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Effects of Gender, Load, and Backpack on the Temporal and Kinematic Characteristics of Walking Gait
Volume III

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This study was conducted to determine the effects of loads worn or carried and the type of backpack used on parameters of the walking gait of men and women. Eleven men and eleven women participated in the test, with walking speed controlled at 4 mi/hr, under each of the following load conditions: Load 1 - baseline (shorts, t-shirt, sneakers); Load 2 - fighting gear (utility shirt and trousers, boots, ALICE fighting gear); Load 3 - combat gear (Load 2 plus PASGT helmet, PASGT armor vest, simulated M16 rifle); Load 4-combat gear and 20-lb

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) backpack load (Load 3 plus backpack with 20-lb load); Load 5 - combat gear and 35-lb backpack load (Load 4 plus an additional 15 lb in pack). The men were also tested under a sixth load condition: Load 6 - combat gear and 50-lb backpack load (Load 4 plus an additional 30 lb in pack). The subjects carried loads 4 through 6 using four different backpack systems. Two of these consisted of Army frames equipped with the standard Army pack. The third was an experimental item, a packboard made of rigid aluminum, used with the Army pack. The fourth backpack was a commercially-available, internal frame system. The dependent measures analyzed were stride length, rate, and velocity, single leg contact time, double support time, swing time, and trunk angle. Analyses of the data indicated that there was little difference in the trunk angles maintained by the men and the women. However, the men generally had greater stride lengths and shorter stride rates than the women. There was a tendency for subjects to decrease stride length and increase stride rate as the load was increased. Also, between Loads 4 and 6, there was an increase in forward lean of the body. Few differences in the characteristics of walking gait could be attributed to differences in backpack designs.

PREFACE

This is the third of four volumes comprising the final report of research performed under Contract Number DAAK60-79-C-0131 with the Individual Protection Laboratory, US Army Natick Research and Development Laboratories, Natick, Massachusetts. The work was formulated and directed by Drs. Carolyn K. Bensel and Richard F. Johnson, Human Factors Group, Individual Protection Laboratory. Dr. Bensel was the contract monitor and Dr. Johnson was the alternate.

The authors would like to express their appreciation to several individuals for their assistance and cooperation during this project. Mr. In-Sik Shin, Mr. Wlodzimierz Erdmann, Mr. Li Cheng Zhi, and Ms. Maureen Breckenridge provided valuable assistance during the data collection and data processing portions of the project. Mr. John Palmgren provided technical assistance particularly for the filming procedures used for data collection. Finally, the efforts and cooperation of Major Richard Bartolomea, Marine Instructor Officer for the R.O.T.C. program at The Pennsylvania State University and his staff were responsible for providing the research facility used for the data collection. The quality of the assistance of these individuals was greatly appreciated.

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Effects of Gender, Load, and Backpack on the Temporal and Kinematic Characteristics of Walking Gait

INTRODUCTION

This is the third of four studies on the biomechanics of load carrying behavior being carried out in the Biomechanics Laboratory at The Pennsylvania State University under the direction and sponsorship of the Army Natick Laboratories. The first two studies in this series were examinations of easy standing, vertical jumping, and combative movement performance of men and women under various backpack and load conditions.[1,2] Because a foot soldier may spend a considerable amount of time walking, it is important to have some knowledge of the influence of the gender of the soldier, of different load carrying systems, and of the magnitude of load on walking gait. Consequently, it was the purpose of this experiment to examine the effects of gender, load and backpack type on the temporal and kinematic characteristics of the walking gait.

Previous research on the biomechanics of load carrying behavior performed by Nelson, Clark, and Hinrichs[3] examined the influence of gender, body size, and backpack on four aspects of the vertical ground reaction force during two speeds of walking - 4.8 and 8.0 km/hr. These speeds are slightly slower and slightly faster than a typical walking speed for most individuals. The four aspects of the ground reaction force examined were: 1) contact time, 2) maximum force during initial contact time, 3) minimum force during mid-support, and 4) maximum force during push-off. The analyses yielded similar trends in ground reaction forces for both speeds of walking. The results also demonstrated differences among males and females and persons of different body sizes. Differences between backpacks were not detected, however, using this ground reaction data. In particular, the results showed that contact time for female and small subjects was less than that for male and large subjects. Few differences were found for the three force parameters (Ref. 3).

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[1] Nelson, R.C. and P.E. Martin. Volume I. Effects of Gender and Load on Combative Movement Performance (Tech. Rep. NATICK/TR-82/011). Natick, Massachusetts: US Army Natick Research and Development Laboratories, February 1982.

[2] Nelson, R.C. and P.E. Martin. Volume II. Effects of Gender, Load, and Backpack on Easy Standing and Vertical Jump Performance (Tech. Rep. NATICK/TR-82/016). Natick, Massachusetts: US Army Natick Research and Development Laboratories, March 1982.

[3] Nelson, R.C., T.E. Clarke, and R.N. Hinrichs. An Investigation into the Biomechanics of Load Carrying: The Effects of Gender, Body Size, and Backpack on Load Carrying Behavior. Natick, Massachusetts: US Army Natick Research and Development Laboratories, in preparation.

PROCEDURES

Test Sessions

Each subject participated in two test sessions. Because it was important for subjects to be thoroughly familiarized with the data collection procedures so as to avoid any disturbance of their normal walking pattern, the first test session was used as a practice session. During this session, the test protocol was explained to each subject. Following this explanation, the subjects performed a number of practice trials under a few selected load conditions. The number of trials and load conditions used during this session varied from subject to subject depending upon how rapidly they adapted to the experimental conditions. At a minimum, each subject performed ten trials under two load conditions. These two load conditions were Loads 1 and 4 which are described later in this volume. In addition to familarizing the subjects with the testing procedures, the practice session also helped to reduce the time needed to do the actual data collection during the second session.

The data collection session consisted of the filming of the walking gait of each subject under several different load and pack configurations. Only one walking speed was used for this study. In earlier work in which walking was analyzed, two walking speeds, 4.8 and 8.0 km/hr were employed. The walking speed used in this project was intermediate to those of the first project. The 6.4 km/hr rate represented a near normal walking speed for most subjects. In order to control the walking speed, it was necessary to have some indication of the speed for each trial. To accomplish this, a system was established to time each subject over a five-meter zone in the filming area. Any trial in which the walking speed was within five percent of the 6.4 km/hr target speed was accepted as a good trial. Those outside of ± 5% range were repeated.

Subjects

Eleven men and eleven women, all students in the Army R.O.T.C. Program at The Pennsylvania State University, served as subjects for the study. This group of twenty-two was a subset of the original thirty subjects who participated in the first study in this series (Ref. 1). These individuals were highly motivated as subjects for this project because of their personal interest and experience in load carrying. As was noted in the report on the first study, these subjects, based on their physical characteristics, were considered to be representative of U.S. Army personnel (Ref. 1). Table 1 contains mean values for the age, height, and weight of the male and female subjects who participated in this study.

Table 1

Physical Characteristics of Subjects

Gender	N	Age (yrs) $\overline{X}$	S.D.	Height (cm) $\overline{X}$	S.D.	Weight (kg) $\overline{X}$	S.D.
Men	11	20.9	1.8	176.9	5.7	71.0	7.2
Women	11	20.8	1.7	166.4	4.8	60.8	10.9

Backpack Systems

The four backpacks used in this study included three with external frames and one with an internal frame. The same top-loading pack, a standard Army item, was used on each of the external frames. A brief description of each system is included here. Appendix A contains additional information on these items.

a. ALICE LC-2 is the Army's standard frame. It is made of aluminum tubing and has foam-padded shoulder and lower back straps. The waist belt, made of wide nylong webbing, is attached to the padded back strap.

b. ALICE LC-1 was the standard Army frame prior to the introduction of the LC-2. The frame itself is one of the same design as the LC-2. However, the shoulder and back straps are of different dimensions and are not foam-padded. In addition, the waist strap is made of narrow webbing and attaches to the frame.

c. LOCO is a commercially-available, internal-frame system. The frame consists of two, vertical, aluminum stays which extend the length of the pack and are on the side of the pack closest to the wearer's body. The pack itself is a top-loading bag to which foam-padded shoulder straps and a waist belt are attached.

d. PACKBOARD is an experimental item which was fabricated for this study. It consists of a flat sheet of aluminum. The shoulder, back, and waist straps attached to it are identical to those used with the ALICE LC-2.

The physical dimensions and weights of the packs are listed in Table 2.

Table 2

Approximate Values for Selected Characteristics of the Four Backpacks

Backpack	Length*	Width*	Depth*	Frame and Bag Weight**
ALICE LC-2	52 cm	46 cm	40 cm	3.23 kg
ALICE LC-1	51	46	39	2.84
LOCO	61	35	30	1.41
PACKBOARD	54	46	32	3.57

* Dimensions were measured with the pack loaded with the basic 9.1 kg load (Load 4) which consisted of a sleeping bag, mattress, waterproof clothes bag, poncho, socks, and undershirt. The length and width dimensions were the greatest values for the frame-pack system in their respective directions. The depth dimension was an estimate of the maximum distance the pack projected from the body.

** Combined weight when empty.

Load Conditions

In addition to using four different backpacks, the subjects performed their normal walking gait under several different load conditions. These loads were the same as those used in the other two studies in this series (Refs. 1 and 2). In all, there were six different load conditions carefully selected so as to cover a wide range of typical military loads. The male subjects performed under all six load conditions, while the female subjects performed only under the first five load conditions. The following summary describes the six load conditions used in the testing. Additional information on the clothing and equipment used is presented in Appendix A.

Load 1 served as the baseline condition. Subjects wore t-shirt, shorts, socks, and sneakers.

Load 2 was considered the fighting gear condition. The subjects wore socks, underwear, utility shirt and trousers, boots, and the standard fighting gear which included a water-filled canteen with cover, intrenching tool with carrier, and two small arms ammo cases containing 1.75 kg sandbags.

Load 3 was designated the combat gear condition. The subjects wore a PASGT helmet and armor vest and carried a simulated M-16 rifle in addition to those items included in Load 2.

Load 4 included all items from Load 3 plus one of the four backpacks containing a 20 pound (9.1 kg) load. This load consisted of a sleeping bag, mattress, waterproof clothes bag, poncho, socks, and undershirt.

Load 5 included all items from Load 4 plus an additional weight of 15 pounds (6.8 kg) placed in the pack. The extra load consisted of three, 5 pound (2.3 kg) barbell disks.

Load 6 was carried by the men only and included all items from Load 4 plus 30 additional pounds (13.6 kg) in the form of three, 10 pound (4.5 kg) disks placed in the pack.

Note that the magni' ıdes of Loads 4, 5, and 6 differed slightly with the backpack used since the weights of the packs differed somewhat. Table 3 summarizes the magnitudes of all loads, including Loads 4, 5, and 6 in combination with each pack.

Table 3

Mean Load Values (kg) for Men and Women for All Load Conditions

Backpack	Load Condition 1	2	3	4	5	6
Men (N=11)	.76	9.46	17.67			
ALICE LC-2				30.01	36.81	43.62
ALICE LC-1				29.60	36.40	43.21
LOCO				28.15	34.95	41.76
PACKBOARD				30.33	37.13	43.94
Load Mean				29.52	36.32	43.13
Women (N=11)	.56	9.04	16.92			
ALICE LC-2				29.26	36.06	
ALICE LC-1				28.85	35.65	
LOCO				27.40	34.20	
PACKBOARD				29.58	36.38	
Load Mean				28.77	35.57	

Data Collection Procedures

Standard high speed cinematography techniques were used to film each subject. Because the movements of the walking gait occur primarily in the sagittal plane of the body, only one camera was used and a planar analysis completed. A Locam camera manufactured by Redlake Corporation and capable of running at speeds as high as 500 frames per second was preset to run at 50 frames per second for this experiment. A timing unit placed in the field of view was used to determine the actual camera speed. In addition, two reference numbers were used to identify the subject and the condition under which he was performing. Markers were placed on critical body locations so as to facilitate the film analysis. These markers were used to estimate the joint centers of the ankle, knee, hip, and shoulder.

