MODIFYING THE SOLDIERS' LOAD CONFIGURATION FOR IMPROVED SOLDIER PERFORMANCE

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ABSTRACT

This study was conducted to compare a modified load (ML) configuration (total mass = 36.5 kg) to a heavier load (total mass = 42.2 kg) comprised of currently issued items (SL) used by U.S. Army dismounted warfighters in theater. Both loads were compared to a baseline, i.e., a no-load (NL) condition (total mass = 9.1 kg). Fourteen Army Infantry Soldiers participated in this study, completing a series of tests in each load configuration. Oxygen uptake and gait kinematics and kinetics were recorded as participants walked (1.34 m/s on 0, 9, and 18% grades) and ran (2.46 m/s on a 0% grade). Rifle marksmanship (prone, kneeling, and standing firing positions) and grenade throws were assessed for accuracy and timeliness or accuracy and precision, respectively. Maximal effort physical activities were completed, consisting of five continuous 30-m rushes and obstacle course runs. Range of motion measurements and participants' assessments of the load configurations were also included. *Results:* Mean oxygen uptake scaled to percentage of $\dot{V}O_2$ max was significantly higher during walking and running for the ML and the SL conditions compared with the NL. Also, for walking at 9% grade, oxygen uptake for the ML was significantly lower than that for the SL. The kinematic and kinetic data generally revealed favorable significant differences for the NL compared with the ML and the SL configurations. On the shooting performance tasks and the maximal effort tasks, performance with the SL configuration differed from that with the NL to a greater extent than the ML configuration did. Participants rated the ML as their preferred configuration. *Summary:* Objective measures revealed several consistent differences between the ML and the SL configurations and some instances in which they were not significantly different. When increased mobility in challenging terrains is the highest priority, the ML appears to be the configuration of choice.

1. INTRODUCTION

The current battlefield in Afghanistan requires highly mobile, dismounted ground forces to face increasing challenges in diverse environments. The lethality of combat in these environments requires members of the armed forces to wear clothing and equipment that will maximize combat effectiveness, while providing a balance between protection and functionality. The Rapid Equipping Force and the Asymmetric Warfare Group conducted a Soldiers' Load Operational Utility Assessment. A number of lighter clothing and equipment items were identified that serve a function similar to items in current use by dismounted troops. The Center for Military Biomechanics Research, Natick Soldier Research, Development and Engineering Center, was asked to do a lab-based assessment of this modified load (ML) and the current standard load (SL). The load configurations were reviewed by the Infantry School at Ft. Benning and accepted as representative loads that Soldiers currently deployed to Afghanistan are using in theater. A no-load baseline configuration (NL) was also included in the assessment. Testing will guide decisions of the U.S. Army regarding which specific Soldier system equipment to procure for current fielding initiatives.

1.1 Energy Cost of Carrying External Loads on the Body

In the current evaluation, energy cost was measured as volunteers walked and ran in the three configurations. Much research has evaluated the effects of load added to the body. Much of this work addresses issues related to the energy cost of carrying backpacks, with energy utilization quantified by taking measurements of the rate of oxygen uptake ($\dot{V}O_2$) during performance of physical activities. In studies done on marching with backpack loads, energy cost increases directly with the mass of the load and the speed of walking (Pandolf, Givoni, & Goldman, 1977; Sagiv et al., 1994).

1.2 Gait Biomechanics as Affected by Load Carriage

Data were acquired in this evaluation on walking and running kinematics and kinetics under the ML, the SL, and the NL configurations. As is the case with the literature on the oxygen cost, much of the research on the biomechanics of load carrying has focused on the effects of the weight of the load. Research demonstrates that increasing the load weight changes the kinematics, kinetics, and muscle response of the human body during locomotion (Harman et al., 2000).

