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A COMPARISON OF TWO COMMERCIAL OFF THE SHELF BACKPACKS TO THE MODULAR LIGHTWEIGHT LOAD CARRYING EQUIPMENT (MOLLE) IN BIOMECHANICS, METABOLIC COST AND PERFORMANCE

Michael LaFiandra
Suzanne Lynch
Peter Frykman
Everett Harman
SPC Hipolito Ramos
Robert Mello

Military Performance Division

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The purpose of this study is to evaluate the effects of an Arc'Teryx internal frame backpack, a Gregory internal framebackpack, and the Modular Lightweight Load Carrying Equipment (MOLLE) and on biomechanics, oxygen consumption andperformance on militarily relevant tasks. MOLLE is an external frame backpack currently fielded by the Marines. TheArc'Teryx and Gregory packs are commercially available backpack systems. Two loads were tested (Fighting = 40 pounds,Approach = 70 pounds) in each of the three backpacks system. Twelve subjects (all of whom were Marines) participated inthe study. The vertical force with which the foot hits the ground at heel strike with Arc'Teryx was about 5% greater than withMOLLE, and about 3.3% greater than with Gregory. For both the Fighting and Approach loads, MOLLE resulted in the greatestforward trunk lean. For the Fighting load, the Arc'Teryx pack was most stable on the back; for the Approach load, the Gregory packwas the most stable. There were no differences in oxygen consumption, heart rate or carbon dioxide production between backpack systems. No differences in marksmanship performance were observed between backpack systems. Additionally, no differences in obstacle course performance were observed between backpack systems in the Fighting configuration. Gregory Approach resulted in a greater time (decrease in performance) to complete the pipe crawl than did MOLLE or Arc'Teryx. MOLLE Fighting took less time to donn than Arc'Teryx and Gregory. No differences in the time to donn the packs were found for the Approach load. Subjects completed the Stand to Prone more slowly with MOLLE Fighting than with Arc'Teryx Fighting. In contrast, subjects completed Stand to Prone more slowly with Arc'Teryx Approach; then with Gregory or MOLLE Approach. Six of the Marines chose Gregory as the best pack. Five of the Marines chose MOLLE as the best pack. None of the Marines chose Arc'Teryx as the best pack.

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TABLE OF CONTENTS

Section | Page

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

On August 14, 2002, the United States Marines Corps presented a Commercial Area Announcement (CAA) soliciting designs for an Improved Load Bearing Equipment (ILBE) system. The Marine Corp System Command (MARCORSYSCOM) determined the top two designs of those submitted from the commercial vendors were Bianchi (Gregory) and Propper International (Arc'Teryx). USARIEM was contacted by MARCORSYSCOM to perform a battery of tests aimed at evaluating these two Commercial off the shelf (COTS) and to compare these packs to MOLLE.

The purpose of this study is to evaluate the effects of the COTS ILBE systems on biomechanics, oxygen consumption and performance on militarily relevant tasks. An additional goal is to compare the two COTS ILBE systems to the Modular Lightweight Load Carrying Equipment (MOLLE) system currently fielded and used by the Marines. Twelve subjects (all of whom were Marines) participated in the study. Biomechanics testing included treadmill walking at 3 mph (1.34 ms^{-1}) with each of the COTS ILBE systems and MOLLE in two different configurations that include a Fighting (loaded with 40 pounds, 18.4 kg) and Approach (loaded with 70 pounds, 31.75 kg) loads. During treadmill walking, kinematic data provided information on the motion of the body segments; kinetic data provided information on the forces exerted on the body; and oxygen consumption data provided information on metabolic cost. Performance measures included a marksmanship task, time to traverse an obstacle course, a 2-mile timed march, and completion of Specific Military Maneuvers (SMMs); these tests were performed while carrying the Fighting (loaded with 40 pounds, 18.4 kg) and Approach (loaded with 70 pounds, 31.75 kg) loads. SMMs included "Stand to Prone," "Prone to Stand," "Donn the backpack," and "Doff the backpack".

The vertical force with which the foot hits the ground at heel strike with Arc'Teryx was about 5% greater than with MOLLE, and about 3.3% greater than with Gregory. For both the Fighting and Approach loads, MOLLE resulted in the greatest forward trunk lean. For the Fighting load, the Arc'Teryx pack was most stable on the back; for the Approach load, the Gregory pack was the most stable. There were no differences in oxygen consumption, heart rate or carbon dioxide production between backpack systems. No differences in marksmanship performance were observed between backpack systems. Additionally, no differences in obstacle course performance were observed between backpack systems in the Fighting configuration. Gregory Approach resulted in a greater time (decrease in performance) to complete the pipe crawl than did MOLLE or Arc'Teryx. MOLLE Fighting took less time to donn than Arc'Teryx and Gregory. No differences in the time to donn the packs were found for the Approach load. Subjects completed the Stand to Prone more slowly with MOLLE Fighting than with Arc'Teryx Fighting. In contrast, subjects completed Stand to Prone more slowly with Arc'Teryx Approach; then with Gregory or MOLLE Approach. There were no statistically significant differences on any of the other SMMs.

Six of the Marines chose Gregory as the best pack. Generally, the Marines liked the overall comfort of the pack and, specifically, the waist belt and donning handles.

Negative comments for Gregory included too many straps, the pack was too tall, and attaching the Fighting load made the pack too large from front to back. Five of the Marines chose MOLLE as the best pack. The Marines liked the external frame, thought MOLLE had the best clearance through the obstacles and liked the pack's modularity. However, several of the Marines commented the external frame pack "dug" into their arm and caused bruising while trying to complete the obstacle course. None of the Marines chose Arc'Teryx as the best pack. While there were positive comments, the Marines disliked the height of the Approach pack (it interfered with the helmet) and found the pack to be uncomfortable when wearing it with body armor.

INTRODUCTION

Journal articles cited in this report were located via several MedLine searches, the last of which was conducted in September 2002. Technical reports and military laboratory work cited in this report were located via a Defense Technical Information Center (DTIC) search for related technical reports (search AML50D) and work units (search SML54E) performed in September 2002 using various combinations of the keywords “backpack” and “load carriage.”

Previous research has shown differences in Ground Reaction Forces (GRF), lower limb joint kinematics (6, 10, 15, 17, 18), and metabolic cost between backpack systems, even when the backpacks’ masses are comparable (3, 4). These differences have been attributed to differences in backpack design, such as center of mass (COM) location. For instance, changes in backpack COM position alter trunk flexion (increase forward lean), thereby influencing the motion of the trunk and lower leg segments and in turn, affecting GRF. Research has also shown maintaining a COM location that is high and close to the body results in a decrease in metabolic cost, and lower limb joint reaction force (12). Quantifying the changes in kinetics and kinematics that may be associated with the different COTS ILBE Systems and MOLLE may provide insight into which backpack will result in the least potential for injury associated with increases in GRF.

GRF is a measure of the force exerted by the foot on the ground in all three planes during gait. Knowledge of GRF enables a researcher to calculate joint reaction forces and torques and thus is important to biomechanical analyses. A force plate treadmill system was designed by the biomechanics team at USARIEM, which specified the requirements of the force plate system and treadmill to the engineers at AMTI (Watertown, MA 02744). AMTI built the integrated force plate treadmill system (FPTM) that is capable of measuring GRF in three planes during walking. Data are sent from the force transducers in the treadmill to a dedicated computer, which also receives information about the treadmill speed and incline. Because subjects walk at a constant speed for several minutes at a time on a treadmill, they reach steady state, a condition necessary to accurately measure oxygen consumption. The FPTM will allow large volumes of biomechanics data to be collected quickly, resulting in greater efficiency of data collection, and allow for oxygen consumption and joint reaction force data to be collected simultaneously. In addition, the use of the treadmill will provide a mechanism by which all subjects can be exposed to the exact same protocol.

The forces exerted between the foot and the ground are only one variable that may be influenced by the design of the backpack. Another variable may be the motion of the backpack in relation to the body (3, 4). Excessive backpack motion may result in an increase in the magnitude, timing and variability of forces exchanged between the backpack and the carrier, which in turn, may require an increase in muscle force to control the motion of the backpack (11, 13). For instance, the small muscle groups of the back act in supporting and stabilizing roles during load carriage; if the motion of the backpack is unstable, these muscles may be placed under greater strain (1). One consequence of increases in muscle force may be an increase in muscle soreness. In addition, excessive motion of the backpack may serve to bounce or perturb the motion of the trunk, thereby resulting in a decrease in stability during walking, and an increase in the potential for falls (11).

Changes in backpack design are additionally associated with differences in performance on militarily relevant tasks, such as time to complete an obstacle course. Harman et al., (3, 4) showed MOLLE was associated with an increase in time to complete an obstacle course (compared to a competing backpack design); this was likely due to MOLLE having a larger front-back dimension than other designs. The larger front back dimension resulted in interference between MOLLE and some of the obstacles. Interference between the load carriage system, the helmet, and the body armor has also been a problem. An after action report from Afghanistan (2) illustrates an incompatibility between the ceramic plates in the ballistic vest, the Kevlar helmet and the All Purpose Load Carrying Equipment (ALICE) rucksack. Simply stated, the three rigid materials (ceramic in the body armor, the metal ALICE frame, and the Kevlar helmet) prevented the soldiers from moving their head when all three were worn at the same time and the soldier was in the prone position. This resulted in soldiers removing the ceramic plate from the body armor, and consequently increasing their risk of injury if fired upon. Further performance testing prior to the procurement of these three systems would have alerted designers to this incompatibility.

Common performance measures used in the evaluation/comparison of backpack systems include a 2-mile timed march, obstacle course traversal, time to complete Specific Military Manuevers (SMMs), and marksmanship (3, 4). These tasks were chosen because they are designed to simulate battlefield activities that may be affected by load carriage. The obstacle course traversal, two-mile timed march and SMMs are timed tasks; the longer it takes the volunteer to complete the task, the lower the score. Previous backpack comparison studies have compared the effects of backpack design on obstacle course performance and on the 2-mile timed march in isolation of each other. This allowed the researchers to report the effect of each backpack on the time to complete each of the tasks individually. For instance, Harman has shown differences in 2-mile timed march performance between backpack designs (weights similar to what we will be testing) are on the scale of 14-19 seconds. Marksmanship is scored by hits/misses on targets of varying distances. Aside from information on performance, the obstacle course and marksmanship task may additionally provide information on incompatibilities between the ILBE systems, the Kevlar helmet and the ballistic vest.

The purpose of this research is to evaluate the effects of two COTS backpacks on biomechanics, oxygen consumption during treadmill walking, and on soldier performance on tasks such as marksmanship, obstacle course performance, SMMs and a 2-mile timed march, and additionally to compare these two COTS designs to MOLLE.

METHODS

RESEARCH VOLUNTEERS

Twelve healthy male subjects participated in the biomechanics, SMMs and Weaponeer data collection. Eleven of those twelve also participated in the obstacle course/2-mile timed march data collection. All subjects were recruited from active duty Marines. Marine Corps System Command (MARCORSYSCOM) assisted in recruiting potential subjects. Only potential subjects over 120 pounds, between the ages of 18 and 35, and that were physically fit (as measured by successful completion of the Marines Physical Fitness test within the previous 6 months) were accepted as volunteers. Subjects had no history of back problems or known current injuries or defects to bones or joints, including herniated intervertebral discs or previous orthopedic injuries that limit the range of motion about the shoulder, hip, knee or ankle joint. Prior to participation, subjects gave informed consent and signed a Volunteer Agreement Affidavit (Natick Form 1487)

The ILBE is being developed as the load-bearing ensemble for the Marine Corps' infantry forces. At the time of this study, Federal law prohibits females from serving in ground combat units and it also prohibits them from holding ground combat military occupational specialties. The initial, primary user of the ILBE will be the infantry Marine. The focus of the Marine Corps' effort to acquire a new ILBE is on a product that meets the needs of infantry Marines, who by law are solely male. Consequently, testing females was not of interest and would not provide useful information to the Marines. Thus, females were not tested.

The investigators have adhered to the policies for protection of human subjects as prescribed in Army Regulation 70-25, and the research was conducted in adherence with the provisions of 45 CFR Part 46.

<u>Research Volunteer Briefing</u>

The principal investigator conducted informed consent briefings to explain the study protocol, associated risks, safeguards to be employed to minimize risks, direct benefits and to answer questions related to participation in the study. Informed consent was obtained from those who chose to volunteer.

SITE OF TESTING AND TRAINING

Biomechanics, marksmanship and SMM data were collected in the Center for Military Biomechanics, located in Building 45 of the U.S. Army Natick Soldier Center, Natick, MA. Physical performance data were collected at the Clothing and Individual Equipment Fightability Course, located at U.S. Army Soldier Systems Center's Military Housing Area, Hudson, MA.

STUDY DESIGN

Prior to data collection, anthropometric measures of hip and shoulder width were taken. Body mass and height were measured using a balance scale.

There were two loads tested; these were designed to replicate a Fighting and an Approach load. Subjects wore Interceptor Body Armor with the ceramic plates during all of the testing. Because neither of the two COTS included a Fighting load carrier (FLC), the subjects wore the FLC designed for MOLLE during all of the testing. Each subject wore their own FLC, which they brought with them from their active duty station. The FLC was fitted to the subject per manufacturer's specifications. The FLC was loaded the same way for all the packs (MOLLE, Gregory, Arc'Teryx) in both configurations (Fighting and Approach); the FLC was loaded with six correctly weighted M16 magazines and 2 demilitarized fragmentation grenades. Additionally, the volunteers were asked to wear Interceptor Body Armor with the ceramic plates installed in the front and back pockets. The body armor weighed approximately 25 pounds.

The load added to the ILBE in the Fighting configuration was 40 pounds minus the weight of the body armor and the weight carried in the FLC. The load added to the ILBE in the Approach configuration was 70 pounds minus the weight of the body armor and the weight carried in the FLC. According to the Marine Corps Combat Readiness Evaluation System for Infantry Units, a Marine in the dismounted environment is expected to be able to carry a load of up to 72 pounds for 20 kilometers (Department of the Navy, 2000). Because we were comparing backpack systems, it was important that the weight added to each backpack was the same; consequently, the weight that the volunteers carry for each backpack system was slightly different (due to differences in the unloaded weight of the individual COTS ILBE systems). Table 1 details the weight of each loaded pack. The total weight of each system is the weight carried in the pack + the weight of the Interceptor Body Armor (with ceramic plates) + the weight of the ammunition carried on the FLC.

Table 1: Weights of the backpacks as tested.

	MOLLE		Gregory		Arc'Teryx	
	In pack	Total	In pack	Total	In pack	Total
Fighting	14.0 (lbs)	**40.0** (lbs)	13.9 (lbs)	**39.9** (lbs)	14.0 (lbs)	**40.0** (lbs)
Approach	47.8	**73.8**	44.2	**69.2**	45.9	**71.9**

COM location will affect the results of the biomechanics, oxygen consumption and performance testing (12). Because it is unknown how each rucksack will be packed in the field, the rucksacks in this study were loaded consistently loaded. To load the backpacks, we assumed the Marine would pack heavier items (for instance the radio, batteries, MREs etc.) near the top of the pack, and lighter items near the bottom (for instance the sleep system). Consequently, the packs were loaded such that the COM was 2/3 of the way from the bottom of the pack to the top of the pack, as close to the carriers back as possible, and in the mid-sagittal plane. After loading the Approach packs, we added 5 pounds of water (in a Camelback®) as high as possible inside the pack. If there was a hood pocket, the Camelback ® was placed in the hood. Figure 1 illustrates the position of the COM for each of the packs in both the Fighting and Approach conditions.

Figure 1: Photographs of Approach Loads with COM marked

MOLLE

Gregory

Arc'Teryx

DATA COLLECTION

Biomechanics Data Collection

The volunteers reported for biomechanics data collection sessions wearing shorts, a T-shirt, socks and combat boots. This was different from the other tests (in which the volunteer was asked to report wearing Battle Dress Uniform) because the reflective markers used for motion capture need to be taped directly to the volunteer's skin. Because the helmet interferes with the placement of the reflective markers on the head, the subjects did not wear a helmet during Biomechanics testing. Reflective markers were placed on the subjects body at the fifth metatarsal head, ankle, knee, hip, shoulder, elbow, wrist, and side of the head, and three points on the backpack.

During one of the biomechanics data collection sessions the subjects walked on the treadmill at 3 mph (1.35 $m \cdot s^{-1}$) with both COTS ILBE systems and MOLLE in the Fighting configuration. In the other biomechanics data collection session the subjects walked on the treadmill at 3 mph (1.35 $m \cdot s^{-1}$) with both COTS ILBE systems and MOLLE in the Approach configuration. Additionally, in one of the biomechanics data collection sessions, subjects walked on the treadmill at 3 mph (1.35 ms^{-1}) with no backpack. The order of backpack conditions was balanced across volunteers. While walking on the treadmill, the subjects carried a mock M-16 at port arms. Several days before the first biomechanics data collection session, the subjects reported to the lab to be familiarized with treadmill walking and the lab procedures.

The subjects wore a Polar Heart Rate monitor chest strap and accompanying wristwatch for all backpack conditions. Oxygen consumption was monitored while walking. The volunteer wore a face mask connected by a flexible hose to a ParvoMedics (Salt Lake City, UT) TrueMax 2400 metabolic measurement system, to monitor oxygen uptake, and display and print oxygen uptake every 30 seconds. The volunteers were given approximately 6 minutes to reach steady state oxygen consumption. After the subject reached steady state oxygen consumption, cameras captured the location of the reflective markers on the volunteer's body. Force plates in the treadmill captured information about the GRF during these strides. The cameras and force plates collected data for 30 seconds, yielding approximately 25 strides of data. Oxygen consumption data was recorded for 2 minutes after the subject has reached steady state oxygen consumption.

Physical Performance Data Collection

The physical performance data collection session included traversing an obstacle course, traversing a Military Operations in Urban Terrain (MOUT) course, and completing a timed 2-mile road march. For all conditions, subjects completed all physical performance data collection wearing BDUs, combat boots, Interceptor body armor (including ceramic plates) and Kevlar Helmet. A mock M16 was slung during traversal of obstacles requiring two hands; otherwise the weapon was carried at port arms.

The two COTS ILBE systems and MOLLE in the Fighting and Approach configurations were tested, resulting in a total of six configurations to be tested. Data were only collected on one configuration per data collection session, and there were at least 2 full days between Physical Performance data collection sessions; each volunteer participated in no more than two Physical Performance data collection sessions per week. The order of backpack configurations was balanced across subjects. Subjects wore the Interceptor Body armor with ceramic plates and the loaded MOLLE FLC during all of the testing.

Previous backpack comparison studies have compared the effects of backpack design on obstacle course performance and on the timed 2-mile road march in isolation of each other. This allowed the researchers to report the effect of each backpack on the time to complete each of the tasks individually. For instance, Harman (3, 4) has shown differences in timed 2-mile road march performance between backpack designs (weights similar to what we will be testing) is on the scale of 14-19 seconds. It can be argued that differences in backpack design that elicit a 14-19 second difference in time to complete a timed two-mile road march are not operationally relevant. The current study is designed not only to test the effect of each ILBE system on the time to complete the obstacle/MOUT course and the 2-mile road march separately, but to provide additional information on the effect of completing the timed two-mile road march on obstacle/MOUT course performance. This will be accomplished by asking each volunteer to complete the obstacle/MOUT course, 2-mile timed march, and then immediately repeat the obstacle/MOUT course. Essentially, the first run through the obstacle course and MOUT course will be a pre 2-mile road march measure of performance, while the second run through the obstacle course will serve as a post 2-mile timed march measure of performance. This will provide information on the effect each ILBE system had on obstacle/MOUT course performance decrements associated with a timed 2-mile road march, thereby better simulating what Marines may experience in the field.

The obstacle course is outdoors and set up on level ground (APPENDIX A). The outdoor obstacle course includes the following: 8.5 m long tire run with 20 tires; 6.1 m long approximately 1 m diameter pipe laid horizontally in the ground; 12.7 m long high crawl space constructed of wood 86.4 cm off the ground; a 12.7 m long low crawl space constructed of wood 61.0 cm off the ground; a 10.0 m long zig-zag enclosed passageway constructed of wood; and a 8.5 m long staggered arrangement of vertical poles alternating to form a serpentine path. The MOUT course is situated in a two-story building immediately adjacent to the obstacle course. The layouts of both floors of the building are similar, consisting of a central corridor with rooms lining both sides. The corridor and the rooms are empty of furnishings. The building is equipped with interior lighting. The volunteers followed a route that included exterior stairs, exterior doors, interior doors, 15 interior steps, interior ship hatch opening, and interior window openings.

One subject pulled a muscle, and another subject complained of shin splints after the first day of data collection. To reduce the potential for further injuries, the subjects were required to complete 10-15 minutes of stretching and warm up before data collection for the remaining data collection sessions. During data collection, the experimenter helped the volunteer donn one of the experimental backpacks. The volunteer walked around the course for up to 2 minutes to make sure all adjustments to the backpack are made properly. After assuring the backpack was properly adjusted, the volunteer completed the obstacle course/MOUT course, timed 2-mile road march and obstacle course/MOUT course again as fast as possible.

Times to complete each of the 14 obstacles in the obstacle/MOUT course, the 2-mile timed march, and each of the 14 obstacles on the second pass through the obstacle/MOUT course were measured individually using electronic timing devices (Brower Timing Devices, Salt Lake City, UT) placed along the course. Video cameras were also used intermittently to record volunteers' activities as they traverse the course.

The volunteers completed a questionnaire regarding experiences on the obstacle/MOUT course and timed march, including the difficulties encountered negotiating the obstacles and the level of body discomfort or soreness attributable to the load-carriage equipment used on that run. A copy of the questionnaire is presented in Appendix B.

SMMs Data Collection Session

The subjects reported for SMM data collection wearing BDU and combat boots. During a practice session, the volunteers were given instruction on how to perform discrete actions associated with field maneuvers (SMMs). During data collection, the subjects performed the same tasks that were practiced in the training session, these were: "Stand to Prone", "Prone to Stand", "drop and disencumber" and "Donn the backpack" with each of the two COTS ILBE systems and MOLLE in the Fighting and Approach configurations (6 total conditions per data collection session). Subjects wore the Interceptor Body armor with ceramic plates and the loaded MOLLE FLC during all of the testing, and were instructed to complete the SMMs as quickly as possible. To execute the "Stand to Prone" the volunteer was asked to walk at approximately 3 mph while carrying a mock M16 rifle. At a verbal sign from the experimenter, the volunteer dropped to a prone position on a mat and shouldered the weapon. To execute the "‘Prone to Stand", the volunteers started in the prone position (with the weapon shouldered). At a verbal sign from the experimenter, the subject jumped to standing position. To execute the "drop and disencumber"’ the volunteer was asked to walk at approximately 3 mph while carrying a mock M16. At a verbal sign from the experimenter, the volunteer removed the rucksack and dropped to the ground. To execute "Donn the backpack" the volunteer started in the standing position with no rucksack. With a verbal sign from the experimenter, the volunteer picked up the rucksack, put it on, and adjusted the straps as needed. The volunteers completed 3 trials of each of the SMMs for each backpack condition to be tested. This resulted in a total of 36 trials (3 trials x 3 configurations x 4 SMMs). Time to complete each SMM was recorded by an experimenter with a stopwatch during data collection. The order of backpack configurations and SMMs performed was balanced across volunteers.