For each male subject, there was a total of 15 conditions. These consisted of the three lowest loads in which no packs were used plus the three highest loads in combination with each of the four backpacks. Consequently, there were 12 conditions that involved the four packs and three without packs. For the female subjects, there were 11 conditions. Since the females were not tested under the highest load, there was one fewer condition for each of the four packs, or four fewer conditions for the females than for the males.

The order of presentation of the backpack and load conditions was similarly determined for both the male and female subjects. All subjects were first tested under Loads 1, 2, and 3 in sequential order. These were then followed by the test conditions involving the four packs. For each subject, the order of presentation of the four packs was randomly determined. Loads 4, 5, and 6 for the men and Loads 4 and 5 for the women were then randomly ordered for each pack. Consequently, each subject performed all loads for a single pack before changing packs. For each backpack and load condition under which a subject performed, one acceptable trial was required. The decision to collect only one trial for each condition was based on the large time demands associated with the film analysis procedures used to obtain the walking data and because each subject was well practiced prior to the data collection. A short rest interval was provided between trials so that the influence of fatigue could be minimized. This interval was approximately two minutes in length which generally was the time needed by the experimenters to make necessary adjustments for changes in pack and load conditions.

The films were analyzed using a Vanguard projection system with a Bendix digitizer. This system provided on-line data recording capabilities on the laboratory computer. Values for seven variables which were used to describe the temporal and kinematic characteristics of the gait of each subject were obtained from the film. During the filming, the field of view was established to include three to four strides. The experimenters were then able to select the two strides which were closest to the center of the field of view. In all trials, the film analysis was initiated at a position when the subject's right heel made contact with the ground and continued until the next right heel strike occurred. This provided two complete strides for analysis and meant that two measures for each variable were obtained. These values were then averaged and the average values for each variable were used in the statistical analysis. The following summarizes the measurement of each of the seven variables:

1. Stride length in meters was measured as the distance from the point of one heel strike to the point of the next heel strike.

2. Stride rate was calculated by measuring the stride time which was the time between two heel strikes, and then taking the reciprocal of the stride time. Stride rate was then represented as the number of strides completed per second.

3. Stride velocity was calculated by taking the product of stride length and stride rate which resulted in stride velocity in meters per second.

4. Single leg contact time was measured as the time from heel strike of one leg until the foot of the same leg left the ground to begin the swing phase.

5. Double support time was the time during which both feet were in contact with the ground. This was the time from heel contact of one leg until the foot of the other leg left the ground.

6. Swing time was the time of non-support for one leg and was measured from a point when the foot of one leg left the ground until heel strike of the same leg.

7. Trunk angle was a measure of the forward inclination of the trunk at a point when the foot of one leg left the ground. The angle measured was that between the horizontal and a line connecting the shoulder joint and the hip joint such that a greater forward inclination resulted in a smaller angular measure.

Statistical Procedures

The program ANOVR, originally created by Gordon F. Pitz of Southern Illinois University and modified by Dr. Paul A. Games[4] of the Educational Psychology Department at The Pennsylvania State University, was used to analyze three different statistical designs used in this pahse of the project. In addition, the Tukey Wholly Significant Difference (WSD) test was used as a follow-up test to determine how sample means differed from one another when significant F values were obtained in the ANOVR results. The following represent the two, 2-factor designs and one, 3-factor design used: Gender vs. Load (for Loads 1-3), Backpack vs. Load (Loads 4-6 for the men only), and Gender vs. Backpack vs. Load (Loads 4-5). A conventional analysis of variance logic was used to assess the results of the ANOVR runs. For the 2-factor designs, the interaction was first examined. The lack of a significant interaction indicated that the effect of one factor was the same from level to level of the second factor. Consequently, the main effects sufficiently described the results of the analysis. If the interaction was significant, however, an examination of the main effects no longer gave an adequate representation of the trends presented in the data. Follow-up analyses, therefore, included an examination of the simple effects. Because of an a priori interest in the main effects, they were examined and reported even when a significant interaction existed. The assessment of the 3-factor design was an extension of this same logic.

[4] Games, P.A., G.S. Gray, W.L. Herron, A. Pentz, and G.F. Pitz. Analysis of Variance with Repeated Measures. University Park, PA: The Pennsylvania State University Computation Center, June 1979.

RESULTS AND DISCUSSION

Stride Velocity

The walking velocity of each subject was limited to a ± 5% range around 6.4 km/hr, or 1.782 m/sec. If the velocity was adequately controlled, then the results of the analysis of variance (ANOVA) of stride velocity should be non-significant. In fact, the results did show that there were no significant differences at the .05 level in walking speed between any of the experimental conditions. The grand mean for the 374 observations which represented all conditions was 1.834 m/sec. This value is slightly higher than the 1.782 m/sec target speed but is well within the ± 5% range (1.699 m/sec to 1.878 m/sec). The mean values for stride velocity generated by each of the three ANOVA runs are shown in Tables 4, 5, and 6. The vertical lines which connect the mean values are used to show non-significance. The ANOVA summary tables are included in Appendix B.

Table 4

Mean Values of Stride Velocity for Gender and Load

Main Effect	Stride Velocity (m/sec)
Gender	
Men	1.826
Women	1.843
Load	
1	1.824
2	1.839
3	1.840

Table 5

Mean Values of Stride Velocity for Gender, Backpack, and Load

Main Effect	Stride Velocity (m/sec)
Gender	
Men	1.829
Women	1.845
Backpack	
ALICE LC-2	1.843
ALICE LC-1	1.828
LOCO	1.841
PACKBOARD	1.836
Load	
4	1.843
5	1.832

Table 6

Mean Values of Stride Velocity for Backpack and Load

Main Effect	Stride Velocity (m/sec)
Backpack	
ALICE LC-2	1.838
ALICE LC-1	1.826
LOCO	1.829
PACKBOARD	1.822
Load	
4	1.833
5	1.826
6	1.829

Effect of Gender and Load

A 2-factor ANOVA was used to evaluate the differences between men and women and among Loads 1, 2, and 3 for the seven variables selected to describe the gait of each subject. The mean values and the statistical results for six of the seven variables (excluding stride velocity) are discussed and presented in tabular form below. The six variables include stride length, stride rate, single leg contact time, double support time, swing time, and trunk angle. The ANOVA summary tables are shown in Appendix C. In all of the following tables presenting statistical results, mean values which are not connected by a horizontal or vertical line are significantly different at the .05 level, and those which are connected are not statistically different. In addition, only the main means were analyzed in follow-up procedures when there was no significant interaction since an examination of simple effects was not required. The cell means are included for completeness, however, regardless of the significance of the interaction.

Table 7 contains the mean values for stride length. The ANOVA results indicated no significant interaction ($F = 2.40$) existed between gender and load. An examination of the main means then showed no significant difference between the men and women ($F = 3.28$), although the men did tend to have longer stride lengths, but a significant load effect ($F = 7.69$) was obtained. Further analysis showed that the subjects had a significantly longer stride length under the intermediate load condition, Load 2, than under Loads 1 and 3, which were not statistically different from each other.

Even though there is a significant load effect, one must question the importance of the observed differences. There appears to be no clear trend between increases in load and changes in stride length. In addition, the differences between the stride lengths for the different loads are quite small. The difference of 1 centimeter between the average stride length for Load 1 and Load 2 is statistically significant, but one can hardly consider this to be an important difference.

Table 7

Mean Values of Stride Length (m) for Gender and Load

Gender	Load 1	Load 2	Load 3	Gender $\bar{X}$
Men	.885	.903	.882	.890
Women	.861	.863	.855	.859
Load $\bar{X}$	.873	.883	.868	

The mean values for stride rate are shown in Table 8. The results of the ANOVA showed the lack of a significant Gender x Load interaction ($F = 0.51$). Both main effects, however, were significant indicating a significant difference between men and women ($F = 7.58$) and between Loads ($F = 7.66$). The results indicated the women had a higher rate of striding than did the men. For the load effect, follow-up procedures demonstrated that the stride rate under Load 3 was significantly greater than the nearly identical stride rates under Loads 1 and 2.

Table 8

Mean Values of Stride Rate (strides/sec) for Gender and Load

Gender	Load 1	Load 2	Load 3	Gender $\bar{X}$
Men	2.05	2.04	2.07	2.05
Women	2.14	2.13	2.18	2.15
Load $\bar{X}$	2.09	2.09	2.13	

Because the product of stride length and stride rate equals stride velocity and, since stride velocity was controlled in this project, one would expect to observe an inverse relationship between stride length and stride rate. Even though the differences within both stride length and stride rate were quite small, this relationship was present: the shortest stride length was associated with the greatest stride rate (and vice versa). The results give some indication that increased load does result in a shortened stride length and an increased stride rate which acts to compensate for the decrease in length. Under the limited number of conditions examined, however, it is difficult to consider this trend to be very meaningful.

The mean values for single leg contact time are contained in Table 9. The results of the ANOVA showed there was no significant Gender x Load interaction (F = 1.19). There was also a non-significant Load effect (F = 2.61) indicating load had little influence on the time of contact for a single leg although the time for Load 3 was slightly less than for Loads 1 and 2. There was, however, a significant Gender effect (F = 7.72). The results showed that the men had a significantly longer time for single leg contact than did the women. This difference may well be related to differences between men and women in stride rate. Because the women had a slightly higher stride rate and, since stride time is the reciprocal of stride rate, the women had a shorter stride time than the men. When the single leg contact time is examined as a percentage of the total time for one complete walking cycle (the time for two strides), the men and women have values which are nearly identical (59.8% for the women and 60.0% for the men).

Table 9

Mean Values of Single Leg Contact Time (msec) for Gender and Load

	Load			
Gender	1	2	3	Gender $\bar{X}$
Men	590	585	580	585
Women	555	562	552	556
Load $\bar{X}$	573	573	566	

Table 10 contains the mean values and the statistical results of the ANOVA for the time of double support. The results indicated that a significant interaction (F = 4.87) between Gender and Load existed for this variable. Consequently, the main effects of Gender and Load alone could not clearly represent the trends present in the data. In addition to examining the main effects, further follow-up procedures were also used to examine the simple effects of Gender and Load.

Table 10

Mean Values of Double Support Time (msec) for Gender and Load

	Load			
Gender	1	2	3	Gender $\bar{X}$
Men	101.0	96.2	98.3	98.5
Women	85.7	91.0	95.1	90.6
Load $\bar{X}$	93.4	93.6	96.7	

Figure 1 is a plot of the cell means for double support time versus Load Condition. As can be seen, the men and women subjects responded quite differently to increases in load. The analysis of the main effects demonstrated that neither the Gender (F = 2.68) nor the Load (F = 1.59) effects were significant, although the men tended to have slightly greater double support times than did the women. Consequently, Gender and Load had little effect on the time of double support when each was averaged over the second factor. An examination of the simple effects, however, showed that the men had a significantly longer time of double support for the baseline condition, Load 1, than the women. In addition, the women had a significantly longer time under Load 3 than Load 1. No other comparisons were significant.

Table 11 contains the mean values for the time of non-support, or swing time, for a single leg. The results indicated that the Gender x Load interaction was not significant (F = 2.39). The Gender main effect was also not significant (F = 2.85), although the women did show a slightly shorter swing time than the men. The only significant result was for the Load effect (F = 8.67). Follow-up procedures showed that the swing time for Load 3 was significantly less than the swing time for Loads 1 and 2. At first, one might think that, due to the decreased non-support time with increased load, there is a greater amount of time spent in support. In view of the results for stride rate and single leg contact time, however, the decrease in swing time is probably due to the increased stride rate (i.e., decreased stride time). Actually the proportion of the total time of one cycle spent in non-support shows very little change.