1.3 Impact of Load Carriage on Performance

Volunteers in the current evaluation performed a number of militarily relevant physical activities, including an obstacle course run, grenade throwing, and 30-m rushes. Timed runs of obstacle courses, which require jumping, crawling, climbing, and balancing, have been used extensively in studies to evaluate different designs of load-carriage equipment (LaFiandra et al., 2003). Grenade throwing distance and accuracy have been tested in studies of various designs of fighting load equipment (Sharp et al., 2009). The 3-5 second rush is a basic activity Soldiers are trained to perform (Department of the Army, 2005) that has been adapted as an objective performance test. Soldiers use the rush to move from one covered protected location to another. Harman et al. (2006) developed a timed test based on the rush.

1.4 Rifle Marksmanship

Rifle marksmanship has been evaluated to determine the effects of load carriage. In some operations, Soldiers walk long distances and perform critical military tasks at the completion of the march. Studies have shown that, after very strenuous marches (maximal speed with loads of 34 to 61 kg over 10- to 20-km distances), there are post-march decrements in marksmanship (Knapik et al., 1990). Marksmanship decrements last for only a few minutes after cessation of strenuous exercise (Knapik et al., 1997). In the present study, marksmanship was tested when the participants were rested and again immediately after they had exercised to exhaustion on a task that required repeatedly lifting a box weighing 20.5 kg

2. METHODS

Participants were 14 U.S. Army Infantry Soldiers (means – age: 25.6 yrs.; ht.: 1.77 m; wt.: 76.12 kg) from the Experimentation Force (EXFOR) at Fort Benning, GA. Informed consent was obtained and the study was conducted in accordance with Army Regulation 70-25. All volunteers were healthy and without musculoskeletal injuries or disorders.

2.1 Load Configurations

Each participant was tested in the NL condition and the two combat load conditions (ML and SL) using a repeated measures design. All configurations entailed wearing a helmet and carrying an M4 Carbine with optical sight. The items comprising the ML and the SL configurations are clothing and equipment likely to be worn or carried by a Rifle Platoon Sergeant operating in Afghanistan (Task Force Devil Combined Arms Assessment Team, 2003). Some components of the ML and the SL configurations are identical. Others are similar in terms of the functions they serve. However, they are different models or brands and differ in mass. In those instances in which a different component is used, the lighter weight item is part of the ML configuration. The NL condition involved minimal clothing and equipment: underwear; T-shirt; socks; combat boots; Advanced Combat Uniform (ACU) shirt and trousers; and Advanced Combat Helmet (ACH). The ML (Fig. 1) and the SL (Fig. 2) configurations included the clothing and equipment that comprise the NL configuration plus additional items, including body armor, an assault pack, grenades, and ammunition. The masses of the three load configurations are given in Table 1. Prior to testing, the order that each volunteer was exposed to the configurations was determined to avoid bias and confounding effects.

Fig. 1. Modified Soldier Load

Fig. 2. Standard Soldier Load.

Table 1. Weights of the NL, ML, and SL Configurations

Item (kg)	NL*	ML	SL
Total Kit Masses	9.10	27.46	33.09
Items Worn on Body	9.10	19.07	21.79
Items Carried in Assault Pack	NA	8.39	11.30
Total Masses, Skin–out*	9.10	36.53	42.16
*NL and Total Skin-out Masses include helmet and weapon.			

2.2 Testing

2.2.1 Biomechanical and Metabolic Analysis of Treadmill Walking and Running

Walking and running were done on a force plate treadmill, fabricated by AMTI (Watertown, MA). Three-dimensional motion was recorded at 120 Hz by 12 ProReflex Motion Capture Unit cameras (Qualisys Medical AB, Gothenburg, Sweden) as the volunteers walked or ran. The outputs of the cameras and the force plates were collected through a single data acquisition system and were time-synchronized. The recorded images were processed using dedicated hardware and software (Qualisys Medical AB, Gothenburg, Sweden) to produce files containing time histories of the three-dimensional coordinates of reflective marker affixed to the participant's body. The Visual3D software program (C-motion Inc., Rockport, MD) was used to process the data files. A ParvoMedics TrueMax 2400 metabolic measurement system was used to take $\dot{V}O_2$ measurements and a Polar Vantage Heart Rate Monitor (Polar USA, Inc., Port Washington, NY) was used to monitor heart rates during treadmill walking and running. The $\dot{V}O_2$ data for a participant were converted to percentage of maximum aerobic capacity ($\dot{V}O_2$ max), as predicted from 2-mi run time on his most recent PT test (Mello, Murphy, & Vogel, 1988).

