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A COMPARISON OF 2 CURRENT-ISSUE ARMY BOOTS, 5 PROTOTYPE MILITARY BOOTS, AND 5 COMMERCIAL HIKING BOOTS: PERFORMANCE, EFFICIENCY, BIOMECHANICS, COMFORT AND INJURY

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The experiment evaluated the physiological, biomechanical, and maximal performance responses of 14 male soldiers wearing 2 current Army boots, 5 prototype Army boots, and 5 commercial hiking boots. Physiological evaluation determined the rate of oxygen consumption for carrying a 60-lb backpack load while walking in each type of boot. Biomechanical analysis quantified gait, posture, and lower-extremity joint forces and torques. Maximal-speed runs with and without a 60-lb backpack were timed on both straight and zigzag 400 m grass courses. Comfort and functionality questionnaires were administered to the volunteers after they walked 6 miles at 3 mph over pavement and wooded trail in each boot-type; blisters and other foot trauma were assessed post-march. Based on their overall performance, the boots were ranked from best to worst as follows: (1) Salomon Adventure 9 Ultralight, (2) Raichle Highline, (Tie for 3,4,5) Prototype 3, Prototype 4, Asolo Meridian, (6) Asolo AFX 535, (7) Prototype 1, (8)Prototype 2 (9) Montrail Moraine, (10) current-issue Army combat boot, (11) current-issue Army jungle boot, and (12) Prototype 5. The performance of all the boots is summarized in a table, and a list is provided of the best performer for each major evaluation variable.

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A comparison of 2 current-issue Army boots, 5 prototype military boots, and 5 commercial hiking boots: performance, efficiency, biomechanics, comfort and injury

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BACKGROUND

Hamill and Bensel (6, 7, 8) conducted biomechanical studies of military footwear in order to identify means of enhancing locomotor capabilities and reducing lower extremity injury rates. Their goal was to develop recommendations for future military footwear with regard to materials, design, construction, fabrication techniques, and any other aspects that would benefit the performance and lower extremity health of military personnel. The biomechanical analyses carried out by Hamill and Bensel, consisting of materials testing and human subject experimentation performed on military boots and commercial shoes and boots, generated recommendations for the design of future military footwear.

In the first phase of the biomechanical analysis of military boots, Hamill and Bensel (6) focused on materials testing. They found that the Army jungle and combat boots compared unfavorably to commercial footwear (basketball shoe, cross trainer, hiking boot and work boot) as to impact absorption. In the second phase of their research, Hamill and Bensel (7, 8) determined how Army and commercial boots compared when worn by human subjects walking at different speeds. During the walks, the jungle and combat boots produced the highest peak impact forces. Further, the magnitudes of the propulsive peak were relatively large as compared to commercially available footwear.

As a follow-up to the work of Hamill and Bensel (6, 9), an applied research program in biomechanics was established to generate concepts for improved military boots. The program was approved as a Department of Army Science and Technology Objective to be conducted jointly by the U.S. Army Natick Soldier Center and the U.S. Army Research Institute of Environmental Medicine. The goals of the program were to identify concepts for military footwear that would improve the locomotor efficiency of the wearer and result in a reduction of stress-related injuries of the lower extremities compared with the standard-issue black leather combat boots. Requirements for improved boots were generated that addressed functional characteristics, such as durability under military field conditions, and biomechanical characteristics, such as impact properties. These requirements formed the basis of a request for proposals for design and fabrication of prototype boots. A group that included three footwear manufacturers was awarded the contract to produce prototypes. The lead contractor was Ro-Search, Inc., a major producer of military footwear. The other footwear manufacturers were Hyde Athletic Industries, Inc. and Rocky Shoes and Boots, Inc.

Five prototype boots were designed and produced by these companies. The experiment described in this report was designed to assess the physiological, biomechanical, and maximal performance responses of men wearing the five prototypes in order to determine which, if any, of the prototype boots showed promise of meeting the program goals of improving the wearer's locomotor efficiency and reducing the likelihood of lower extremity injuries. To provide a basis of comparison, two current-issue Army boots, the combat and jungle boots, were included in the experiment, as were five commercial hiking boots.

LIST OF SYMBOLS, ABBREVIATIONS AND ACRONYMS

mph	miles per hour
psi	Pounds per square inch
USARIEM	U.S. Army Research Institute of Environmental Medicine
USASBCC	U.S. Army Soldier, Biological, and Chemical Command
USASSC	U.S. Army Soldier Systems Center in Natick, MA

DISCLAIMER

The conclusions, recommendations, and any other opinions expressed in this report are those of the authors alone and do not reflect the opinion, policy, or position of the Department of the Army or the United States Government.

DISTRIBUTION STATEMENT

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EXECUTIVE SUMMARY

The experiment evaluated the physiological, biomechanical, and maximal performance responses of 14 male soldiers wearing 2 current Army boots, 5 prototype Army boots, and 5 commercial hiking boots. Physiological evaluation determined the rate of oxygen consumption for carrying a 60-lb backpack load while walking in each type of boot. Biomechanical analysis quantified gait, posture, and lower-extremity joint forces and torques. Maximal-speed runs with and without a 60-lb backpack were timed on both straight and zigzag 400 m grass courses. Comfort and functionality questionnaires were administered to the volunteers after they walked 6 miles at 3 mph over pavement and wooded trail in each boot-type; blisters and other foot trauma were assessed post-march. All testing was performed at the U.S. Army Soldier Systems Center in Natick, MA, and on the roads and in the forest of the town of Natick, MA, from the fall of 1996 to the fall of 1997.

Based on their overall performance, the boots were ranked using a point system. From best to worst the boots were:

1.	Salomon Adventure 9 Ultralight (boot 12)	100
2.	Raichle Highline (boot 9)	90
Three-way tie:		
4.	Prototype 3 (boot 3)	84
4.	Prototype 4 (boot 4)	84
4.	Asolo Meridian (boot 11)	84
6.	Asolo AFX 535 (boot 10)	73
7.	Prototype 1 (boot 1)	70
8.	Prototype 2 (boot 2)	67
9.	Montrail Moraine (boot 8)	65
10.	Army combat boot (boot 6)	59
11.	Army jungle boot (boot 7)	51
12.	Prototype 5 (boot 5)	50

The poor performance of the current-issue Army combat and jungle boots supports the initiative to develop new standard-issue boots.

The performance of all the boots is summarized in a table, and a list is provided of the best performer for each major evaluation variable, enabling boot designers and developers to select the best features of all the boots for incorporation into a future military boot.

INTRODUCTION

At the beginning of Army basic training, every recruit is issued leather combat boots that are used for all training activities, other than group calisthenics and running. Following basic training, soldiers wear their boots for many activities including field exercises, garrison work, combat scenarios and actual combat. Essentially the boot is used in all circumstances in which specialized footwear (safety shoes, cold weather boots, hot weather boots etc.) is not required. Army-issue boots differ from commercially available hiking boots in that the latter are used primarily for hiking while Army boots are used for running, jumping, climbing, crawling, marching, hiking, as well as other activities. Also, hikers are largely expected to stay on trails and do some hill climbing on rocky surfaces, whereas soldiers may be required to take off-trail routes through dense forest, brush, mud, and water. In addition, the Army-issue boots are used in built-up areas, where soldiers encounter paved surfaces, stairways, and building interiors. Thus, unlike hiking boots, the Army boots are used for a variety of physical activities performed in a wide range of environments.

Hamill and Bensel (6) reviewed requirements that have been used to guide development of recent generations of the Army leather combat boots, and identified three levels of requirements. Primary requirements deal with the boot's ability to (1) enhance the locomotor capabilities of the wearer, (2) minimize the occurrence of lower extremity injury and pain, and (3) provide comfort. Secondary requirements include (1) the weight of the boot, (2) how high the boot comes up the ankle, (3) the design of the closures, (4) water resistance and (5) durability of the material. Tertiary requirements include the cost and rate of production. Incorporating these and other characteristics into a single item of footwear make development of Army boots a challenging undertaking.

Previous military footwear research has been aimed at developing recommendations for new designs. Biomechanical analysis of military boots has involved comparisons of military and commercial footwear via materials testing and human subject experimentation. Hamill and Bensel (6, 9) conducted biomechanical studies of military footwear focused specifically on identifying means of enhancing locomotor capabilities and reducing lower extremity injury rates. The goal of the work was to develop recommendations for future military footwear with regard to materials, design, construction, fabrication techniques, and any other aspects that would benefit the performance and lower extremity health of military personnel. The biomechanical analyses carried out by Hamill and Bensel, consisting of materials testing and human subject experimentation performed on military boots and commercial shoes and boots, generated recommendations for the design of future military footwear.