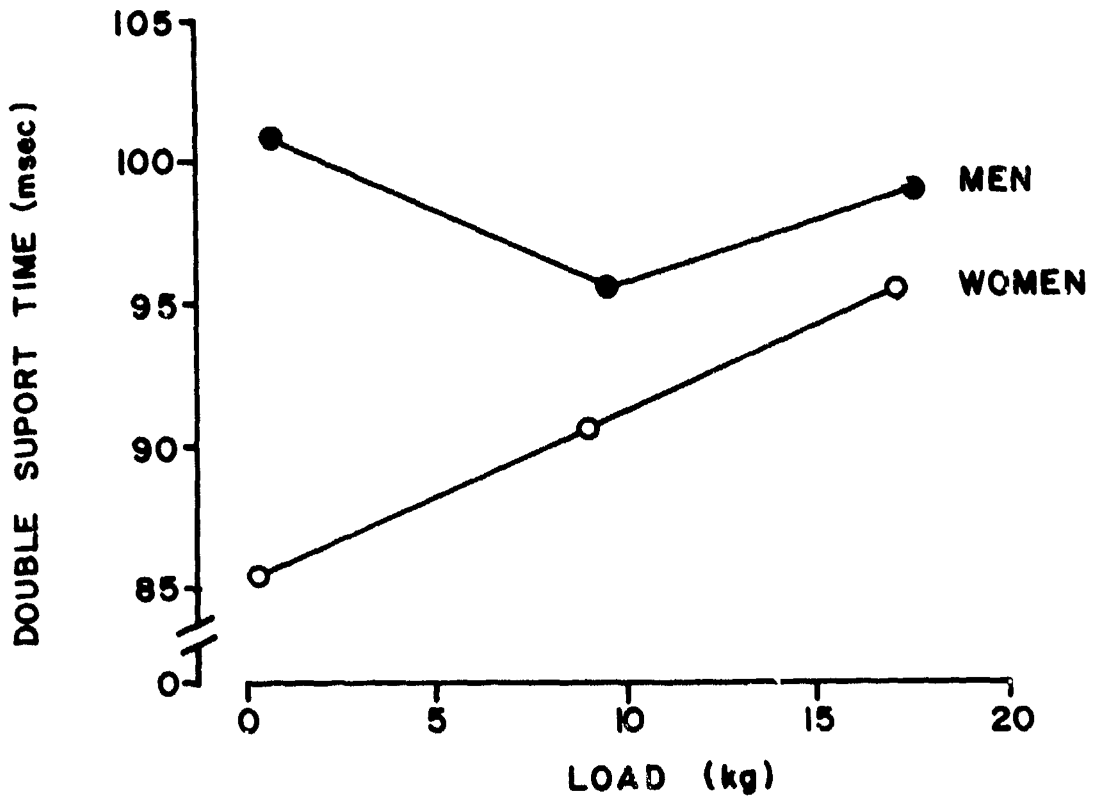

Figure 1. Mean double support time versus Load Condition for the men and women subjects.

Table 11

Mean Values of Swing Time (msec) for Gender and Load

	Load			
Gender	1	2	3	Gender $\bar{X}$
Men	339	395	387	391
Women	382	380	368	376
Load $\bar{X}$	385	388	377	

Trunk angle was the only variable examined that was not restricted to the temporal and kinematic characteristics of gait. Instead, it provided a measure of the way the subjects maintained their trunks under the various Load and Backpack conditions. The statistical results and means for trunk angle are presented in Table 12. The ANOVA results demonstrated that no significant differences existed for the trunk angle. The F-values for the interaction and the Gender and Load main effects were 1.16, 0.01, and 1.00, respectively. The main means for Gender were nearly identical, while those for Load were also quite similar, although there was a weak trend toward an increased trunk angle with added load.

Table 12

Mean Values of Trunk Angle (degrees) for Gender and Load

	Load			
Gender	1	2	3	Gender $\bar{X}$
Men	91.2	90.5	91.1	90.9
Women	84.5	93.2	94.1	90.6
Load $\bar{X}$	87.8	91.8	92.6	

In summary, a 2-factor ANOVA was used to assess the influence of Gender and Load on several variables used to describe walking gait. In general, the men demonstrated greater stride lengths, single leg contact times, double support times, and swing times, and lower stride rates than the women. The differences, however, were only significant for swing time and stride rate. Increased load produced only small changes in the measured variables. The subjects demonstrated somewhat greater stride rates, double support times, and trunk angles, and slightly lower single leg contact times and swing times as load was increased. The only significant results, however, were for stride rate and swing time, and the significant differences existed only for Load 3 in comparison with Loads 1 and 2. In addition, significant differences were obtained for stride length but these differences were quite small.

Based on these results, there were no strong trends present in the data. With only a few significant differences represented, the increased loads used in this portion of the analysis appear to have had only a small influence on the walking gait of the male and female subjects tested in this study.

Effect of Gender, Backpack, and Load

A 3-factor ANOVA design was used to examine the influence of Gender, Backpack and Load on the seven variables used to describe the subjects' walking gaits. This constituted a 2 x 4 x 2 design in which the four packs were analyzed in conjunction with Loads 4 and 5 only. These two load conditions were the only ones involving the four packs that were completed by both the men and women subjects. The results of the 3-factor ANOVA are discussed and presented below in tabular form for all variables except stride velocity, which was discussed previously. Because of the complexity of the 3-factor design and the large number of means generated in ANOVA runs, only main means will be presented in the tables. If a significant interaction exists, then appropriate surface or cell means will be discussed and displayed by plotting. Appendix D contains the ANOVA summary tables and tables of the individual cell means.

Table 13 shows the main mean values for stride length. The results showed that all interactions were non-significant except the Gender x Load interaction ($F = 4.73$). This interaction indicated that the men and women responded differently to the increase in load from Load 4 to Load 5. The results for the main effects showed there were no significant differences between Backpacks ($F = 0.13$). The results were significant, however, for the Gender ($F = 9.01$) and the Load ($F = 13.84$) main effects. The men had significantly longer stride lengths than the women, and stride length was significantly shorter under Load 5 than Load 4.

Table 13

Mean Values of Stride Length for Gender, Backpack, and Load

Main Effect	Stride Length (m)
Gender	
Men	.880
Women	.828
Backpack	
ALICE LC-2	.855
ALICE LC-1	.853
LOCO	.853
PACKBOARD	.855
Load	
4	.858
5	.850

Figure 2 is a plot the Gender x Load cell means which were derived by averaging over Backpack. This demonstrates that the men and women responded somewhat differently to increased load. The follow-up procedures showed that the men had significantly greater stride lengths at both Loads 4 and 5 than the women, and that the stride lengths for the women for Load 4 were significantly greater than those for Load 5. Demonstrating a similar trend as that discussed previously for the analysis of stride length for Gender and Load, the difference in stride length between Loads 4 and 5 cannot be considered important, even though it was significant. The greatest difference between Loads 4 and 5 was demonstrated by the women and that difference was only 1.4 centimeters.

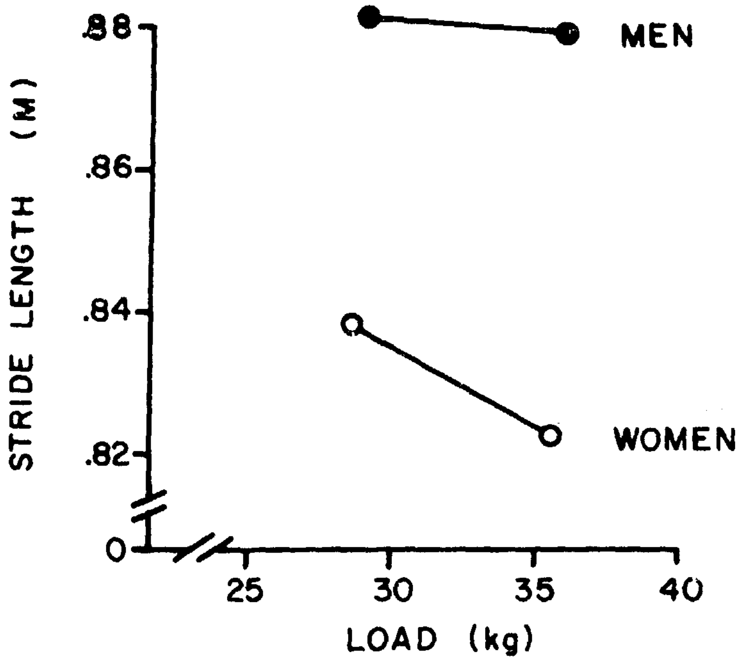

Figure 2. Means for stride length versus Load Condition for the men and women subjects.

The main means for Gender, Backpack, and Load for stride rate and the statistical results for the analysis are shown in Table 14. The results showed that none of the interactions were significant. In addition, the main effects for Backpack and Load were also non-significant. The mean values for the four packs were nearly identical as were those for Loads 4 and 5. The only significant difference was that between the men and women subjects (F = 14.78). The results showed that the men had lower stride rates than did the women. This is in agreement with the trend shown for the three lowest loads in the analysis of Gender and Load effects.

Table 14

Mean Values of Stride Rate for Gender, Backpack, and Load

Main Effect	Stride Length (m)
Gender	
Men	2.08
Women	2.23
Backpack	
ALICE LC-2	2.16
ALICE LC-1	2.15
LOCO	2.16
PACKBOARD	2.15
Load	
4	2.15
5	2.16

Table 15 contains the main means and the ANOVA results for single leg contact time. The results were nearly identical to those found for stride rate. All main effects and interactions were non-significant except for the main effect of Gender (F = 8.04). The men demonstrated a longer contact time than the women. This is quite similar to the trend found for single leg contact time for the Gender and Load ANOVA. As discussed previously, the difference between men and women may be closely related to the differences in stride rate or its reciprocal, stride time. Single leg contact time, represented as a percentage of the total cycle time, is nearly identical for the men and women (60.6% and 61.5%, respectively). Consequently, the results for single leg contact time seem to be providing information similar to that provided by the analysis of stride rate.

Table 15

Mean Values of Single Leg Contact Time for Gender, Backpack, and Load

Main Effect	Single Leg Contact Time (msec)
Gender	
Men	583
Women	552
Backpack	
ALICE LC-2	569
ALICE LC-1	571
LOCO	562
PACKBOARD	568
Load	
4	566
5	569

The results of the ANOVA of double support time are shown in Table 16. There were no significant results, although there was some tendency for the subjects to have shorter times while carrying the LOCO and also while under Load 5. Because these differences are quite small, however, these trends could not be considered meaningful.

Table 17 contains the ANOVA results and main mean values for swing time. The results showed that the Gender x Load interaction was significant ($F = 4.34$) and that the main effects for both Gender ($F = 22.57$) and Load ($F = 19.16$) were also significant. The analysis of the Gender and Load main effects showed that the men had a larger swing time than the women and that the subjects had a longer time under Load 4 than Load 5. These trends were in agreement with those found in the ANOVA analysis of Gender and Load. These differences in swing time are quite probably related to stride rate changes since the proportions of time spent in non-support change very little with changes in load and show little difference between men and women. The differences or changes in swing time due to the Gender and Load effects seem to parallel those of stride rate.

Table 16

Mean Values of Double Support Time
for Gender, Backpack, and Load

Main Effect	Double Support Time (msec)
Gender	
Men	102
Women	103
Backpack	
ALICE LC-2	105
ALICE LC-1	104
LOCO	100
PACKBOARD	102
Load	
4	102
5	104

Table 17

Mean Values of Swing Time
for Gender, Backpack, and Load

Main Effect	Swing Time (msec)
Gender	
Men	398
Women	346
Backpack	
ALICE LC-2	360
ALICE LC-1	363
LOCO	365
PACKBOARD	363
Load	
4	366
5	360

Figure 3 is a plot of the Gender x Load means obtained by averaging over the four packs. The significant interaction indicated that the men and women reacted differently to the increase in load and the diagram in Figure 3 demonstrates this. The follow-up procedures showed the women had a shorter time of non-support under Load 5 than Load 4, while the times for the men were not significantly different. In addition, the men and women differed significantly at both Loads 4 and 5. These results suggest that the difference in swing time between the means for Loads 4 and 5 was primarily due to differences displayed by the women, since the male values were quite similar.