For each load configuration, a participant completed three 10-min trials of walking on the force plate treadmill at a speed of 1.34 m/s. A different grade setting was used on each trial, 0%, 9%, and 18%. There was one, 10-min running trial for each load condition at a treadmill speed of 2.46 m/s and a 0% grade. Prior to the days of testing, volunteers were familiarized with walking and running on the treadmill with and without the load configurations at these speeds and grades. Within a running or a walking trial, force plate and camera outputs were recorded for 2 min after the trial had been underway for 5 min. Ten strides, five initiated with a right heel strike and five with a left heel strike, were selected for subsequent analysis from the recorded ground reaction force (GRF) data and motion data. At approximately 7 min into the trial, oxygen uptake was measured for 90 s.

2.2.2 Rifle Marksmanship in Prone, Kneeling, and Standing Firing Positions

Marksmanship was evaluated in USARIEM's Warfighter Cognitive Performance Lab using a modified Engagement Skills Trainer (EST 2000; Cubic Simulation Systems, Inc., Orlando, FL). Each participant practiced marksmanship skills using an M4 simulated weapon. All Tables of Fire (TF) and firing positions in the USARIEM Marksmanship Test (UMT) were encountered for about 2 h per day for 5 days before experimental testing began. Participants had a total of 450 min of spaced practice. Participants performed brief, specially constructed scenarios to evaluate marksmanship, friend or foe discriminations, and engaging targets that were elevated. This was to ensure that baseline performance of the participants was highly practiced and stable so that comparisons of baseline performance with performance under conditions of load would be valid and have greater statistical power.

Marksmanship testing was conducted during a 3-h interval scheduled on three separate days to permit testing of the three loads. Participants began these evaluations in a rested state. Two to four participants were tested simultaneously for 50 min (session 1) by completing the six TFs of the UMT. During the second hour, participants walked 100 m to watch a movie in an air conditioned room (20^{o}C) for approximately 50 min. They continued to wear their assigned loads, stood (without support), and were not allowed to lean or rest against the room's walls. Participants then returned to the Lab and performed an equivalent version of the UMT (session 2) for 50 min. Subsequently, on two different days, participants, returned to be tested with a similar regime (equivalent version of the UMT) wearing another one of the load configurations. Measures of accuracy (hit or miss) and timeliness (latency) to engage targets were collected for each target presented.

2.2.3 Rifle Marksmanship After Repetitive Box Lifting

This activity consisted of an individual repeatedly lifting a 20.5-kg box (L 38 cm x W 23 cm x H 11 cm), placing it on a 1.55-m high platform (simulating the bed height of the newest Army 5-ton truck), and returning to the starting position for another lift. There are opposing handles on two sides of the box. A volunteer continued to perform this lifting sequence until he was no longer able to keep pace with a metronome (12 lifts per minute). The participants immediately carried the box approximately 25 m and commenced a target acquisition test on the EST 2000. The time from the end of the lifting task to the start of the test was less than 30 s.

During this marksmanship test, participants shot from a kneeling unsupported firing position at E-silhouette targets. These targets were presented at a simulated distance of 150 m (targets were elevated 18 m above the horizon and were displaced 0.75 degrees right or left of the centerline of the shooting lane). The volunteers had seconds to engage each target before it disappeared from view. If the shooter hit the target, it disappeared immediately. Targets were presented asynchronously for 10 min. Shooting accuracy (the number of targets hit) and trigger pull latency (the time from target presentation until trigger pull) were assessed for each volunteer in each load condition.

