LEAP, and building clearing tasks. Shooting performance, movement time, and perceived performance were utilized to assess the impacts of CIE on all aspects of Soldier performance, including human factors.

4.4.1. Dynamic Marksmanship Performance Discussion

The results from the static and dynamic marksmanship tasks indicated some sensitivity to changes in CIE. Increased encumbrance had a great effect on measures of lethality (i.e. precision) and stability for the slow, deliberate shooting style of the static shooting task, yet was not as apparent in the dynamic task where speed was a priority. However, the mobility measures during the dynamic task did show sensitivity to CIE differences.

It is suspected that some of the effects of CIE were dampened by the software zeroing methods during the shooting scenarios. Prior to each trial, the participants were required to software zero the weapon. The potentially dramatic effects from the CIE encumbrance, particularly on accuracy or hit location relative to the target center, were likely negated due to the zeroing process. In operational environments, Soldiers do not zero their sights between every engagement. The difference in their CIE worn during initial zeroing within the safe zone of their base and later engagements outside of the safe zone can be extreme. Therefore, future testing should consider not software zeroing prior to each trial, in order to capture differences in performance due to the CIE encumbrance levels.

Other methodology improvements include the assessment of multiple simulated distances in order to increase difficulty of task. This would help quantify the effects of CIE encumbrance on various operational engagement ranges. Additional target transitions with height variations would also make the methodology more operationally relevant since threats are often identified in a variety of postures and locations (i.e. crouching, standing, in windows or buildings at various heights, etc.). These transitions would help identify CIE interferences across both gross and fine body readjustments to sight picture. Transitioning across a greater angle will also increase sensitivity as it will require greater readjustments. Finally, integrating the static shooting into the dynamic scenario can be accomplished in order to streamline the scenario and capture all measures in a single trial, reducing methodology time for completion.

4.4.2. MOUT Performance Discussion

The results from the MOUT task only indicated CIE effects on timing data (target acquisition and total trial times), not marksmanship. Since this scenario required very close-range shooting, simulating an urban environment, it is not surprising that the hit rate was not impacted by CIE. Extreme encumbrance due to the equipment worn would be needed to see an effect on marksmanship accuracy at such a close range. However, the entire marksmanship process consists of the approach, acquisition, aiming, and engagement of threats. Although the building clearing task was conducted utilizing deliberate tactical movements, the mass and bulk of the greatest encumbrance condition (Condition III) did slow down the Soldiers in moving towards and acquiring each threatening target. Future studies should try to capture the amount and time of bodily exposure to threats during the movement and acquisition phase of marksmanship in the urban environment. This may help quantify the tradeoffs between mobility, lethality, and survivability when assessing the mass and bulk impacts of new CIE items.

Threat order of exposure did change marksmanship performance, but had no interaction with CIE conditions. The "Go" targets after being exposed to "No Go" targets had shorter aiming times and greater probability of hit. This may be a product of the images used, where non-threatening images were very easy to recognize when compared to threatening images. Alternatively, the participants may have anticipated the non-threat proceeding the threat based on an assumption that the test design would not place two threats in sequence and had fewer threats than non-threats, therefore priming the shoot response. Future test design may consider equal number of threats versus non-threats to prevent this type of anticipation or testing bias.

Significant differences seen across most of the marksmanship and timing measures for Sequence 3 could indicate an issue with some of the imagery presented in that set-up. The focus group sessions provided feedback that Sequence 3 had a confusing image that could be interpreted as a threat or non-threat. This could be improved in the future by using a different target discrimination task that is more operationally relevant and consistent across imagery to avoid confusion in test participants.

In addition, the significant differences seen across trial iteration seen in some of the measures indicates that there was possibly a learning effect. Additional practice trials through the actual facility spaces would have helped plateau any learning prior to actual testing. The focus groups expressed concern about the placement of the images on the targets, stating that they were confused at first as to where to shoot (at the image or at the target's center of mass). This initial confusion may have caused some of the differences between the first trial and second or third trials, particularly in the lethality measures.

Improvements for the methodology include the embedment of images or threats into target so that the participants are shooting at the center of mass on target rather than on image. Additionally, the performance measurements for this building clearing methodology could be improved so as to capture the behavioral differences in tactical movement during the building clearing that may be affected by CIE configuration.

4.4.3. LEAP Performance Discussion

The findings indicate that the obstacle course was able to discriminate differences in the conditions at both the individual obstacle level (tunnel, run, ladder/stairs, agility run, casualty drag, windows, bounding rushes, balance beam, crawl, walls) and the cumulative total course times (obstacles only, transitions only, total completion). Whether these differences in performance were due to mass/load, bulk, or design of each condition is not known; it is likely all contributed to the differences in performance to some degree. Subjective comments allow for additional understanding of what aspects of the condition caused degradation in performance. For example, in the case of this study, there were multiple comments regarding the restriction and difficulty negotiating certain obstacles due to the rifleman gear placed on the TAP and restrictions in shoulder movement from the DAPS system in Condition III.