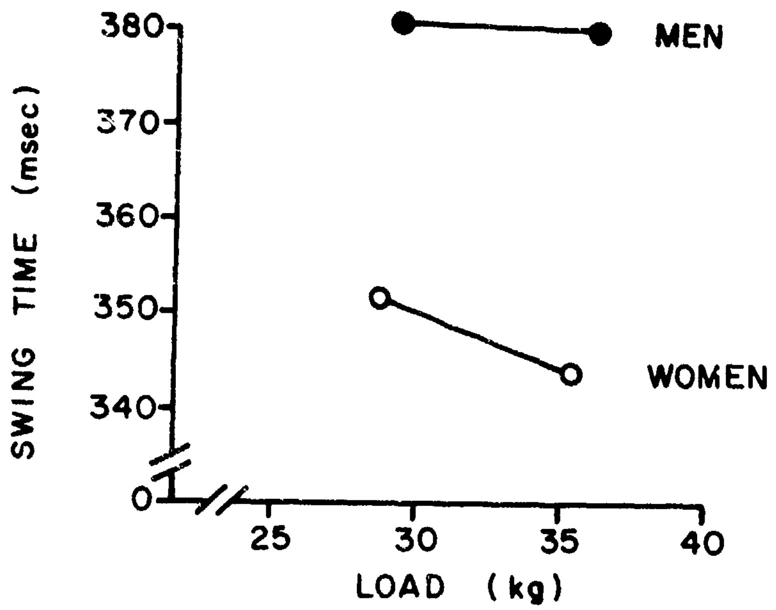

Figure 3. Means for swing time versus Load Condition for the men and women subjects.

The main means and statistical results for trunk angle are shown in Table 18. None of the interactions were significant. In addition, the difference between the men and women subjects was not significant ($F = 1.68$). The main effects for Backpack and Load, however, were significant ($F = 4.30$ and $F = 215.33$, respectively). The trunk angle for the subjects under Load 5 was shown to be significantly less than that under Load 4, indicating the subjects had a slightly greater forward trunk lean with the heavier load. The follow-up procedures showed that the trunk angle was significantly less for the ALICE LC-2 pack than for the LOCO and PACKBOARD packs. Although significant results were obtained, a close examination of the mean values for all three factors showed that the means were all quite similar. The greatest difference was that between Load 4 and Load 5 and that difference was only 1.7 degrees. Consequently, these differences are of limited practical importance.

Table 18

Mean Values of Trunk Angle for
Gender, Backpack, and Load

Main Effect	Trunk Angle (degrees)
Gender	
Men	84.2
Women	85.5
Backpack	
ALICE LC-2	84.1
ALICE LC-1	84.7
LOCO	85.2
PACKBOARD	85.4
Load	
4	85.7
5	84.0

In summary, a 3-factor ANOVA was used to examine the influence of Gender, Backpack, and Load on selected characteristics of walking gait. In general, the men showed greater stride lengths, lower stride rates, greater single leg contact times, and greater swing times than the women. Only one significant difference was found for the packs. This difference was found for the trunk angle measure, but the magnitude of the difference was so small that it was not considered meaningful. Finally, the results for the Load effect showed that, under Load 5, the subjects had shorter stride lengths, shorter swing times, and smaller trunk angles than under Load 4. These differences, however, were all quite small. In view of the results of the 3-factor design, it appears that the different packs and loads used in this portion of the analysis had very little influence on the gait characteristics of the male and female subjects tested in this study. The major influence on gait appears to be that due to the Gender factor since the greatest number of differences occurred between the men and the women, and the magnitudes of the differences were relatively large.

Effect of Backpack and Load

A 2-factor ANOVA was used to examine the differences between the four Backpacks and Loads 4, 5, and 6 for the seven variables used to describe walking gait. For this portion of the analysis, only the male subjects were examined, since the women were not tested with Load 6. Values for the main means for Backpack and Load and for the individual cell means are presented below in tabular form for the following six variables: stride length, stride rate, single leg contact time, double support time, swing time, and trunk angle. The results of the analysis of stride velocity was discussed previously and will not be included below. The ANOVA summary tables can be found in Appendix E. The individual cell means were examined by follow-up procedures only when a significant Backpack x Load interaction existed. They are included for completeness regardless of the significance of the interaction.

The ANOVA results and mean values for stride length are shown in Table 19. The results showed that the Backpack x Load interaction was not significant (F = 0.54). In addition, the main effect of Backpack was not significant (F = 0.84). The only significant result was for the Load main effect (F = 3.63). The follow-up procedures showed that the stride length under Load 4 was significantly greater than those for Loads 5 and 6. The stride lengths under Loads 5 and 6 were not significantly different from each other, although the stride length for Load 6 was slightly less than that for Load 5. All of these differences were quite small, however, and cannot be considered to be of any practical significance. The greatest difference between any two of the three loads was only 7 millimeters.

Table 19

Mean Values of Stride Length (m) for Backpack and Load

	LOAD			
Backpack	4	5	6	Pack $\bar{X}$
ALICE LC-2	.885	.879	.875	.880
ALICE LC-1	.884	.877	.875	.878
LOCO	.879	.884	.878	.880
PACKBOARD	.879	.872	.870	.874
Load $\bar{X}$	.882	.878	.875	

Table 20 contains the mean values and ANOVA results for stride rate, and Table 21 contains the same information for single leg contact time. The results showed there were no significant differences present for stride rate or for single leg contact time. An examination of the mean values shows that the means for the four Backpacks and for the three Loads were nearly identical for both variables.

Table 20

Mean Values of Stride Rate (strides/sec) for Backpack and Load

Backpack	LOAD 4	5	6	Pack $\bar{X}$
ALICE LC-2	2.09	2.09	2.10	2.09
ALICE LC-1	2.07	2.08	2.09	2.08
LOCO	2.08	2.07	2.09	2.08
PACKBOARD	2.08	2.08	2.10	2.09
Load $\bar{X}$	2.08	2.08	2.10	

Table 21

Mean Values of Single Leg Contact Time (msec) for Backpack and Load

Backpack	LOAD 4	5	6	Pack $\bar{X}$
ALICE LC-2	583	585	586	585
ALICE LC-1	582	588	580	583
LOCO	577	580	586	581
PACKBOARD	584	585	585	585
Load $\bar{X}$	581	584	584	

The results of the ANOVA and mean values for double support time are shown in Table 22. The results showed that the Backpack x Load interaction and the Backpack main effect were not significant (F = 1.66 and F = 1.95, respectively. The values of the main means for the four packs were all quite similar. The main effect for Load was the only significant result (F = 6.49). The follow-up procedures showed that the average value for double support time for Load 6 was significantly greater than that for Load 4. This difference, however, was only 6 milliseconds and thus is not considered to be very meaningful.

Table 22

Mean Values of Double Support Time (msec) for Backpack and Load

Backpack	LOAD 4	5	6	Pack $\bar{X}$
ALICE LC-2	105	105	111	107
ALICE LC-1	100	106	101	102
LOCO	97	98	110	102
PACKBOARD	104	102	108	105
Load $\bar{X}$	102	103	108	

Table 23 shows the mean values and the results of the ANOVA for swing time. These results showed that the Backpack x Load interaction was not significant (F = 0.75), while both the Backpack and Load main effects were statistically significant (F = 4.65 and F = 16.22, respectively). The follow-up procedures showed that the average value for swing time with the ALICE LC-2 pack was significantly less than that with the ALICE LC-1 and the LOCO packs and that swing time with the PACKBOARD was significantly less than that with the LOCO. In addition, the follow-up analysis found the average swing time for Load 6 to be significantly less than those for Loads 4 and 5. For both the Backpack comparisons and the Load comparisons, the maximum difference was 10 milliseconds. These differences are considered to be quite small and do not demonstrate any trend which is important from a practical standpoint.

Table 23

Mean Values of Swing Time (msec) for Backpack and Load

Backpack	LOAD 4	5	6	Pack $\bar{X}$
ALICE LC-2	376	372	368	372
ALICE LC-1	385	377	376	379
LOCO	386	386	374	382
PACKBOARD	379	378	367	374
Load $\bar{X}$	381	378	371	

The final analysis was that of trunk angle; the means and ANOVA results are presented in Table 24. The interaction between Backpack and Load for trunk angle was found to be non-significant ($F = 0.29$) as was the main effect of Backpack ($F = 0.44$). The mean values for the four packs were nearly identical. The only significant result was that for the main effect of Load ($F = 102.03$). The follow-up procedures showed all three Load means were significantly different from one another. As the load was increased from Load 4 to Load 6, the trunk angle decreased slightly. This decreasing angle indicated that the subjects demonstrated a greater forward lean with increased load.

Table 24

Mean Values of Trunk Angle (degrees) for Backpack and Load

	LOAD			
Backpack	4	5	6	Pack $\bar{X}$
ALICE LC-2	84.6	83.2	81.5	83.1
ALICE LC-1	85.1	83.5	81.7	83.4
LOCO	84.7	83.4	82.1	83.4
PACKBOARD	85.4	83.8	82.2	83.8
Load $\bar{X}$	85.0	83.5	81.9	

In summary, a 2-factor ANOVA was used to assess the influence of four Backpacks and three Loads on the characteristics of the walking gait of the male subjects. The results showed there were few significant trends in the data. In general, the difference in packs had very little influence on the measured characteristics of gait. Only for swing time was any significant difference found, and this difference was quite small. In examining the Load effect, stride length was found to be greatest under Load 4, double support time was shortest for Load 4, swing time was shortest for Load 6, and trunk angle decreased as the load increased from Load 4 to Load 6. With the possible exception of trunk angle, all differences were quite small and were considered to be of little practical importance. Consequently, the change in packs and the differences in load had little influence on the measured characteristics of gait.

Comparative Analysis of the Influence of Load

Because of the complexity of the experimental design used in this study and because of the variety of pack and load conditions employed, it was not possible to examine the influence of all loads in one statistical treatment. The conditions were confounded by the incorporation of the four packs with Loads 4, 5, and 6 only. In addition, the women were not tested under Load 6. In an attempt to assess the influence of increasing load on the gait of the male and female subjects, mean values for each load were computed for three variables. These variables were stride length, stride rate, and trunk angle. The selection of these three variables was based on the ANOVA results for the three statistical designs used to analyze Gender, Backpack, and Load effects. The mean values for the six loads are presented in Table 25. For Loads 4, 5, and 6, the data for the four packs were used to calculate a mean value for each load.

Table 25

Mean Values of Stride Length, Stride Rate, and Trunk Angle for All Loads

Gender	Variable	1	2	3	4	5	6
Men (n=11)	Stride Length (m)	.885	.903	.882	.882	.878	.875
	Stride Rate (str/sec)	2.05	2.04	2.07	2.08	2.08	2.10
	Trunk Angle (deg)	91.2	90.5	91.1	85.0	83.5	81.9
Women (n=11)	Stride Length (m)	.861	.863	.855	.835	.821	
	Stride Rate (str/sec)	2.14	2.13	2.18	2.22	2.24	
	Trunk Angle (deg)	84.5	93.2	94.1	86.5	84.5	

For the variable stride length, the data suggested that increased load resulted in a shortening of the length of step. For the men, this trend was quite weak. Although the trend was somewhat stronger for the women, the differences were still relatively small and cannot be considered to be very meaningful.

The same general pattern was true for stride rate, except that the trend was reversed. This was expected since stride length and stride rate are inversely related when velocity is controlled. As was found for stride length, the differences between loads were quite small. This was particularly true for the men.

A somewhat more distinctive change was noted in the trunk angle. Figure 4 is a plot of the angle values for the load conditions for both the men and women subjects. The women showed an unusual increase in the angle from Load 1 to Load 2. Because added load was distributed nearly equally about the body, one would expect little change in the angle. No reasonable explanation can be given for this observed change. The remainder of the pattern for the women and the pattern for the men can be explained by the positioning of the added load. As the load was increased from Load 2 to Load 3 for the women and Load 1 to Load 3 for the men, little change occurred in the forward inclination of the trunk. This can be attributed to the relatively equal distribution of the added load on the anterior and posterior surfaces of the body. As the load was increased to Load 4, the packs were added to the body. This load was positioned almost entirely on the posterior surface of the body. In order to balance this added load, the subjects needed to lean forward. The extra weight for Loads 5 and 6 were added to the pack and, consequently, required further forward leaning. Although these observed changes in trunk angle tended to confirm the measurement techniques used in this study, they were not particularly enlightening since the manner in which individuals adjust their trunk position according to the magnitude and distribution of a carried load is well known.