2.2.4 Grenade Throws

Training hand grenades, weighted to simulate a live grenade, were used for this activity. A target, 1 m in diameter, was placed on the ground. A line was drawn on the ground, 30 m from the center of the target. The activity required that an individual throw a grenade at the target, without crossing the line. Volunteers began in a squatting position, with both feet behind and parallel to the line and the non-throwing shoulder pointed toward the target. They stood, took one step forward (with the foot on the side of the non-throwing arm), and threw the grenade at the target. The distance from the line to the grenade point-of-initial-contact (distance thrown), and the distance of each grenade point-of-initial-contact to the center of the target (accuracy) were recorded.

2.2.5 30-m Rushes

Two, padded gym mats were placed on the floor approximately 30 m apart. This activity started with a volunteer in a prone position on one mat facing the opposing mat. Upon an auditory signal, the volunteer got up and ran forward, assumed a prone position on the opposing mat 30 m away, and faced the direction of the starting position. Five seconds later there was another auditory signal, upon which the volunteer proceeded in the same manner back to the starting position. This cycle was repeated until five, 30-m rushes were completed. For scoring, the time to complete each individual rush and the total time to complete the five rushes were recorded. Volunteers participated in one trial (i.e., five rushes) under each load condition. They were encouraged to complete each rush as quickly as possible. On a day preceding testing, volunteers were familiarized with this activity by performing two to three rushes as quickly as possible.

2.2.6 Obstacle Course Runs

The obstacle course included: a set of four hurdles, 0.6 m high; a field of 9 rubber cones delineating a zigzag running pattern, 27 m long and 1.5 m wide; a crawl space, 0.6 m high, 0.9 m wide, and 3.7 m long; a horizontal shimmy pipe, 3.7 m long; a 1.4-m high sheer wooden wall without footholds or ropes, and a 27-m straight run. Total course completion time and times to complete each obstacle or course segment were recorded using electronic timing devices (Brower Timing Devices, Salt Lake City, UT) placed along the course. The score was the total time to complete one run of the entire course.

2.2.7 Range of Motion Measurement and Subjective Assessments

During this portion of the study, range of motion, ability to perform certain movements, ease of use, and comfort were assessed for each load configuration. The volunteers executed a series of simple body mobility tasks. They were given three successive trials on each task in each load configuration. The maximum extent of movement possible was measured either by using a goniometer or a meter stick. The score on a mobility task was the mean of the three trials under a given load condition.

Information was acquired from the volunteers throughout the study regarding the load configuration being tested. The Borg (1970) rating of perceived exertion (RPE) scale was used, which is a 15-category scale for rating perceived exertion, from no exertion at all (rest) to maximal exertion. A questionnaire, referred to as the rating of pain, soreness, and discomfort (RPSD) questionnaire (Corlett & Bishop, 1976), was also administered to the volunteers. In this questionnaire, the respondent is to use a 5-point scale to rate the level of pain, soreness, discomfort, or restriction being experienced at specific parts of the body. Volunteers completed another questionnaire at the end of testing in which they gave overall acceptability ratings to the ML and the SL load configurations.

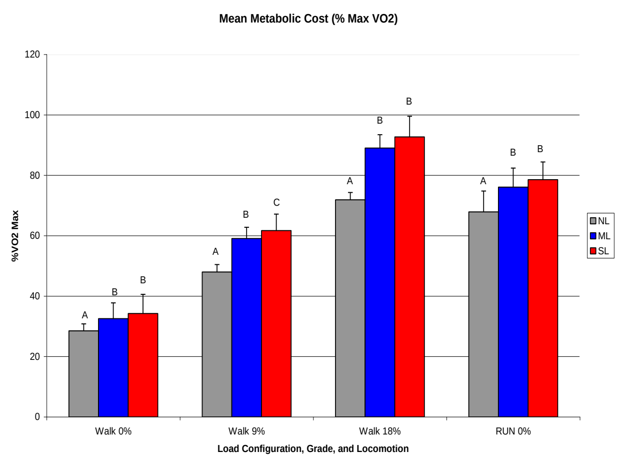
2.3 Data Processing and Statistical Analysis

All statistical analyses were accomplished using SPSS or Statistica. All dependent measures were subjected to one-way, repeated measures analyses of variance (ANOVAs) to assess the differences among the three load configurations (ML, SL, NL), with $\alpha = .05$. When appropriate, tests of simple effects or post-hoc analyses were performed using the Bonferroni or the Tukey's test procedures, with $\alpha = .05$.