Findings from this study of the timing effects of wearing different equipment configurations through the LEAP course were similar to past LEAP equipment studies. Research conducted by the United States Marine Corps, United States Army, and the Canadian military has found that different CIE configurations resulted in different LEAP completion times (Bossi, Kelly, Wojtarowicz, Jones, & Ducharme, 2014; Brewster, 2014; Dutton & Stryker, 2015; Tack et al., 2012). These teams, along with other researchers, have presented evidence that heavier load configurations can lead to longer LEAP completion times (Bossi, Jones, Kelly, & Tack, 2016; Jones, Sy, Jenkins, DuCharme, & Bossi, 2014; Tack et al., 2012). Other studies using alternative military mission focused tasks have similarly found that heavier load configurations reduced Soldier performance (Peoples, Silk, Notley, Holland, & Collier, 2010).

4.5. Discussion of Subjective Opinions

Overall, other than the lack of protection in combat environments, the participants favored Condition I over II and Condition II over III. This pattern was observed regarding comments and ratings for RPE, fit, comfort, mission performance, mobility, marksmanship, compatibility with mission equipment, and acceptability. The ratings provided degraded with each consecutive condition. In particular, the participants experienced higher exertion, equipment interference, and decreased performance when wearing the more encumbered conditions than the less encumbered conditions. After completing the study tasks, most of the participant feedback consisted of issues regarding the bulk of the loaded conditions. The TAP was commonly mentioned, with participants explaining that the item negatively affected their maneuverability and stability due to its added bulk and front-heavy setup. Feedback specific to Condition III focused on the restriction caused by the ancillary armor, particularly the DAPS, noting that the added bulk was obstructive to movement and hindered their performance while completing the study tasks. The participants' performance was also affected by fatigue, with prior exertion from completing previous tasks noted as a reason for reduced performance.

4.6. Limitations

4.6.1. Limitations of Biomechanics Analysis

The biomechanical performance analysis with IMUs had several important limitations that should be considered when analyzing or citing the presented data. For instance, the IMU sensors that were utilized for this methodology had limited operational range that could have affected some of the outcome measures. Specifically, the accelerometers saturated if accelerations exceeded ±6g, and the reported sampling frequency of all the IMU sensors was only 128Hz. Errors, typically underestimations, in calculated distance travelled by IMUs generally increase as accelerometer g-range decreases. The error is even more pronounced at elevated movement speeds. For the foot march sections of the mission scenario, participants moved at a relatively slow 3mph pace so foot accelerometers rarely saturated. However, for faster activities, such as the sprint and agility run obstacles, the foot accelerometers did experience short duration saturations during foot-strikes. To resolve this issue as much as possible, calculations were taken on a stride-by-stride basis (as opposed to over the whole trajectory) to reduce the integration duration which limited error propagation. Aliasing was also concerning since peaks in acceleration or angular velocity may have been missed during the sprinting and quick cutting maneuvers due to the relatively low sampling rate. That being said, APDM's sensors actually collected raw data at a much higher rate before filtering and down sampling to the sampling frequency that was reported to the user (using proprietary algorithms). If those data were not properly filtered prior to down sampling, errors would certainly accumulate over time for these relatively high-speed activities. Nonetheless, due to the short durations of both the sprint and the agility run, the ultimate influence of this limitation on the calculations was minor.

In addition to error caused by sensor specifications, drift error can grow monotonically over time, which results from numerical integration of small errors in the raw acceleration or angular velocity signal. Kinematic measures that were derived from these raw signals via integration (e.g. orientation, velocity, and position) were subject to drift error. The method of combatting drift error employed by the algorithms of this study was activity or obstacle-specific but generally exploited: 1) short duration integration intervals (e.g. for gait, integration was performed over the duration of each stride), 2) known obstacle dimensions (e.g. foot IMU height must be similar to the beam height when the foot lands on the beam), 3) known movement trajectory constraints (e.g. participants must run near all the flags of the agility course and complete the course in the correct order, and 4) zero velocity updates (i.e. the IMU velocity must be zero at certain times during the obstacle or activity). While these methods were not perfect, the corrected results certainly provided sufficient estimates of kinematics to achieve the goals of this study.