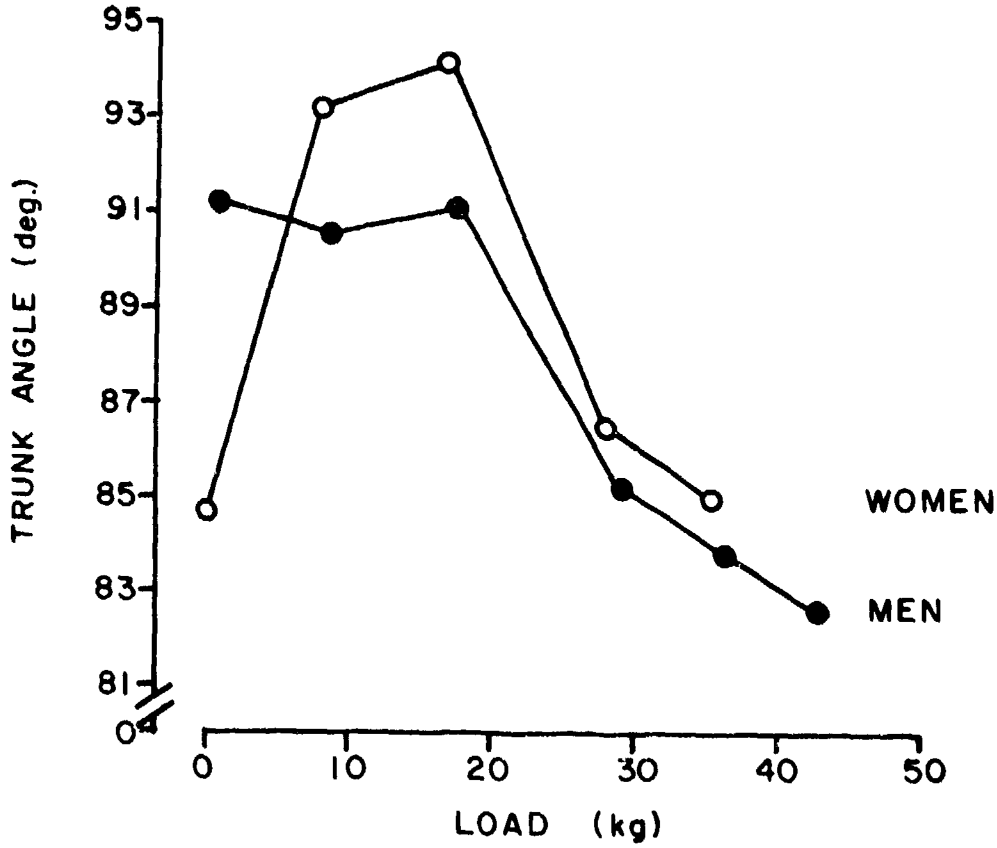

Figure 4. Trunk angle values versus Load Condition for the men and women subjects.

SUMMARY AND RECOMMENDATIONS

It was the purpose of this study on the biomechanics of load carrying behavior to examine the effect of gender, backpack, and load on selected characteristics of walking gait. Data for seven variables used to describe certain features of gait were obtained using standard cinematography and film analysis procedures. These data were then analyzed using three ANOVA designs. Men and women and Loads 1, 2, and 3 were first compared in a 2-factor design. The men and women were again compared in a 3-factor design involving the four pack systems and Loads 4 and 5. Finally, the data for Loads 4, 5, and 6 for the men only were examined in conjunction with the four packs in a 2-factor design. Because it was not possible to examine the influence of all loads in one statistical treatment, a comparative analysis across all loads was also performed on the data.

The results suggested that the major differences in the data were due to gender, while changes in load and pack had little influence on the variables being examined. In general, the men had greater stride lengths and lower stride rates than women. Differences in single leg contact time, double support time, and swing time paralleled the differences between men and women for stride rate. Finally, there was little difference in trunk angle between men and women.

For the load effect, there was some tendency for the subjects to decrease stride length and increase stride rate as the load was increased. These changes, however, were quite small and were considered to hold little practical significance. There was some change in the posture of the subjects, as measured by trunk angle, as the load was increased. In general, there was little change until Load 4 was reached. This load was the first to involve the backpacks and represented the first additional load that was not distributed evenly on the anterior and posterior surfaces of the body. As the load was increased from Load 4 to Load 6, there was a gradual decrease in the measured trunk angle. This increased forward lean was the result of the added load being placed almost exclusively on the posterior surface of the body. As was noted earlier, this pattern of trunk angle changes was not particularly enlightening since it is well known how trunk position changes when different loads and distributions of load are added to the trunk.

For the backpack effect, only two significant results were found in all the ANOVA tests involving the packs. In both cases, the differences were of such small magnitude that they were not considered to be of any practical significance. Consequently, it is concluded that the subjects demonstrated quite similar gait characteristics regardless of the backpack worn.

In previous work by Nelson, Clarke and Hinrichs (Ref. 3), contact time for a single leg was examined for males and females, three body sizes, and three backpacks. Although the contact times reported in this earlier study are somewhat different than those obtained here because of the different walking speeds employed, the overall results of both studies are quite similar. Both found differences between males and females, but no differences between backpacks. Consequently, the results for single leg contact time of this analysis support those for contact time reported by Nelson et. al (Ref. 2). It should be noted that the backpacks used in this project and those used in the earlier one were not identical, but they were similar.

Considering pack and load effects to be the major concern of this project and the gender effect to be of secondary importance, it must be concluded that the procedures used and the variables describing gait did not detect any meaningful differences between backpacks and loads. This failure to discriminate may have been due to the control placed on the velocity of walking. A lack of control on velocity, however, would have provided no basis for comparison and any differences would have been confounded by the variations in walking velocity.

Although the results showed that very few differences existed between the backpacks and between the loads, this conclusion may be considered an important finding. If the normal activities of a foot soldier involve carrying the packs primarily during transport maneuvers, as opposed to carrying the pack in combat, then the results of this study suggest that it does not matter which of these four backpacks is used. It is difficult, however, to suggest the same for various loads. It must be remembered that the data were collected when the subjects were not fatigued. The results, therefore, can only be extended to a non-fatigued state. This is why it is particularly difficult to extend this same reasoning to the loads. Although the four packs may show few differences, even over a long period of walking, it is difficult to suggest that different loads may not have different degrees of effect on gait over a long period of time.

Based on the results of this testing, certain recommendations can be made for future consideration. First, it may be worthwhile to have some detailed knowledge of the normal routine of a typical foot soldier. This should include not only a description of the various types of activities and movements a soldier performs, but also a detailed analysis of the duration of these various activities. To provide an example of the value of this type of data, the performance tests used in the first study in this series were designed to simulate various movements a soldier may perform in combat (Ref. 1). All subjects were tested under at least two load conditions that involved wearing the ALICE LC-2 pack. If the movements used in the testing were not representative of actual combat maneuvers, then it becomes difficult to extend the results to soldiers in combat. Assuming the movements used in the testing were appropriate as was believed, some of the information gained may have little value if a soldier rarely wears a pack in actual combat situations.

Second, it would be inappropriate to reexamine walking gait in a similar manner unless two or more different speeds were being examined or unless the subjects were tested in both non-fatigued and fatigued states. The less important of these two suggested alternatives would be that of testing under different speeds. Placing controls on walking speed may actually be introducing a certain artificiality for many subjects. In all likelihood, an individual will select a speed and pattern of walking that is reasonably comfortable to him and this may be somewhat different from those speeds which are tested. Testing under fatigued conditions, however, is more critical since it may be quite likely for a soldier to perform under a fatigued state. It may also be true that differences in backpack design influence the movement patterns of an individual only after he is fatigued.

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Appendix A

Clothing and Equipment Used in This Study

Clothing, Body Armor, and Sleeping Gear

The items worn by the subjects or stowed in the packs are standard products from the Army's inventory. The Army nomenclature for each item and its military specification, which contains a description of the item, are listed below.

Nomenclature	Specification
Socks, Wool, Cushion Sole	MIL-S-48
Boot, Combat, Leather, Black, Direct Molded Sold	MIL-B-43481E
Shirt, Utility, Durable Press	MIL-S-43929B
Trousers, Utility, Durable Press	MIL-T-43932C
Undershirt, Cotton, White	JJ-U-513D
Helmet, Personnel Armor System Ground Troops (PASGT)	LP/P DES 12-78A
Body Armor, Fragmentation Protective Vest, Personnel Armor System Ground Troops (PASGT)	MIL-B-44053
Sleeping Bag, Intermediate Cold, Synthetic Fill	MIL-S-44016
Mattress, Pneumatic, Insulated	MIL-M-43968
Bag, Waterproof, Clothing	MIL-B-3108
Poncho, Wet Weather	MIL-P-43700

Load Carrying Equipment

In the Army, all items worn or carried by the soldier are divided into two categories, a fighting load and an existence load. The former consists of items essential for the immediate mission, such as the clothing and armor being worn, a rifle, ammunition, and a canteen. The existence load consists of items needed to sustain the soldier in the field for a period of time, such as sleeping gear, rations, and additional clothing. Carrying equipment has been developed to accommodate some of the items comprising the fighting and the existence loads. The load carrying gear which was used in the present study is described below.

Fighting Gear (Figure A-1)

This standard Army equipment consists of a belt and suspenders, made of nylong webbing and nylon duck, to which other items are attached by means of slide keepers. The equipment hung on the belt includes:

a. a cover made of nylon duck that holds a steel cup with a .9-liter capacity and a .9-liter canteen for water.

b. a plastic case that holds a folding intrenching tool.

c. two cases made of nylon duck which hold ammunition rounds and also have straps from which grenades can be hung.

d. a small pouch for first aid dressings or a compass.

The Army nomenclature and military specification for each component of the fighting gear are listed below.

Nomenclature	Specification
Belt and Suspenders, All-Purpose Lightweight Individual Carrying Equipment (ALICE)	MIL-B-43826 and MIL-S-43819
Canteen, Water, 1-Quart Capacity	MIL-C-43103

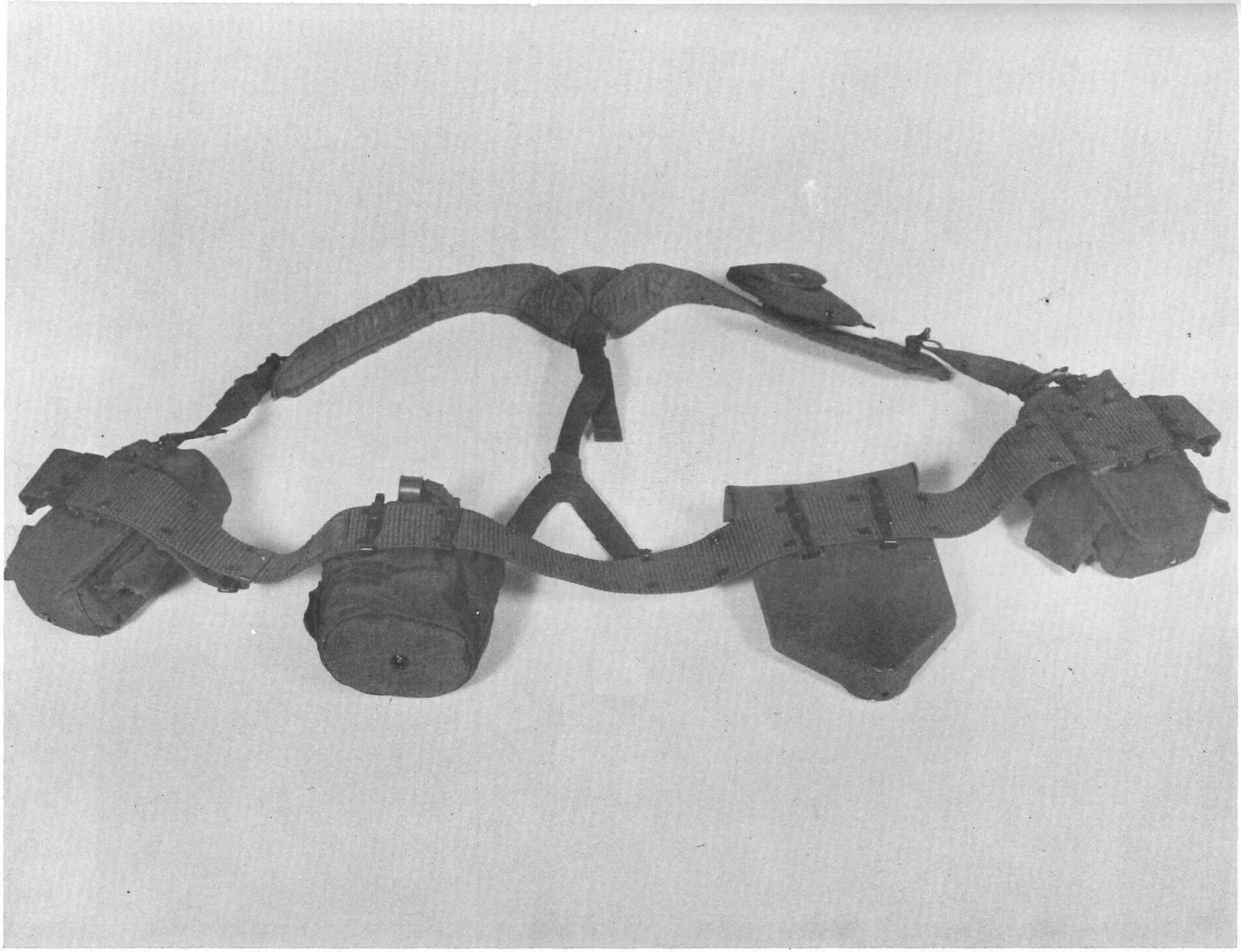

Figure A-1. ALICE Fighting Gear.