In the first phase of the biomechanical analysis of military boots, Hamill and Bensel (6) focused on material testing. The military footwear tested consisted of the current-issue black leather "combat boot" and the hot weather jungle boot. Hamill and Bensel used an impact tester on the combat and the jungle boots and the commercial footwear (a basketball shoe, cross trainer, hiking boot and work boot) to measure peak deceleration of the impact head, time to peak deceleration, and peak pressure. Time to peak deceleration was defined as the amount of time from initial contact of the impact head with the shoe to the maximum deceleration. Peak pressure was defined as force per unit area exerted on the shoe by the impact head at the time of the maximum deceleration. In general, it was found that the jungle and combat boots had higher peak decelerations, shorter times to peak deceleration, and higher peak pressures than the commercially available shoes and boots. Thus, the Army-issue boots compared unfavorably to the commercial footwear. For all the footwear, there was lower peak deceleration and lower peak pressure at the heel than at the forefoot.

In the second phase of their research, Hamill and Bensel (7, 8) determined how Army and commercial boots compared when worn by human subjects. The researchers tested the footwear during walks at three speeds: 1.15 m/s, 1.5 m/s and 3.4 m/s. During the walks, the jungle and combat boots produced the highest peak impact forces. Further, the magnitudes of the propulsive peak were relatively large as compared to commercially available footwear. In contrast, vertical ground reaction force peaks during running were either essentially the same or lower for jungle and combat boots. The researchers also showed that heart rate did not vary significantly as a function of footwear during any locomotor activities. Men's oxygen consumption was not affected by footwear, but women's oxygen consumption did vary depending on which boot was being worn. There was no relationship between men's or women's oxygen consumption and footwear mass or footwear hardness. Kinematic analysis revealed high ankle flexion velocities for jungle and combat boots possibly causing the straining of the long plantar ligaments.

In a similar experiment, Williams et al. (17) compared the current-issue combat and jungle boots to commercially available boots and to a hybrid boot which had the outer sole of an Army jungle boot coupled with a polyurethane midsole, which is not a normal feature of the jungle boot. It was found that the commercially available boots tested superior to the standard issue jungle and leather combat boots on impact tests. On the performance tests, greater shock absorption and lower power requirements were obtained with the commercially available boots. These findings suggest that at least some commercially available boots embody characteristics that are superior to those of standard-issue military boots.

Nigg et al (14) found larger rear-foot angles (inversion) at foot strike with the harder midsoles and proposed that the angular differences associated with differences in midsole hardness reflected a protective mechanism. Also, Clarke, Frederick and Hamill (2) found softer midsoles associated with greater maximum pronation and total rear-foot movement. McNitt-Gray (13) found that peak vertical ground reaction forces in a jump from 0.72 m are approximately 6 times body weight. Robinson, Frederick, and Cooper (15) found that the rigidity of stiffeners placed anterior and posterior to the lateral and medial malleoli affected the time to complete an agility course. The fastest course times were clocked when basketball shoes were worn, while the slowest times were produced when boots with stiffeners of the highest bending moment were used. In Hamill and Bensel's study (9), the footwear with the highest uppers (work boot, combat boot, and jungle boot) produced the longest times to complete the agility course. The longer time to complete the agility course may be due to the fact that the boots with the highest uppers were heavier, but this was not specifically reported. Also, these three boots produced more limited and rapid ankle dorsiflexion, suggesting the restriction on ankle motion inhibited rapid changes in direction and pace.

Knapik et al. (11) conducted a study to assess injuries associated with long road marches. Light infantry soldiers carried 46 kg a total of 20 km. Twenty four percent suffered one or more injuries, resulting in 44 days of limited duty. Foot blisters accounted for 35% of the total injuries, making it the most common injury associated with the march. Blisters are generally caused by ill-fitting boots that rub against the skin (16).

Five prototype Army boots were fabricated which incorporated some of the apparently desirable features of commercial hiking boots. The experiment described in this report evaluated the physiological, biomechanical, and maximal performance responses of 14 male soldiers wearing the 5 prototype Army boots, 2 current-issue Army boots, and 5 commercial hiking boots. Physiological evaluation determined the rate of oxygen consumption when volunteers carried a 60-lb backpack load while walking in each type of boot. Biomechanical analysis quantified gait, posture, and lower-extremity joint forces and torques. Maximal-speed runs with and without a 60-lb backpack were timed on both straight and zigzag 400 m grass courses. Comfort and functionality questionnaires were administered to the volunteers after they walked 6 miles at 3 mph over pavement and wooded trail in each boot-type. Blisters and other foot trauma were assessed post-march. All testing was performed at the U.S. Army Soldier Systems Center in Natick, MA, and on the roads and in the forest of the town of Natick, MA, from the fall of 1996 to the fall of 1997.

The 60 lb load selected for this study is supported by the U.S. Army field manual on foot travel (Department of the Army, 1990), which states that up to 72 lb may be carried on "prolonged dynamic operations." The 60 lb backpack weight falls within a range typical of Army field operations.

METHODS

BOOTS

Five different prototype boots were manufactured for this study (Figures 1-5). They were compared to the current-issue Army combat boot and the current-issue Army jungle boot (Figures 6 and 7). In addition, 5 high quality commercial hiking boots (Figures 8-13) were included in the study to determine if any of their features might be worthy of incorporation into future military boots, for a total of 12 different boots studied.

The 12 experimental boots were assigned identification numbers for the experiment. The 5 prototypes were designated as boots 1-5. The current-issue Army combat boot was designated as boot 6. The current-issue Army jungle boot was designated as boot 7. The Montrail Moraine was designated as boot 8. The Raichle Highline was designated as boot 9. The Asolo AFX 535 was designated as boot 10.