Prior to any post-processing steps to remove any sources of error and prior to data collection, the IMU monitors must be securely attached to each body segment. The data are most accurate when the monitor is attached to a rigid base and must have minimal motion relative to the underlying body segment. However, rigid bases, such as bony landmarks, are not always available, and tight straps may interfere with muscle contraction. The strap, athletic tape, and zip-ties utilized in this study resolved these concerns for the most part. There were only a couple of instances of the tape loosening around the foot IMU, and the sternum IMU slid down the torso on a few participants. If any IMU became loose or shifted, the IMU taping was reinforced or reapplied and the series of calibration motions was repeated. In post-processing, this new set of calibration motions was utilized to define the orientation of the IMUs relative to their respective body segments from the time of tape reapplication to the end of the scenario. The original set of calibration motions was still utilized for the data pertaining to the beginning and onwards until the point in time when the IMU became loose or shifted (assuming this was evident by examining the data). The data were ignored if the data were deemed unsalvageable.

Conducting this experiment outside of a controlled laboratory setting greatly increased the variability of the biomechanics data set. Nevertheless, the outdoor experiment allowed a more operationally-relevant and realistic mission scenario. To reduce the variability, each facet of the scenario was controlled as much as possible. For instance, during the foot march, each participant was required to follow the same path, perform the cognitive tasks at the same time intervals, and remain at a constant pace. The environmental conditions, such as temperature, humidity, soil moisture content, and grass moisture could not be tightly controlled. Additionally, while almost identical paths were followed by all participants during the foot march and LEAP, slight trajectory variability was inevitable. This was particularly evident in the wooded section of the foot march, where participants had to choose the exact paths to take around or over roots, mud, fallen branches, small bushes, and a couple of streams. While these are just some examples, all terrain irregularities and weather conditions affected participant biomechanics to some extent which, increased the variability of the data. These outdoor-related variability issues added to the inherent variability of movement patterns amongst human test participants. With increased variability in the biomechanics measures as a result of outdoor testing, the determination of statistically significant differences between equipment conditions was less likely. While the required study sample size was primarily driven by the power analysis of the cognitive measures, the large number of participants allowed the determination of statistically significant differences for the biomechanics measures between the three equipment conditions despite the increased variation.

4.6.2. Limitations of Marksmanship Analysis

The FN Expert system was designed to be a training aide for shooting. The system was adapted for use in research, by further analyzing the raw output files and aiming data collected by the system. Unfortunately, the system has some limitations for use due to the nature of its design. These limitations include shooting distance. One simulated and actual shooting distance has to be designated prior to scenario execution due to the zeroing process and file writing. Unfortunately, during the active MOUT building clearing scenario, the actual shooting distance to the target varied based on the time and movement of the Soldier through the space. This may have resulted in dropped shots and missing data points. Due to the limitations in how the system records the data, it isn't possible to distinguish between actual missed shots that are off target due to poor aiming and shots that the system failed to record due to the distance and/or angle of the shot.

The FN expert system utilizes an infrared beam and reflectors on the targets. This allows for ease of use and reduced safety risks. However, the system cannot distinguish between targets and simply records sequential shots. This manner of recording causes difficultly in distinguishing between targets during post-processing, particularly when there are many missed shots or shots that failed to record.

4.6.3. Limitations of the Methodology

The equipment (both the items and the placement of gear on the body/equipment) used in a study is chosen to allow standardization, repeatability, data sensitivity, and other research characteristics in addition to matching a "standard" (doctrinal) layout. However, the items and layouts chosen may not reflect the typical items and layouts used by Soldiers/units participating in the data collection. This difference will likely drive their opinions of the study and their performance to some degree. Ideally, future research should seek to use equipment and configurations (e.g., unit "SOP") that match those used by the unit participating in the exercise. However, this often is not possible; when it is not, the participants should be trained/briefed as to the reasons why particular configurations were chosen and why they may differ from what they use in the field.

Some participants considered some study conditions/configurations as too easy or unrepresentative of field conditions. Although (for example) in the present work, some found the ruck march's unloaded condition too easy, the loaded configuration was challenging. The test configurations and conditions were chosen to meet the goals of research and to permit condition differences to be apparent. These choices always need to be balanced and considered along with the tradeoffs they create, one of which may be a difference from field conditions. Again, training the participants in the differences between the research conditions and field operations will be beneficial.

Similarly, the choice of test stimuli (and many other test parameters) must strike a balance between operational realism and test-related requirements such as test sensitivity, test design, and so forth. For instance, the high-level targets in 14-021 were higher than a Soldier would normally encounter, but test design, sensitivity, and equipment concerns led to that height being used. Other than height, the marksmanship parameters were similar to those encountered in the field.