Nomenclature	Specification
Cup, Water Canteen, Steel, 1-Quart	MIL-C-43761
Cover, Canteen	MIL-C-43742
Intrenching Tool, Folding, Lightweight	MIL-I-43684
Intrenching Toll Carrier	MIL-I-43831
Case, Small Arms, Ammo, 30-Round	MIL-C-43827
Case, First Aid/Compass	MIL-C-43745

Carrying Gear for Existence Load

Four pack and frame combinations were used in this study. They included standard Army, experimental, and commercial items. Three were backpacks with external frames (ALICE LC-1, ALICE LC-2, and PACKBOARD) and one was an internal-frame system (LOCO). The same pack was used on each of the external frames. These items are described below.

ALICE Pack (Figure A-2). This standard Army equipment is a component of a load carrying system designated as All-Purpose Lightweight Individual Carrying Equipment (ALICE). The Alice pack is made of nylon duck and nylon webbing and weighs 1.3 kg. It has a large, top-loading, main compartment, an outside pocket on each of two sides and the front, and three smaller pockets above the center outside pocket. The maximum capacity of the pack is approximately 32 kg. The main compartment can be closed by means of a drawstring and is covered by a storm flap. The flap is secured by two, vertical straps which encircle the pack. Each outside pocket has a drawstring closure and is covered by a flap which is secured by a single strap. Strips of webbing sewn on the outside surface of the main compartment can be used for attaching items. A pocket large enough to accommodate a field radio is sewn inside the main compartment on the surface closest to the wearer's back. There are also "D" rings and tie strings inside the main compartment which can be used to shorten the pack if it is not filled to capacity. The pack is attached to a frame by means of an envelope at the top of the pack which slides over the top of the frame and a strap with a buckle on the bottom of each side of the pack which wraps around the frame.

ALICE LC-2 Frame (Figure A-3). This standard Army frame with its associated straps is also a component of the ALICE system and is used with the ALICE pack. It carries the designation "LC-2" to differentiate it from a frame (LC-1) which it replaced in the Army's inventory. The ALICE LC-2 frame is structured of aluminum tubing. It is 50.8 cm high and 31.1 cm wide. There are two, aluminum, horizontal members made from flat stock which extend from one side of the frame to the other and are riveted to the aluminum tubing. One, aluminum, vertical member, also made from flat stock, is riveted to the top and the bottom of the frame. Toward the top of the frame, this vertical piece and the aluminum tubing are angled toward the wearer's back. Two metal loops are attached to the top, horizontal, tubular portion of the frame. These are used to retain one end of the shoulder straps. There is also a grommet at the lower portion of each side of the frame through which the other end of each shoulder strap passes and is secured.

Figure A-2. ALICE Pack.

Figure A-2. ALICE Pack.

Figure A-3. ALICE LC-2 Frame.

Figure A-3. ALICE LC-2 Frame.

At the top of each shoulder strap is a rectangular piece of foam spacer material, 22.9 cm long, 7.0 cm wide, and 1.3 cm thick, covered with nylon duck and nylon webbing. The remainder of the strap is unpadded, nylon webbing. A quick-release device and a buckle used for length adjustment are incorporated into each shoulder strap. The lower back strap, which is 43.8 cm long and 12.7 cm high, is also made of foam spacer material, 1.3 cm thick, covered with nylon duck. The back strap is secured to the frame by use of narrow webbing which passes through a buckle. The waist belt is comprised of two pieces of nylon webbing 4.4 cm wide. One end of each piece is sewn to the backstrap. Each piece includes an adjustment mechanism used to shorten or lengthen the belt. The belt is secured around the waist by a plastic, quick-release device. The frame with its associated straps weighs 1.7 kg.

ALICE LC-1 Frame (Figure A-4). This was developed for use with the ALICE pack and was standard army equipment prior to the introduction of the ALICE LC-2. The LC-1 and the LC-2 frames have the same dimensions and are of the same basic design. However, the materials used in their shoulder, waist, and back straps are different. The top portion of each shoulder strap, measuring 38.7 cm long and 6.4 cm wide, is made of a cloth spacer material covered with nylon duck and nylon webbing. The remainder of the strap is narrow nylon webbing. A quick-release device is incorporated into the left shoulder strap and both straps have buckles for length adjustments. The lower back strap, which is 34.3 cm long and 7.6 cm high, is also made of a cloth spacer material covered with nylon duck. The back strap is secured to the frame by use of webbing which is attached to a turnbuckle. The waist belt is made of two pieces of nylon webbing 2.5 cm wide. One end of each piece is wrapped around the lower, tubular portion of the frame. Each piece includes a buckle for adjusting the length of the belt. The belt is secured around the waist by a metal and plastic quick-release device. The frame with its associated straps weighs 1.4 kg.

PACKBOARD (Figure A-5). This experimental equipment, fabricated for the study, is made from flat aluminum stock. The PACKBOARD is 54.6 cm high and measures 34.9 cm across at its widest point. It accommodates the ALICE pack. Two horizontal slits were cut in the aluminum at the top of the PACKBOARD for attachment of the shoulder straps. Two vertical slits were cut on each side toward the bottom for attachment of the lower back strap and the straps on the ALICE pack. There are two additional openings in this area for securing the bottom ends of the shoulder straps to the PACKBOARD. The shoulder, waist, and back straps are the same ones used with the ALICE LC-2 frame. A flat, rectangular pad of foam spacer material, 29.2 cm high, 25.4 cm wide, and 13. cm thick, is attached to the PACKBOARD directly above the backstrap and covered with nylon duck. The PACKBOARD and associated straps weigh 2.3 kg.

LOCO (Figure A-6). This system is manufactured by Lowe Alpine Systems/ International Equipment Manufacturing. It is a top-loading, internal-frame backpack. The frame consists of two, vertical, aluminum stays which extend the length of the pack, a distance of 59.7 cm. The stays can be removed from their pockets, which are sewn to the outside surface of the pack, and are flexible enough to be bent by hand. The stay pockets are 7.6 cm apart. The pack is constructed of pack cloth.

Figure A-4. ALICE LC-1 Frame.

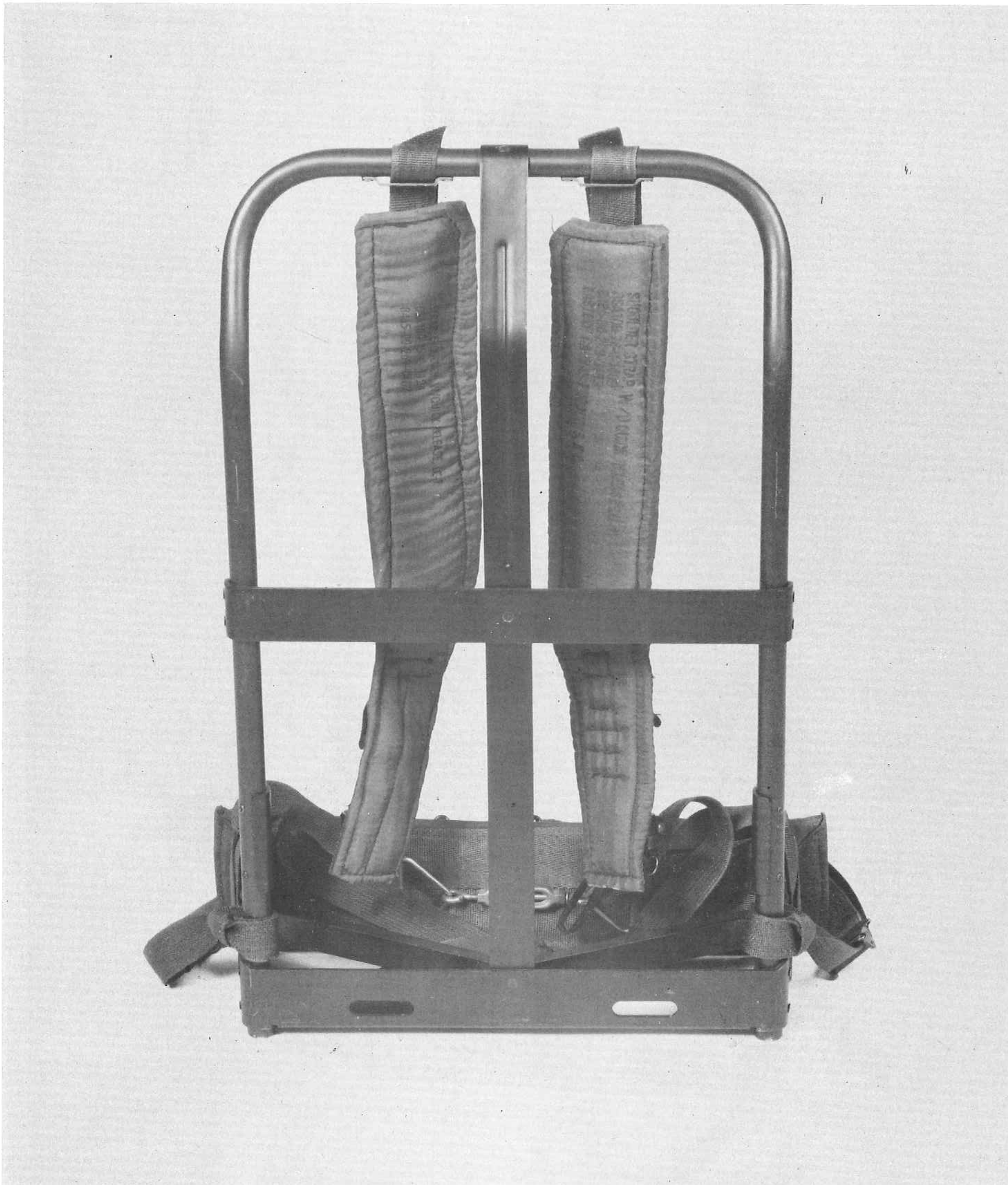

Figure A-4. ALICE LC-1 Frame.

Figure A-5. PACKBOARD.