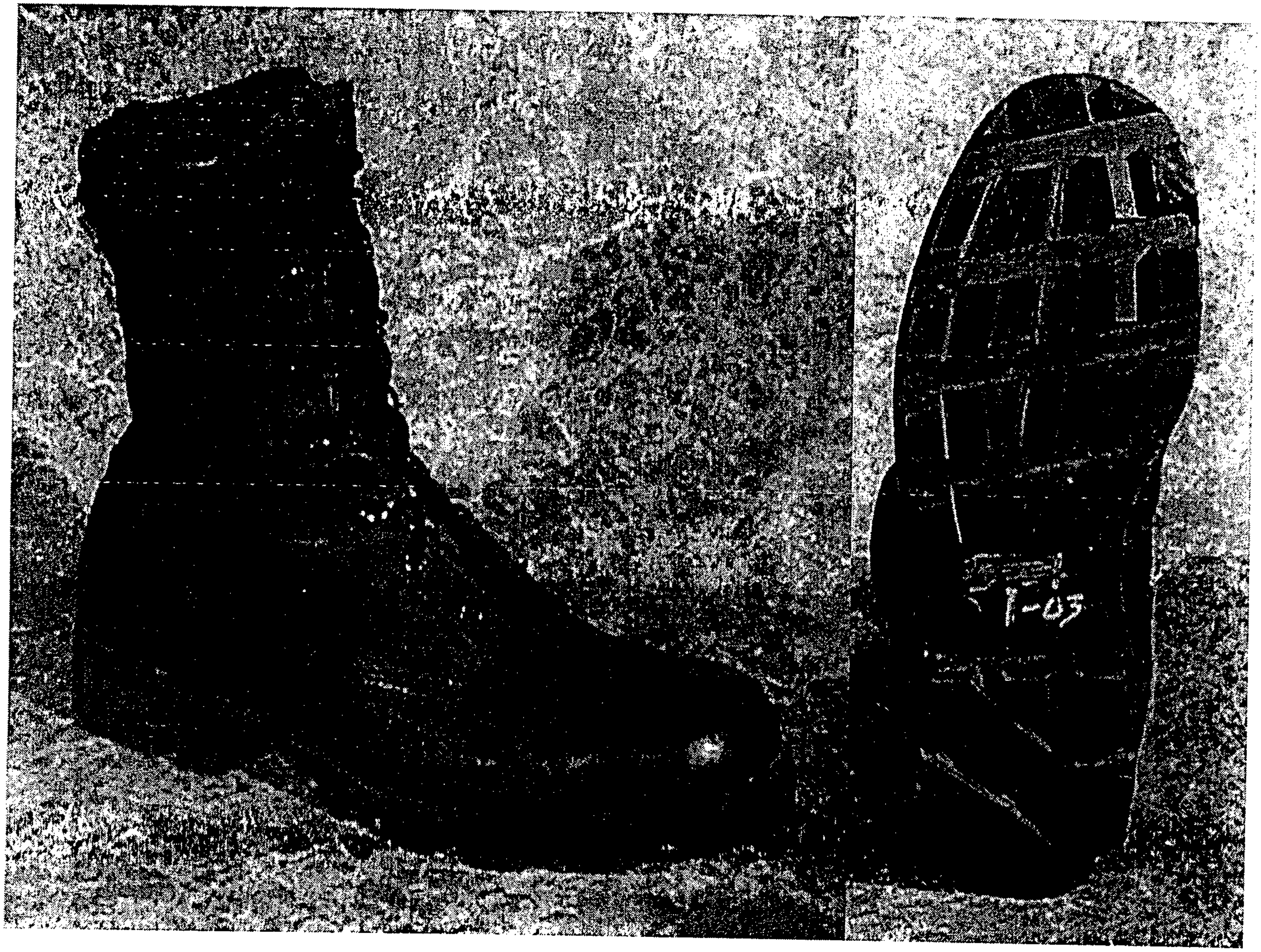

Figure 1. Boot 1 - Prototype 1

Figure 2. Boot 2 - Prototype 2

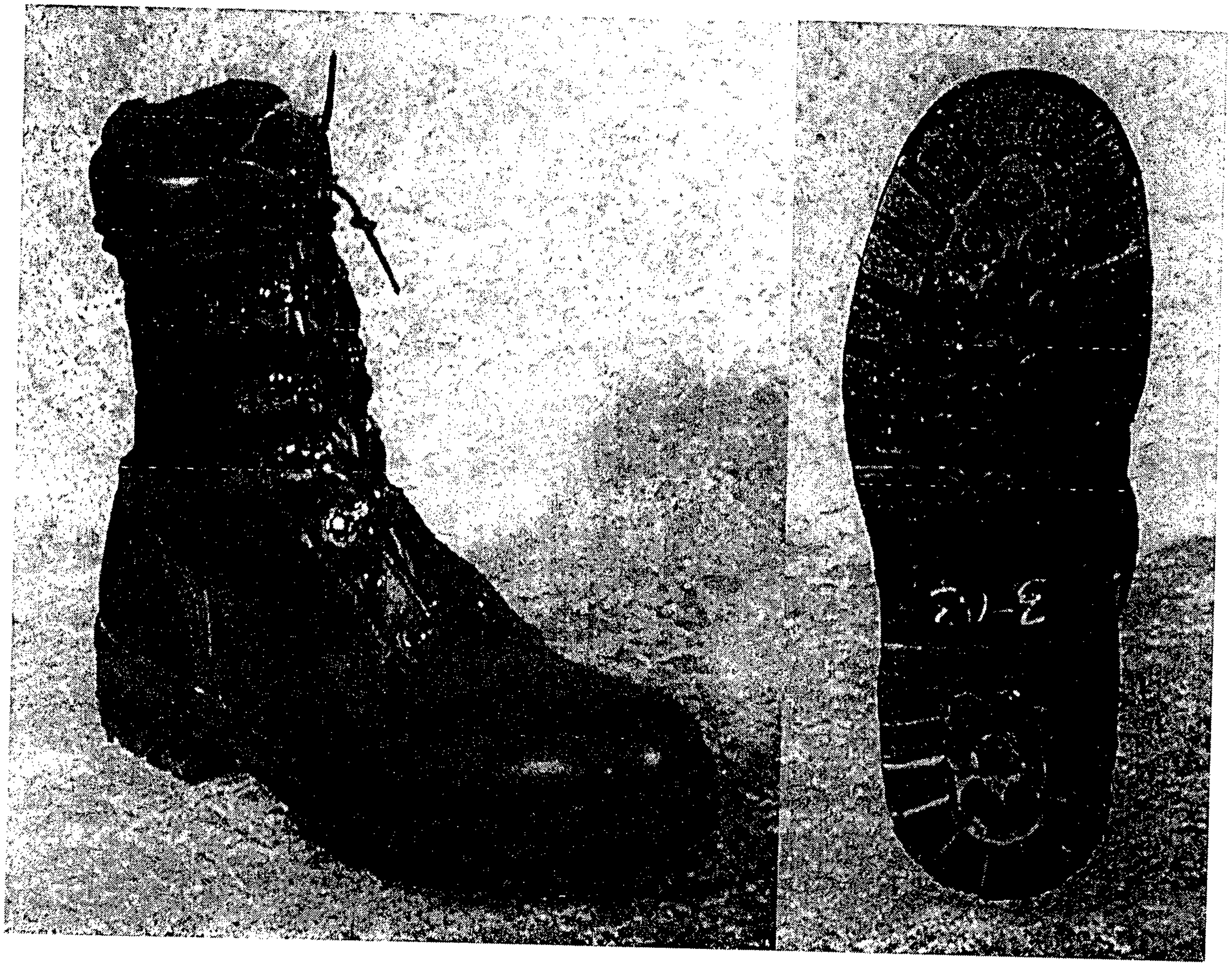

Figure 3. Boot 3 - Prototype 3

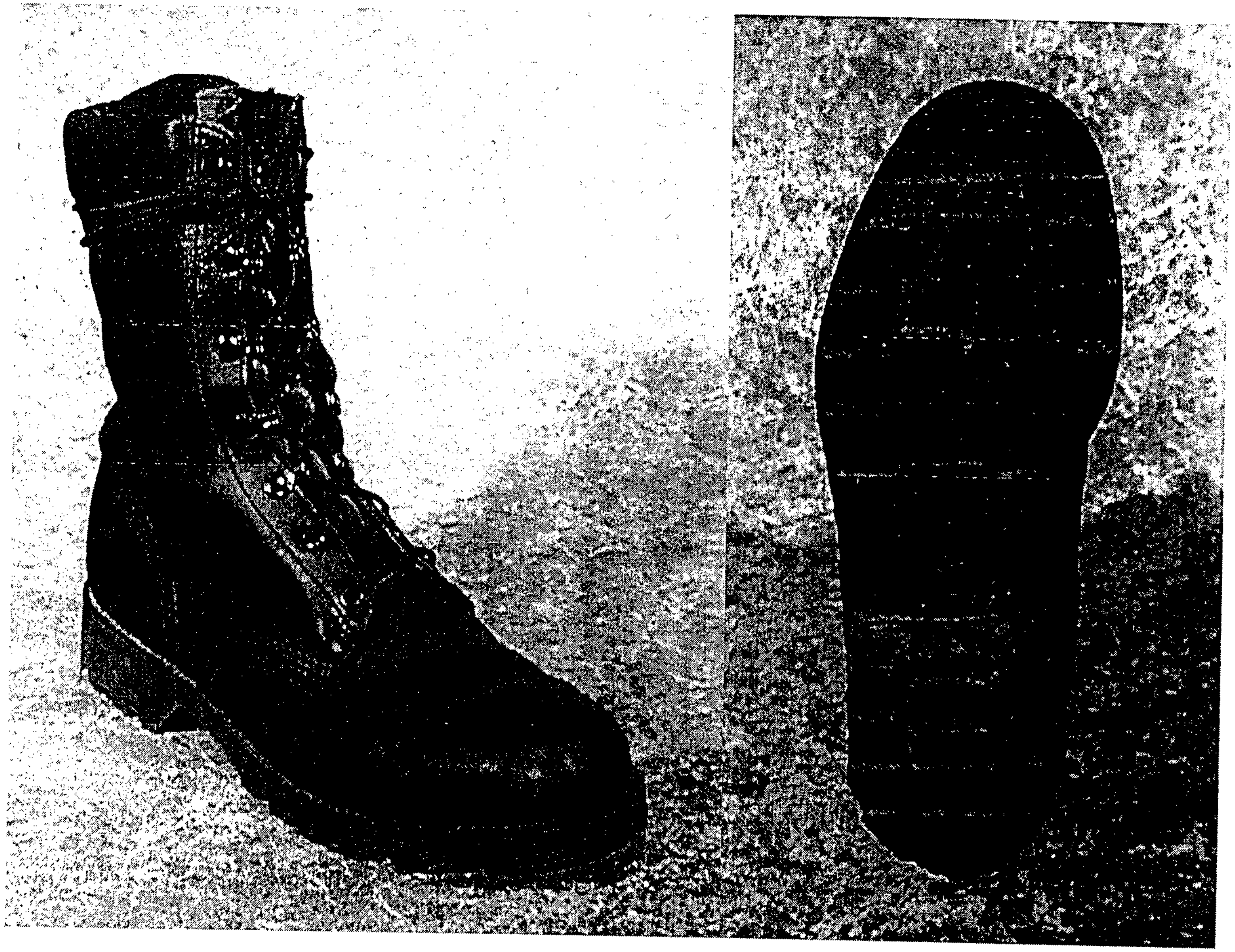

Figure 4. Boot 4 - Prototype 4

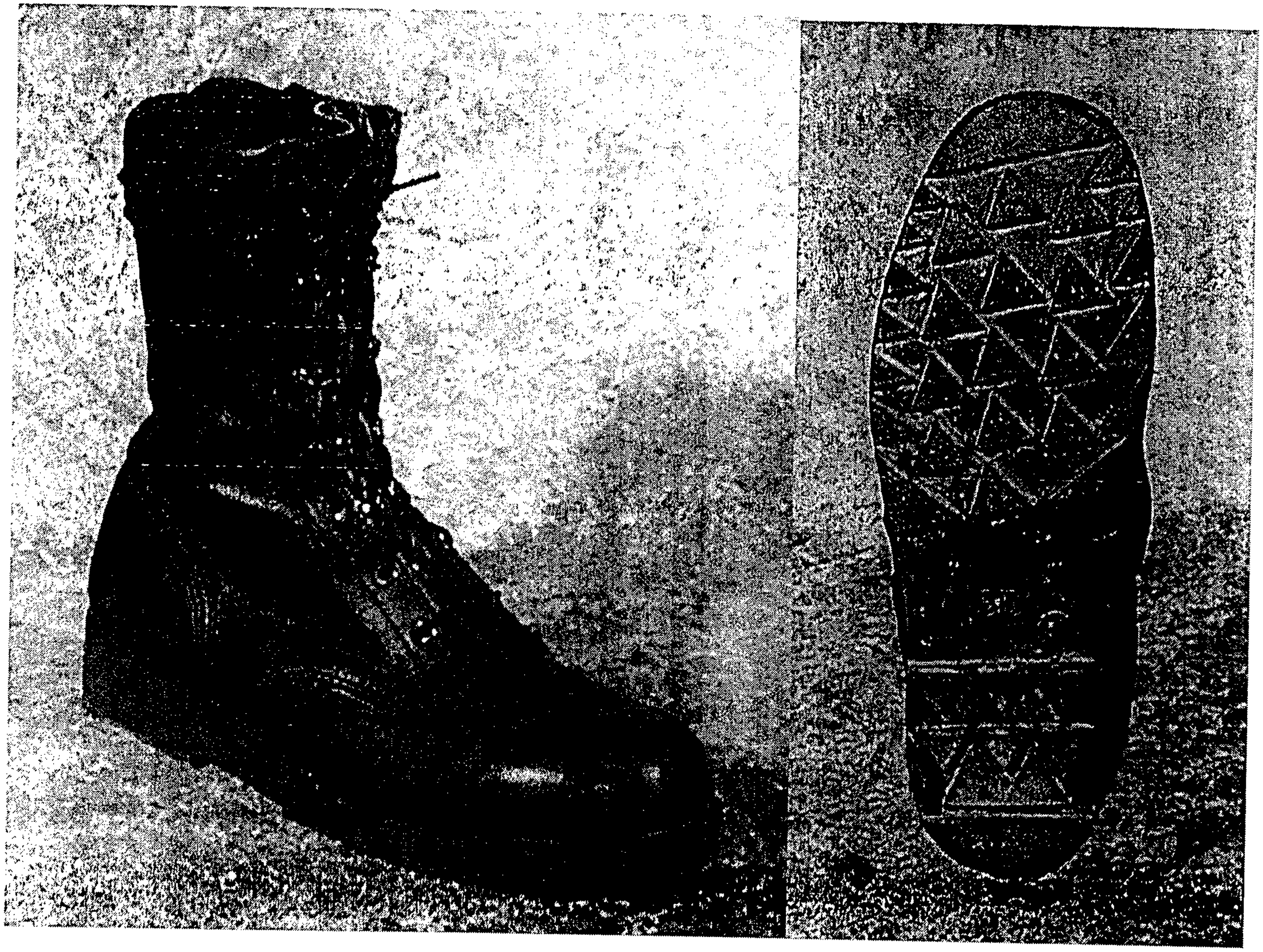

Figure 5. Boot 5 - Prototype 5