3. RESULTS

3.1 Treadmill Walking and Running

Analyses of percentage of predicted $\dot{V}O_2$ max for walking and running demonstrated the high level of physical exertion experienced by Soldiers while wearing the ML and the SL configurations. At the 9% grade, there was a significant difference between the ML and the SL conditions, achieving 60 and 63% of $\dot{V}O_2$ max, respectively. The Soldiers approached their maximum physical capacity levels at the 18% grade, achieving 88% and 92% of their predicted $\dot{V}O_2$ max for the ML and the SL, respectively (Fig. 3).



Note: Load configurations that do not share the same letter differed significantly in post-hoc tests (p < .05).

Fig. 3. Mean (SD) percentage of $\dot{V}O_2$ max for each load configuration and grade during walking and running.

Analysis of kinematic measures for walking revealed that, regardless of grade, load configuration did not have a significant effect on step time, cycle time, or stride length. However, the analyses of double support time, stance time, and swing time as a percentage of stride time did yield a significant effect of load configuration at each grade. For these variables, the ML and the SL configurations did not differ from each other, but were significantly different from the NL configuration. Double support and stance times were longer by about 18% and 4%, respectively, and swing time shorter by about 8% for the ML and the SL conditions than for the NL. At each grade, stride widths were greater with the ML and the SL configurations than with the NL condition. A significant effect of load configuration on stride width was obtained only in the analysis of the 9% grade data. Again, there was no difference between the ML and the SL configurations. Both these configurations differed significantly from the NL condition, with stride widths being an average of 9% greater when the ML or the SL configurations were used.

With regard to GRFs during walking, analyses of the heel-strike, mid-stance, and toe-off data expressed as peak vertical force normalized to body mass yielded peak forces at 0% grade that were significantly higher with the ML and the SL configurations than with the NL configuration. Further, the heel-strike, mid-stance, and toeoff forces with the SL were significantly higher than the forces with the ML configuration. Analyses of peak heel-strike and peak toe-off vertical force normalized to total mass (i.e., body mass plus mass of clothing and equipment load) revealed that the SL configuration was significantly different than the NL configuration, but did not differ from the values for the ML configuration. For peak braking and propulsive forces normalized to body mass, the forces for the NL configuration were lower in magnitude than those for the ML and the SL configurations, which did not differ significantly from each other. When peak braking and propulsive forces were normalized to total mass, there were no significant differences among load conditions.

The 9% grade data for peak vertical force at heel strike and at toe-off, with force normalized to body mass, yielded values for the NL that were significantly lower than those for the ML and SL configurations. In addition, peak forces at heel strike and at toe-off were significantly lower with the ML than with the SL configuration. When normalized to total mass, the magnitudes of the vertical forces at mid-stance and at toe-off were significantly lower for the NL condition than for the ML and the SL configurations, which did not differ from each other. For peak propulsive force normalized to body mass, the NL configuration had the lowest magnitude forces. The values for the NL configuration were significantly different from those for the ML and the SL configurations, which did not differ from each other. The ML and the SL configurations did differ significantly on peak braking force, with the higher magnitude forces being associated with the ML configuration. Again, the NL configuration yielded values of braking force that were significantly lower than those for the other two conditions. When peak braking and propulsive forces were normalized to total mass, there were no significant differences among the load configurations.

At 18% percent grade, the data for peak vertical force at heel strike and at toe-off, with force normalized to body mass, yielded peak forces for the NL configuration that were significantly lower than those for the ML and SL configurations. In addition, peak vertical force at heel strike was significantly lower with the ML than with the SL configuration. Peak vertical forces at toe-off for the ML and SL configurations were not significantly different. When normalized to total mass, the only difference was a significantly higher force with the ML than with the NL condition for peak vertical force at toe-off. For peak braking force and peak propulsive force normalized to body mass, the NL configuration had the lowest magnitude forces. The values for the NL configuration were significantly different from those for the ML or the SL configurations, which did not differ from each other. Again, there were no significant differences among load conditions when peak braking and peak propulsive forces were normalized to total mass.