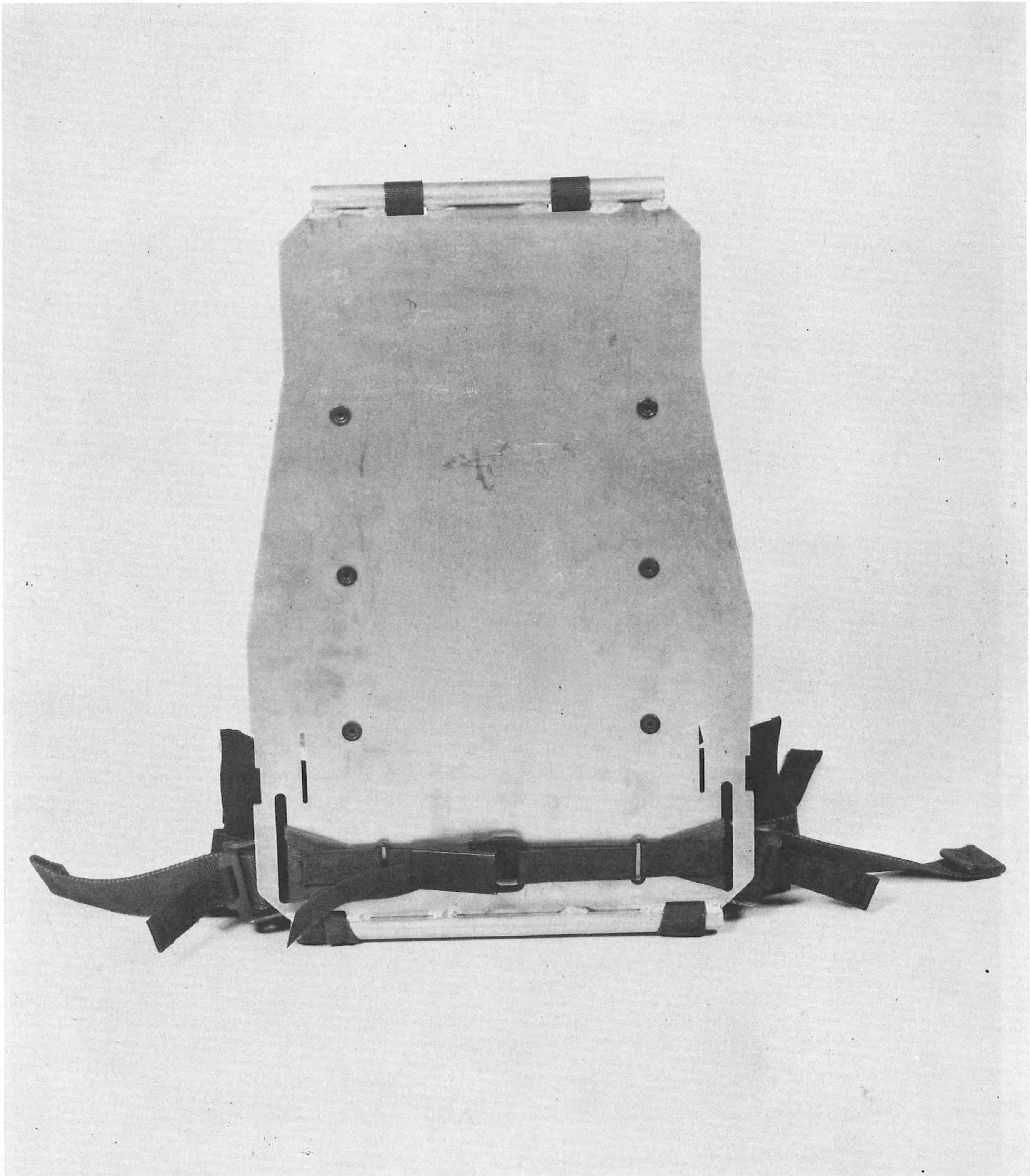

Figure A-5. PACKBOARD.

Figure A-6. LOCO.

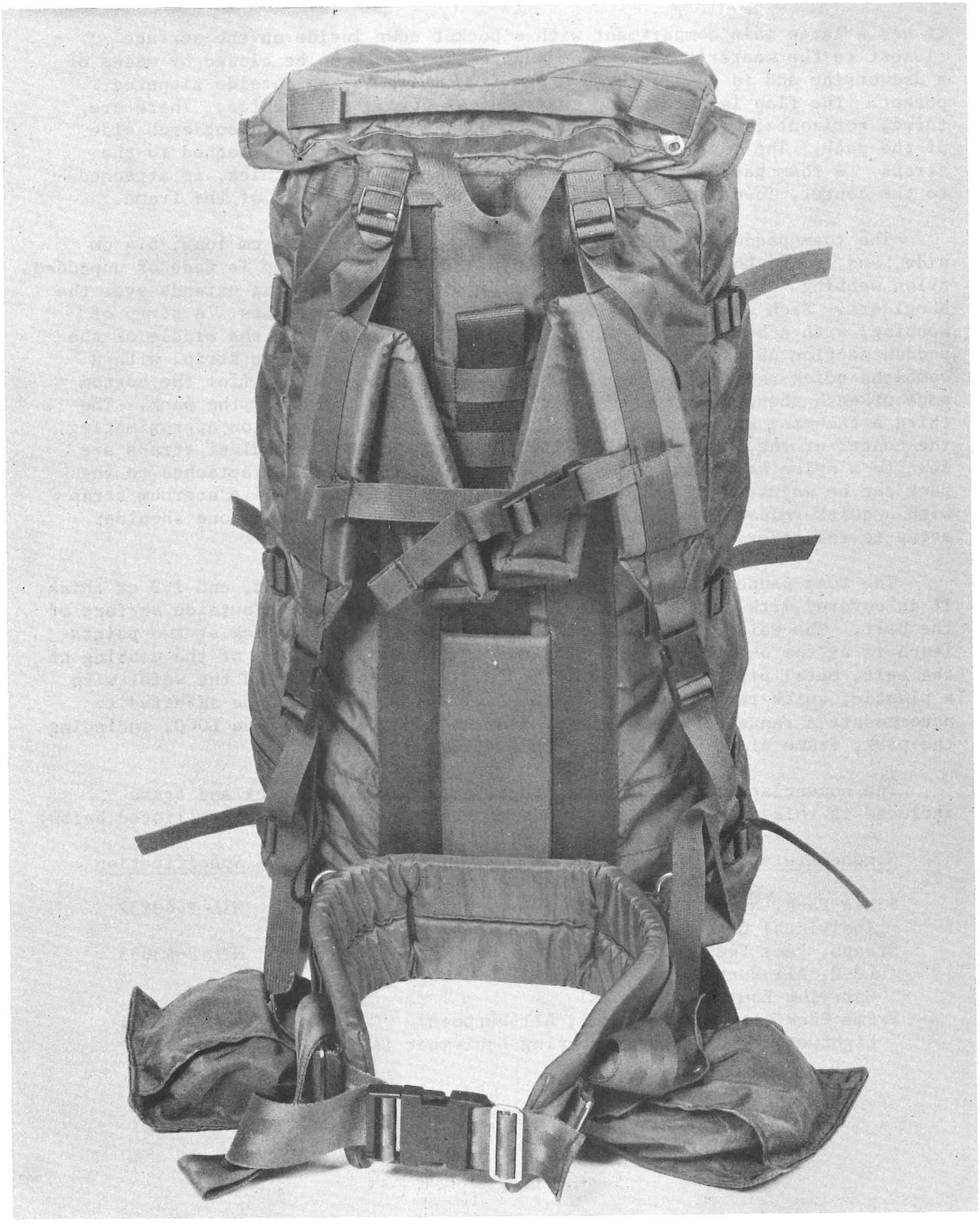

Figure A-6. LOCO.

It has a large main compartment with a pocket sewn inside on the surface closest to the wearer's back. The main compartment can be closed by means of a drawstring and is covered by a storm flap which has an outside zippered pocket. The flap is secured by two vertical straps and buckles. There are three, horizontal straps made of nylon webbing which extend along each side of the pack. The pack can be compressed by use of buckles attached to the straps. A foam pad, 17.8 cm high, 7.6 cm wide, and .6 cm thick, is attached to the center, lower portion of the pack, between the stays of the frame.

The foam-padded portion of each shoulder strap is 39.4 cm long, 6.4 cm wide, and 1.3 cm thick. The remainder of the shoulder strap is made of unpadded nylon webbing. The straps are designed such that the padding extends over the shoulders. Each strap is attached to the pack at three points. A strip of webbing, with a buckle for length adjustments, extends from the middle of the padded section on each strap to the top of the pack. Another strip, with a combined quick-release and length-adjustment device, extends from the bottom edge of each shoulder strap's padded section to the bottom of the pack. The third attachment point is at the center of the pack, a location approximating the center of the wearer's back. Here, the ends of both shoulder straps are sewn to a nylon webbing strap. The point at which the strap attaches to the pack can be adjusted by use of a vertical ladder of webbing. A sternum strap with a quick-release and length-adjustment buckle extends from one shoulder strap to the other.

The foam-padded waist belt is 77.5 cm long, 10.2 cm high, and 1.3 cm thick. It is covered with pack cloth. Nylon webbing is sewn to the outside surface of the belt. The waist belt is attached to the bottom of the pack at two points (each is at the outside edge of a frame stay pocket) by means of the webbing on the belt, metal pins, and buckles. The belt is secured around the waist with a plastic, quick release device and webbing straps which can be adjusted to accommodate a range of waist circumferences. The weight of the LOCO, including the pack, frame stays, and straps, is 1.4 kg.

The nomenclature and military specification for each pack and frame included in this study which is or was in the Army's inventory are listed below.

Nomenclature	Specification
Field Pack, Nylon, Large, All-Purpose Lightweight Individual Carrying Equipment (ALICE)	MIL-F-43832
Straps, Pack Frame and Strap/Frame Assembly, LC-2, All-Purpose Lightweight Individual Carrying Equipment (ALICE)	MIL-S-43835
Frame Pack with Straps, LC-1, All-Purpose Lightweight Individual Carrying Equipment (ALICE)	MIL-F-43834

Appendix B

ANOVA Summary Tables - Stride Velocity Analyses

Table B-1

ANOVA Summary of Stride Velocity for Gender and Load (1-3)

SOURCE OF VARIANCE	DF	M.S.	F	Prob
Between Subjects				
Gender	1	0.4923×10^{-2}	0.397	0.536
Error	20	0.1241×10^{-1}		
Within Subjects				
Load	2	0.1920×10^{-2}	1.790	0.180
Gender x Load	2	0.2868×10^{-2}	2.675	0.081
Error	40	0.1072×10^{-2}		

Table B-2

ANOVA Summary of Stride Velocity for Gender, Backpack, and Load (4-5)

SOURCE OF VARIANCE	DF	M.S.	F	Prob
Between Subjects				
Gender	1	0.1130×10^{-1}	0.241	0.629
Error	20	0.4697×10^{-1}		
Within Subjects				
Pack	3	0.2010×10^{-2}	0.819	0.376
Gender x Pack	3	0.1776×10^{-2}	0.724	0.405
Error	60	0.2453×10^{-2}		
Load	1	0.5128×10^{-2}	2.153	0.158
Gender x Load	1	0.6960×10^{-3}	0.292	0.595
Error	20	0.2382×10^{-2}		
Pack x Load	3	0.8390×10^{-4}	0.052	0.821
Gender x Pack x Load	3	0.7157×10^{-3}	0.446	0.512
Error	60	0.1603×10^{-2}		

Table B-3

ANOVA Summary of Stride Velocity for Backpack and Load (4-6)

SOURCE OF VARIANCE	DF	M.S.	F	Prob
<u>Between Subjects</u>				
Error	10	0.6657×10^{-1}		
<u>Within Subjects</u>				
Pack	3	0.1481×10^{-2}	0.427	0.528
Error	30	0.3466×10^{-2}		
Load	2	0.5114×10^{-3}	0.383	0.550
Error	20	0.1336×10^{-2}		
Pack x Load	6	0.2861×10^{-3}	0.226	0.645
Error	60	0.1268×10^{-2}		

APPENDIX C

ANOVA Summary Tables - Analyses of Gender and Load (1-3)

Table C-1

ANOVA Summary of Stride Length for Gender and Load (1-3)

SOURCE OF VARIANCE	DF	M.S.	F	Prob
Between Subjects				
Gender	1	0.1546×10^{-1}	3.275	0.085
Error	20	0.4719×10^{-2}		
Within Subjects				
Load	2	0.1202×10^{-2}	7.692	0.002
Gender x Load	2	0.3742×10^{-3}	2.396	0.107
Error	40	0.1562×10^{-3}		

Table C-2

ANOVA Summary of Stride Rate for Gender and Load (1-3)

SOURCE OF VARIANCE	DF	M.S.	F	Prob
Between Subjects				
Gender	1	0.1465	7.581	0.012
Error	20	0.1933×10^{-1}		
Within Subjects				
Load	2	0.1016×10^{-2}	7.664	0.002
Gender x Load	2	0.6788×10^{-3}	0.512	0.604
Error	40	0.1326×10^{-2}		

Table C-3

ANOVA Summary of Single Leg Contact Time for Gender and Load (1-3)