Weaponeer

The Weaponeer Rifle Marksmanship Simulator is a training device used by the U.S. Army in its basic rifle marksmanship training courses, and is familiar to most Army soldiers. The Weaponeer utilizes a modified M16 rifle that simulates the recoil and sound of firing. It presents a variety of stationary and pop-up targets. The Weaponeer permits evaluation of both the speed-accuracy component, (i.e., accuracy of hitting rapidly appearing pop-up targets) and the variability component, (i.e., tightness of the shot group) (7). Soldier performance on the Weaponeer has been shown to be predictive of live fire performance on the rifle range (16), and has been used successfully at USARIEM to assess soldier performance under various operational and environmental conditions (8, 9).

Each volunteer was given marksmanship instruction and daily practice for five sessions on the Weaponeer Rifle Marksmanship Simulator. This amount of training was chosen to minimize the effect of learning during the study. Training and practice was conducted using the same methodology as in previous USARIEM studies (9). The volunteers were asked to report wearing BDUs and combat boots. Volunteers trained in the standing-foxhole supported, the prone, and the kneeling positions. These are the same positions that the volunteers were in during the actual testing. After the first two training sessions, the volunteers completed marksmanship tasks while wearing body armor (including the ceramic plates), a Kevlar helmet and the helmets. Each training sessions consisted of (a) practice shooting at the 25 m zeroing target with and without sandbag support; and (b) practice shooting at 32 pop-up targets (at simulated distances of 75, 150, and 300 meters), with sandbag support. A trainer closely observed each volunteers firing technique. Appropriate feedback and instructions were given to improve and optimize their shooting proficiency.

Volunteers also practiced RFT (Rapid Firing Test) shooting procedure during each training session. During the RFT, the volunteer was required to fire at twelve quick presentations of the 175 and 300 m targets. Each randomly presented target was up for only two seconds (compared to six seconds under the previous training procedure), so quick, accurate aiming and firing is important to score 'hits'. About sixty seconds was required to complete one round of twelve targets. This test is repeated two more times in the RFT procedure. Late shots and misses were recorded in addition to hits.

During the actual testing, the volunteers were asked to complete marksmanship tasks while wearing body armor with the ceramic plates and a Kevlar helmet. The subject was allowed a single warm-up round of 12 targets at the beginning of each testing session, and then completed the RFT as they did in the practice sessions. During the RFT, the volunteer was required to fire at 12 quick presentations of the 175 and 300 m targets. Each randomly presented target was present for 2 seconds. This test was repeated two more times in the RFT procedure (three repetitions for each pack, configuration and posture). The volunteer wore the same backpack and configuration but would complete the RFT for each of the different firing postures during the each data collection session. In total, the volunteers were asked to complete the RFT while wearing each of the COTS ILBE systems and MOLLE in the Fighting and Approach configurations, for a total of 6 sessions of Weaponeer data collection. The order or backpack systems, backpack configurations and firing postures were balanced across subjects.

DATA ANALYSIS

Force Plate Treadmill/Gait Kinetics

The FPTM will provide 6 continuous voltage output signals corresponding to force in three orthogonal directions (x, y, z) for each force plate. All six output channels of the force transducer will be connected via wires to the analog inputs of a dedicated computer. The voltages at each input channel will be converted at the rate of 1000 Hz to digital values and stored in computer data files. Factory-provided calibration factors will be used to convert the raw data into actual forces. Custom written software (patent pending) was used to convert the data from the treadmill into usable data. The treadmill provides information on the forces and torques exerted on the front plate and back plate; the custom written software translates these data into information on the forces exerted on the right foot and left foot.

Gait Kinematics

Images of the volunteers walking with SLCS and MOLLE were collected at 100 Hz by 7 cameras using the Qualisys motion analysis system. Before each testing session, reflective markers were placed, using double-sided adhesive tape, on the right side of the body over the fifth metatarsal head, ankle, knee, hip, shoulder elbow, wrist, and side of the head, as well as at three points on the backpack. The motion analysis system only measures the position of the reflective markers in three dimensions. The Qualisys hardware and software will produce files containing histories of the 3D coordinates of each reflective marker. Custom-written software, based on the methods of Winter (19), and used in previous load carriage studies (5, 12), will process the data files to produce histories of numerous kinematic variables describing the volunteer's posture and gait as well as the three-dimensional linear and angular accelerations of the pack. The custom written program will also determine lower limb joint reaction forces and torques, as well as ground reaction force in three orthogonal directions. Other variables descriptive of the curve shapes were calculated for statistical comparisons.

The records of the various kinetic and kinematic variables will be processed to produce variables for statistical analysis. This was done by determining minima and maxima of each variable and the times of occurrence as percent of stride. Averages of variables over the complete stride were also determined when appropriate.

Oxygen Uptake

Oxygen uptake was measured using a ParvoMedics (Salt Lake City, UT) TrueMax 2400 metabolic measurement system, which monitored oxygen uptake, and displayed and printed oxygen uptake every 30 seconds. The rate of oxygen consumption was expressed both in absolute terms (L/min) and relative to the individual's body mass (ml/kg/min).

Heart Rate

Heart Rate data were monitored during the Biomechanics data collection sessions using a Polar Vantage NV Heart Rate Monitor. This system consists of a wristwatch and chest strap. The chest strap contains a transmitter that senses heart rate, and sends information about heart rate to the wristwatch. Heart rate data were written on a data collection sheet in 30-second intervals during the time oxygen consumption is being measured.

Weaponeer

The Weaponeer provided a print out of the test results that contains information on hits, misses and late shots for both the 175 M and the 300 M target separately. For the purpose of these analyses, late shots were considered misses. The information from the print out was used to calculate the proportion of hits to the total number of shots. A proportion of 1 indicates all shots hit the target, while a proportion of 0 indicates none of the shots hit the target.

Obstacle Course

As the subject traverses the obstacle course, the time to complete each obstacle was sent from the individual timing gates near the obstacles to a central, hand-held timer. A research assistant recorded the time taken for each obstacle from the hand-held timer onto a data collection sheet, and then entered the data into a computer. The time to complete the 2-mile march was measured with a standard stopwatch and entered in a computer.

Specific Military Manuevers SMMs

The time to complete each military maneuver is measured using a standard stopwatch. One research assistant recorded all of the times for the first data collection session; a second research assistant recorded the times for the remaining data collection sessions (sessions two thru six). The times to complete the SMMs were recorded on data collection sheets and entered into a computer.

Statistics

A 3x2 analysis of variance (ANOVA) with repeated measures was used to test for main effects of system (MOLLE, Gregory, and Arc'Teryx) configuration (Fighting and Approach) and system * configuration interactions on gait biomechanics, oxygen consumption, heart rate and performance (SMMs, and obstacle course). Alpha was set to 0.05 for main effects and interaction effects. The effect of configuration is not of interest in this study. The results for the configuration comparison will be reported; however, these results will not be elaborated upon. If there was a significant main effect of system or a significant system * configuration, further analysis was performed. Focused analysis testing for differences between systems (MOLLE, Gregory and Arc'Teryx) within each configuration (Fighting and Approach) was conducted using an ANOVA with repeated measures testing for main effects of system within a configuration. If a main effect of system was determined, Duncan post hoc was performed to determine specifically which system(s) is different from the others. Due to the number of comparisons in the post-hocs, alpha was set to 0.0167 (14).

Statistical analysis of the Weaponeer data was a two-step process. In the first step, a 3x2 analysis of variance (ANOVA) with repeated measures was used to test for main effects of backpack system (MOLLE, Gregory and Arc'Teryx) and firing posture (standing, kneeling and prone). Alpha was set to 0.05. If a there was a significant main effect of system or a system * firing posture interaction, the second step was to perform a single factor analysis of variance (ANOVA) with repeated measures to test for differences in marksmanship performance between load carriage systems (2 COTS ILBE and MOLLE) in each firing posture and in each backpack configuration. Due to the number of comparisons, alpha was reduced to 0.0085 for the second step of these analyses. The 175 M and 300 M data were analyzed separately (14).

RESULTS

BIOMECHANICS

A total of 135 biomechanics variables were calculated that describe the kinematic (motion) and kinetic (forces) effect each backpack and each configuration has on the subject. While all of these variables are important for determining the effect each backpack has on the subject, only the variables in which there was a significant main effect of backpack system (MOLLE vs Gregory vs Arc'Teryx) or a significant system * configuration interaction will be reported. The results of all of the statistics performed on the entire biomechanics dataset can be found in Appendix C.

Biomechanics: Gait Parameters

While there was no significant main effect of backpack system on stride length or stride length / height, there was a significant system*configuration interaction effect (Table 2).

Table 2: P-Values for Main Effects and Interactions for Gait Parameters

	Main Effects		Interaction
	System	Configuration	System* Configuration
Stride Length	0.2232	0.6830	0.0327
Stride Length/Height	0.2173	0.6656	0.0349

P-Values greater than 0.05 indicate there is no statistical difference between backpack SYSTEM, between Configurations, or there was no SYSTEM*Configuration interaction for that specific comparison.

For the Fighting load, subjects had the longest stride length while carrying the Gregory pack; this was significantly greater than their stride length while carrying MOLLE Fighting or Arc'Teryx Fighting (Figures 2 and 3, Tables 3 and 4). No statistically significant differences were found between MOLLE Fighting and Arc'Teryx Fighting.

In contrast, in the Approach load, subjects had the longest stride length while carrying the MOLLE pack; this was significantly greater than their stride length while carrying Gregory Approach or Arc'Teryx Approach (Figure 2 and Table 3). No statistically significant differences were found between Gregory Approach and Arc'Teryx Approach.

Figure 2: Stride Length

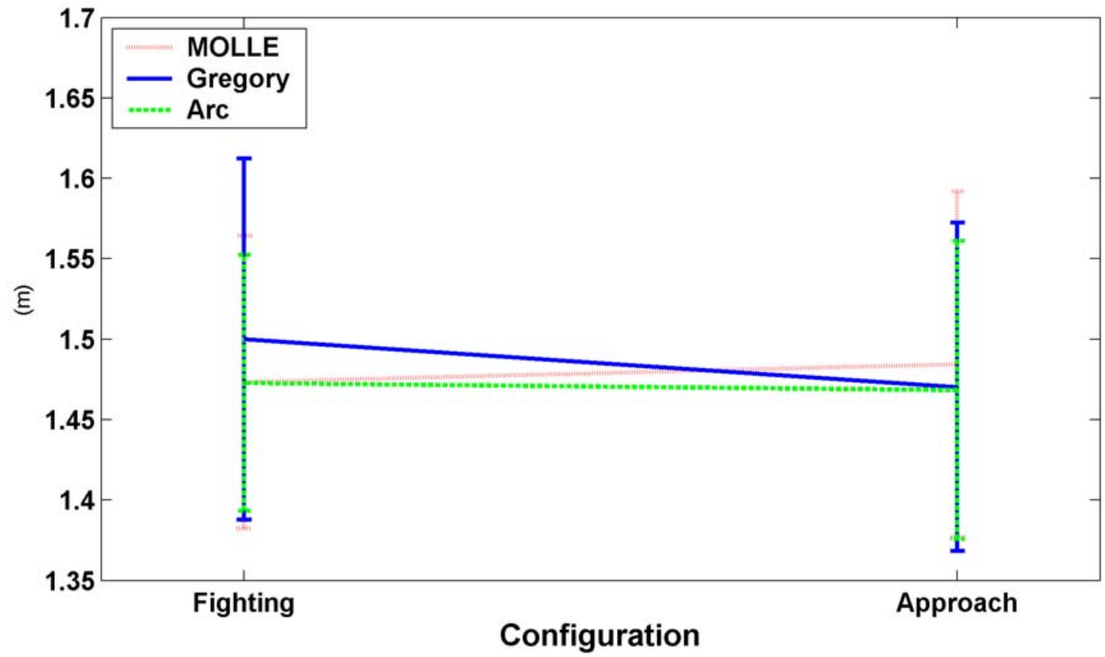


Table 3: Stride Length #

	Fighting	Approach
MOLLE	1.473 B (m)	1.484 A (m)
	(0.091)	(0.107)
Gregory	1.500 A	1.470 B
	(0.112)	(0.102)
Arc'Teryx	1.473 B	1.468 B
	(0.08)	(0.093)

# indicates statistically significant system*configuration interaction
Within a Configuration Packs with same letter are not Statistically Different
Means +/- Standard Deviation

Figure 3: Stride Length/Height

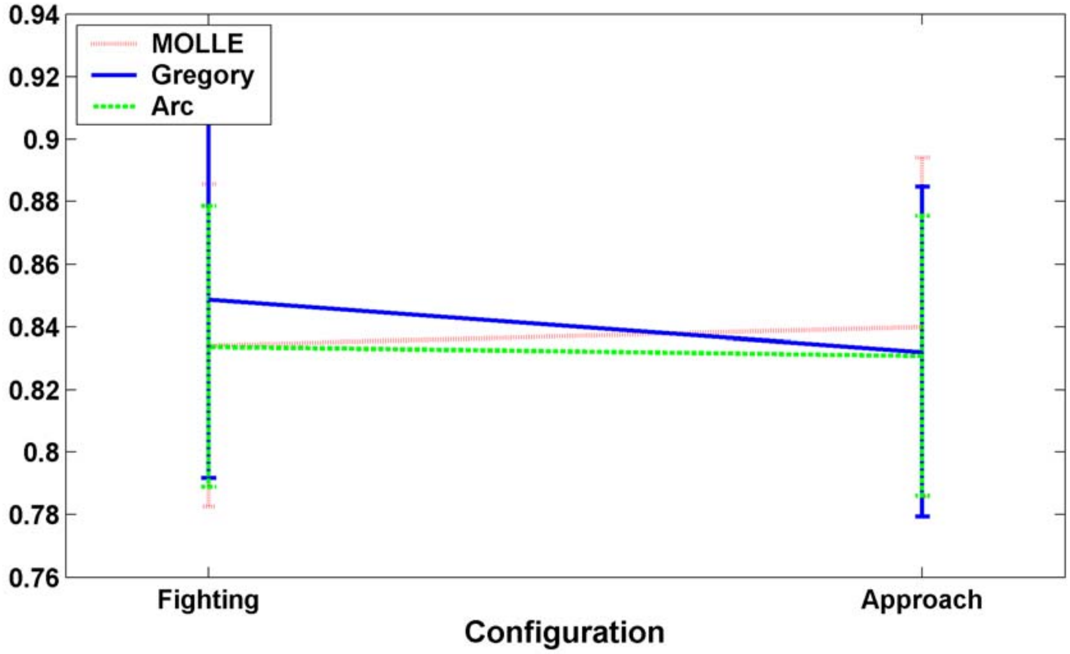


Table 4: Stride Length/Height #

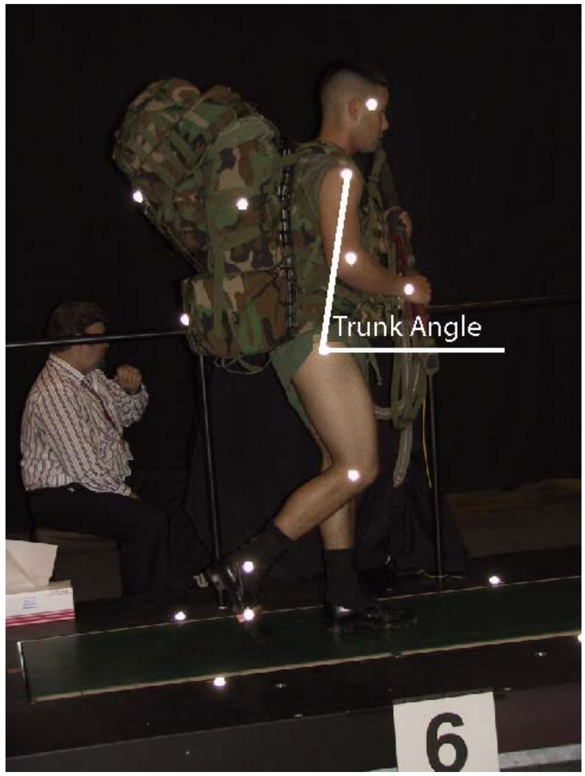
	Fighting	Approach
MOLLE	0.834 B	0.840 A
	(0.052)	(0.054)
Gregory	0.849 A	0.832 B
	(0.057)	(0.053)
Arc'Teryx	0.834 B	0.831 B
	(0.045)	(0.045)

# indicates statistically significant system*configuration interaction
Within a Configuration Packs with same letter are not Statistically Different
Means +/- Standard Deviation

Biomechanics: Joint Kinematics

Trunk angle is a measure of the forward lean of the trunk while walking (Figure 4); a trunk angle of 90° represents completely vertical posture (no forward lean, the subject is standing completely upright). As the subject leans forward, the trunk angle measurement decreases toward 0. A trunk angle of greater than 90° occurs if the subject is leaning slightly backwards. Backward leaning may occur just before heelstrike when the leg is swinging forward, and the hip is slightly in front of the shoulder. Trunk range of motion is the maximum trunk angle minus the minimum and represents the change in forward lean during the stride.

Figure 4: Trunk Angle Defined



There was a significant main effect of backpack system and a significant system*configuration interaction on minimum trunk angle (Table 5). The minimum trunk angle represents the trunk angle when the subject has the greatest forward lean. For both the Fighting and Approach loads, there was the greatest forward trunk lean (trunk angle closest to 0) with MOLLE. This was significantly greater than with Gregory or Arc'Teryx. In the Fighting configuration, Arc'Teryx had a significantly greater forward trunk lean than Gregory. In contrast, in the Approach configuration, Gregory resulted in a greater forward trunk lean than Arc'Teryx (Figure 5 and Table 6).

Table 5: P-Values for Main Effects and Interactions for Trunk Angle Variables

	Main Effects		Interaction
	System	Configuration	System* Configuration
Minimum Trunk Angle	0.0097	0.0001	0.0165
Maximum Trunk Angle	0.2125	0.0001	0.0287
Trunk Range of Motion	0.0004	0.0013	0.7334

P-Values greater than 0.05 indicate there is no statistical difference between backpack SYSTEM, between Configurations, or there was no SYSTEM*Configuration interaction for that specific comparison.

Figure 5: Minimum Trunk Angle

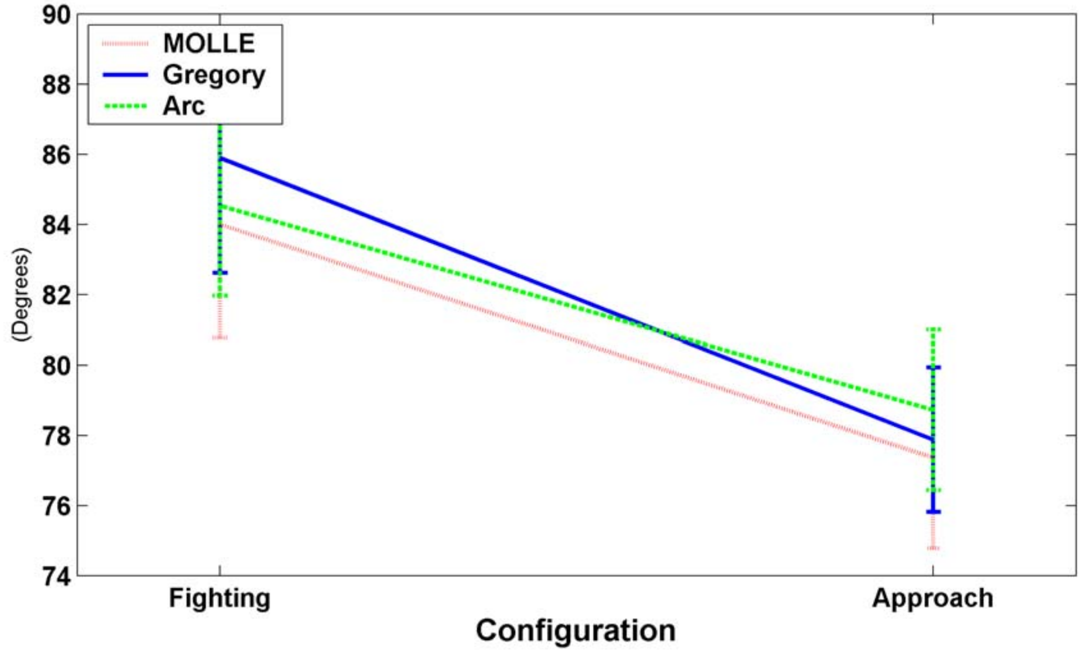


Table 6: Minimum Trunk Angle * ^ #

	Fighting	Approach
MOLLE	83.991 C (Degrees)	77.361 C (Degrees)
	(3.232)	(2.579)
Gregory	85.889 A	77.872 B
	(3.281)	(2.06)
Arc'Teryx	84.523 B	78.721 A
	(2.564)	(2.282)

* indicates statistically significant effect of system
^ indicates statistically significant effect of Configuration (Fighting vs. Approach)
# indicates statistically significant system*configuration interaction
Within a Configuration Packs with same letter are not Statistically Different
Means +/- Standard Deviation

There was a significant system*configuration interaction on maximum trunk angle. The maximum trunk angle represents the subjects' most upright posture (or backward lean if the angle is greater than 90 °) . For the Fighting load, the Gregory pack resulted in the greatest maximum trunk angle; this was significantly greater than MOLLE, which was significantly greater than Arc'Teryx (Figure 6 and Table 7). For all three packs in the Fighting configuration, the maximum trunk angle was greater than 90°, indicating a slight backward lean. This is relatively common and likely not of operation importance. In contrast, for the Approach load, Arc'Teryx resulted in a statistically significant greater forward trunk lean than MOLLE and Gregory. There were no differences between MOLLE Approach and Gregory Approach.

Figure 6: Maximum Trunk Angle

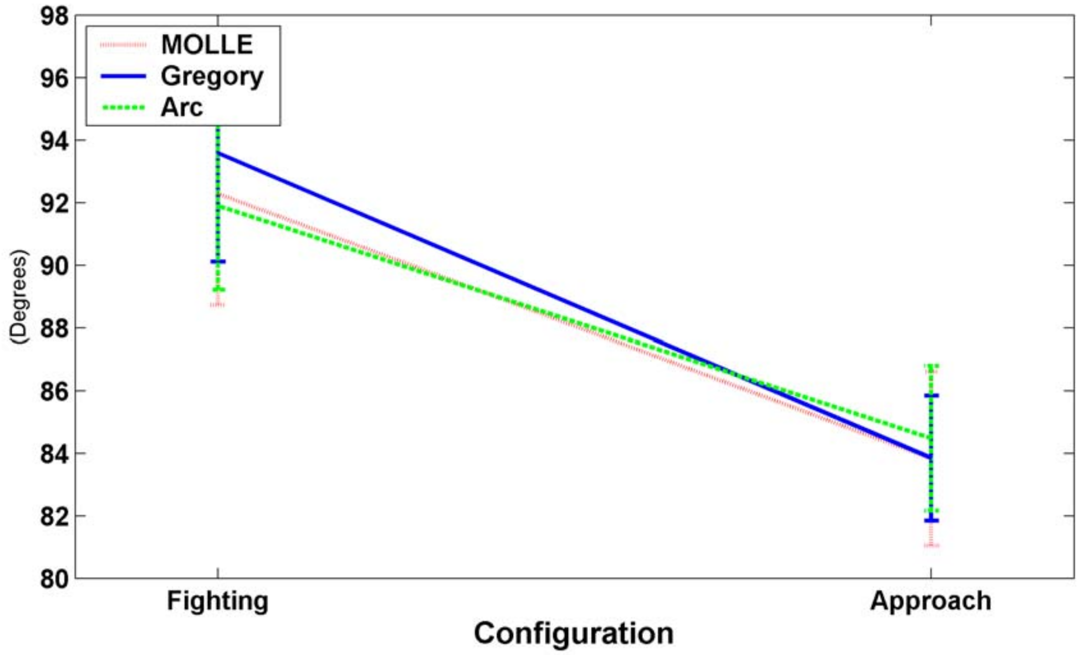


Table 7: Maximum Trunk Angle ^ #

	Fighting	Approach
MOLLE	92.283 B (Degrees)	83.825 B (Degrees)
	(3.553)	(2.78)
Gregory	93.586 A	83.841 B
	(3.473)	(2.003)
Arc'Teryx	91.894 C	84.480 A
	(2.68)	(2.318)

^ indicates statistically significant effect of Configuration (Fighting vs. Approach)
# indicates statistically significant system*configuration interaction
Within a Configuration Packs with same letter are not Statistically Different
Means +/- Standard Deviation

There was a significant main effect of backpack system on trunk range of motion. MOLLE resulted in the greatest range of motion. This was significantly greater than the trunk range of motion with Gregory, which was significantly greater than with Arc'Teryx (Figure 7 and Table 8).