In the analyses of the gait data for running, stance times and swing times as a percentage of stride time did not reveal differences between the ML and the SL configurations, but both these conditions differed significantly from the NL configuration. Stance time increased on average by 14 % and swing time decreased by 10% for the ML and SL configurations when compared to the NL configuration.

The analyses of step time, cycle time, and stride length during running revealed differences between the ML and the SL configurations. For these variables, the values for the ML configuration did not differ significantly from those for the NL configuration, but both configurations yielded values that differed significantly from the values for the SL configuration.

Analyses of GRFs for running revealed that, at heel-strike, peak vertical force normalized to body mass was lowest for the NL configuration. This differed significantly from the forces for the ML and the SL. There was also a difference between the ML and the SL conditions: Significantly higher forces were found for the SL configuration. For peak braking force at heel-strike normalized to body mass, the forces for the NL configuration were significantly lower than those for the ML and the SL configurations. There were no significant differences between the ML and the SL configurations on this measure.

3.2 Rifle Marksmanship in Prone, Kneeling, and Standing Firing Positions

The results of marksmanship showed a significantly lower percentage of hits with the SL than with the NL configuration in three of four firing positions (prone unsupported was unaffected). In the kneeling position, the ML configuration also resulted in a lower percentage of hits than the NL did. Firing latency was not significantly affected by load condition in any of the firing positions.

3.3 Rifle Marksmanship After Repetitive Box Lifting

The exhaustive whole-body exercise of box lifting had a transient negative effect on accuracy, regardless of load configuration. Accuracy for all load configurations was degraded during the initial 2 min of rifle firing; thereafter, it returned to normal levels. In each configuration, participants were about 22% less accurate in the first 2-min sampling period than in the last four sampling periods (Fig. 4).

With the ML and the SL configurations, trigger pull latency increased immediately. There were no significant differences between the ML and the SL configurations for trigger pull latency throughout the shooting test. With the NL configuration, participants engaged targets 14% faster in the first 4 min of the test than they did with the ML or the SL configurations.

While the increased latency did not impact accuracy after the initial 2 min of rifle firing, increased time to engage targets may have a negative impact on Soldiers' fighting effectiveness and survival.

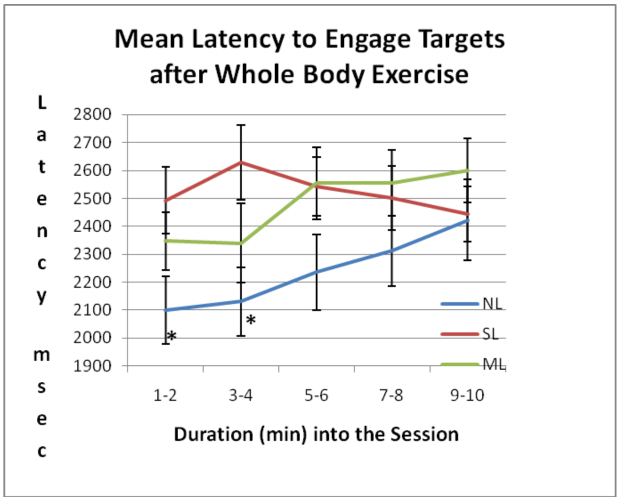


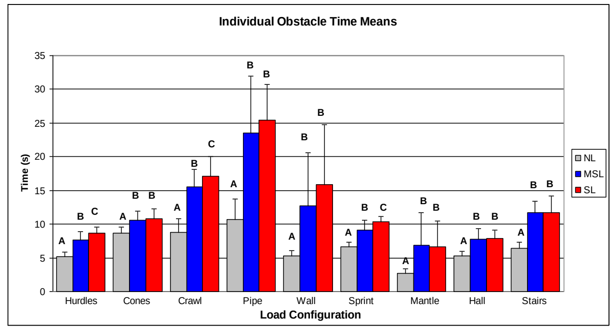
Fig. 4. Mean (SD) latency to engage targets for each load condition after an exhaustive, repetitive lifting task. *p < .05