SOURCE OF VARIANCE	DF	M.S.	F	Prob
Between Subjects				
Gender	1	0.1347×10^{-1}	7.724	0.012
Error	20	0.1744×10^{-2}		
Within Subjects				
Load	2	0.3683×10^{-3}	2.613	0.086
Gender x Load	2	0.1670×10^{-3}	1.185	0.317
Error	40	0.1410×10^{-3}		

Table C-4

ANOVA Summary of Double Support Time for Gender and Load (1-3)

SOURCE OF VARIANCE	DF	M.S.	F	Prob
Between Subjects				
Gender	1	0.1024×10^{-2}	2.678	0.117
Error	20	0.3825×10^{-3}		
Within Subjects				
Load	2	0.7559×10^{-4}	1.594	0.219
Gender x Load	2	0.2310×10^{-3}	4.872	0.014
Error	40	0.4742×10^{-4}		

Table C-5

ANOVA Summary of Swing Time for Gender and Load (1-3)

SOURCE OF VARIANCE	DF	M.S.	F	Prob
Between Subjects				
Gender	1	0.3262×10^{-2}	2.846	0.107
Error	20	0.1146×10^{-2}		
Within Subjects				
Load	2	0.6423×10^{-3}	8.666	0.001
Gender x Load	2	0.1771×10^{-3}	2.390	0.106
Error	40	0.7411×10^{-4}		

Table C-6

ANOVA Summary of Trunk Angle for Gender and Load (1-3)

SOURCE OF VARIANCE	DF	M.S.	F	Prob
Between Subjects				
Gender	1	1.455	0.013	0.911
Error	20	112.3		
Within Subjects				
Load	2	144.2	0.997	0.330
Gender x Load	2	167.3	1.157	0.295
Error	40	144.6		

APPENDIX D

ANOVA Summary Tables - Analyses
of
Gender, Backpack, and Load (4-5)

Table D-1

ANOVA Summary of Stride Length for Gender, Backpack and Load (4-5)

SOURCE OF VARIANCE	DF	M.S.	F	Prob
Between Subjects				
Gender	1	0.1166	9.010	0.007
Error	20	0.1294×10^{-1}		
Within Subjects				
Pack	3	0.3390×10^{-4}	0.127	0.725
Gender x Pack	3	0.4657×10^{-3}	1.750	0.201
Error	60	0.2661×10^{-3}		
Load	1	0.3369×10^{-2}	13.840	0.001
Gender x Load	1	0.1151×10^{-2}	4.727	0.042
Error	20	0.2434×10^{-3}		
Pack x Load	3	0.4754×10^{-4}	0.302	0.589
Gender x Pack x Load	3	0.3233×10^{-3}	2.053	0.167
Error	60	0.1575×10^{-3}		

Table D-2

ANOVA Summary of Stride Rate for Gender, Backpack, and Load (4-5)

SOURCE OF VARIANCE	DF	M.S.	F	Prob
Between Subjects				
Gender	1	0.9870	14.782	0.001
Error	20	0.6677×10^{-1}		
Within Subjects				
Pack	3	0.2433×10^{-2}	0.906	0.353
Gender x Pack	3	0.2263×10^{-2}	0.843	0.370
Error	60	0.2685×10^{-2}		
Load	1	0.4400×10^{-2}	1.981	0.175
Gender x Load	1	0.4009×10^{-2}	1.805	0.194
Error	20	0.2221×10^{-2}		
Pack x Load	3	0.6242×10^{-3}	0.539	0.471
Gender x Pack x Load	3	0.4030×10^{-3}	0.348	0.562
Error	60	0.1158×10^{-2}		

Table D-3

ANOVA Summary of Single Leg Contact Time for Gender, Backpack, and Load (4-5)

SOURCE OF VARIANCE	DF	M.S.	F	Prob
Between Subjects				
Gender	1	0.4114×10^{-1}	8.037	0.010
Error	20	0.5119×10^{-2}		
Within Subjects				
Pack	3	0.5683×10^{-3}	2.507	0.129
Gender x Pack	3	0.4801×10^{-4}	0.212	0.650
Error	60	0.2266×10^{-3}		
Load	1	0.1861×10^{-3}	1.138	0.299
Gender x Load	1	0.3369×10^{-4}	0.206	0.655
Error	20	0.1635×10^{-3}		
Pack x Load	3	0.3976×10^{-4}	0.319	0.578
Gender x Pack x Load	3	0.1116×10^{-4}	0.090	0.768
Error	60	0.1246×10^{-3}		

Table D-4

ANOVA Summary of Double Support Time for
Gender, Backpack, and Load (4-5)

SOURCE OF VARIANCE	DF	M.S.	F	Prob
Between Subjects				
Gender	1	0.3820×10^{-4}	0.049	0.827
Error	20	0.7763×10^{-3}		
Within Subjects				
Pack	3	0.2176×10^{-3}	2.581	0.124
Gender x Pack	3	0.6207×10^{-4}	0.736	0.401
Error	60	0.8430×10^{-4}		
Load	1	0.1418×10^{-3}	3.871	0.063
Gender x Load	1	0.2475×10^{-4}	0.675	0.421
Error	20	0.3665×10^{-4}		
Pack x Load	3	0.8795×10^{-4}	1.458	0.241
Gender x Pack x Load	3	0.4292×10^{-4}	0.712	0.409
Error	60	0.6032×10^{-4}		

Table D-5

ANOVA Summary of Swing Time for Gender, Backpack, and Load (4-5)

SOURCE OF VARIANCE	DF	M.S.	F	Prob
Between Subjects				
Gender	1	0.4982×10^{-1}	22.572	<0.001
Error	20	0.2207×10^{-2}		
Within Subjects				
Pack	3	0.2431×10^{-3}	1.562	0.226
Gender x Pack	3	0.3731×10^{-3}	2.397	0.137
Error	60	0.1556×10^{-3}		
Load	1	0.1554×10^{-2}	19.161	<0.001
Gender x Load	1	0.3523×10^{-3}	4.343	0.050
Error	20	0.8111×10^{-4}		
Pack x Load	3	0.2031×10^{-3}	2.386	0.138
Gender x Pack x Load	3	0.7391×10^{-4}	0.869	0.362
Error	60	0.8510×10^{-4}		

Table D-6

ANOVA Summary of Trunk Angle for Gender, Backpack, and Load (4-5)

SOURCE OF VARIANCE	DF	M.S.	F	Prob
Between Subjects				
Gender	1	74.36	1.684	0.209
Error	20	44.15		
Within Subjects				
Pack	3	13.87	4.303	0.010
Gender x Pack	3	7.594	2.357	0.140
Error	60	3.222		
Load	1	129.9	215.329	<0.001
Gender x Load	1	2.458	4.075	0.057
Error	20	0.6032		
Pack x Load	3	0.9633	0.978	0.335
Gender x Pack x Load	3	1.663	1.689	0.209
Error	60	0.9850		

Table D-7

Cell Mean Values of Stride Length (m) for Gender, Backpack, and Load

	Men		Women	
Pack	Load 4	Load 5	Load 4	Load 5
ALICE LC-2	.885	.879	.837	.819
ALICE LC-1	.884	.877	.830	.822
LOCO	.879	.884	.835	.815
PACKBOARD	.879	.872	.838	.829

Table D-8

Cell Mean Values of Stride Rate (stride/sec) for Gender, Backpack, and Load

	Men		Women	
Pack	Load 4	Load 5	Load 4	Load 5
ALICE LC-2	2.09	2.09	2.21	2.25
ALICE LC-1	2.07	2.08	2.21	2.23
LOCO	2.08	2.07	2.24	2.26
PACKBOARD	2.08	2.08	2.22	2.23

Table D-9

Cell Mean Values of Single Leg Contact Time (msec) for Gender, Backpack, and Load

	Men		Women	
Pack	Load 5	Load 5	Load 4	Load 5
ALICE LC-2	583	585	553	554
ALICE LC-1	382	588	556	558
LOCO	577	580	545	548
PACKBOARD	584	585	553	551

Table D-10

Cell Mean Values of Double Support Time (msec)
for Gender, Backpack, and Load

	Men		Women	
Pack	Load 4	Load 5	Load 4	Load 5
ALICE LC-2	105	105	101	108
ALICE LC-1	100	106	103	106
LOCO	97	98	100	103
PACKBOARD	104	102	103	100

Table D-11

Cell Mean Values of Swing Time (msec)
for Gender, Backpack, and Load

	Men		Women	
Pack	Load 4	Load 5	Load 4	Load 5
ALICE LC-2	376	372	352	338
ALICE LC-1	385	377	351	340
LOCO	386	386	350	340
PACKBOARD	379	378	349	349

Table D-12

Cell Mean Values of Trunk Angle
(degrees) for Gender, Backpack, and Load

	Men		Women	
Pack	Load 5	Load 5	Load 4	Load 5
ALICE LC-2	84.6	83.2	85.2	83.4
ALICE LC-1	85.1	83.5	85.7	84.7
LOCO	84.7	83.4	87.6	85.1
PACKBOARD	85.4	83.8	87.4	84.9

APPENDIX E

ANOVA Summary Tables - Analyses
of
Backpack and Load (4-6)

Table E-1

ANOVA Summary of Stride Length for Backpack and Load (4-6)

SOURCE OF VARIANCE	DF	M.S.	F	Prob
Between Subjects				
Error	10	0.2081×10^{-1}		
Within Subjects				
Pack	3	0.3020×10^{-3}	0.841	0.482
Error	30	0.3592×10^{-3}		
Load	2	0.5462×10^{-3}	3.632	0.045
Error	20	0.1504×10^{-3}		
Pack x Load	6	0.9066×10^{-4}	0.543	0.478
Error	60	0.1670×10^{-3}		

Table E-2

ANOVA Summary of Stride Rate for Backpack and Load (4-6)

SOURCE OF VARIANCE	DF	M.S.	F	Prob
Between Subjects				
Error	10	0.8448×10^{-1}		
Within Subjects				
Pack	3	0.1444×10^{-2}	0.697	0.423
Error	30	0.2073×10^{-2}		
Load	2	0.2821×10^{-2}	1.733	0.217
Error	20	0.1628×10^{-2}		
Pack x Load	6	0.3505×10^{-3}	0.453	0.516
Error	60	0.7738×10^{-3}		

Table E-3

ANOVA Summary of Single Leg Contact Time for Backpack and Load (4-6)

SOURCE OF VARIANCE	DF	M.S.	F	Prob
Between Subjects				
Error	10	0.7757×10^{-2}		
Within Subjects				
Pack	3	0.1070×10^{-3}	0.538	0.480
Error	30	0.1989×10^{-3}		
Load	2	0.1344×10^{-3}	0.828	0.384
Error	20	0.1624×10^{-3}		
Pack x Load	6	0.1119×10^{-3}	0.954	0.352
Error	60	0.1173×10^{-3}		

Table E-4

ANOVA Summary of Double Support Time Backpack and Load (4-6)

SOURCE OF VARIANCE	DF	M.S.	F	Prob
Between Subjects				
Error	10	0.9451×10^{-3}		
Within Subjects				
Pack	3	0.1854×10^{-3}	1.947	0.193
Error	30	0.9522×10^{-4}		
Load	2	0.4340×10^{-3}	6.486	0.029
Error	20	0.6691×10^{-4}		
Pack x Load	6	0.1458×10^{-3}	1.664	0.226
Error	60	0.8759×10^{-4}		

Table E-5

ANOVA Summary of Swing Time for Backpack and Load (4-6)

SOURCE OF VARIANCE	DF	M.S.	F	Prob
Between Subjects				
Error	10	0.2475×10^{-2}		
Within Subjects				
Pack	3	0.6666×10^{-3}	4.652	0.010
Error	30	0.1433×10^{-3}		
Load	2	0.1192×10^{-2}	16.218	0.002
Error	20	0.7350×10^{-4}		
Pack x Load	6	0.8338×10^{-4}	0.747	0.408
Error	60	0.1116×10^{-3}		

Table E-6

ANOVA Summary of Trunk Angle for Backpack and Load

SOURCE OF VARIANCE	DF	M.S.	F	Prob
Between Subjects				
Error	10	57.21		
Within Subjects				
Pack	3	2.524	0.441	0.522
Error	30	5.730		
Load	2	103.9	102.033	<0.001
Error	20	1.018		
Pack x Load	6	0.3541	0.293	0.600
Error	60	1.208		