Figure 7: Trunk Range of Motion

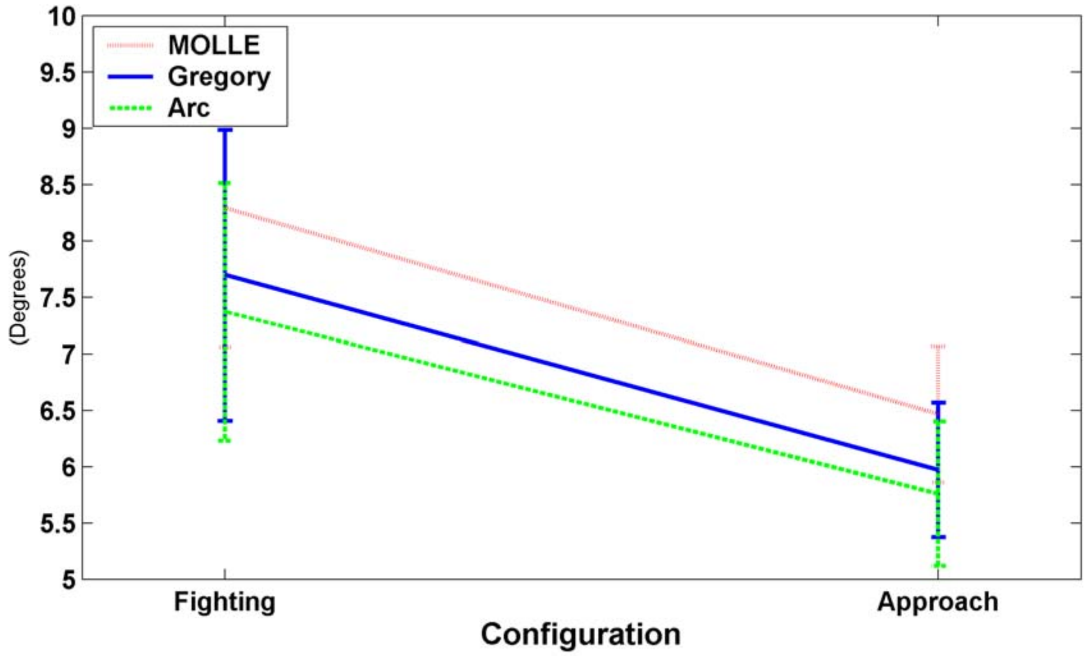


Table 8: Trunk Range of Motion * ^

	Fighting	Approach
MOLLE [A]	8.292 (Degrees)	6.464 (Degrees)
	1.236	0.605
Gregory [B]	7.69	5.970
	1.289	0.598
Arc'Teryx [C]	7.371	5.759
	1.143	0.642

* indicates statistically significant effect of system
^ indicates statistically significant effect of Configuration (Fighting vs. Approach)
Packs with same letter are not Statistically Different
Means +/- Standard Deviation

Hip flexion extension is a measure of the amount the leg is swinging during gait (Figure 8). Values greater than 180° indicate hip extension, while values less than 180° indicate hip flexion. There was a significant main effect of backpack system on hip flexion/extension range of motion (Table 9).

Figure 8: Hip Angle Defined

Table 9: P-Values for Main Effects and Interactions for Hip Angle Variables

	Main Effects		Interaction
	System	Configuration	System* Configuration
Hip Flexion/Extension Range of Motion	0.0072	0.0001	0.6415
Maximum Hip Flexion/Extension Angle	0.0906	0.1855	0.0004
Time of Maximum Hip Flexion/Extension Angle	0.0390	0.7601	0.3198

P-Values greater than 0.05 indicate there is no statistical difference between backpack SYSTEM, between Configurations, or there was no SYSTEM*Configuration interaction for that specific comparison.

The greatest hip flexion/extension range of motion was observed with the Arc'Teryx system. This was significantly greater than that observed with Gregory, which was significantly greater than that observed with MOLLE (Figure 9 and Table 10).

Figure 9: Hip Flexion/Extension Range of Motion

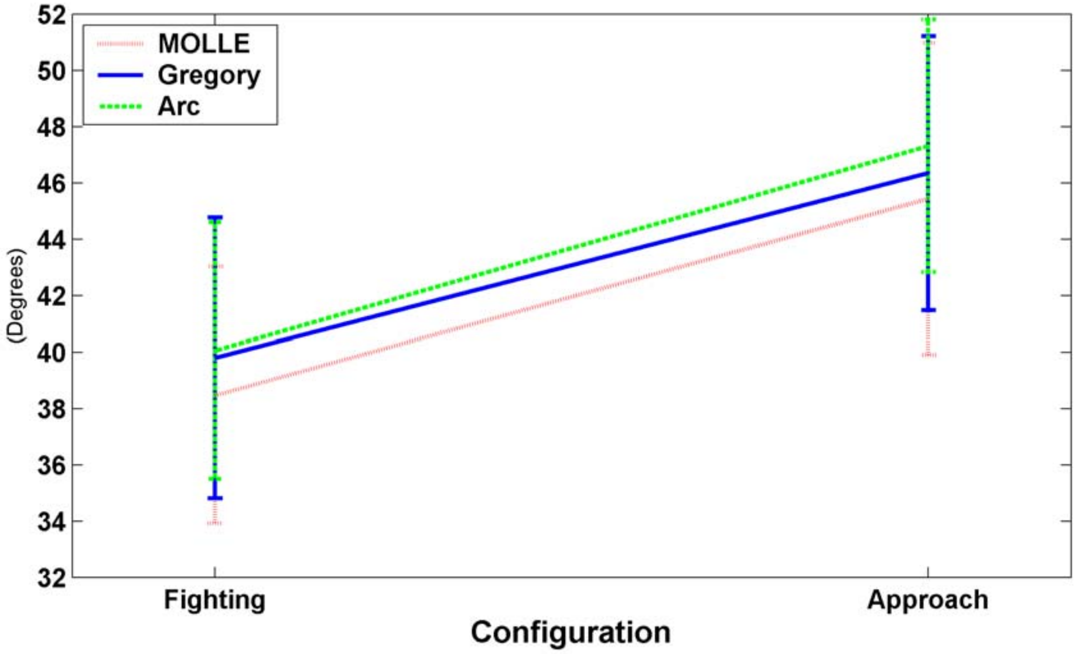


Table 10: Hip Flexion/Extension Range of Motion * ^

	Fighting	Approach
MOLLE [C]	38.465 (Degrees)	45.434 (Degrees)
	(4.554)	(5.535)
Gregory [B]	39.794	46.348
	(4.982)	(4.867)
Arc'Teryx [A]	40.042	47.312
	(4.555)	(4.49)

* indicates statistically significant effect of system
^ indicates statistically significant effect of Configuration (Fighting vs. Approach)
Packs with same letter are not Statistically Different
Means +/- Standard Deviation

There was a significant system * configuration interaction effect on maximum hip flexion/extension angle (Table 9). For the Fighting load, the greatest hip extension occurred while carrying the Gregory pack. This was significantly greater than with Arc'Teryx, which was significantly greater than with MOLLE. In contrast, in the Approach load, the greatest hip extension was observed while carrying Arc'Teryx. This was significantly greater than with Gregory, which was significantly greater than with MOLLE (Figure 10 and Table 11).

Figure 10: Maximum Hip Flexion/Extension Angle

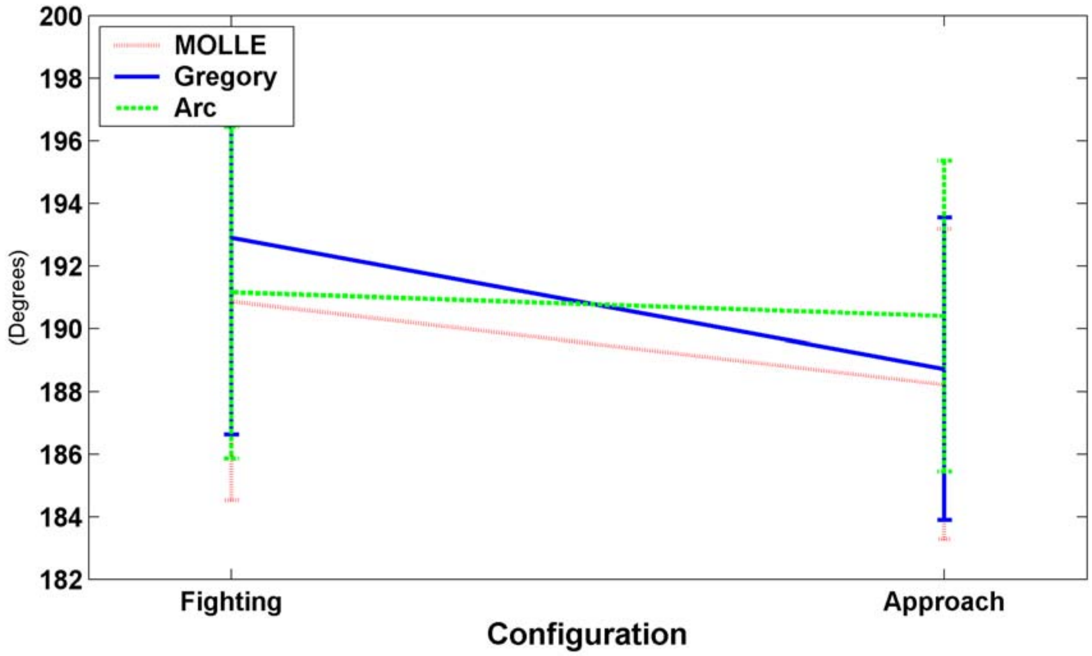


Table 11: Maximum Hip Flexion/Extension Angle #

	Fighting	Approach
MOLLE	190.861 C (Degrees)	188.220 C (Degrees)
	6.337	4.948
Gregory	192.900 A	188.716 B
	6.279	4.833
Arc'Teryx	191.155 B	190.394 A
	5.291	4.958

# indicates statistically significant system*configuration interaction
Within a Configuration Packs with same letter are not Statistically Different
Means +/- Standard Deviation

There was a significant main effect of system on the time of maximum hip flexion/extension angle (Table 9). Across configurations, peak hip extension occurred slightly earlier when walking with the Arc'Teryx system than when walking with either the MOLLE or the Gregory systems. There were no statistically significant differences found between MOLLE and Gregory (Figure 11 and Table 12).

Figure 11: Time of Maximum Hip Flexion/Extension Angle

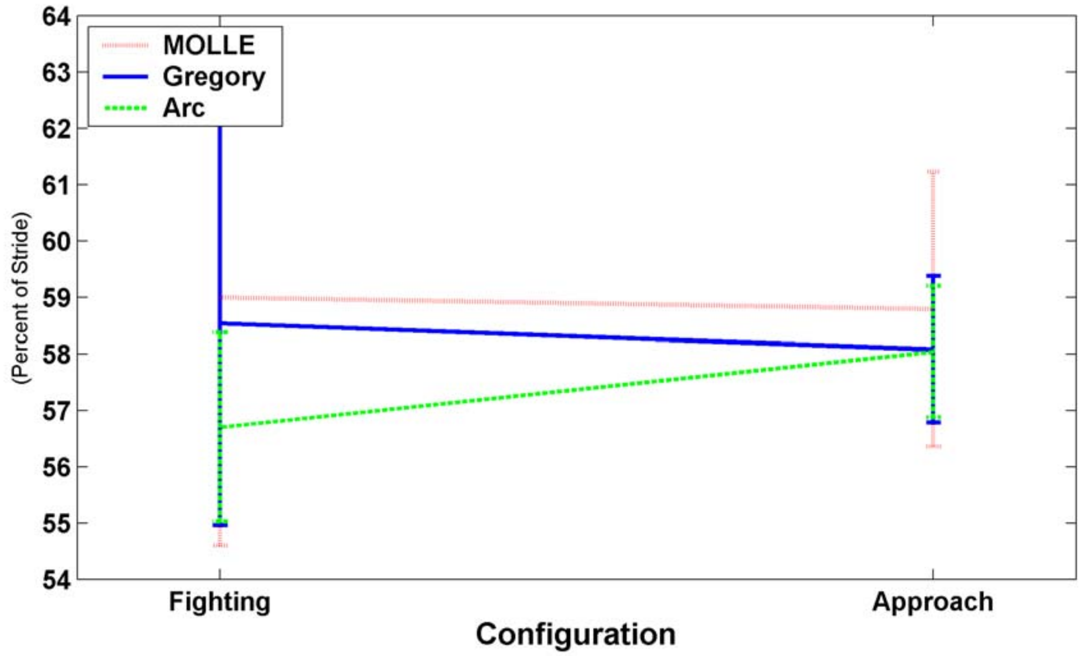


Table 12: Time of Maximum Hip Flexion/Extension Angle *

	Fighting	Approach
MOLLE [A]	58.995 (Percent of Stride)	58.788 (Percent of Stride)
	(4.396)	(2.436)
Gregory [A]	58.535	58.077
	(3.574)	(1.296)
Arc'Teryx [B]	56.698	58.037
	(1.678)	(1.166)

* indicates statistically significant effect of system
Packs with same letter are not Statistically Different
Means +/- Standard Deviation

Shoulder flexion/extension angle is a measure of the position of the upper arm during walking (Figure 12). There are many factors aside from backpack design that may affect shoulder flexion extension, such as the way the subject is holding the weapon. A value of 0 indicates the upper arm is hanging vertically from the shoulder. Values greater than 0 indicate shoulder flexion (i.e., the upper arm is in a position so that the elbow is in front of the shoulder). Values less than 0 indicate the shoulder is in extension (i.e., the upper arm is in a position so that the elbow is behind the shoulder).

Figure 12: Shoulder Angle Defined

There was a significant system * configuration interaction effect on maximum shoulder flexion/extension angle (Table 13). In the Fighting configuration, MOLLE resulted in the most neutral (closest to 0) shoulder angle. This was significantly different from Arc'Teryx, which was significantly different from Gregory. For the Fighting loads, Gregory resulted in the greatest shoulder flexion. In contrast, for the Approach loads, MOLLE resulted in the greatest shoulder flexion, and there were no differences between Gregory and Arc'Teryx (Figure 13 and Table 14).

Table 13: P-Values for Main Effects and Interactions for Shoulder Angle Variables

	Main Effects		Interaction
	System	Configuration	System* Configuration
Maximum Shoulder Flexion/Extension Angle	0.3137	0.3223	0.0347
Shoulder Flexion/Extension Range of Motion	0.0194	0.0011	0.5855

P-Values greater than 0.05 indicate there is no statistical difference between backpack SYSTEM, between Configurations, or there was no SYSTEM*Configuration interaction for that specific comparison.

Figure 13: Maximum Shoulder Flexion/Extension Angle

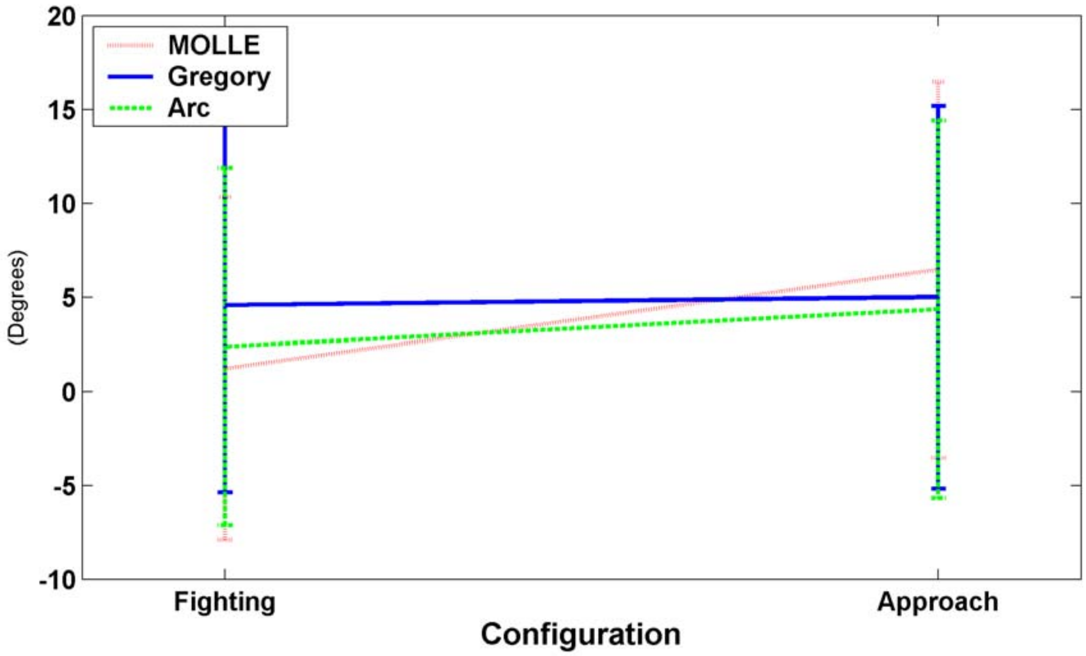


Table 14: Maximum Shoulder Flexion/Extension Angle #

	Fighting	Approach
MOLLE	1.197 C (Degrees)	6.468 A (Degrees)
	(9.111)	(9.997)
Gregory	4.580 A	5.006 B
	(9.968)	(10.188)
Arc'Teryx	2.383 B	4.358 B
	(9.503)	(10.035)

# indicates statistically significant system*configuration interaction
Within a Configuration Packs with same letter are not Statistically Different
Means +/- Standard Deviation

Shoulder range of motion is a measure of the amount of shoulder movement that occurs during walking. There was a significant main effect of backpack system on shoulder flexion/extension range of motion (Table 13). The greatest range of motion was observed while walking with MOLLE. The range of motion while walking with MOLLE was significantly greater than while walking with Gregory, which was significantly greater than while walking with Arc'Teryx (Figure 14 and Table 15). Restricted range of shoulder flexion/extension motion may be the result of the large amount of shoulder padding that is part of the Arc'Teryx system.

Figure 14: Shoulder Flexion/Extension Range of Motion

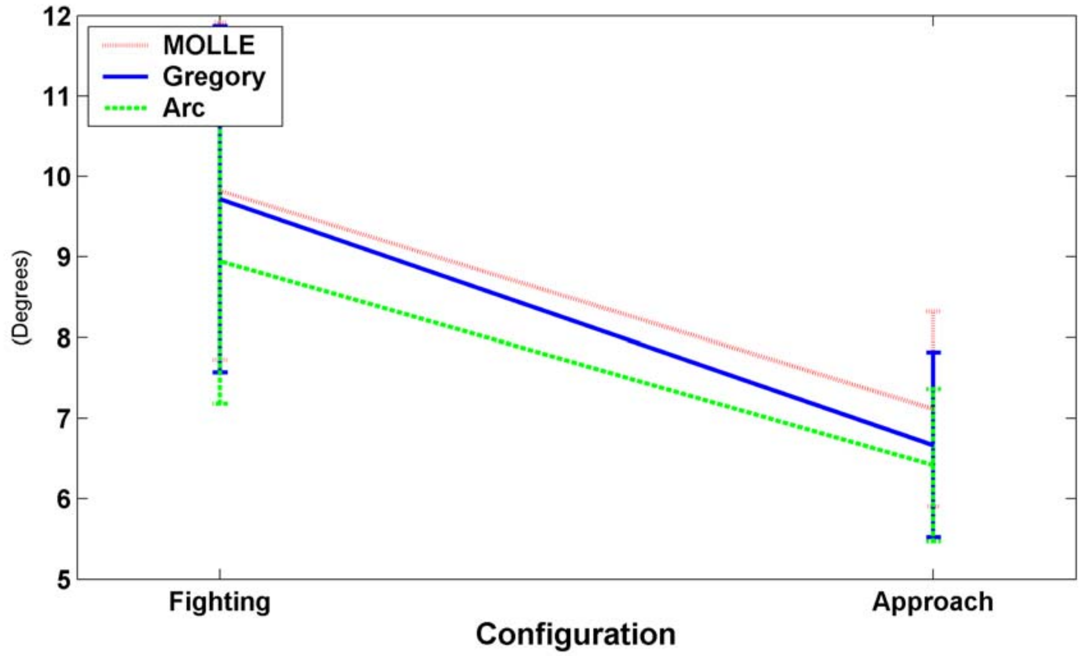


Table 15: Shoulder Flexion/Extension Range of Motion * ^

	Fighting	Approach
MOLLE [A]	9.818 (Degrees)	7.114 (Degrees)
	(2.092)	(1.209)
Gregory [B]	9.718	6.667
	(2.148)	(1.146)
Arc'Teryx [C]	8.944	6.414
	(1.762)	(0.946)

* indicates statistically significant effect of system
^ indicates statistically significant effect of Configuration (Fighting vs. Approach)
Packs with same letter are not Statistically Different
Means +/- Standard Deviation

Biomechanics: Ground Reaction Forces

The maximum (or peak) vertical ground reaction force at heel strike is a measure of the vertical force with which the foot strikes the ground. Generally, higher forces are considered to be undesirable and can lead to injuries such as stress fractures and over time, overuse injuries. There was a significant main effect of system on the maximum heel strike vertical ground reaction force (Table 16).

Table 16: P-Values for Main Effects and Interactions for Ground Reaction Forces

	Main Effects		Interaction
	System	Configuration	System* Configuration
Maximum Heel Strike Vertical Ground Reaction Force	0.0462	0.0001	0.5368
Maximum Heel Strike Vertical Ground Reaction Force/Total Load	0.0240	0.5574	0.5460
Time of Maximum Heel Strike Vertical Ground Reaction Force	0.0402	0.8881	0.6312

P-Values greater than 0.05 indicate there is no statistical difference between backpack SYSTEM, between Configurations, or there was no SYSTEM*Configuration interaction for that specific comparison.

Arc'Teryx resulted in statistically significant greater peak vertical ground reaction forces at heel strike than MOLLE and Gregory (Figure 15 and Table 17). Across configurations, the vertical ground reaction force experienced with Arc'Teryx was about 5% greater than the vertical ground reaction force experienced with MOLLE, and about 3.3% greater than with Gregory. No statistically significant differences in vertical ground reaction force were found between MOLLE and Gregory.