Figure 6. Boot 6 - Current-issue Army boot, commonly referred to as "Combat Boot." Officially designated as Boot, Combat, Mildew and Water resistant, Direct Molded Sole.

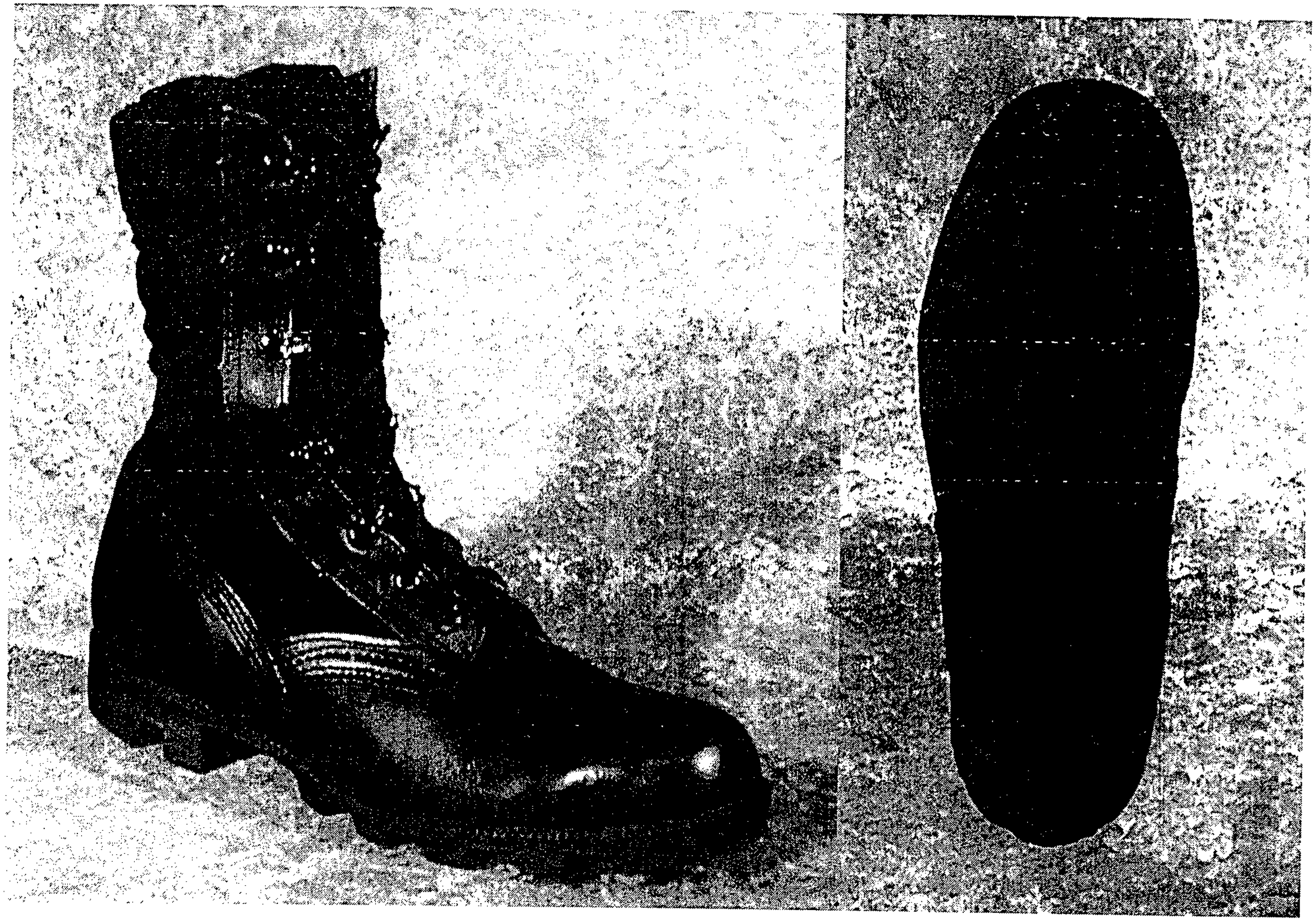

Figure 7. Boot 7 - Current-issue Army boot, commonly referred to as "Jungle Boot." Officially designated as Boot, Hot Weather, Type I, Black, Hot-Wet.