3.4 Grenade Throws, 30-m Rushes, and Obstacle Course Runs

Participants were able to complete the 30-m rushes at a significantly quicker pace with the ML configuration than with the SL, although times with these conditions were significantly slower than NL times. On the grenade throws, accuracy was not affected by the configuration, but mean distance thrown was: Performance with the SL was significantly poorer than that with the NL and the ML condition did not differ from either of the other two. On the obstacle course, total time for the NL was significantly faster than that for the ML and the SL conditions, which did not differ from each other. On some individual obstacles, however, the ML was significantly faster than the SL (Fig. 5).

3.5 Range of Motion Measurement and Subjective Assessments

On the range of motion tests, there was a significantly greater range of arm abduction and arm forward extension with the NL than with the other two conditions. Comparison of ML and SL revealed significantly more restriction of these arm movements



Note: Load configurations that do not share the same letter differed significantly in post-hoc tests (p < .05).

Fig. 5. Mean (SD) for each load configuration of the time to complete individual obstacles.

with the SL condition. Analysis of hip flexion revealed a significant decrease in range of motion for the ML and SL configurations when compared to the NL. The ML and the SL configurations were not significantly different from each other. For hip flexion with the knee flexed, the range of motion was most restricted with the SL configuration. The SL configuration was significantly less than the NL configuration. The ML was not significantly different from the NL or the SL configurations

The study volunteers viewed the ML configuration more favorably than the SL configuration. On the RPSD, volunteers assigned higher ratings of discomfort to the SL than to the ML configuration. The greatest difference between the two configurations was in discomfort ratings assigned to the back of the body. On the end of testing questionnaire, a question was posed to the participants in which they were given a list of pairs of bipolar adjectives related to the load characteristics (e.g., heavy-light, hot-cool). The volunteers were to rate each adjective pair using a 7-point scale (from extremely heavy to extremely light, extremely hot to extremely cool, etc.). Adjectives are presented in Fig. 6.

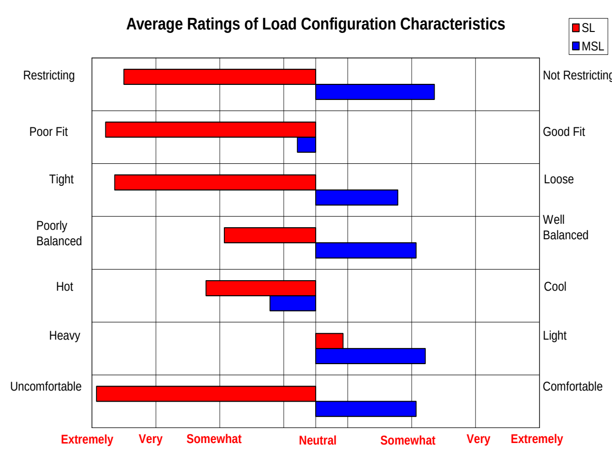


Fig. 6. Average ratings for the ML and SL load configurations on a series of bipolar adjectives.

4. DISCUSSION

Much of the research on military load carrying has been focused on assessing effects of load mass and load bearing equipment design on the load carrier's energy usage (Pandolf et al., 1977). However, the negative implications of carrying a load during military operations extend beyond the energy expended by the Soldier (Knapik, Harman, & Reynolds, 1996). In the present study, several classes of dependent measures were collected to determine the critical impact of three load configurations on Soldier effectiveness—physiological, biomechanical, and rifle marksmanship—performing militarily relevant physical activities. The findings, considered collectively, suggest that load adversely affects several phenomena that influence a Soldier's ability to perform his/her mission effectively.