Figure 15: Maximum Heel Strike Vertical Ground Reaction Force

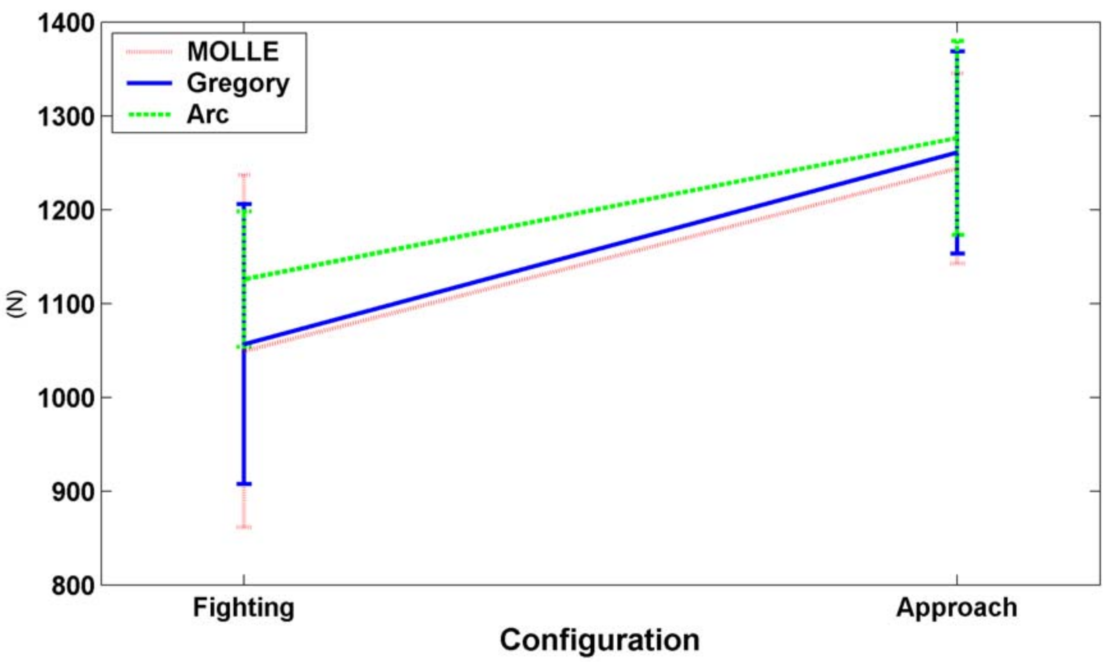


Table 17: Maximum Heel Strike Vertical Ground Reaction Force * ^

	Fighting	Approach
MOLLE [B]	1049.183 (N)	1244.096 (N)
	(187.683)	(101.395)
Gregory [B]	1056.652	1260.856
	(149.264)	(107.77)

Arc'Teryx [A]	1125.687	1276.609
	(72.292)	(103.331)

* indicates statistically significant effect of system
^ indicates statistically significant effect of Configuration (Fighting vs. Approach)
Packs with same letter are not Statistically Different
Means +/- Standard Deviation

The total amount of weight carried will influence the maximum vertical ground reaction force; heavier objects (objects with greater mass) are expected to result in greater vertical forces. One way to account for minor differences in weight of the backpack systems and differences in the subjects' body weight is to divide the maximum vertical ground reaction force by the total weight (subjects body weight + the weight of the backpack). There was a main effect of backpack system on the maximum vertical ground reaction force divided by total load (Table 16). Walking with Arc'Teryx resulted in the greatest peak heel strike vertical ground reaction force divided by total load. These results were statistically significant. No statistically significant differences in peak heel strike vertical ground reaction force divided by total load were found between MOLLE and Gregory (Figure 16 and Table 18).

Figure 16: Maximum Heel Strike Vertical Ground Reaction Force/Total Load

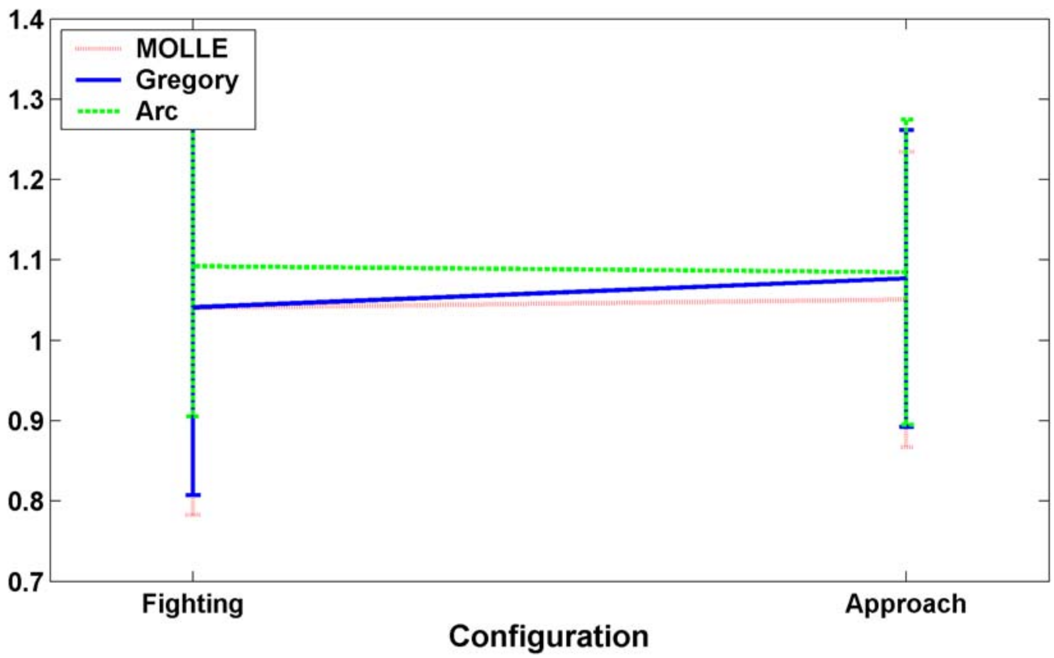


Table 18: Maximum Heel Strike Vertical Ground Reaction Force/Total Load *

	Fighting	Approach
MOLLE	1.041 [B]	1.051 [B]
	(0.258)	(0.184)
Gregory	1.041 [B]	1.077 [A]
	(0.234)	(0.185)

Arc'Teryx	1.092 A	1.085 A
	(0.187)	(0.19)

* indicates statistically significant effect of system
Within a Configuration Packs with same letter are not Statistically Different
Means +/- Standard Deviation

Although biomechanists refer to the variable as 'Maximum Heel Strike Vertical Ground Reaction Force' the peak actually occurs some time after heel strike. During walking, there is a short amount of time between when the foot initially makes contact with the floor, and when the peak force occurs. This is usually is on the order of about 0.1-0.2 seconds, or some time in the first 20-25% of the stride cycle. There was a significant main effect of backpack system on the time of maximum heelstrike ground reaction force (Table 17). When walking with Arc'Teryx, the maximum heel strike ground reaction force was slightly delayed (~1-1.5% of stride) compared to MOLLE and Gregory; this was statistically significant. However, no statistically significant differences were found between MOLLE and Gregory (Figure 17 and Table 20).

Figure 17: Time of Maximum Heel Strike Vertical Ground Reaction Force

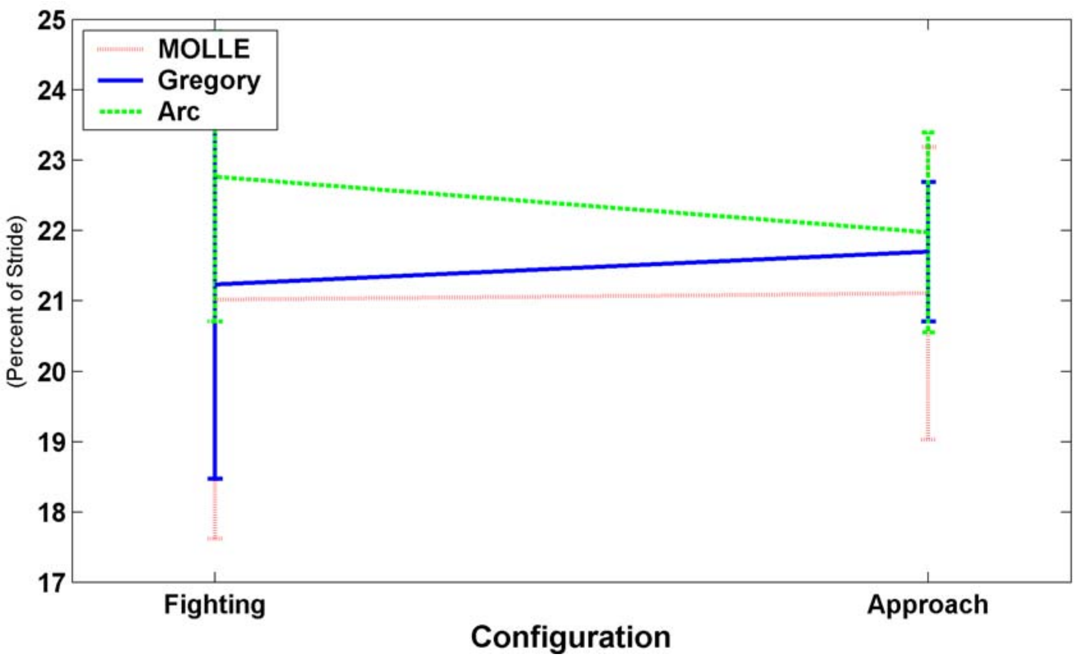


Table 19: Time of Maximum Heel Strike Vertical Ground Reaction Force *

	Fighting	Approach
MOLLE B	21.013 (Percent of Stride)	21.104 (Percent of Stride)
	(3.391)	(2.078)
Gregory B	21.228	21.693
	(2.756)	(0.993)
Arc'Teryx A	22.761	21.969
	(2.063)	(1.422)

* indicates statistically significant effect of system

Packs with same letter are not Statistically Different
Means +/- Standard Deviation

Biomechanics: Joint Torque

There was a significant main effect of system on the time of maximum knee joint torque (Table 20). While walking with MOLLE, maximum knee joint torque occurred slightly later in the stride (~1.1 % compared to Gregory and ~1.7% compared to Arc'Teryx) than when walking with the other packs. The differences between MOLLE and the two other packs were statistically significant; however, the differences between Gregory and Arc'Teryx were not (Figure 18 and Table 21).

Table 20: P-Values for Main Effects and Interactions for Joint Torque

	Main Effects		Interaction
	System	Configuration	System* Configuration
Time of Maximum Knee Joint Torque	0.0333	0.0537	0.9459

P-Values greater than 0.05 indicate there is no statistical difference between backpack SYSTEM, between Configurations, or there was no SYSTEM*Configuration interaction for that specific comparison.

Figure 18: Time of Maximum Knee Joint Torque

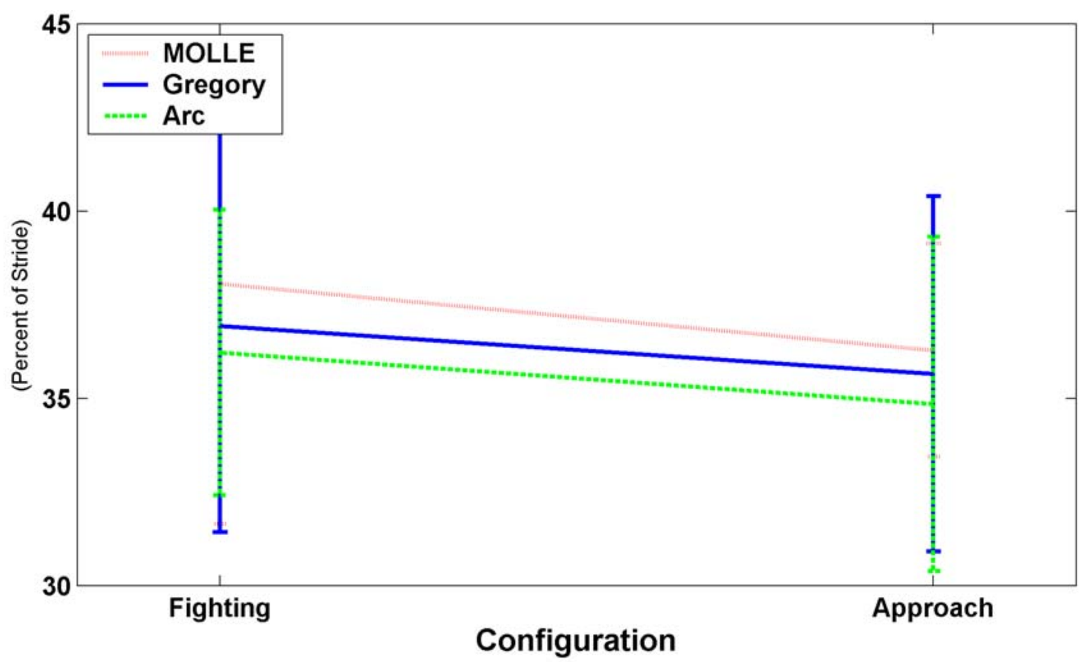


Table 21: Time of Maximum Knee Joint Torque *

	Fighting	Approach
MOLLE [B]	38.057 (Percent of Stride)	36.281 (Percent of Stride)
	(6.411)	(2.848)
Gregory [A]	36.933	35.654
	(5.503)	(4.747)

Arc'Teryx [A]	36.226 (3.81)	34.848 (4.47)

* indicates statistically significant effect of system
Packs with same letter are not Statistically Different
Means +/- Standard Deviation

Biomechanics: Backpack – Backpack/Body Parameters

The standard deviation (STD) of the vertical distance between body COM and BPCOM is a measure of the stability of the backpack in relation to the body. Increases in the STD of the vertical distance between the body COM and the BPCOM indicate the backpack is moving in relation to the body. Lower values indicate less movement of the backpack in relation to the body. There was a significant system * configuration interaction observed on the STD of the vertical distance between the body COM and the BPCOM (Table 22).

Table 22: P-Values for Main Effects and Interactions for Backpack-Backpack/Body Parameters

	Main Effects		Interaction
	System	Configuration	System* Configuration
Standard Deviation of Vertical Distance Between Body and Backpack COM	0.4484	0.5148	0.0401
Maximum BPCOM Vertical Position	0.0001	0.0001	0.0001
Minimum BPCOM Vertical Position	0.0001	0.0001	0.0001
Minimum BPCOM Horizontal Acceleration	0.0004	0.0039	0.0655
Minimum BPCOM Horizontal Velocity	0.0006	0.0017	0.0561
Maximum BPCOM Horizontal Velocity	0.0014	0.0005	0.0033
Maximum BPCOM Horizontal Acceleration	0.0014	0.0059	0.0106
Time of Maximum BPCOM Horizontal Acceleration	0.0135	0.5721	0.4369
Time of Maximum BPCOM Vertical Position	0.0269	0.1361	0.3644

P-Values greater than 0.05 indicate there is no statistical difference between backpack SYSTEM, between Configurations, or there was no SYSTEM*Configuration interaction for that specific comparison.

In the Fighting load, Arc'Teryx resulted in the least amount of vertical movement of the backpack in relation to the body; this was statistically different from MOLLE. In turn, MOLLE resulted in less movement of the backpack compared to Gregory (also statistically significant). In the Approach load, Gregory resulted in the least amount of movement of the backpack in relation to the body. The differences between Gregory Approach and the other Approach packs were statistically significant, however, the differences between MOLLE Approach and Arc'Teryx Approach were not statistically significant (Figure 19 and Table 23).

Figure 19: Standard Deviation of Vertical Distance Between Body COM and BP COM

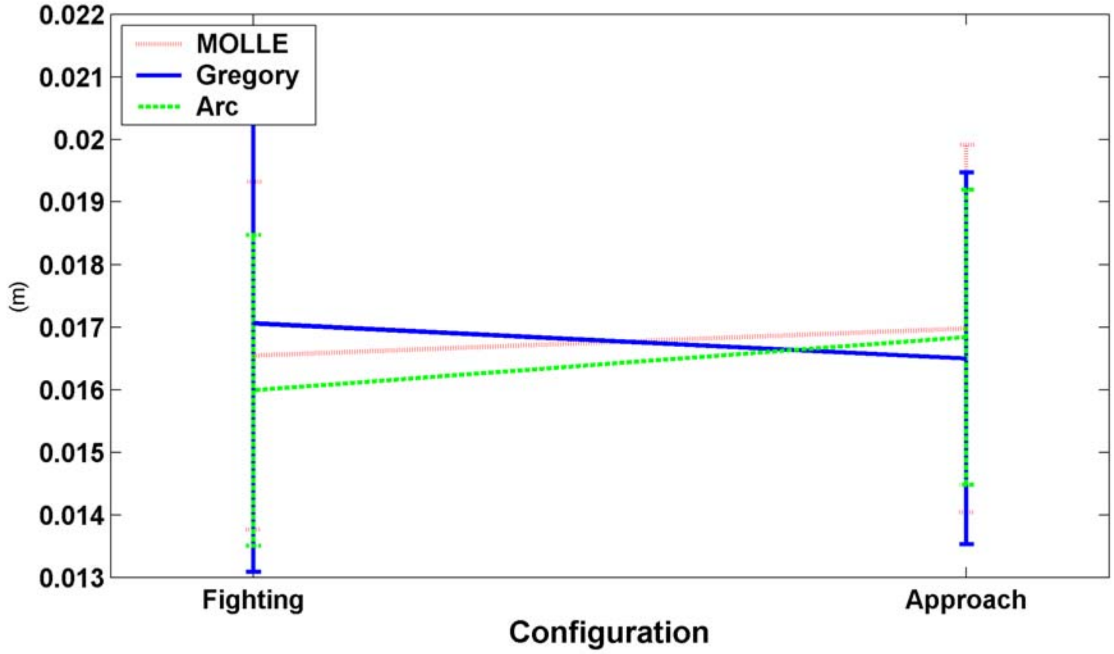


Table 23: Standard Deviation of Vertical Distance Between Body COM and BP COM #

	Fighting	Approach
MOLLE	0.0165 B (m)	0.0170 A (m)
	(0.0078)	(0.0029)
Gregory	0.0171 A	0.0165 B
	(0.0039)	(0.0029)
Arc'Teryx	0.0159 C	0.0170 A
	(0.0024)	(0.0023)

# indicates statistically significant system*configuration interaction
Packs with same letter are not Statistically Different
Means +/- Standard Deviation

The BPCOM moves up and down during walking. One way of quantifying this is by measuring the maximum and minimum position of the BPCOM. There was a significant main effect of system and a significant system * configuration on the maximum and minimum vertical position of the BPCOM; however, no differences were found on the range of movement of the BPCOM (Table 22). The same trends were found for both the minimum and maximum vertical position of the BPCOM. For both the Fighting and Approach loads, Arc'Teryx resulted in a significantly greater maximum and minimum vertical position of the BPCOM than MOLLE and Gregory. For the Fighting load, MOLLE resulted in a significantly greater maximum and minimum vertical position of the BPCOM than Gregory, while in the Approach load, Gregory resulted in a significantly greater maximum and minimum vertical position of the BPCOM than MOLLE (Figures 20 and 21 and Tables 24 and 25).

Figure 20: Maximum BPCOM Vertical Position

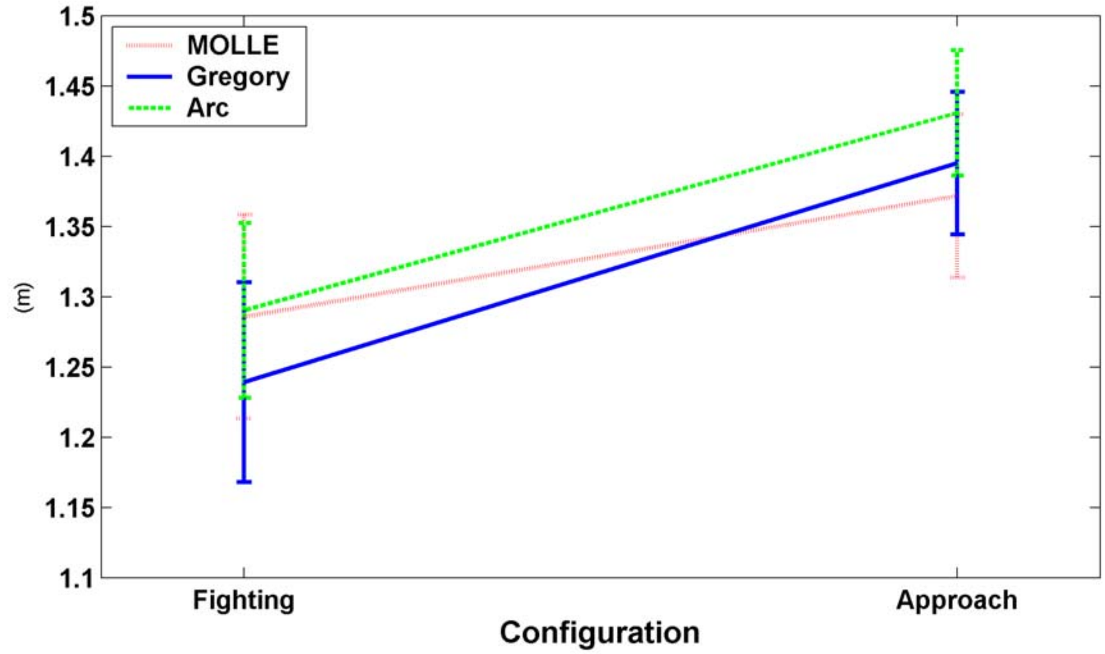


Table 24: Maximum BPCOM Vertical Position * ^ #

	Fighting	Approach
MOLLE	1.286 [B] (m)	1.372 [C] (m)
	(0.073)	(0.058)
Gregory	1.239 [C]	1.395 [B]
	(0.071)	(0.051)
Arc'Teryx	1.290 [A]	1.431 [A]
	(0.062)	(0.045)

* indicates statistically significant effect of system
^ indicates statistically significant effect of Configuration (Fighting vs. Approach)
# indicates statistically significant system*configuration interaction
Within a Configuration Packs with same letter are not Statistically Different
Means +/- Standard Deviation

Figure 21: Minimum BPCOM Vertical Position

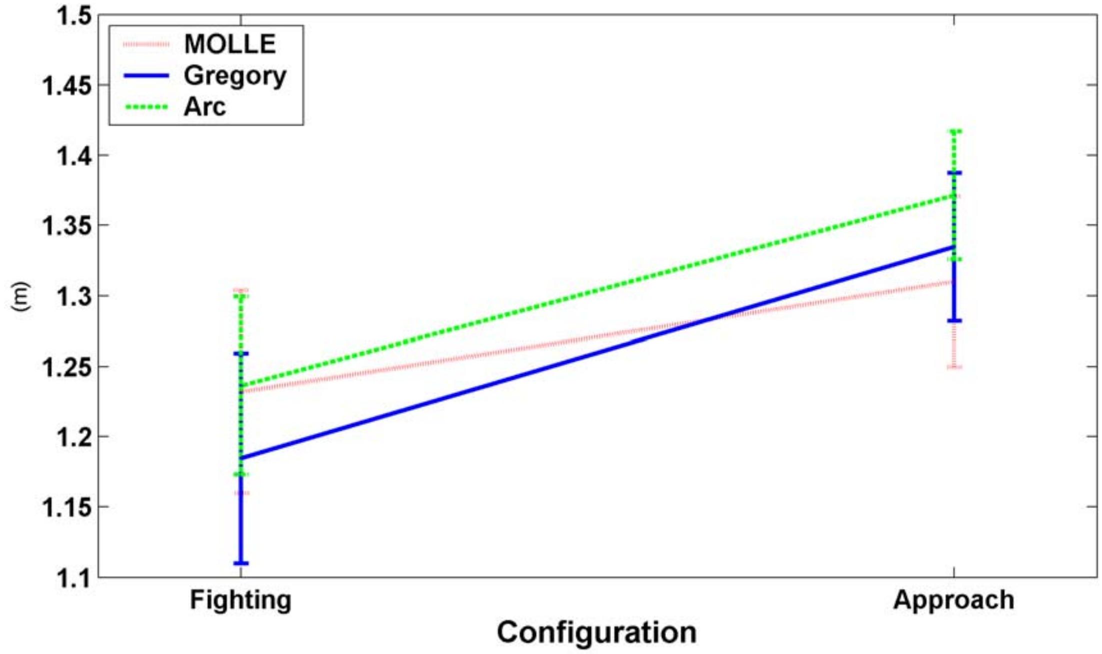


Table 25: Minimum BPCOM Vertical Position * ^ #

	Fighting	Approach
MOLLE	1.232 [B] (m)	1.310 [C] (m)
	(0.072)	(0.06)
Gregory	1.185 [C]	1.335 [B]
	(0.075)	(0.053)
Arc'Teryx	1.236 [A]	1.371 [A]
	(0.063)	(0.046)

* indicates statistically significant effect of system
^ indicates statistically significant effect of Configuration (Fighting vs. Approach)
# indicates statistically significant system*configuration interaction
Within a Configuration Packs with same letter are not Statistically Different
Means +/- Standard Deviation

There was a significant main effect of backpack system and a significant system * configuration interaction on maximum BPCOM horizontal anterior velocity (Table 22). For the Fighting load, Gregory resulted in a statistically significant greater maximal BPCOM horizontal anterior velocity than MOLLE, which in turn, was significantly greater than Arc'Teryx. In contrast, for the Approach Load, MOLLE resulted a statistically significant greater maximum horizontal anterior velocity than Gregory, which in turn, was significantly greater than Arc'Teryx (Figure 22 and Table 26).