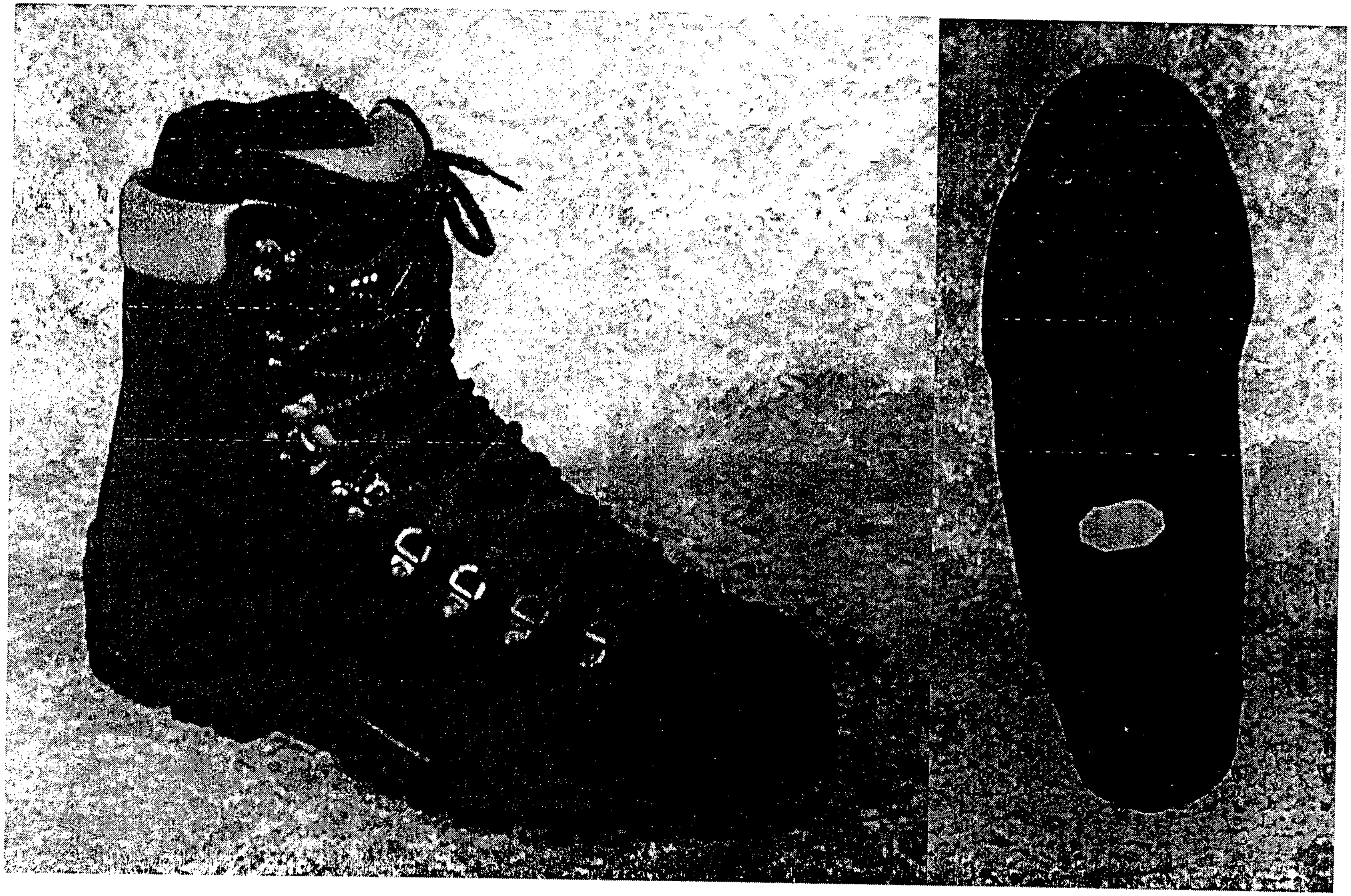

Figure 8. Boot 8 - Montrail Moraine

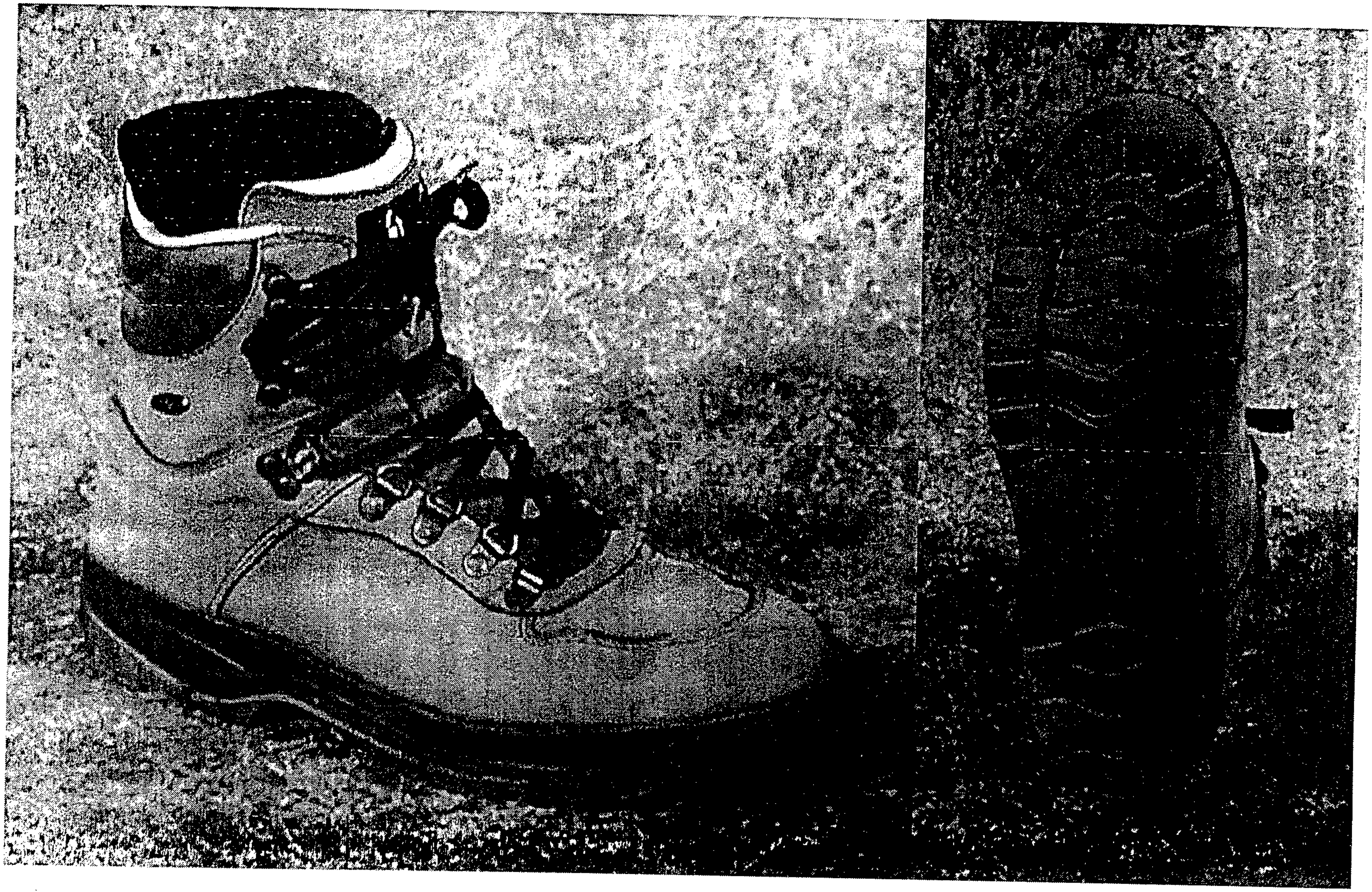

Figure 9. Boot 9 - Raichle Highline

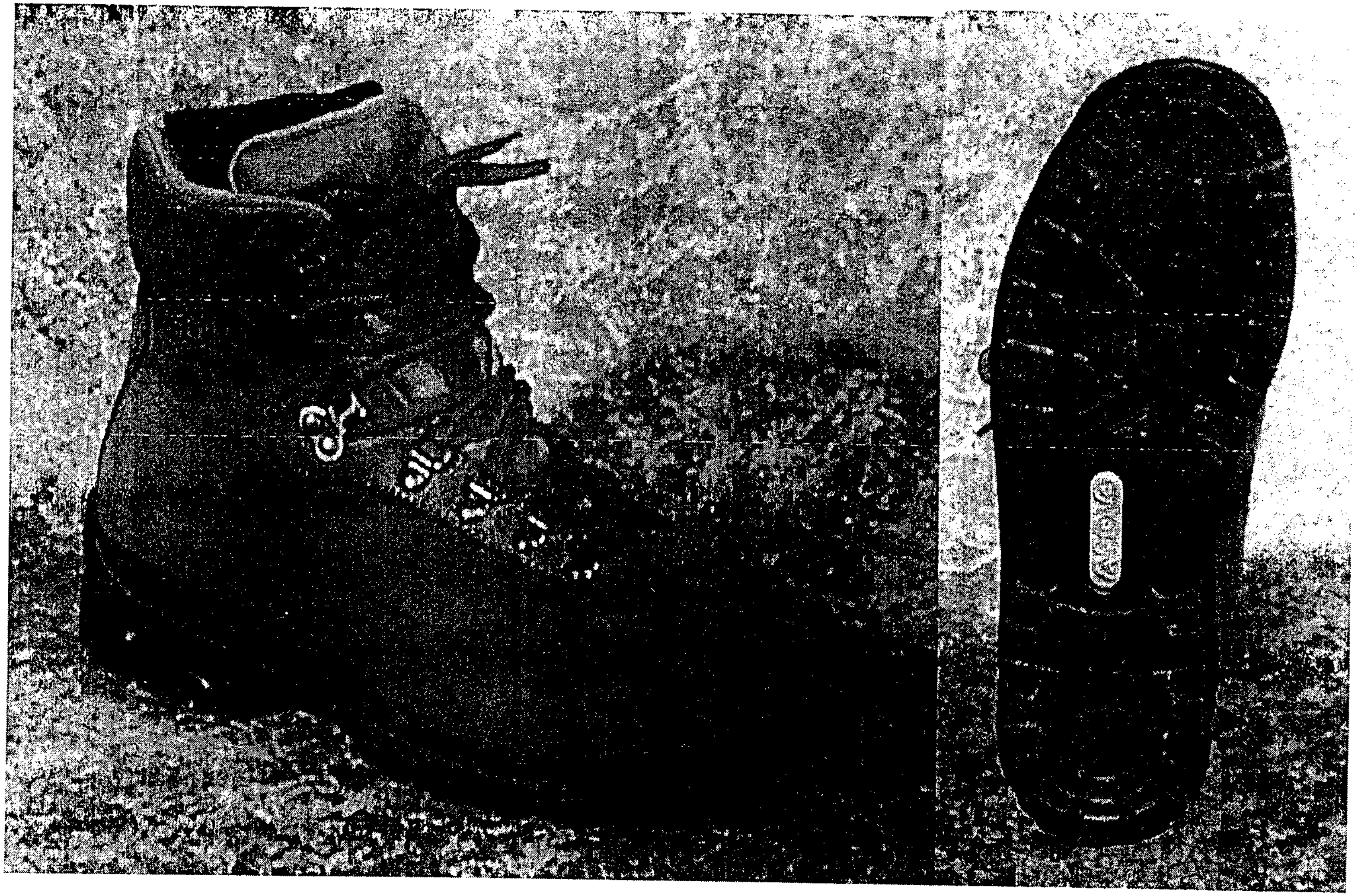

Figure 10. Boot 10 - Asolo AFX 535

Figure 11. Boot 11 - Asolo Meridian

Figure 12. Boot 12 - Salomon Adventure 9 Ultralight

Figure 13. Boot 12 - Salomon Adventure 9 Ultralight, shown with integrated ankle brace and lacing cover open

The Asolo Meridian was designated as boot 11, and the Salomon Adventure 9 Ultralight was designated as boot 12. The boots are referred to by their numbers throughout this report.

It is extremely expensive to start production of any new boot. In a large production run, the initial costs are spread over the entire run, so that the cost per boot is relatively low. Because a prototype run is very limited in number, the per-boot cost is extremely high. Making boots of different sizes multiplies a good part of the cost. To avoid prohibitive materiel costs for this study, the prototypes were made in only one size. A men's size 9 in regular width was selected because it is a common shoe size in the United States.

The 5 Prototype Boots (Boots 1-5)

The uppers of the 5 prototype boots were basically the same. Their common features include the following:

Last. All prototypes were made over MIL-5 lasts, the same last system used for fabrication of standard Army combat boots. However, the depth of the last was increased by 5/32 in, to allow for the thickness of a removable insert placed in the boots.

Upper. All prototypes have an identical upper, which is similar in design to the upper on the standard black leather combat boot. However, the foam in the padded collar on the prototypes is thicker than that on the standard boot and the collar cover on the prototypes is a soft glove leather. The finished height on a size 9R prototype is 10 in, about 1/2 in shorter than the height of the standard leather boot in the same size. A softer temper leather is used for the upper of the prototypes, which is more flexible than the leather used in the standard boot. The interior of the vamp of the prototypes is lined with an absorbent material, Aero-Spacer Dri-Lex®. The standard leather combat boot does not have an interior lining. The prototypes have a two-piece backstay and counter pocket. On the standard boot, there is a combined backstay and counter pocket, made out of one piece of leather.

Removable Insert. There is a molded, contoured, polyurethane insert with a Cambrelle® cover in all prototypes except #4. The insert is a polyurethane polyether molded directly to a Cambrelle® top cloth. This is the same insert used in the standard leather boot.

The soles of the 5 prototype boots were all different. The following are descriptions of the soles of each of the 5 prototype boots:

The Sole of Prototype 1. This prototype is flat-lasted with a direct-molded sole construction. The sole design is a modified version of the present Army standard hot weather boot sole. The sole incorporates a polyurethane polyether insert as a "mid-heel." The properties of the insert are:

Thickness: 5/16 in
Density: .35 g/cm^3
Hardness: 30 Shore A $\pm$ 3

The insole is made of a 3/16 in layer of 25 Shore A polyurethane foam, cemented to a four-iron cellulose fiber insole that incorporates a scrim cloth on the bottom.

The Sole of Prototype 2. This prototype is flat-lasted with a cemented-on sole. It has a unit sole constructed by cementing a pre-molded polyurethane midsole to a rubber, pre-molded cup outsole. The midsole has the following characteristics:

Thickness: 1 in at back of heel, tapering off to a point halfway toward the front of the sole, where the thickness is 7/16 in
Density: .41 g/cm^3
Hardness: 65-68 Shore C

The insole is a four-iron leather insole.

The Sole of Prototype 3. This prototype is flat-lasted with a direct-injected polyurethane mid-sole and a pre-molded high wall rubber cup tread outsole. The midsole is polyurethane with the following characteristics:

Thickness: From 1/4 inch at center of foot to 3/8 inch at edge of foot
Density: .60 g/cm^3
Hardness: 50 Shore A $\pm$ 5

The insole is a four-iron leather insole.

The Sole of Prototype 4. This prototype is constructed using the Process 82 Comfort Welt® construction. The key feature of this construction is the use of a previously attached welt to accomplish the lasting of the upper without the need for a structural insole. The "welt lasting" is performed on the mold last itself, and once the upper has been formed over the mold last, the sole is molded and vulcanized directly to the welt and to the lasting edge of the upper. In the process of construction, a cavity is formed in the sole.

A Comfort Core® insert is used in this prototype. This is an insert that is molded to match the cavity formed in the sole. The insert also has a molded, contoured top portion with a sock lining cover. The insert has the following characteristics:

Thickness: Center section of foot: 0.48 in From center section to edge: 0.24 in Section under heel: 1.00 in
Density: .40 g/cm^3
Hardness: 26 Shore A

The Sole of Prototype 5. This prototype is flat-lasted with a direct-molded sole construction. The sole has a wedge-shaped polyurethane polyether insert between the upper and lower portions of the sole. The wedge extends from the heel to the arch. The wedge has the following characteristics:

Thickness: 3/4 in at back of heel, tapering to a point halfway toward front where thickness is 7/32 in
Density: .35 g/cm^3
Hardness: 30 Shore A $\pm$ 3

The insole is a sandwich with a bottom layer of four-iron Texorist® on scrim cloth, covered by two layers of 1/8-in Poron®, with a hardness of 25 Shore A. The upper layer of Poron® is cemented and stitched to a top layer of Cambrelle® on foam.