The significant effects were usually ascribable to differences in weight between the NL configuration and the ML and SL configurations, differences of 27 or 33 kg. The mass of the ML configuration was less than that of the SL configuration by only 6 kg. However, some measures taken in this study also revealed significant differences between these two configurations, in spite of the small weight difference. Energy cost expressed as percentage of predicted aerobic capacity was significantly lower, by about 4.5%, with the ML than with the SL during treadmill walking at a 9% grade. During running on the level and during walking at the 0% and the 18% grades, oxygen uptake was somewhat lower, but not significantly so, with the ML configuration than with the SL. The findings suggest that Soldiers in a field situation may benefit from use of the somewhat lighter weight configuration both in endurance times on prolonged foot marches and in fitness to fight upon the conclusion of prolonged marches.

Several measures of ground reaction force during treadmill walking and running also revealed significant differences between the ML and the SL configurations. Peak vertical GRF at heel strike was on average 4% lower in magnitude with the ML configuration for walking at the 0, 9, and 18% grades and for level running. Again the differences between the two military loads were not great. However, use of the ML may benefit the Soldier, particularly during long marches, to the extent that the probability of incurring overuse injuries of the lower extremities is decreased due to the somewhat reduced forces to which the body is exposed at heel strike (Knapik et al., 1996).

Performance of physical activities that involved the participants running at their own pace differentiated between the two military load configurations. During the obstacle course, the hurdles, high crawl, and sprint segments required significantly longer times to complete when the SL configuration was used. This may have been due to the somewhat heavier weight of the SL or to items on the SL configuration that encumbered body movement.

Rifle firing accuracy, but not latency, was also affected differentially by the two military loads, i.e., ML and SL. In the prone supported and the standing unsupported positions, a lower number of hits were scored when the SL configuration was worn compared with the ML. Also, in these firing positions, the number of hits with the SL configuration was significantly lower than the number with the NL configuration, whereas use of the ML configuration did not yield numbers of hits that differed from the score with the minimal load configuration.

The analyses of the ranges of movement of the hip during flexion and the arm in abduction and forward extension provide some support for findings that the SL encumbered body movements to a greater extent than the ML configuration did. These findings support the results of the hurdle segment of the obstacle course where the SL configuration resulted in slower times than the ML configuration and Soldiers were observed to have greater difficulty lifting the leg high enough to get over hurdles. On both of the arm motion tests, the extent of movement was significantly reduced with the SL configuration when compared to the ML configuration. These arm motion restrictions with the SL configuration may be a contributing factor to the decrements found on the marksmanship test for the prone and the standing firing positions.

Participants' responses on questionnaires administered throughout testing were consistent in rating the SL configuration less favorably than the ML. There was greater discomfort reported on the RPSD questionnaire when wearing the SL configuration in both the front and back areas of the body. Two specific movements in this study that are of particular consequence to Soldiers are the kneeling and the prone firing positions. Both of these movements were found to be more difficult to accomplish while wearing the SL configuration when compared to the ML configuration. Additionally, the subjective ratings of load configuration characteristics showed that the SL configuration was extremely uncomfortable, restricting of motion, poorly fit to the body, very tight, and poorly balanced, whereas the ML configuration had more favorable ratings for these same characteristics. The perceived compatibility and acceptance by Soldiers for use in their missions is a consideration that is also important.

CONCLUSIONS

In contrast to the subjective measures, the majority of the objective measures taken during this study did not reveal extensive differences between the SL and ML configurations. The differences that were found between the two configurations were subtle and the majority appeared to be due to the weight difference between the configurations. Given the components that comprise the configurations, each of the configurations may have advantages in terms of functionality in specific situations and terrains. Ballistic coverage was not assessed in this study. Ultimately, trade-offs between physical performance and Soldier protection must be considered when deciding between these configurations.

In specific instances where increased mobility in challenging terrains is considered the highest priority, the ML configuration appears to be the configuration of choice. In these extreme conditions, even small savings in energy cost and a slight increase in physical performance measures of marksmanship and Soldier mobility may provide an advantage for the Soldier.

From the results of this study, the impact of weight that the Soldier carries is becoming clearer. Future work is planned to assess the Soldier's physical and cognitive performance levels with incremental loading. This may further define the balance between Soldiers' equipment capabilities and physical performance trade-offs when planning missions in challenging terrains.

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