Figure 22: Maximum BPCOM Horizontal Anterior Velocity

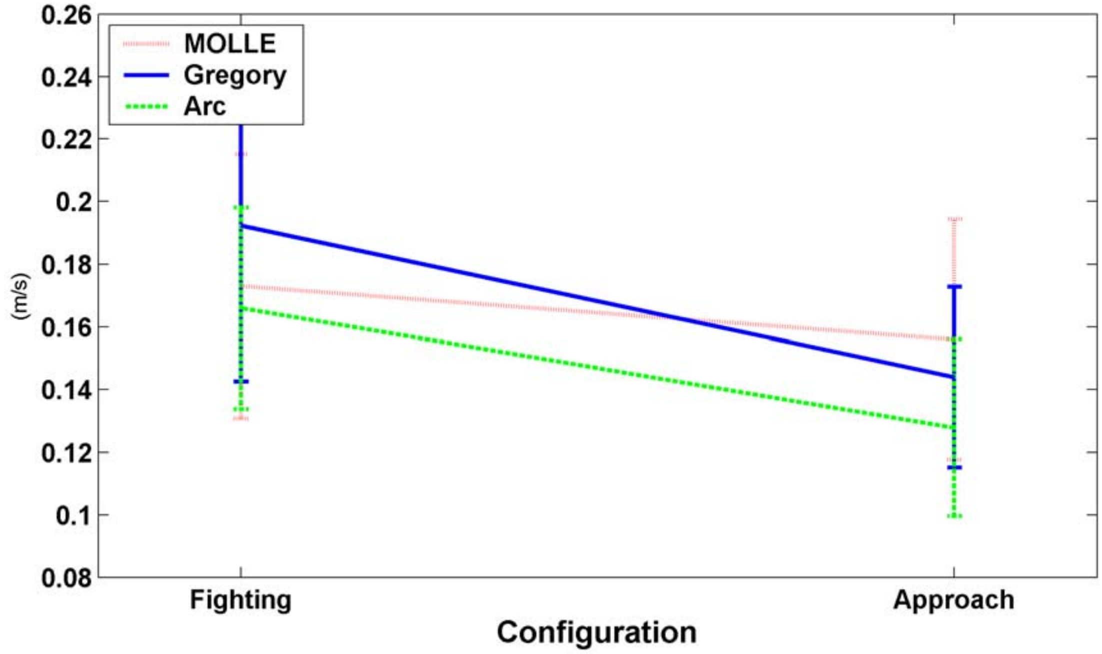


Table 26: Maximum BPCOM Horizontal Anterior Velocity * ^ #

	Fighting	Approach
MOLLE	0.173 [B] (m/s)	0.156 [A] (m/s)
	(0.042)	(0.038)
Gregory	0.192 [A]	0.144 [B]
	(0.05)	(0.029)
Arc'Teryx	0.166 [C]	0.128 [C]
	(0.032)	(0.028)

* indicates statistically significant effect of system
^ indicates statistically significant effect of Configuration (Fighting vs. Approach)
\# indicates statistically significant system*configuration interaction
Within a Configuration Packs with same letter are not Statistically Different
Means +/- Standard Deviation

While walking on a treadmill, the body and the backpack move forward and backward with each stride. There was a significant main effect of backpack system and a significant system * configuration interaction on maximum BPCOM horizontal posterior velocity (Table 22). For the Fighting load, Gregory and MOLLE resulted in a statistically significant greater maximum BPCOM horizontal posterior velocity than Arc'Teryx. In contrast, for the Approach Load, MOLLE resulted in a statistically significant greater maximum BPCOM horizontal posterior velocity than Gregory, which in turn, was significantly greater than Arc'Teryx (Figure 23 and Table 27).

Figure 23: Maximum BPCOM Horizontal Posterior Velocity

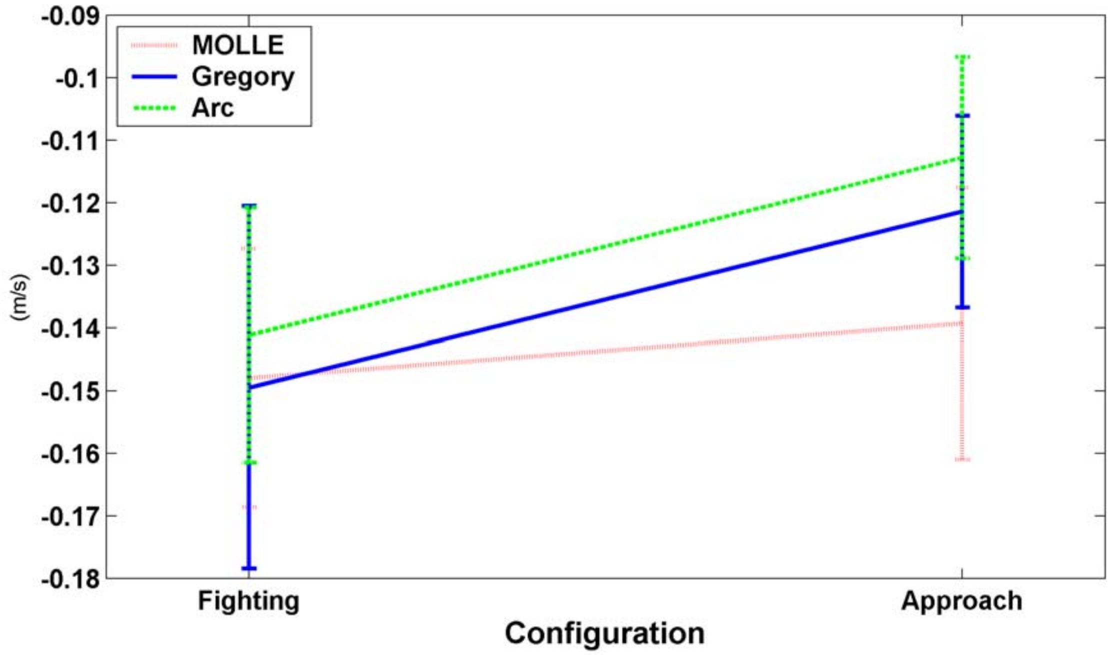


Table 27: Maximum BPCOM Horizontal Posterior Velocity * ^

	Fighting	Approach
MOLLE	-0.148 B (m/s)	-0.139 C (m/s)
	(0.021)	(0.022)
Gregory	-0.149 B	-0.121 B
	(0.029)	(0.015)
Arc'Teryx	-0.141 A	-0.113 A
	(0.02)	(0.016)

* indicates statistically significant effect of system
^ indicates statistically significant effect of Configuration (Fighting vs. Approach)
Within a Configuration Packs with same letter are not Statistically Different
Means +/- Standard Deviation

There was a significant main effect of backpack system and a significant system * configuration interaction on the maximum BPCOM horizontal anterior acceleration (Table 23). This may be an important variable, because acceleration is related to force. For the Fighting load, Gregory resulted in the greatest maximum BPCOM horizontal anterior acceleration; this was significantly greater than MOLLE and Arc'Teryx. No statistically significant differences were found between MOLLE Fighting and Arc'Teryx Fighting. For the Approach load, no statistically significant differences were found between MOLLE and Gregory; however, walking with both MOLLE and Gregory resulted in greater maximum horizontal anterior acceleration than with Arc'Teryx (Figure 24 and Table 28).

Figure 24: Maximum BPCOM Horizontal Anterior Acceleration

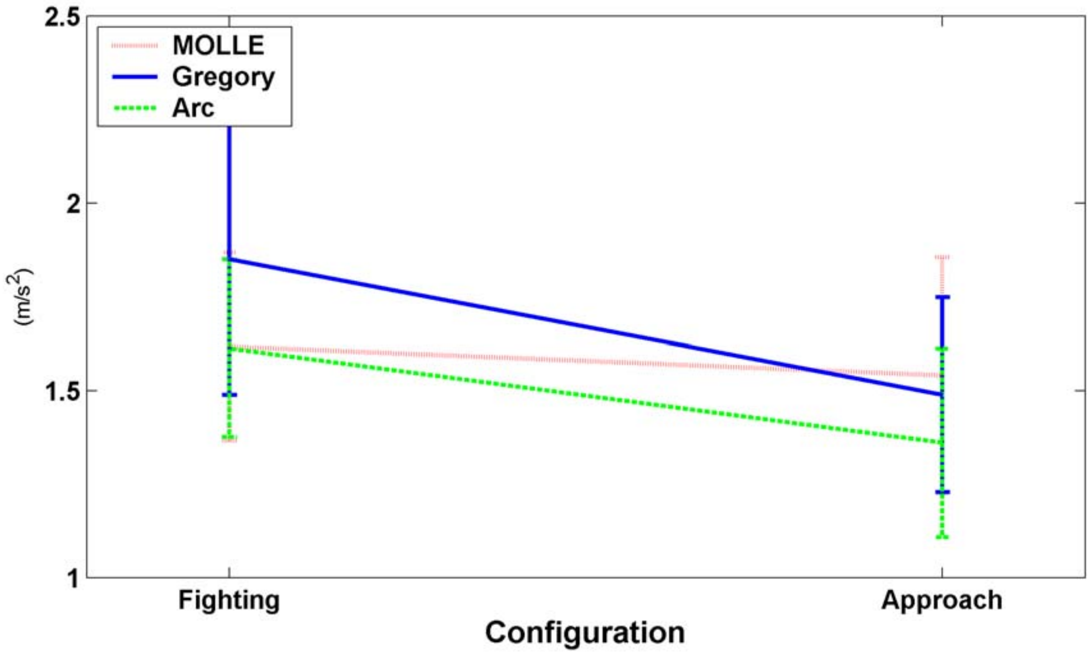


Table 28: Maximum BPCOM Horizontal Anterior Acceleration * ^ #

	Fighting	Approach
MOLLE	1.617 B (m/s^2)	1.541 A (m/s^2)
	(0.25)	(0.315)
Gregory	1.850 ^{A}	1.488 ^{A}
	(0.362)	(0.26)
Arc'Teryx	1.612 ^{B}	1.360 ^{B}
	(0.237)	(0.252)

* indicates statistically significant effect of system
^ indicates statistically significant effect of Configuration (Fighting vs. Approach)
# indicates statistically significant system*configuration interaction
Within a Configuration Packs with same letter are not Statistically Different
Means +/- Standard Deviation

There was a significant main effect of backpack system and a significant system * configuration interaction on the maximum BPCOM horizontal posterior acceleration (Table 23). For the Fighting load, Gregory resulted in the greatest maximum BPCOM horizontal posterior acceleration; this was significantly greater than MOLLE Fighting, which in turn, was significantly greater than Arc'Teryx Fighting. For the Approach load, MOLLE resulted in the greatest maximum BPCOM horizontal posterior acceleration; this was significantly greater than Gregory Approach, which in turn, was significantly greater than Arc'Teryx Approach (Figure 25 and Table 29).

Figure 25: Maximum BPCOM Horizontal Posterior Acceleration

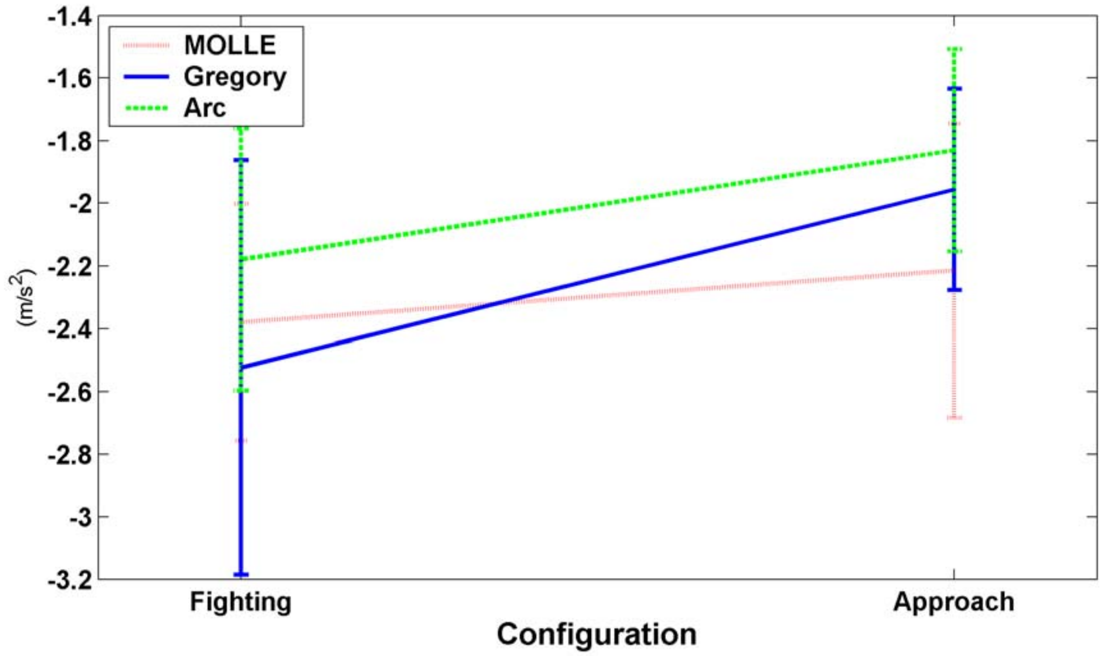


Table 29: Maximum BPCOM Horizontal Posterior Acceleration * ^

	Fighting	Approach
MOLLE	-2.380 B (m/s^2)	-2.215 C (m/s^2)
	(0.378)	(0.47)
Gregory	-2.524 C	-1.956 B
	(0.662)	(0.321)
Arc'Teryx	-2.179 A	-1.831 A
	(0.418)	(0.324)

* indicates statistically significant effect of system
^ indicates statistically significant effect of Configuration (Fighting vs. Approach)
Within a Configuration Packs with same letter are not Statistically Different
Means +/- Standard Deviation

There was a significant main effect of backpack system on the time of maximum BPCOM horizontal acceleration (Table 23). Maximum BPCOM horizontal acceleration occurred earlier in the stride while carrying Gregory than while carrying MOLLE or Arc'Teryx. No statistically significant differences were found between MOLLE and Arc'Teryx (Figures 26 and 27 and Table 30).

Figure 26: Time of Maximum BPCOM Horizontal Anterior Acceleration

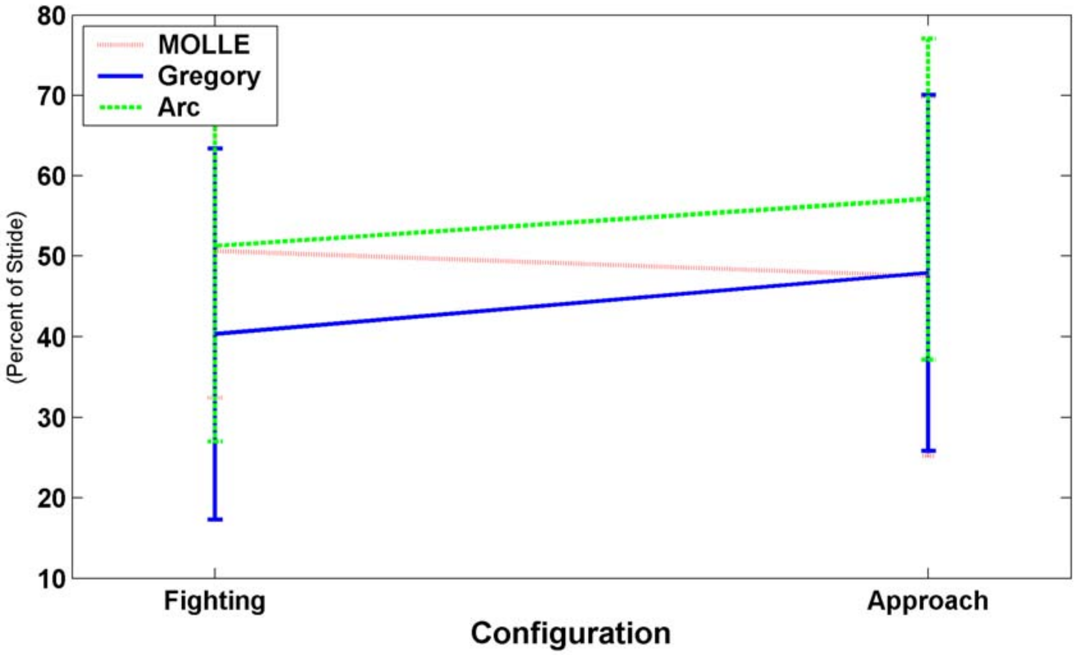
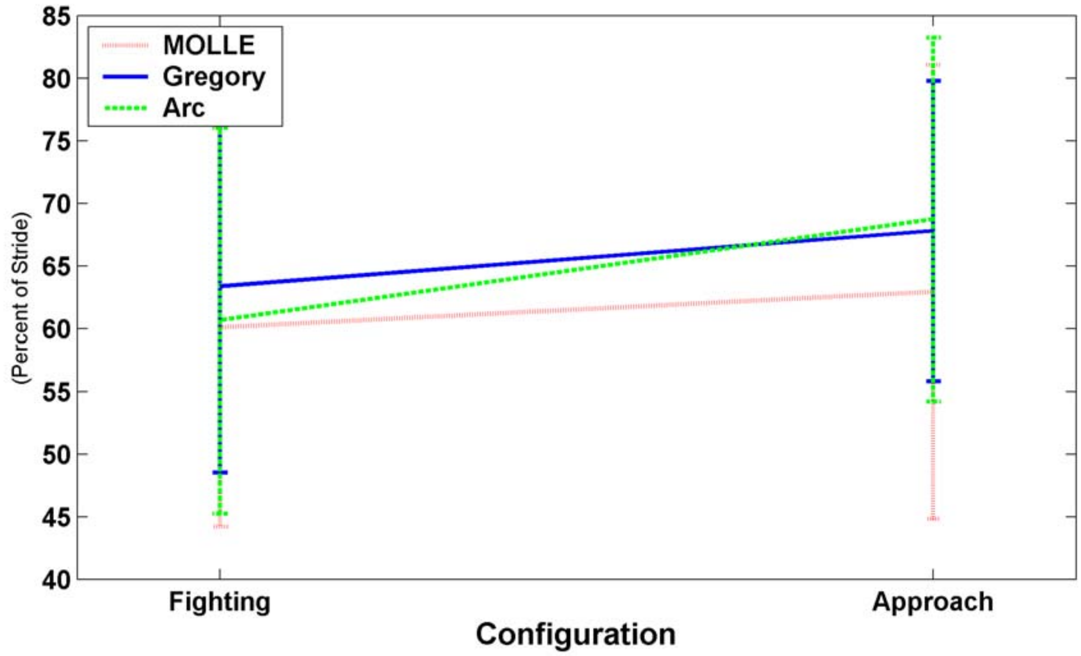


Table 30: Time of Maximum BPCOM Horizontal Acceleration *

	Fighting	Approach
MOLLE [A]	50.640 (Percent of Stride)	47.501 (Percent of Stride)
	18.191	22.314
Gregory [B]	40.333	47.943
	23.062	22.117
Arc'Teryx [A]	51.274	57.141
	24.268	19.926

* indicates statistically significant effect of system
Packs with same letter are not Statistically Different
Means +/- Standard Deviation

Figure 27: Time of Maximum BPCOM Vertical Position



OXYGEN UPTAKE/HEART RATE

There were no statistically significant main effects of backpack system or system * configuration interaction effects on oxygen consumption, carbon dioxide production, heart rate, oxygen consumption per unit body mass or oxygen consumption per unit total mass (Table 31). This indicates walking with each of the backpacks results in comparable levels of metabolic cost (Figures 28-32).

Table 31: P-Values for Main Effects and Interactions for Oxygen Consumption

	Main Effects		Interaction
	System	Configuration	System * Configuration
Oxygen Consumption (VO_2)	0.1682	0.0001	0.7318
Carbon Dioxide Production (VCO_2)	0.3731	0.0005	0.2987
Heart Rate	0.2540	0.1834	0.4565
Oxygen Consumption/Body Weight (VO_2/BM)	0.0714	0.0001	0.7986
Oxygen Consumption/Total Weight (VO_2/TM)	0.2145	0.0557	0.9023

P-Values greater than 0.05 indicate there is no statistical difference between backpack SYSTEM, between Configurations, or there was no SYSTEM*Configuration interaction for that specific comparison.

As expected, there was a significant main effect of configuration (Fighting vs. Approach) on oxygen consumption, carbon dioxide production and oxygen consumption per unit body mass. However, the focus of this study was to compare MOLLE to Gregory to Arc'Teryx; consequently, a discussion of the effect of configuration will be omitted.