The Current-Issue Army combat boot (Boot 6)

The official designation for this boot is "Boot, Combat, Mildew and Water resistant, Direct Molded Sole." The upper, which is unlined, is fabricated of chrome tanned, grain-out, cattle hide leather, treated for mildew and water resistance. The upper has a rigid toe-box, made of Surlyn®, a one-piece, combined backstay and counter, and a padded collar. The heel counter is made of leatherboard. The boot closure system is a combination of eyelets and closed loops. The rubber outsole has a deep lug design, designated as the Trac Shun® pattern. The outsole is direct molded to the leather insole using a method of vulcanization. A zinc-coated steel shank extends from the middle of the heel through the arch and ends just back of the ball area. The boot has a removable Poron® insert that extends from heel to toe, made of closed-cell urethane foam with a fiberboard backing.

The Current-Issue Army jungle boot (Boot 7)

The official designation for this boot is "Boot, Hot Weather, Type I, Black, Hot-Wet." The fore-foot part of the upper is leather as is the area along the closure system. The rest of the upper is nylon Cordura®. The entire upper on this boot is unlined. Two screened eyelets are set in the upper leather in the medial side of the boot in the waist area to facilitate water drainage. Nylon tape (1 inch) is on the back of the boot (backstrap area) and around the collar. A nylon tape (2 inch) also runs diagonally across the ankle. The toe box is same as in the combat boot, as is the heel counter, and Poron® inert. A Panama® tread pattern outsole is direct molded to the leather insole. A 0.28cm stainless steel plate is inserted between the leather insole, which is split in half and resewn around the edges. The plate extends the entire length of the boot. The steel shank is same as in the "combat boot."

The Montrail Moraine (Boot 8)

This boot, formerly called the One Sport Moraine, is a high top style made with one piece upper with a folded gusset and a mobile tongue. The upper material is 3.0 mm waterproof full grain nubuck leather and is lined with Cambrelle®. The insole is nylon fiber composite, and the boot is built using rigid board lasting construction. The outsole is made of Vibram® 1034 with a polyurethane midsole. The midsole and outsole are molded onto the board lasted upper. This boot uses plastic toe and heel counters and also has a removable foam foot bed with a Cambrelle® top surface.

The Raichle Highline (Boot 9)

This boot is a high top moccasin toe style boot made with a 2.3 mm full grain nubuck leather upper lined with Cambrelle®. The tongue is gussetted and the lacing system uses metal loops in the fore-foot and hooks in the ankle area. There is a removable three layer foot bed. The midsole is Raichle's Legaro® polyurethane with a Pizol® outsole. The outsole has a progressive rocker in the fore-foot that is a Raichle trademark feature. This rocker is a tapering of the midsole from the ball of the foot to the toe end of the sole.

The Asolo AFX 535 (Boot 10)

The upper is made of water repellent, 2.2-2.5 mm, full grain nubuck with a liner made with brushed PA 150, brushed PA 50, brushed nylon PA 150, brushed nylon PA 35, felt and Cambrelle® using traditional assembly methods for construction The insole is Asoflex® covered with Top 2. The outsole is Vibram® Kamen® with an internal polyurethane shock absorber. The lacing system uses traditional metal, lacing loops. This boot has a removable foam foot bed.

The Asolo Meridian (Boot 11)

The upper is made of water repellent, full grain nubuck and has an inner lining made with brushed PA 50, brushed nylon PA 150, brushed nylon PA 35 and Cambrelle® using traditional assembly methods for construction. This boot uses a Bio Frame®, which is a boot construction method incorporating a plastic frame directly molded to the outer surface of the boot upper with a specially formulated proprietary outsole molded on to the boot at the same time. The Bio Frame® has a built-in ankle stabilizer. The midsole of this boot is polyurethane foam. The sole is edged in a polyurethane rand and has an internal shock absorber built into the heel of the boot. The lacing system uses small pulleys instead of lacing loops for the fore-foot section of the boot and the lacing around the ankle uses traditional lacing hooks attached to the ends of the ankle stabilizer to allow the wearer to tighten the stabilizer. This boot has a removable foam foot bed.

The Salomon Adventure 9 Ultralight (Boot 12)

The upper is made of waterproofed 2.0 mm suede leather and polyurethane coated Cordura® 6000 fabric. The Inner lining is made with a polyurethane foam/ nylon tricot laminate and the shank is made of polypropylene. The outsole is a Salomon Contagrip Hiking Soft® outsole with a polyurethane midsole for increased shock absorption. The lacing system is not attached to the outer skin of the boot and allows the boot to be laced snug to the wearers foot without distorting the outer surface of the boot. This lacing system allows the boot to accommodate feet of different volumes within a given boot size. This boot also incorporates a zippered lacing cover and a plastic, wraparound, hinged ankle stabilizer to provide lateral support and has a removable foam foot bed.

Table 1 provides various information about the 12 experimental boots.

Table 1. Descriptive information on the boots tested (all size 9 regular)

Boot Number	Boot name	Weight per pair		Height	
		kg	lb	cm	in
1	Prototype 1	1.63	3.59	25.4	10.0
2	Prototype 2	1.66	3.65	25.4	10.0
3	Prototype 3	1.71	3.76	25.4	10.0
4	Prototype 4	1.55	3.42	25.4	10.0
5	Prototype 5	1.70	3.74	25.4	10.0
6	Army combat	1.86	4.09	26.0	10.24
7	Army jungle	2.01	4.42	23.5	9.25
8	Montrail Moraine	1.96	4.31	20.1	7.91
9	Raichle Highline	1.63	3.58	19.3	7.60
10	Asolo AFX 535	1.45	3.19	19.1	7.52
11	Asolo Meridian	1.86	4.09	19.6	7.72
12	Salomon Adventure 9 Ultralight	1.60	3.58	23.3	9.15

RESEARCH VOLUNTEERS

Because only men's size 9 boots were available for testing, only volunteers who wore men's size 9 were recruited for the experiment. Each volunteer tried on the test boots to make sure they fit. It was difficult to find the required number of volunteers that wanted to do the study, had the available time, and fit into the boots. Therefore, both permanent party test volunteers and military and civilian employees of USARIEM and at USASSC were accepted. Some of the volunteers had sedentary jobs, but more physically demanding jobs were represented as well. Table 2 shows some basic information about the volunteers including their habitual physical activity levels.

The principal investigator or an assisting investigator briefed all potential research volunteers. Informed consent was obtained from those who chose to volunteer. Because several of the tests, such as the 6-mile backpack hike, were administered to each volunteer only once per week, the testing of all 12 boots took each volunteer at least 12 weeks of actual testing. There were 3-5 test sessions per week. Typically, each test session took 1-3 hours, which included testing, waiting for other volunteers to be tested, and resting between trials.

Table 2. Subject characteristics (n=14, all male)

Sub. Number	Rank	Age (years)	Wt (kg)	Ht (cm)	MOS	Activity score
1	SGT	27	70.5	167.6	Biol. Lab Tech	1
2	SGT	34	75	170.2	Field Medic	1
3	CPL	32	91.2	177.8	Field Medic	2
4	CPT	30	97.5	175	Company Commander	2
5	CIV	26	97.7	188	Plumber	2
6	1SG	41	85.5	175	1st SGT, HQ Company	3
7	SFC	41	74.5	170.2	Parachute Rigger	4
8	MSG	27	77.1	173	Biol. Lab Tech	2
9	SGT	26	70.9	172.7	Parachute Rigger	4
10	CIV	25	85	182.9	Sheet Metal Worker	3
11	SGT	28	77.7	177.8	Med. Maint. Tech.	2
12	PV2	18	73.95	175	Military Police	3
13	PFC	19	73.65	175	Military Police	3
14	PV2	18	85.5	175	Military Police	3
Mean (SD)		27.8 (7.3)	81.12 (9.33)	175.37 (5.23)		2.5 (0.94)

Activity score: 0 = sedentary, 4 = very physically active. CIV = civilian

THE TEST BATTERY

Table 3 provides a summary of the tests performed by volunteers while wearing each of the 12 experimental boots.

Table 3. The tests administered

Test Procedure	unloaded	with 60 lb backpack
anthropometry	+	
rate of oxygen uptake, 3.5 mph walking	+	+
rate of oxygen uptake, 6.5 mph running	+	
biomechanical analysis	+	+
6 mile hike		+
400 m straight grass run	+	+
400 m zigzag grass run	+	+

+ = test administered

Physical Performance

One of the most critical factors to be considered in evaluating soldier/equipment interaction is the effect of the equipment on the performance of tasks by the soldier in scenarios involving the preparation for and engagement in combat.

Timed 400 m Grass Runs. Because the speed at which a soldier can run can greatly affect both his chances of avoiding injury on the battlefield, and the effectiveness of the fighting unit, timed 400 m runs were included in the testing. The research volunteers were timed during maximal-speed runs over a 400 m grass course and a 400 m zigzag course while carrying and not carrying a 60 lb backpack. Timing was accomplished by two experimenters using hand-held stopwatches.