4.6.4. Limitations of Cognitive Analyses

The present findings provide compelling evidence that wearing CIE such as the plate carrier body armor and the IOTV degrades cognitive control processes. Nonetheless, two primary limitations are worth noting. First, the foot marches were performed over the same course, at the same pace, across all individuals. This design choice introduced the possibility that certain blocks of trials could always fall on either relatively easy or difficult terrain, making comparisons across blocks of trials problematic. However, this design also better enabled the project team to compare across conditions, and control physical exertion intensity across participants. Relatedly, although data on heart rate, gait, speed, etc. were collected during the foot march, they were not time locked to the cognitive data, making calculations of associations between physical and cognitive data problematic. Second, the research was carried out under varying environmental conditions of New England spring, summer, and fall, and ambient temperature has been shown to influence cognitive performance. However, temperatures for this study fell well between the cold and heat stress shown to influence cognitive control (Taylor, Watkins, Marshall, Dascombe, & Foster, 2015).

The present findings add to the growing body of literature that shows that sustained physical exertion while wearing CIE impairs cognitive control processes. Like earlier laboratory based studies finding that load carriage during simulated patrol impairs vigilance and response inhibition (Eddy et al., 2015; Mahoney et al., 2007), the present research indicates that such impairments are accentuated in more operationally-relevant scenarios, where CIE loads, variable terrain, and unpredictable temperatures better mimic real-world conditions

5. Conclusion

The objective of this study was to establish a test methodology utilizing an operational scenario for assessing the effects of CIE on Soldier physical and cognitive performance. This objective was accomplished by translating established scientifically based cognitive and physical metrics (which are sensitive to changes in CIE/fatigue) into an integrated, repeatable, field test battery that supports the methodology development. The scenario was designed to have Soldiers perform an operationally relevant and fatiguing set of tasks (e.g., movement to an objective, action on an objective, etc.). Scientists from the NSRDEC Biomechanics and Engineering, Cognitive Science, and Human Factors Teams have established common measures of performance in the form of a Soldier-relevant field test methodology. The methodology included controlled foot marches, LEAP obstacles, and a weapon simulator for marksmanship. A MOUT course was also included within the mission scenario.

The results reported herein detail the test methodology findings. From a cognitive science perspective, findings suggest that performing a foot march wearing CIE such as the plate carrier body armor and IOTV degrades cognitive control processes, primarily response inhibition. From a human factors perspective, the timing portion of the obstacle course was found to be sensitive to the differences in configuration and, even with the hard stops before and after each obstacle, can still be used to assess the effects of equipment on physical performance. For marksmanship, findings suggest that both static and dynamic marksmanship scenarios are necessary to fully assess the effects of equipment on the marksmanship process in its entirety. These scenarios were found to be sensitive to changes in CIE configuration. The MOUT scenario was only sensitive to configuration changes for measures of mobility, but not lethality or decision making.

Subjective opinions consisting of participant ratings and comments were sensitive to the configurations worn and demonstrated that the users had a strong preference for the lower encumbrance configurations across the battery of tasks performed. Additionally, the subjective measures provided insight into the users' experiences by identifying specific reasons for their preferences and also explanations for the performance differences observed.

From a biomechanics perspective, the IMU-derived performance measures generally revealed marked degradations in performance with heavier body-borne loads. This was consistently found during the foot marches and during the LEAP obstacle course. The objective of measuring traditional biomechanical metrics of performance in a field setting were accomplished through this methodology. However, there were a few biomechanical metrics that seemed to be more sensitive to smaller changes in body-borne load, and therefore may be more useful to utilize in future studies. For the foot march, the metrics that seemed to be the most sensitive to small changes in load (as determined by significant differences between equipment Condition II and III) included: PCA pelvis, stride length, standard deviation of mediolateral torso lean angle, and standard deviation of anteroposterior torso lean angle. For the agility run during the LEAP, more sensitive metrics included: speed, stride length, standard deviation of stride width, standard deviation of foot yaw, PCA pelvis standard deviation of anteroposterior lean angle, pelvis mediolateral acceleration at the turns, and pelvis mediolateral tilt at the turns. For the bounding rush obstacle, more sensitive metrics included: duration of each rush, standard deviation of time from stand to prone, and vertical standing velocity. For the balance beam obstacle, more sensitive metrics included: duration, step frequency, stride duration, sacrum mediolateral acceleration RMS, sacrum anteroposterior acceleration RMS, and torso anteroposterior angular velocity RMS. For the windows and wall obstacles, only time to complete revealed significant differences between the two heaviest load configurations.

From the physiologic perspective, practical measurement techniques utilized within this methodology allow for the collection and assessment of important physiologic metrics. These metrics and analysis techniques can be accomplished in the field setting during rigorous Soldier tasks in a non-intrusive manner. This research finds significant outcomes on the detrimental effects of encumbering the Soldier with CIE on physiologic performance during Soldier tasks.

Together, the results suggest that physical and cognitive indices of Soldier performance change, and often degrade, as a function of CIE, and that the present operationally-relevant scenario is sensitive to detect such changes.

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