Figure 28: Volume of Oxygen Consumed (VO_2)

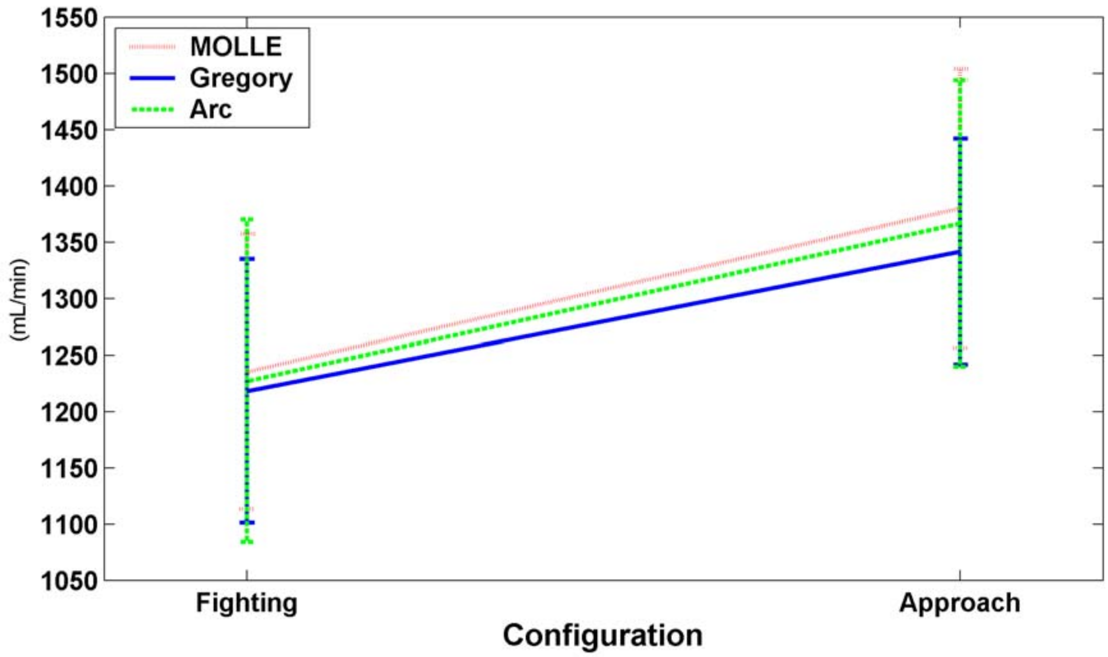


Figure 29: Volume of Carbon Dioxide Produced (VCO_2)

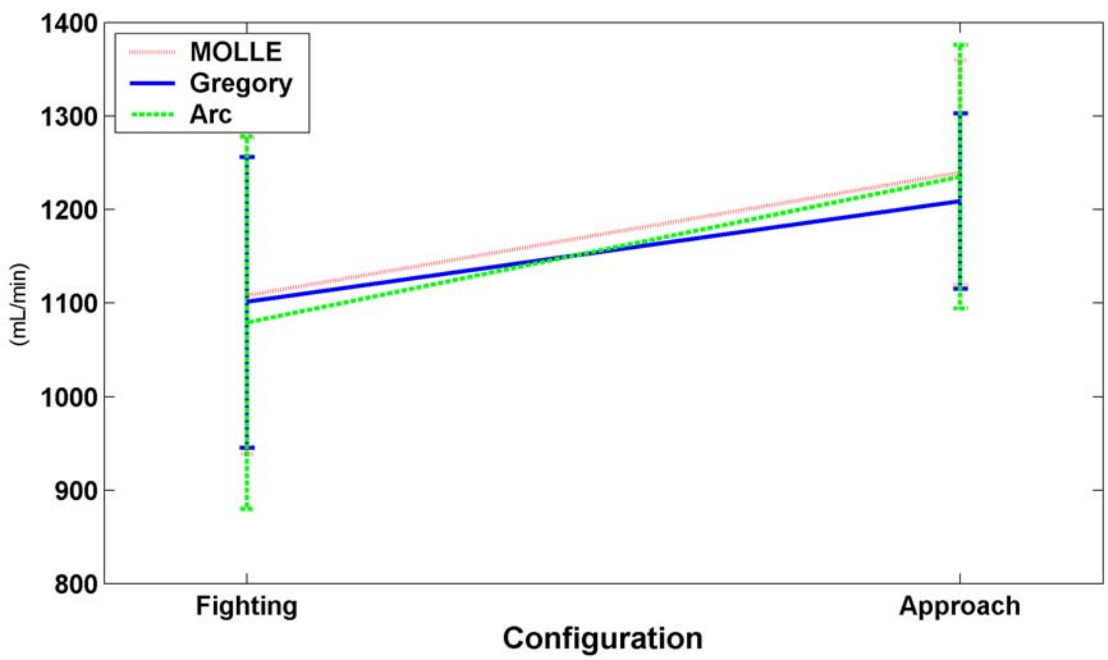


Figure 30: Heart Rate

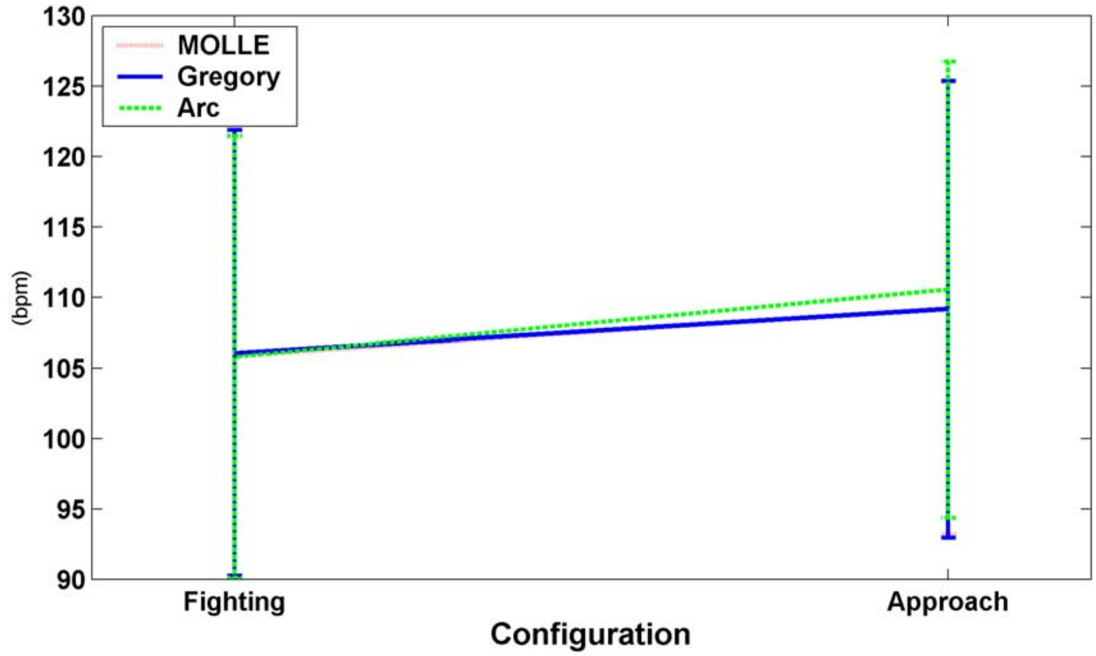


Figure 31: Volume of Oxygen Consumed/ Body Weight (VO_2/BW)

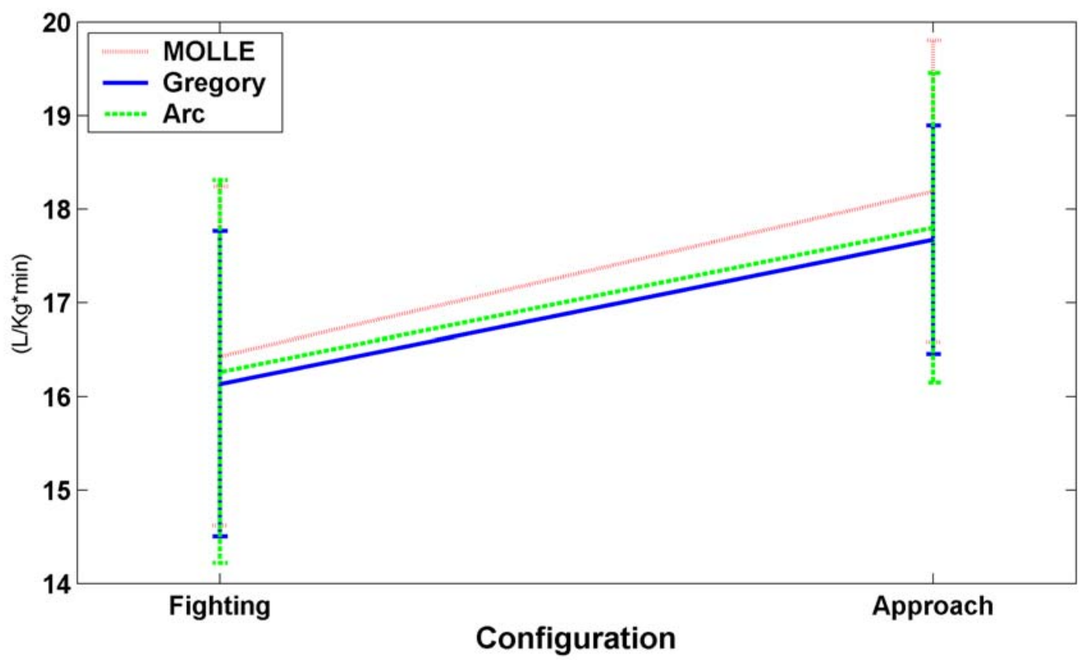
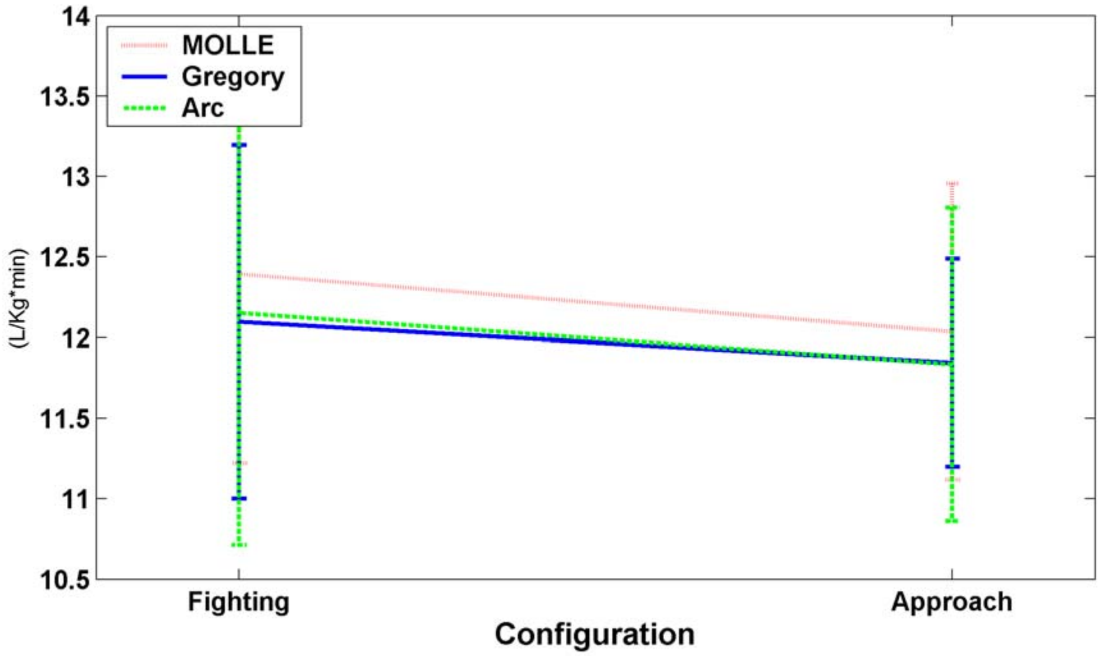


Figure 32: Volume of Oxygen Consumed/ Total Weight (VO_2/TW)



WEAPONEER

All three backpacks in both configurations had a similar effect on marksmanship ability when firing at both the 175 M and the 300 M targets; no significant main effect of system or firing posture was found on marksmanship performance for either target (Table 32).

Table 32: P-Values for Main Effects and Interactions for Marksmanship Performance

	Main Effects		Interaction
	System	Firing Posture	System*Posture
175 M Target	0.5189	0.0001	0.2478
300 M Target	0.2630	0.0021	0.4070

P-values greater than 0.05 indicate there is no statistical difference between backpack system, between firing posture or there was no system*posture interaction for that specific comparison.

When shooting at the 175 M targets, the highest marksmanship scores were in the standing position. A statistically significant higher ratio of hits/total shots was observed in the standing position than in the prone position, which in turn, was statistically greater than the performance in the kneeling position (Table 33).

When shooting at the 300 M targets, the highest marksmanship scores were in the kneeling position. A statistically significant higher ratio of hits/total shots was observed in the kneeling position than in the standing or prone positions, which were not significantly different.

Table 33: Marksmanship Results

	175 Meters	300 Meters
Standing	0.6169[A]	0.1688[B]
	(0.2659)	(0.0805)
Kneeling	0.3941[C]	0.2046[A]
	(0.2232)	(0.0713)
Prone	0.5451[B]	0.1629[B]
	(0.2809)	(0.0892)

Means (Standard Deviation) Within a column, means with the same letter are not significantly different.

OBSTACLE COURSE

For the Fighting Load, there was no significant main effect of backpack system (MOLLE vs. Gregory vs. Arc'Teryx) on the amount of time taken to traverse the obstacle course (Table 34). As expected, there were statistically significant differences between the pre 2-mile and post 2-Mile runs through the obstacle course. However, the lack of a statistically significant System * Pre-Post Interaction indicates the performance decrement resulting from the 2-mile timed march was not different between the backpack systems. That is, each of the backpacks resulted in comparable performance decrements after the 2-mile timed march.

Table 34: P-Values for Main Effects and Interactions for Obstacle Course Performance – Fighting Load

	Main Effects		Interaction
	System	Pre-Post	System * Pre-Post
Time to Complete Tires	0.5965	0.0001	0.0861
Time to Crawl Through Pipe	0.9785	0.0382	0.1103
Time to Complete High Crawl	0.8043	0.0003	0.3002
Time to Complete Low Crawl	0.4607	0.0237	0.2595
Time to Complete Zigzag	0.3512	0.0081	0.1357
Time to Complete Poles	0.7783	0.0003	0.2415
Time to Move Through Interior Doors	0.8467	0.0278	0.2116
Time to Climb Stairway	0.9971	0.0012	0.5867
Time to Climb Through Large Window	0.3935	0.1845	0.533
Time to Climb Through Medium Window	0.5973	0.4098	0.5038
Time to Move Through Ship Hatch	0.6511	0.5248	0.4659
Final Door	0.3945	0.1868	0.3194
Total Time for all Obstacles	0.7968	0.0001	0.5091
Two Mile March Time	0.1296	0.0001	0.1468

P-Values greater than 0.05 indicate there is no statistical difference between backpack SYSTEM, between the PRE 2-mile and the POST 2-mile trial, or there was no SYSTEM*Trial interaction for that specific comparison.

For the Approach Load, there was no significant main effect of backpack system (MOLLE vs. Gregory vs. Arc'Teryx) on the amount of time taken to traverse the obstacle course (Table 35), except for the time to crawl through the 6.1 m long, approximately 1 m diameter pipe.

Table 35: P-Values for Main Effects and Interactions for Obstacle Course Performance – Approach Load

	Main Effects		Interaction
	System	Pre-Post	System * Pre-Post
Time to Complete Tires	0.7118	0.0001	0.0049
Time to Crawl Through Pipe	0.0259	0.0107	0.9556
Time to Complete High Crawl	0.2163	0.0010	0.7428
Time to Complete Low Crawl	0.3638	0.0111	0.8367
Time to Complete Zigzag	0.5728	0.0006	0.5659
Time to Complete Poles	0.5170	0.0064	0.5756
Time to Move Through Interior Doors	0.9286	0.0001	0.9391
Time to Climb Stairway	0.6575	0.0002	0.5940
Time to Climb Through Large Window	0.7316	0.5056	0.9723
Time to Climb Through Medium Window	0.1748	0.1943	0.6934
Time to Move Through Ship Hatch	0.3753	0.4884	0.3792
Final Door	0.1617	0.0001	0.9934
Total Time for all Obstacles	0.0867	0.0004	0.8325
Two Mile March Time	0.1611	0.0001	0.1071

P-Values greater than 0.05 indicate there is no statistical difference between backpack SYSTEM, between the PRE 2-mile and the POST 2-mile trial, or there was no SYSTEM*Trial interaction for that specific comparison.

It took longer to crawl through the pipe while carrying Gregory Approach than while carrying MOLLE Approach or Arc'Teryx Approach (Table 36). While the differences between Gregory and the other 2 packs were statistically significant, the difference between MOLLE and Arc'Teryx was not. It is important to note that the increased time to crawl through the pipe with Gregory was not great enough to cause a statistically significant change in the total time to complete the obstacle course.

Table 36: Pipe Crawl Results

MOLLE	Gregory	Arc'Teryx
56.213	79.211	62.152
(22.404)^{B}	(43.096)^{A}	(28.298)^{B}

Means (Standard Deviation) within a column, means with the same letter are not significantly different.

As expected, there were statistically significant differences between the Pre 2-Mile and Post 2-Mile runs through the obstacle course while carrying the Approach load. However, the lack of a statistically significant System * Pre-Post Interaction on all obstacles (except the tire run) indicates the performance decrement resulting from the 2-mile timed march was not different between the backpack systems for the Approach load. That is, on the entire obstacle course (aside from the tire run), each of the backpacks resulted in comparable performance decrements.

At the conclusion of the obstacle course and 2-mile timed march, subjects were asked to complete a rating of pain soreness and discomfort (PSD Rating). There were no differences in Pain, Soreness or Discomfort between the backpack systems or configurations on any of the body segments except for the back of the upper arm, the back of the upper leg, and the back of the foot. Additionally, there was a significant system*configuration interaction on PSD Rating for the back of the upper leg. MOLLE resulted in the worst score for pain, soreness and discomfort on the back of the upper arm, and on the back of foot; Gregory resulted in the best score. No statistically significant differences were found between Gregory and Arc'Teryx, or between MOLLE and Arc'Teryx (Table 37).

Table 37: Rating of Pain Soreness and Discomfort For Body Segments Affected by Backpack Design.

	back of upper arm	back of upper leg	back of foot
MOLLE	0.50 [A]	0.40 [A]	0.450 [A]
	(0.688)	(0.502)	(0.759)
Gregory	0.05 [B]	0.278 [AB]	0.055 [B]
	(0.236)	(0.461)	(0.235)
Arc'Teryx	0.167 [AB]	0.111 [B]	0.222 [AB]
	(0.383)	(0.323)	(0.427)

Within a Comparison Packs with same letter are not Statistically Different

When interpreting Pain, Soreness and Discomfort data, it is important to note that these are self-reported data. Ratings of Pain Soreness and Discomfort are on a scale of 0 to 5, 5 representing the most pain, soreness and discomfort, and 0 representing no pain. Even though MOLLE resulted in the greatest amount of pain, soreness and discomfort, all of the mean values for MOLLE were less than 1.0; this indicates minimal pain, soreness and discomfort.

SPECIFIC MILITARY MANUEVERS

There was a significant main effect of backpack system and a significant system * configuration interaction on the time to Donn the Backpack (Table 38). Donning MOLLE Fighting takes less time than donning Arc'Teryx Fighting or Gregory Fighting. In contrast, no statistically significant differences were found for the Approach Load (Figure 33 and Table 39).

Table 38: P-Values for Main Effects and Interactions for Specific Military Manuevers

	Main Effects		Interaction
	System	Configuration	System * Configuration
Time to Complete Stand to Prone	0.6292	0.0001	0.0093
Time to Complete Prone to Stand	0.6041	0.0107	0.7950
Time to Donn the Backpack	0.0028	0.0029	0.0195
Time to Doff the Backpack	0.1714	0.0001	0.0049

P-Values greater than 0.05 indicate there is no statistical difference between backpack SYSTEM, between configurations, or there was no SYSTEM*Configuration interaction for that specific comparison.

Figure 33: Time to Donn the Backpack

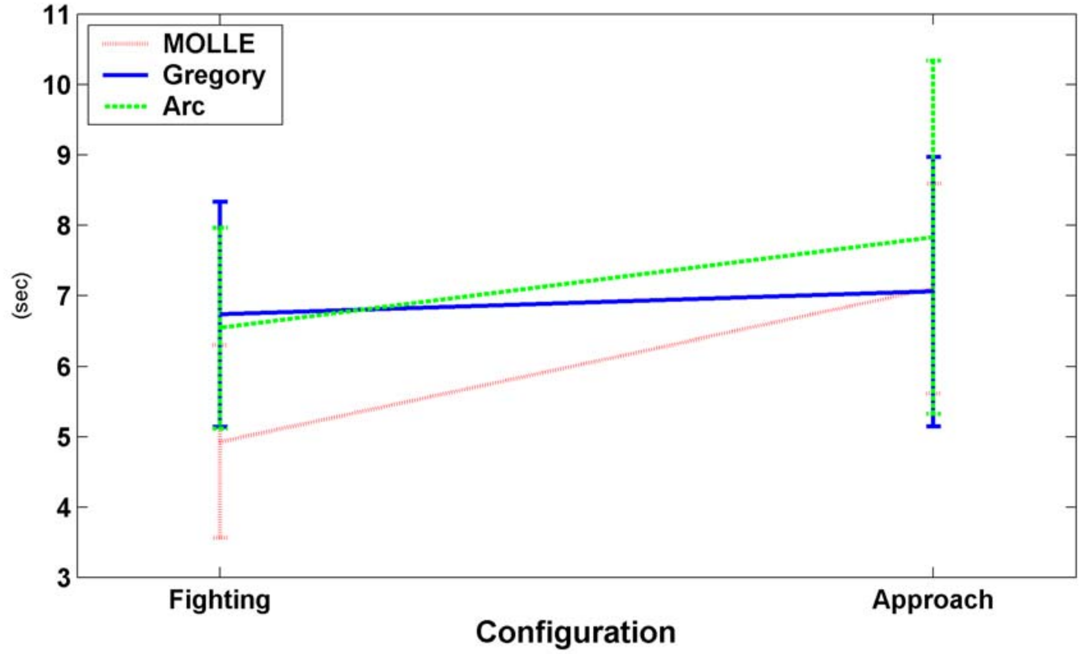


Table 39: Time to Donn the Backpack * ^ #

	Fighting	Approach
MOLLE	4.928 [B] (sec)	7.100 [A] (sec)
	(1.37)	(1.488)
Gregory	6.733 [A]	7.056 [A]
	(1.597)	(1.911)
Arc'Teryx	6.537 [A]	7.828 [A]
	(1.424)	(2.509)

* indicates statistically significant effect of system
^ indicates statistically significant effect of Configuration (Fighting vs. Approach)
# indicates statistically significant system*configuration interaction
Within a Configuration Packs with same letter are not Statistically Different

Additionally, there was a significant System*Configuration Interaction on the time to complete Stand to Prone (Table 39). In the Fighting load subjects completed the Stand to Prone more slowly with MOLLE than with Arc'Teryx, however, neither MOLLE nor Arc'Teryx was statistically different from Gregory. In contrast, for the Approach load, subjects completed Stand to Prone most slowly with Arc'Teryx, which was significantly slower than both Gregory and MOLLE. There were no statistically significant differences between Gregory and MOLLE in the Approach load (Figure 34 and Table 40).

Figure 34: Time to Complete Stand to Prone

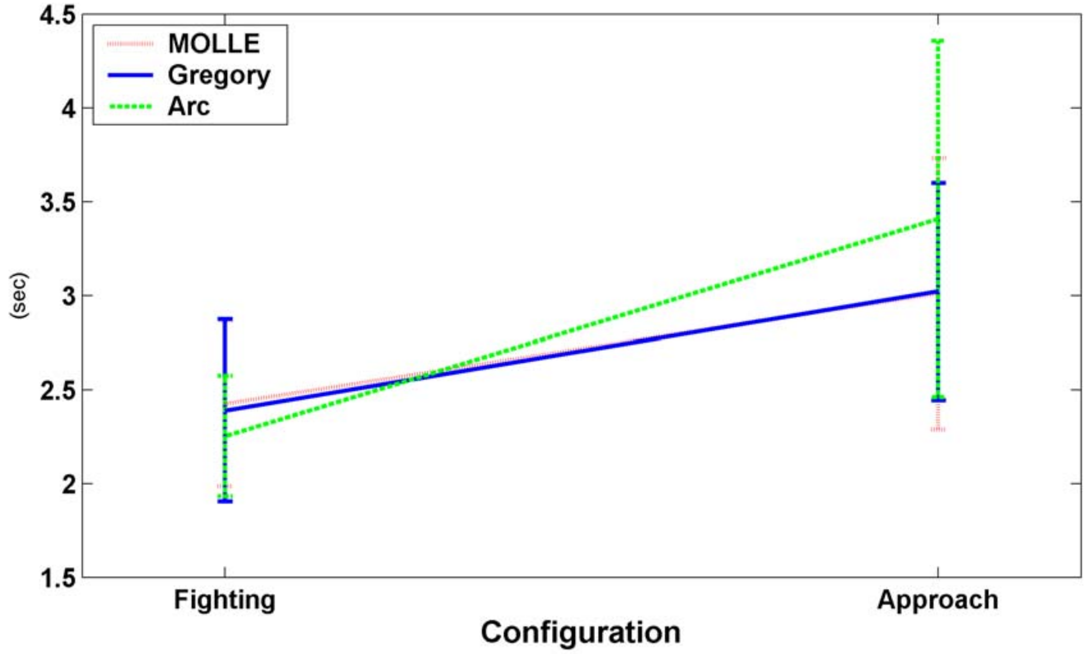


Table 40: Time to Complete Stand to Prone **^ #**

	Fighting	Approach
MOLLE	2.425 A (sec)	3.010 B (sec)
	(0.441)	(0.723)
Gregory	2.388 BA	3.021 B
	(0.484)	(0.578)
Arc'Teryx	2.252 B	3.407 A
	(0.321)	(0.949)

^ indicates statistically significant effect of Configuration (Fighting vs. Approach)
# indicates statistically significant system*configuration interaction
Within a Configuration Packs with same letter are not Statistically Different

2-MILE RUN

No differences were found between backpack designs on the time taken to complete the 2-mile run (Table 41). Mean values are presented in Table 42.

Table 41: P-Values for 2-Mile Run Times

	p-Value
Fighting Load	0.9340
Approach Load	0.1220

P-Values greater than 0.05 indicate there is no statistical difference between backpack SYSTEM within the configuration.

Table 42: Mean Values for 2-Mile Run Times

	Fighting	Approach
MOLLE	22.93 (min)	29.26 (min)
	(3.07)	(3.13)
Gregory	23.76	26.86
	(3.00)	(4.364)
Arc'Teryx	22.64	28.13
	(2.99)	(2.93)

Within a configuration, there is no difference between packs.

RESPONSES TO POST SPECIFIC MILITARY MANUEVERS QUESTIONNAIRE:

After each session of Specific Military Manuevers data collection, the Marines were asked to write down any comments they had on the system they tested that day. The following is a list of their comments, as they wrote them.

MOLLE

- General
  - Load shifts too much
  - Can fire in prone position with both packs
  - Sternum strap gets caught underneath shoulder strap
  - When donning pack, had to look for straps
  - Sternum strap got caught underneath shoulder straps
- Fighting
  - Day pack was very good
  - Good design for pack
  - Sternum strap is ok
  - Sternum strap is difficult to access and clip
  - Sternum strap on day pack created less fumbling and allowed movement
  - Does not stay on back very well
  - Slipped forward during IMT movements
  - Waist belt required
  - Likes no waist belt on Fighting load
  - Doffing is difficult because straps get caught on arms
  - Needs a little improvement in conforming to the body
- Approach
  - Sternum straps needs to be kept in place,
  - Sternum strap buckle moves around; hard to grab
  - Sternum strap is very hard to get to
  - Sternum strap needs a guide
  - Can’t find sternum strap
  - No problems with donning besides sternum strap
  - Shrugging shoulders and sucking in gut to tighten/hook
  - Ok in prone when engaging on target
  - Need to toss head to side to aim weapon
  - Pack leans to the side as well
  - Feels good on back, less movement, fits to body
  - Backpack shifts from side to side when doing Stand to Prone
  - Liked having frame to grab for donning

  - Like external frame
  - Uncomfortable frame
  - Frame is ok, but prefer internal
  - Did not like frame right under your armpits
  - Feels heavier than other packs
  - Waist belt is hard to tighten; from rear forward would help pull weight on to hips
  - Good weapons carriage when weapon sits on shoulder
  - Uncomfortable

Gregory

- General
  - Change the way waist belt tightens (pull forward instead)
  - Hip belt tightening tabs could be bigger
  - Like donning handles
  - Too many stray straps
  - Shoulder straps dig into arms
- Fighting
  - Shoulder strap contour is good
  - Shoulder straps fell off and got in way of Approach pack; straps thin and easy-not bulky
  - Shoulder straps were too far wide on arms
  - Do not like lack of sternum strap
  - Better with sternum strap
  - Bad day pack
  - No sternum strap is bad; having waist belt is good
  - Sternum strap would help
  - Day pack needs a sternum strap, but does not need waist belt
  - Needs sternum strap
  - Fine when tightening down straps; too many to grab though
- Approach
  - The best pack for IMT's
  - Better than all the other Approach packs
  - Velcro very good
  - Waist strap "cutting in to side" a little
  - Too many straps
  - Big pack has a lot of straps
  - Likes mobility of the pack
  - Can get it on fast and sturdy
  - Likes the way it secures; likes buckles that don't get stuck under things
  - During Prone to Stand and Stand to Prone, pack moved a lot left to right; everything else was good
  - Pack was top heavy and hard to donn
  - Handles should be deeper on the pack
  - Donning handles very good
  - Donning handles are good
  - Donning is easier with the handles
  - Handles on side of pack are very useful
  - Sternum strap easy to grab and tighten
  - Sternum strap is placed well
  - Liked sternum strap; stable sternum strap

- Comfortable in prone position
- More comfortable to be in prone with this pack
- When prone, weight shifts nicely for clear field of fire; not that uncomfortable
- Cannot get a good sight with Approach load while in prone
- Quick release is easily accessible
- Shape of the shoulder straps help
- Contour of shoulder straps is good
- Cinching straps need more lead
- Waist belt difficult to tighten

<u>Arc'Teryx</u>

- General
  - Sternum strap often goes under shoulder strap
  - Straps need to be sewn differently so they don't cinch down too far- nothing to hold onto and pull thru
  - All straps need leaders…not able to hold onto them and pull
- Fighting
  - Awesome, easy to deal with, stays on well and very comfortable, love the Fighting pack
  - Good pack, comfortable
  - Like sternum strap
  - Clips are good for doffing
  - Fighting pack shifts too much, pushes Kevlar around
  - Dislike waist belt, but it is a comfortable pack
- Approach
  - In prone, impossible to sight weapon; difficult to drop down
  - Firing in prone is difficult
  - No head movement in prone
  - No problem aiming in prone position
  - Difficult to assume prone position and sight in; near impossible to get good sight alignment in prone position
  - Can't tilt head back in prone position
  - Firing in prone is difficult with weight on back
  - Cannot see with Approach pack; difficult to get up from prone
  - Prone to Stand and Stand to Prone both difficult moves
  - In prone and ready position, not able to shoot
  - Head notch is too low
  - Straps too short on shoulders
  - Adjustment needed for shoulder strap
  - Not enough length on shoulder strap material to tighten
  - When donning, nothing to hold onto; enough head room as long as pack is back far enough
  - Harder to donn pack
  - Nothing to grab when donning
  - Donning is very difficult; sternum straps clip in wrong direction for me
  - When donning, difficult without hand straps, nothing to grab onto; dislike Approach pack
  - Difficult to donn quickly because there is not enough material on the straps to grab quickly

- Needs donning handles
- Easy to donn (straps do not get stuck)
- Doffing is easy
- Need to lift plates in vest to close belt
- It is the most difficult and uncomfortable pack out of all 3
- Too loose
- 1 large open pocket makes it difficult to pack
- Pack is too long as well as too tall
- Sternum strap left to right is good, but too tall for a smaller marine
- Straps are good; curve into chest is good
- Quick release needs to be worked on

RESPONSES TO EXIT SURVEY:

At the conclusion of the test, the Marines were asked a series of questions about each of the backpack system. The following is a list of the questions asked followed by their responses.

Overall, Which Carrying System Did You Like Best?

- 5 MOLLE
- 6 Gregory
- 0 Arc'Teryx

Overall Comments about MOLLE:

- Even after being shown how to properly adjust the MOLLE, I feel it still put the most stress on my body through out all of the exercises. The most stress I felt was on my upper back and shoulders. The other problem was that the pack shifted from side to side and moved forward putting the weight on your neck.
- During the obstacle course, the MOLLE clearance through the obstacles was a little bit better than the rest. The plastic frame did sometimes dig into your arm when crawling on your side. For everything else, the pack felt good.
- During the obstacle course, the MOLLE clearance through the obstacles was better than the other packs tested.
- The plastic frame did sometimes dig into your arm when crawling on your side. For everything else the pack felt good.
- The MOLLE was much more durable and size-efficient to fit through the pipe crawl especially.
- The frame allowed air to the back.
- The frame did stick out on its end corners, but still worked well.
- Weaponeer was difficult/pack would shift weight in order to fire.
- The treadmill went well and the IMT's as well.
- The frame was digging into any arm and back during low crawl.
- Had trouble on the off center pipes; the pack is too wide.
- The clip on the sternum strap needs to be set on the strap so it doesn't slide back under the arm.
- Had trouble getting through windows.

- MOLLE is a very good system now, after all of its improvements in terms of reinforcing the frame.
- The system was never taught to Marines. With it being a different concept from ALICE, Marines should have been instructed on how to properly use it.
- MOLLE is a good system for shooting you have clear fields of fire, and it is also pretty easy to donn and doff the pack both Fighting and Approach.
- It is really hard to crawl both low and high with the Approach pack.
- In IMT's the purpose to me was to get ready and to go execute an objective or get ready to execute an objective quickly. If this is the purpose the MOLLE is an uncomfortable pack to wear if your in a hurry
- It is very stable, but the structure makes it difficult to work with.
- Best suited for encountering obstacles.
- The pack is tight to the body in which gives you the lowest profile while in the prone position which made it easier.
- Best suited for firing the weapon, no problem keeping the weapon in my shoulder with the flak vest and FLC on, the external frame was not as comfortable as I would have thought
- The MOLLE was not the most comfortable pack, although it was fairly easy to shoot and maneuver with it
- The exterior frame is better for ventilation and has a better support
- The rucksack is very well designed it comfortably fits the equipment I need
- MOLLE did not fit well at all.
- The pack moved around a lot and really threw off my balance.
- The same went for the Fighting load; it was not very secure on my back.
- Going through the obstacle course it was very uncomfortable and hard to maneuver.

<u>What did you like best about MOLLE?</u>

- Quick Release straps
- It does not get too complicated – easy to use
- I think it does not get to complicated it is simple to use, once you are properly trained.
- It gets the job done.
- I prefer the external frame because it was open and seemed to distribute the weight better.
- It felt good on the march.
- Did not give me much trouble on the obstacle course.
- Its ability to be set up to the users liking and needs, unfortunately this great feature is often times not used for the sake of uniformity.
- I like the sleeping bag compartment and the other pouches.
- It is very stable; you can fire a weapon well if it is put on properly.
- The lower profile and the fact that the daypack mounts up high keeping all of the weight of the pack closer to your body.
- It was a good pack size, not too big or small
- The shoulder straps are a very versatile length. (Good for short and tall people)

- Durability

<u>What did you dislike most about MOLLE?</u>

- Puts a lot of stress on your shoulders and upper back.
- Too many straps hanging down when you are looking to donn the pack quickly.
- The plastic frame sometimes digs into your shoulder and arm.
- Sternum strap would cut into my throat.
- Had sore shoulders, the external frame.
- The waist strap could be more comfortable and the sleeping system may need a larger compartment.
- The sternum strap tucks under the shoulder strap and is hard to get to, my issued MOLLE pack for the field is starting to rip at the seams.
- It is uncomfortable for the most part.
- The sternum strap chokes you and it pinches under your arm pits
- The top corner of the external frame “cut” into my triceps on the low crawl causing significant bruising and discomfort.
- Frame was uncomfortable
- The width of the shoulder strap it’s to wide for smaller people.
- The way the pack was fitted to my body

<u>What would you change on MOLLE system?</u>

- Include arched shoulder straps and more padding like Gregory pack
- I would make side straps on the sides for easier donning like on the Gregory pack.
- The clip on the sternum strap put the frame inside the pack and put handles on the side to put it on.
- The MOLLE concept means a change to the concept of pack systems, with it the users should have been taught this different Approach and made to understand that they needed a new mindset when dealing with the system.
- Reinforce the seams
- The sternum strap, the shoulder strap and some how making the frame easy to work with.
- The way that the waist belt tightens, Make it so that the fasteners is on the hips so that the straps can be pulled forward to tighten. This would give a better mechanical advantage and allow the individual to get the belt tighter without assistance.
- The frame
- The width of the shoulder straps
- Snaps, buckles, and how it fits to the contours of the body

<u>Overall comments about Gregory system</u>

- Comfortable pack in all aspects of the testing, pack sits very high and the day pack sticks out more off the back of the pack.
- Not as low profile as the MOLLE, difficult to employ the weapon and engage the target, it was hard to keep the butt stock from moving on my shoulder while firing.

Nearly impossible to get good sight alignment in the prone. Bulkiness of the pack made the kneeling portion unstable.

- I felt Gregory was the most comfortable it was also easy to maneuver with this pack.
- The Gregory is too tall and with the Fighting pack attached it comes too far off your back.
- Overall was the best pack. It strapped on my back and didn't move. It was the easiest for me to encounter the obstacles, and 2mile walk and IMT's with this pack could use a few changes and it would be perfect.
- The Gregory is a great pack. I like the way it has Velcro holders for the straps (No electric tape needed), The shoulder straps fit well with the flack vest and FLC on and is very comfortable to run or walk with.
- The Approach pack is really tall and it was tough getting through crawling obstacles, you had to slant the pack a certain way in order to fit it through. 2mile and run was ok with Approach pack.
- Had a lot of trouble on the obstacle course, The pack was too high, had trouble on the tube, high and low crawl and the zigzag.
- The Gregory system is a better pack out of all the packs. The amount of straps was not necessary. The obstacles like the pipe crawl, low crawl and road march and IMT's were fine. The system was longer than the other systems and it seemed easier to fire the weaponeer, Fighting pack needs sternum strap.
- The Gregory was a close second to MOLLE. I think with some small modification it can be right there with MOLLE the pack felt good overall, I think it needs a sternum strap for the Fighting load. It had the least amount of clearance on the obstacle course.
- I felt that the Gregory was the best overall pack for comfort. The pack was a little bit taller when Fighting through the tunnel, low and, high crawl, the top of the pack would hit.
- The Gregory is the best overall, it is easy to engage the targets with and it was the most comfortable during movement, on the other hand it still remains to be seen how strong the internal frame is and it was the most difficult to tackle The course with

<u>What did you like best about Gregory?</u>

- The waist belt, how comfortable it is and especially how well balanced it sits in your body.
- I like the frame and the carry handles.
- The shoulder strap, it was closer to my shoulders and I was able to close the sternum strap faster.
- I like the handles on the side for donning.
- The pack is easy to throw on both Fighting and Approach. This pack is the most comfortable of all three, its handles on the pack make it easy to donn and carry, and you can grab handles to tighten.
- The shoulder straps, the sternum strap fits right and it is very comfortable.
- The fit, sternum strap accessibility, side handles and overall the feel.
- The shape of the shoulder straps is very nice.

- It was comfortable.
- The external reinforced handles make it easier to donn the pack quickly.

<u>What did you dislike most about Gregory?</u>

- The way the daypack mounts. Makes the load harder to balance and it creates a higher profile going through lower obstacles and getting through the windows of the building.
- It seemed to be a little bulky.
- The height of the pack.
- The Fighting pack, and material. The Fighting pack of the ARC system would be perfect.
- It is hard to maneuver through some obstacles with its height.
- It was really tall and sat high on the back.
- The size of the pack and it had too many straps.
- The configuration stuck out further than all the packs, which made it difficult to maneuver at times.
- I think there are too many strap holders, they sometimes get in the way of the straps that are used for tightening.
- Its shoulder straps dig in to your arms, and the daypack needs a sternum strap.
- Sits a little high.

<u>What would you change on the Gregory system?</u>

- Make a good system to hold the Isomat and make the sleeping system pouch bigger.
- Shoulder straps and adding a sternum strap to daypack.
- Less straps, just some small modifications by infantry marines
- I would change the waist strap to fit comfortably with the flack jacket.
- The size of the Fighting pack and less straps.
- Make it sit lower on the back and there are too many straps dangling.
- Make the pack sit lower on the back.
- The day pack, modify the waist belt strap. You need to be able to pull straps forward.
- The placement of the donning handles.
- I would try to move the position of the daypack.
- Better strap handles all around. Also change the waist belt mechanism.

<u>Overall comments about Arc'Teryx system</u>

- Most comfortable pack to wear. Most difficult pack to shoot with. The pack is too tall to practice military applications. The narrow frame made some of the obstacles easier to negotiate.
- I thought this pack was fairly comfortable, but it was too big.
- Was the most comfortable, but my back got very hot.
- The Approach load for me was very hard to handle. It was hard to shoot with, do obstacles and IMT's. The pack overall was not very effective. However, the Fighting pack is the best overall.

- The pack is very uncomfortable to fire with. The pack hits your head when you are trying to aim through your weapons sight. Also there is not enough slack to pull anything with. Very hard to fit to the body; I don't like it at all.
- It is nearly impossible to shoot accurately with the Approach pack on. The Approach pack sits snugly on the back when on a road march.
- Had trouble shooting in the prone, the pack is to long. Did not have problems on the obstacle course, feels like the pack rolls on the back.
- This was the second easiest pack to use on the obstacle course. The two-mile march seemed most difficult with this pack. IMT's went fine, as long as the pack was tightened down. On the treadmill this pack was okay. Waist strap wasn't made for flack jackets, so it would interfere. The occipital cavity was too small, on the Weaponeer, the helmet would interfere with the top of the pack. The pack was difficult to use, had to release shoulder straps on top all the way to fire in the prone.
- This pack finished last, but only needs a few modifications. The frame was good and I like the components. The Fighting load was nice. The pack has some small things that need to be fixed.
- It was the easiest to move through the course, but it was the most uncomfortable to hike with. Because of its height, it is harder to shoot with.
- The pack had good and bad points: the pack itself was comfortable, but became loose during the obstacle course and the run. While in the prone position the pack shifted forward and made it difficult to see.

<u>What did you like best about Arc'Teryx?</u>

- The daypack was narrow and the waist strap kept the pack tight.
- It fits through anything.
- I like the Fighting pack; I also like the design and the frame. Just some small features need work.
- The actual pack went well, liked the side pouches. Easy to get in and out of the system.
- Had no trouble on the obstacles, felt pretty good overall.
- Fits snugly on the back.
- The pack fits through obstacles well; it is very low.
- Fighting pack stayed tight to my body perfectly and comfortably through all tests.
- The comfort.
- It was complete with all belts and straps.
- Comfort of the pack straps, when carrying the pack.

<u>What did you dislike most about Arc'Teryx?</u>

- Too tall. All but impossible to fire in the prone. Requires too much effort to engage the targets. Because the pack hits the kevlar and pushes head down.
- It was too big.
- The height of the pack and the design of the ruck.
- Everything else is not a very effective load system for our purposes.
- No strap elasticity. Sits on your head, very uncomfortable to walk with.

- You can’t shoot with the Approach pack on, can’t grip shoulder straps to tighten pack. I don’t like the waist strap on the Fighting pack.
- Had no handles to donn it. Had soreness on the shoulders. Also had to many straps.
- The shoulder strap and sternum strap were the worst out of all systems.
- The straps have some problems. They need a more rigid material. Some of the latches have some problem.
- Very uncomfortable, it has only one main compartment, I can see it would be very hard to pack and access gear.
- Handles to donn the pack need to be more like the rubber handles on the Gregory.

<u>What would you change on the ARCTEYX system?</u>

- The sternum strap is backwards. New handles for donning and bigger pouch for sleeping system.
- The straps and tie down system and quick release.
- The pack just needs to be more comfortable.
- The shoulder, sternum and waist strap. The configuration of the pack.
- Put handles on the side; try to shorten it up.
- Alter the top, make handles. Make shoulder straps longer to grab easier.
- Everything. The way it sits on your head, the straps, and the quick release.
- Approach load isn’t easy to use. Put the Fighting on the Gregory.
- Take off the zippers on the sides; they will blow in the field.
- I would make it a little wider and not so tall.
- Waist belt adjustment, height of the pack, and the way the daypack mounts.

DISCUSSION

Subtle differences in biomechanics were observed between MOLLE, Gregory and Arc'Teryx. MOLLE demonstrated the greatest forward lean, trunk and shoulder range of motion, and the latest time of maximum knee joint torque in both the Fighting and Approach configurations. In the Fighting configuration, MOLLE demonstrated the greatest peak shoulder flexion during walking. In the Approach configuration, walking with MOLLE resulted in the greatest stride length, greatest shoulder flexion, and greatest posterior BPCOM velocity of the Approach loads.

The center of mass of the MOLLE pack was slightly more posterior than the center of mass of Gregory or Arc'Teryx (Figure 1), which likely explains the increased forward trunk lean observed while walking with MOLLE. A more posterior center of mass is typically associated with an increased metabolic cost (Obusek 1997). Additionally, carrying heavy loads typically results in a decrease in stride length. A shorter stride length is considered a negative aspect of load carriage, requiring an increase in stride frequency to maintain walking speed. An increase in stride frequency may contribute to additional metabolic costs. However, no differences in metabolic cost between backpack designs were observed in the present experiment.

It may be the case that the external frame design of MOLLE allowed for the greater shoulder range of motion observed while carrying this pack. This is further substantiated by the increase in shoulder flexion observed while walking with MOLLE in the Approach configuration. That is, while carrying an internal frame pack, shoulder motion may be constrained by the proximity of the backpack in relation to the body. Consequently, the external frame design and shoulder pad configuration of MOLLE, which provides an offset between the body and the backpack frame, may allow for greater freedom of shoulder motion during walking.

Across configurations, Gregory resulted the earliest time of maximum BPCOM horizontal acceleration. Gregory Fighting resulted in the most upright posture, greatest stride length, greatest peak hip flexion/extension angle, greatest shoulder flexion, greatest posterior BPCOM acceleration and greatest anterior BPCOM horizontal velocity of the Fighting loads. Notably, Gregory Approach was the most stable backpack in terms of vertical movement between the carrier and the backpack. This is especially important because an unstable load may result in excessive movement of the backpack in relation to the body; which in turn, may require large amounts of muscle force to control the load.

In general, Arc'Teryx resulted in the greatest hip flexion/extension range of motion, the earliest peak hip flexion/extension, the greatest maximum heel strike vertical GRF, the greatest peak heel strike vertical GRF/Total load and the latest time of peak heel strike GRF. An increase in hip flexion/extension range of motion is part of a complex adaptation in gait during load carriage that serves to maintain or increase stride length when transverse plane pelvic rotation is constrained. The benefit of increasing hip flexion/extension range of motion is the ability to maintain stride length. The costs of increasing hip flexion/extension range of motion may include an increase in metabolic cost and an increase in the vertical amplitude of the center of mass. It may be the case that the Arc'Teryx pack constrained transverse plane pelvic rotation, requiring the increased hip flexion/extension range of motion. However transverse plane pelvic rotation was not specifically measured in this study, and none of the costs of increasing hip flexion/extension were observed. Additionally, Arc'Teryx resulted in the least shoulder flexion/extension range of motion. This is likely due to the thickness and density of the shoulder padding. Across configurations, the vertical ground reaction force experienced with Arc'Teryx was about 5% greater than the vertical ground reaction force experienced with MOLLE, and about 3.3% greater than with Gregory. Arc'Teryx Fighting was the most stable Fighting load in term of vertical movement between the carrier and the backpack. Walking with Arc'Teryx Approach resulted in the most upright posture and the greatest peak hip flexion of the Approach loads.

The differences in obstacle course and specific military maneuver performance were minimal. That is, no differences in obstacle course performance were observed between backpack systems in the Fighting configuration. Gregory Approach resulted in a greater time (decrease in performance) to complete the pipe crawl than did MOLLE or Arc'Teryx, this was likely due to the height of the backpack or the anterior-posterior length of the pack when the Fighting load is attached to the Approach pack. As expected, there were differences between the pre 2-Mile and post 2-Mile runs through the obstacle course while carrying the Approach load. These differences are an expected consequence of the fatigue resulting from completing the 2-mile time run. Notably, the differences in performance between the PRE and POST 2-mile runs were consistent across backpack designs (except the tire run), indicating the performance decrement resulting from the 2-mile timed march was not different between the backpack systems for the Approach load. This suggests the fatigue resulting from the 2-mile run was consistent across backpack designs.

MOLLE Fighting took less time to donn than Arc'Teryx and Gregory; the difference in time to donn between MOLLE Fighting and the other Fighting loads was minimal –less than 2 seconds. No difference in time to donn was observed for the Approach packs. Subjects completed Stand to Prone more slowly with Arc'Teryx Approach than with Gregory or MOLLE Approach. There were no statistically significant differences on any of the other SMMs.

There were no differences in oxygen consumption, heart rate or carbon dioxide production between backpack systems. No differences in marksmanship performance were observed between backpack systems.

Six of the Marines chose Gregory as the best pack. Generally, the Marines liked the overall comfort of the pack and, specifically, the waist belt and the donning handles. Additionally, the Marines liked the shape of the shoulder straps and the way the backpack secured to the body. Negative comments for Gregory included too many straps, the pack was too tall, and attaching the Fighting load made the pack too large from front to back. Additionally, Marines could not get a good weapon's sight with the

Approach pack in the prone position. Five of the Marines chose MOLLE as the best pack. The Marines liked the external frame (additionally, they liked having the frame to grab for donning), thought MOLLE had the best clearance through the obstacles and liked the pack's modularity. However, several of the Marines commented the external frame pack "dug" into their arm and caused bruising while trying to complete the obstacle course. Additionally, the Marines did not like the way the sternum strap attached to the shoulder straps, noting it was difficult to grab and could needed a guide. None of the Marines chose Arc'Teryx as the best pack. While there were positive comments, the Marines disliked the height of the Approach pack (it interfered with the helmet) and found the pack to be uncomfortable when wearing it with body armor.

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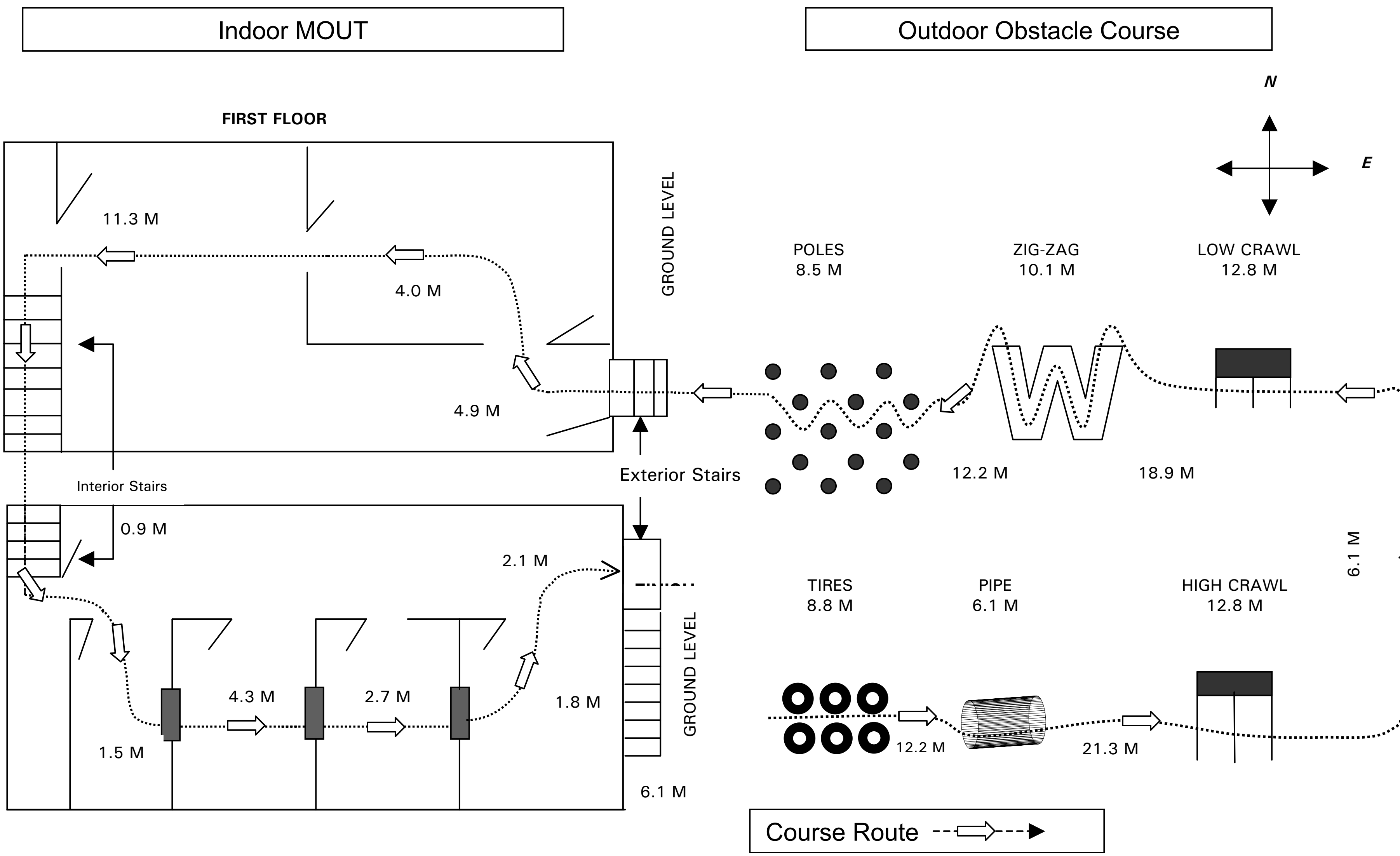
APPENDIX A

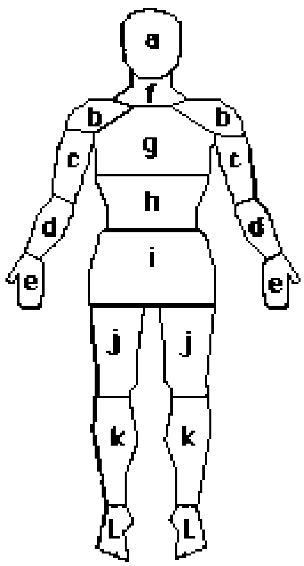


Indoor MOUT
Outdoor Obstacle Course
N
E
FIRST FLOOR
11.3 M
4.0 M
4.9 M
GROUND LEVEL
Interior Stairs
Exterior Stairs
0.9 M
2.1 M
4.3 M
2.7 M
1.8 M
1.5 M
6.1 M
GROUND LEVEL
POLES
8.5 M
ZIG-ZAG
10.1 M
LOW CRAWL
12.8 M
12.2 M
18.9 M
6.1 M
TIRES
8.8 M
PIPE
6.1 M
HIGH CRAWL
12.8 M
12.2 M
21.3 M
Course Route

APPENDIX B
MARINE BACKPACK STUDY
OBSTACLE AND MOUT COURSE QUESTIONNAIRE

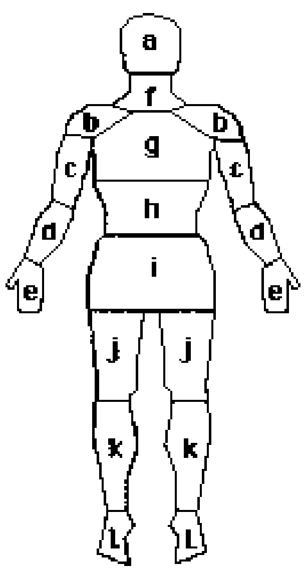
Subject Number: __________ Date: __________ Pack / Configuration: __________

1. Rate the degree of SORENESS, PAIN, or DISCOMFORT that you are currently feeling for Body Parts A through L. Do so for the FRONT and the BACK of the body.



FRONT of Body

	a	b	c	d	e	f	g	h	i	j	k	L
NONE	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
SLIGHT	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
MODERATE	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
SEVERE	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
EXTREME	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐



BACK of Body

	a	b	c	d	e	f	g	h	i	j	k	L
NONE	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
SLIGHT	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
MODERATE	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
SEVERE	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
EXTREME	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

2. For the outdoor course obstacles listed below, please rank the tasks from 1-6 with increasing difficulty - - with a "**1**" indicating the obstacle that was the **EASIEST** to get through today, and a **"6"** indicating the obstacle that was the **MOST DIFFICULT** to get through today.

_____ Tire run

_____ Pipe crawl

_____ High crawl

_____ Low crawl

_____ Zig-zag run

_____ Poles

a. For the obstacle that you selected above as **most difficult** to get through today, explain the problems that you experienced negotiating this obstacle:

3. Put a check mark next to **EVERY** outdoor course obstacle that you had difficulty fitting through because of the size or external dimensions of the backpack you wore today. If you did not have difficulty fitting through any of the obstacles today, indicate that by putting a check mark next to the last item on the list below.

_____ Tire run

_____ Pipe crawl

_____ High crawl

_____ Low crawl

_____ Zig-zag run

_____ Poles

_____ No difficulty fitting through any of the obstacles

4. Put a check mark next to **EVERY** outdoor course obstacle on which some part of the backpack got caught or snagged today. If no part of the backpack got caught or snagged on an obstacle today, indicate that by putting a check mark next to the last item on the list below.

_____ Tire run

_____ Pipe crawl

_____ High crawl

_____ Low crawl

_____ Zig-zag run

_____ Poles

_____ No part of the backpack got caught or snagged

5. For the sections of the building listed below, please rank them from 1-6 with increasing difficulty, with a "**1**" indicating the section that was the **EASIEST** to get through today, and a **"6"** indicating the section that was the **MOST DIFFICULT** to get through today.

_____ Stairs into building

_____ Doorways on first floor

_____ Stairs in building from first to second floor

_____ Wall openings on second floor

_____ Doorways on second floor

_____ Ship Hatch

a. For the section of the building that you selected above as **MOST DIFFICULT** to get through today, explain the problems that you experienced negotiating this section:

6. Put a check mark next to **EVERY** section of the building that you had difficulty fitting through because of the size or external dimensions of the backpack you wore today. If you did not have difficulty fitting through any of the sections today, indicate that by putting a check mark next to the last item on the list below.

_____ Stairs into building

_____ Doorways on first floor

_____ Stairs in building from first to second floor

_____ Wall openings on second floor

_____ Doorways on second floor

_____ Ship Hatch

_____ No difficulty fitting through any section of the building

7. Put a check mark next to **EVERY** section of the building on which some part of the backpack got caught or snagged today. If no part of the backpack got caught or snagged on a section of the building today, indicate that by putting a check mark next to the last item on the list below.

_____ Stairs into building

_____ Doorways on first floor

_____ Stairs in building from first to second floor

_____ Wall openings on second floor

_____ Doorways on second floor

_____ Ship Hatch

_____ No part of the backpack got caught or snagged

APPENDIX C

Gait Parameters

Variable	System	Configuration	System*Configuration
Stride Length	0.2232	0.683	0.0327
Stride Length/Height	0.2173	0.6656	0.0349
Stride Frequency	0.3447	0.9615	0.3854
Time at Toe Off	0.1761	0.2247	0.2929
Double Support Time	0.1723	0.2228	0.2956
Single Support Time	0.1723	0.2228	0.2956

Joint Kinematics

Variable	System	Configuration	System*Configuration
Ankle Range of Motion	0.4896	0.0421	0.8978
Maximum Knee Flexion/Extension Angle	0.891	0.2431	0.4906
Time of Maximum Knee Flexion/Extension Angle	0.0679	0.0028	0.31
Minimum Knee Flexion/Extension Angle	0.8145	0.1645	0.7721
Time of Minimum Knee Flexion/Extension Angle	0.0834	0.0258	0.6365
Knee Range of Motion	0.7701	0.687	0.432
Maximum Hip Flexion/Extension Angle	0.0906	0.1855	0.0004
Time of Maximum Hip Flexion/Extension Angle	0.039	0.7601	0.3198
Minimum Hip Flexion/Extension Angle	0.4416	0.0002	0.0686
Time of Minimum Hip Flexion/Extension Angle	0.5882	0.7513	0.8986
Hip Flexion/Extension Range of Motion	0.0072	0.0001	0.6415
Maximum Hip Abduction/Adduction Angle	0.0525	0.2181	0.2591

Time of Maximum Hip Abduction/Adduction Angle	0.0351	0.7795	0.566
Minimum Hip Abduction/Adduction Angle	0.8048	0.9328	0.5331
Time of Minimum Hip Abduction/Adduction Angle	0.2743	0.3028	0.0604
Hip Abduction/Adduction Range of Motion	0.0717	0.0656	0.4904
Maximum Trunk Angle	0.2125	0.0001	0.0287
Time of Maximum Trunk Angle	0.6453	0.0678	0.1075
Minimum Trunk	0.0097	0.0001	0.0165
Time of Minimum Trunk	0.1864	0.2879	0.9051
Trunk Range of Motion	0.0004	0.0013	0.7334
Maximum Shoulder Flexion/Extension Angle	0.3137	0.3223	0.0347
Time of Maximum Shoulder Flexion/Extension Angle	0.1706	0.2576	0.7074
Minimum Shoulder Flexion/Extension Angle	0.4532	0.0456	0.0601
Time of Minimum Shoulder Flexion/Extension Angle	0.3336	0.0164	0.9341
Shoulder Flexion/Extension Range of Motion	0.0194	0.0011	0.5855
Maximum Shoulder Abduction/Adduction Angle	0.3385	0.0914	0.5652
Time of Maximum Shoulder Abduction/Adduction Angle	0.8565	0.698	0.3749
Minimum Shoulder Abduction/Adduction Angle	0.4848	0.8786	0.8938
Time of Minimum Shoulder Abduction/Adduction Angle	0.8423	0.5387	0.3306

Shoulder Abduction/Adduction Range of Motion	0.2156	0.0196	0.221

Impulses

Variable	System	Configuration	System*Configuration
Total Vertical Impulse	0.7543	0.0002	0.9256
Average Vertical Impulse	0.8789	0.0001	0.6592
Total Average/Total Load	0.435	0.2139	0.2807
Total Braking Impulse	0.6196	0.2107	0.5775
Average Braking Impulse	0.866	0.263	0.8752
Braking Average/Total Load	0.8181	0.4841	0.848
Total Propulsive Impulse	0.7205	0.2909	0.5315
Average Propulsive Impulse	0.6923	0.3584	0.4566
Propulsive Average/Total Load	0.5499	0.1289	0.4935
Total Medial Impulse	0.3962	0.2377	0.4945
Average Medial Impulse	0.8971	0.001	0.4456
Medial Average/Total Load	0.6201	0.5075	0.6519
Total Lateral Impulse	0.7849	0.0009	0.5116
Average Lateral Impulse	0.4766	0.0001	0.8219
Lateral Average/Total Load	0.5056	0.0041	0.8363

Joint Reaction Forces

Variable	System	Configuration	System*Configuration
Average Ankle Joint Reaction Force	0.7616	0.0002	0.9209
Ankle Joint Reaction Force/Total Load	0.9732	0.0541	0.6754
Maximum Ankle Joint Reaction Force	0.3166	0.0001	0.4508
Time of Maximum Ankle Joint Reaction Force	0.685	0.1178	0.3924
Maximum Ankle Joint Reaction Force/Total Load	0.4659	0.1432	0.9063
Average Joint Reaction Knee	0.778	0.0001	0.9309
Knee Joint Reaction Force/Total Load	0.9721	0.0529	0.6176
Maximum Knee Joint Reaction Force	0.3526	0.0001	0.5013
Time of Maximum Knee Joint Reaction Force	0.6916	0.1176	0.5173

Maximum Knee Joint Reaction Force/Total Load	0.5018	0.1523	0.9292
Average Hip Joint Reaction Force	0.7833	0.0001	0.699
Hip Joint Reaction Force/Total Load	0.9935	0.0528	0.7185
Maximum Hip Joint Reaction Force	0.4279	0.0001	0.6067
Time of Maximum Hip Joint Reaction Force	0.6638	0.0624	0.416
Maximum Hip Joint Reaction Force/Total Load	0.5965	0.1069	0.9537

Ground Reaction Force

Variable	System	Configuration	System*Configuration
Maximum Heel Strike Vertical Ground Reaction Force	0.0462	0.0001	0.5368
Time of Maximum Heel Strike Vertical Ground Reaction Force	0.0402	0.8881	0.6312
Maximum Heel Strike Vertical Ground Reaction Force/Total Load	0.024	0.5574	0.546
Maximum Heel Strike Braking Ground Reaction Force	0.5141	0.1737	0.5045
Time of Maximum Heel Strike Braking Ground Reaction Force	0.1092	0.5184	0.7309
Maximum Heel Strike Braking Ground Reaction Force/Total Load	0.4344	0.0483	0.6116
Maximum Heel Strike Lateral Ground Reaction Force	0.2871	0.0002	0.52
Time of Maximum Heel Strike Lateral Ground Reaction Force	0.1814	0.8709	0.6255
Maximum Heel Strike Lateral Ground Reaction Force/Total Load	0.301	0.0048	0.5503
Maximum Push Off Vertical Ground Reaction Force	0.1138	0.0001	0.2463

Time of Maximum Push Off Vertical Ground Reaction Force	0.5495	0.1369	0.6383
Maximum Push Off Vertical Ground Reaction Force/Total Load	0.2403	0.24	0.3114
Maximum Push Off Propulsive Ground Reaction Force	0.714	0.3064	0.748
Time of Maximum Push Off Propulsive Ground Reaction Force	0.453	0.0313	0.0792
Maximum Push Off Propulsive Ground Reaction Force/Total Load	0.6181	0.093	0.8281
Maximum Push Off Lateral Ground Reaction Force	0.3844	0.1167	0.3657
Time of Maximum Push Off Lateral Ground Reaction Force	0.4121	0.0219	0.5037
Maximum Push Off Lateral Ground Reaction Force/Total Load	0.4317	0.4942	0.5526
Minimum Midstance Vertical Ground Reaction Force	0.2818	0.0001	0.4583
Time of Minimum Midstance Vertical Ground Reaction Force	0.8037	0.2096	0.4489
Minimum Midstance Vertical Ground Reaction Force/Total Load	0.4261	0.1339	0.9109
Minimum Vertical Ground Reaction Moment	0.4468	0.331	0.7859
Time of Minimum Vertical Ground Reaction Moment	0.3499	0.6162	0.9019
Maximum Vertical Ground Reaction Moment	0.1813	0.3175	0.0957
Time of Maximum Vertical Ground Reaction Moment	0.1311	0.4934	0.0792
Maximum Ankle Flexion/Extension Angle	0.1109	0.041	0.9622
Time of Maximum Ankle Flexion/Extension Angle	0.107	0.5975	0.3344
Minimum Ankle Flexion/Extension Angle	0.9565	0.4011	0.7381

Time of Minimum Ankle Flexion/Extension Angle	0.2255	0.4787	0.553

Joint Torque

Variable	System	Configuration	System*Configuration
Peak Ankle Joint Torque	0.8477	0.7744	0.1323
Time of Maximum Ankle Joint Torque	0.1195	0.3759	0.3866
Minimum Ankle Joint Torque	0.6564	0.0001	0.5931
Time of Minimum Ankle Joint Torque	0.232	0.5584	0.3956
Peak Knee Joint Torque	0.3302	0.0004	0.1691
Time of Maximum Knee Joint Torque	0.0333	0.0537	0.9459
Minimum Knee Joint Torque	0.8038	0.934	0.1418
Time of Minimum Knee Joint Torque	0.0977	0.5034	0.3422
Peak Hip Joint Torque	0.1817	0.0008	0.1034
Time of Maximum Hip Joint Torque	0.3691	0.0062	0.6865
Minimum Hip Joint Torque	0.9567	0.2633	0.1243
Time of Minimum Hip Joint Torque	0.0876	0.5086	0.4182

Backpack/Body Parameters

Variable	System	Configuration	System*Configuration
Average Horizontal Distance Between Body COM and BP COM	0.0001	0.0001	0.0001
Average Vertical Distance Between Body COM and BP COM	0.1787	0.239	0.1847

STD Horizontal Distance Between Body COM and BP COM	0.5744	0.003	0.5598
STD Vertical Distance Between Body COM and BP COM	0.4484	0.5148	0.0401

Backpack Parameters

Variable	System	Configuration	System*Configuration
Maximum BPCOM Vertical Position	0.0001	0.0001	0.0001
Time of Maximum BPCOM Vertical Position	0.0269	0.1361	0.3644
Minimum BPCOM Vertical Position	0.0001	0.0001	0.0001
Time of Minimum BPCOM Vertical Position	0.8546	0.5842	0.1677
Range BPCOM Vertical Position	0.5329	0.0077	0.4907
Maximum BPCOM Vertical Velocity	0.5673	0.0001	0.8321
Time of Maximum BPCOM Vertical Velocity	0.3114	0.102	0.4489
Minimum BPCOM Vertical Velocity	0.9632	0.0769	0.5181
Time of Minimum BPCOM Vertical Velocity	0.5911	0.004	0.5391
Maximum BPCOM Anterior Horizontal Velocity	0.0014	0.0005	0.0033
Time of Maximum BPCOM Anterior Horizontal Velocity	0.8141	0.2172	0.2089
Maximum BPCOM Horizontal Posterior Velocity	0.0006	0.0017	0.0561
Time of Minimum BPCOM Horizontal Posterior Velocity	0.2225	0.7519	0.2798
Maximum BPCOM Vertical Acceleration	0.5573	0.0159	0.6951

Time of Maximum BPCOM Vertical Acceleration	0.3421	0.782	0.8777
Minimum BPCOM Vertical Acceleration	0.4977	0.0002	0.5522
Time of Minimum BPCOM Vertical Acceleration	0.3418	0.1588	0.1812
Maximum BPCOM Horizontal Anterior Acceleration	0.0014	0.0059	0.0106
Time of Maximum BPCOM Horizontal Anterior Acceleration	0.0135	0.5721	0.4369
Maximum BPCOM Horizontal Posterior Acceleration	0.0004	0.0039	0.0655
Time of Maximum BPCOM Horizontal Posterior Acceleration	0.2606	0.5967	0.1697

P-values less than 0.05 are considered statistically significant.