Physiology

Rate of Oxygen Consumption. For volunteers eating a normal mixed diet, the rate of oxygen consumption is closely related to the rate of energy utilization. Thus, in order to determine if the boots differ as to the amount of energy required to walk or run in them, the rate of oxygen uptake of the volunteers was measured while they walked on a level treadmill at 3.0 mph in each of the 12 test boots, both while unloaded and while carrying a 60 lb backpack. They were also tested while running unloaded at 6.5 mph. The volunteers had to wear a face-mask or mouthpiece by which their expired air was collected and analyzed. The custom-made oxygen-uptake analysis system incorporated an air-flow meter, oxygen analyzer, carbon-dioxide analyzer, pulse counter, and Hewlett-Packard desktop computer and printer which could determine and print out every 30 seconds the rate of oxygen consumption and ventilation per minute expressed both in absolute terms and relative to the individual's body mass. The walking or running duration per test speed was about five minutes to allow the volunteer to reach a steady-state oxygen uptake.

Biomechanics

Foot Contact Pressure. The pressure on different segments of the feet associated with each boot was measured by placing Tekscan in-shoe pressure sensor insoles (Tekscan, Boston, MA) into each boot between the boot insole and the plantar surface of the wearer's socked foot. The sensors were made of thin, flexible, Mylar, on the opposite sides of which lines of electro-conductive ink were printed at right angles to each other. Because the lines were spaced 1 cm apart, there was an intersection of two crossing ink lines at the center of each square centimeter on each insole. The pattern of electro-conductive ink on the sensor pads was such that the sensors could be cut to fit a variety of shoe sizes without disconnecting any of the individual sensors. Foot pressure on the pad squeezed the ink lines on the opposite sides of the Mylar closer together, reducing the electrical resistance between them. Sixty times per second the computer monitored the electrical resistance at each square centimeter on the pad. Software converted the electrical resistances to actual pressures based on initial calibration of the system.

The computerized Tekscan analysis system was used to determine the skin contact pressures on different segments of the foot as the volunteers walked with each of the different boots at 3.5 mph. The video and force plate data collection was synchronized with the Tekscan data collection through the use of a common triggering switch. Foot contact pressures were expressed as both the array average (the mean of all individual sensor values including those which recorded zero pressure for each pad over the entire stride) and as the array maximum (the maximum individual sensor value recorded for each pad over the entire stride). A custom-written computer program determined the time of heel-strike and toe-off from the Tekscan in-shoe sensor data. The data from each stance was extracted from the rest of the trial, and stance time was taken as the difference in time between heel strike and toe off.

For the purpose of analysis, the Tekscan® data was partitioned into 6 separate foot sections: (1) rear medial foot, (2) rear lateral foot, (3) mid medial foot, (4) mid lateral foot, (5) medial fore-foot, and (6) lateral fore-foot. The border between the medial and lateral foot segments was taken as the midline of the foot. The rear-foot was defined as the rear 33% of foot length. The mid-foot was defined as the next 22% of foot length. Fore-foot was defined as the remaining 45% of the foot including the toes. For each percentage of stance, the maximum pressure, average pressure and standard deviation of the pressure within each section of the foot was calculated. In addition, the peak pressure for each section over the entire stride and the percent of stance at which the peak pressure occurred was calculated.

Kinematics and Kinetics. Both without a load and while carrying a 60 lb backpack, the volunteers walked at 3.5 mph across a force platform, within the field of view of six Qualisys (Glastonbury, CT) cameras while walking in each of the 12 different boots. They were also monitored while running without a load at 6.5 mph in each of the boots. Biomechanical analysis of the camera data was performed using both Qualisys and custom software.

During the biomechanical testing, volunteers wore the standard Army physical training uniform, consisting of gray T-shirt and shorts with combat boots. Spherical reflective markers approximately one inch in diameter were affixed to the skin (or boot) using double sided tape. Markers were placed on the right side of the body at the base of the 5th metatarsal, lateral malleolus of the ankle, lateral femoral condyle of the knee, greater trochanter of the hip, acromion process of the shoulder, zygomatic arch of the head, lateral epicondyle of the elbow, and the radial styloid process of the wrist. In order to detect rear-foot motion, two markers were placed on the dorsal surface of the calf in line with the Achilles tendon, and two other markers were placed on the rear of the shoe, vertically bisecting the heel area from a rear view.

Volunteers walked along a level, 15-foot walkway at 3.5 mph paced by a custom-built system that cued the volunteer to the appropriate walking speed with a striped cord moving at 3.5 miles/hr located next to the walkway. Neither a rifle nor other weapon was carried. An electronic timing device (Brower Timing Systems, Salt Lake City, UT) insured that volunteers walked across the force plate at 3.5 miles/hr $\pm$5%. Trials during which the walking speed was not between 2.85 miles/hr and 3.15 miles/hr were discarded, and the trial was repeated. The same system was used to ensure precision of $\pm$5% in running speed during the 6.5 mph run trials. A video motion analysis system (Qualisys, Glastonbury, CT) using six cameras recorded the body movements of the volunteers in three dimensions as they crossed a force plate (AMTI, Newton, MA) embedded flush with the floor. The sampling frequency of the cameras was 60 Hz. The force plate recorded the ground reaction forces as the volunteers stepped on the plate. The sampling frequency of the force plate was 1,000 Hz. Three trials were conducted for each experimental condition. The unloaded and loaded walking, and unloaded running conditions for each boot were all tested in a single session, with the volunteers resting between trials as needed and having a 15-min rest break after each block of trials.

Under the assumption of bilateral symmetry, segmental movement data for the left side of the body was generated by phase shifting the right side data by 180°. A 12-segment model of the human body was constructed (two feet, two shanks, two thighs, two forearms, two upper-arms, a trunk and a head), and the mass inertial properties of the segments were taken from estimates given by Dempster (4). A custom-written software program performed a standard link segment analysis frame-by-frame for a single stride. The single stride selected for analysis was centered on the point when the right foot struck the force plate. The stride was defined as that portion of the gait cycle from the point in time at which the right foot crossed in front of the left leg to the point in time at which the right foot next crossed in front of the left leg. The custom program calculated the location of the body center of mass as described by Winter (18) and plotted its coordinates for each frame of video data. The program also determined stride length, stride frequency, and body segment displacements, velocities, and accelerations. Joint reaction forces at the ankle, knee, and hip joints were calculated using inverse dynamics.

The trunk angle was defined as the acute angle between the trunk segment and the vertical axis. For a subject facing towards the right, the trunk angle is positive measured clockwise from the vertical and negative measured counter-clockwise from the vertical. The hip angle was defined as the angle on the ventral side of the body between the thigh segment and the plane defined by the segment connecting right and left hips with the trunk segment. The knee angle was defined as the angle on the dorsal side of the body between the thigh and shank segments, and the ankle angle was defined as the angle on the ventral side of the body between the shank and foot segments.

Rear-foot angle was defined as the rear-view deviation in degrees between the line formed by the 2 markers in line with the subject's Achilles tendon and the 2 markers vertically bisecting the shoe heel area, with a negative angle indicating supination, and a positive angle pronation.

Because the duration of a single stride varied across subjects, it was necessary to normalize the differing time scales to allow for the direct comparison of the timing of events within the gait cycle across subjects. This was accomplished by expressing the time course of all the biomechanical variables as a percentage of the stride cycle.

Jump landing tests were conducted with the volunteer wearing the same set of markers as used during the walking and running biomechanical tests. A 24 inch high wooden box was placed adjacent to the force platform. The unencumbered volunteer stood atop the box in an upright position. Upon signal from an experimenter, the volunteer stepped straight out over the force platform and dropped to its surface. Volunteers were specifically instructed to neither jump upwards nor downwards when leaving the box, but rather to step straight out and drop, allowing the knees to flex during the shock absorption phase of landing, and achieving an upright position on the platform without bouncing up and down.

Comfort and Injury Risk Assessment

The comfort and injury production of each of the boots was assessed by having the volunteers walk 6 miles in each pair of boots while carrying a 60-lb backpack. Injuries were defined as blisters, hot spots, and any other foot trauma resulting from the 6-mile backpack hike. The volunteers walked in a group and were paced at 3 mph. The first 1.5 miles was on paved road, after which the volunteers rested for 10 minutes. They then entered a forest and walked 3 miles on a moderately hilly wooded trail. After another 10-minute rest, they walked 1.5 miles back to the starting point. Following each hike the volunteers' feet were examined for blisters and chafing of the skin. The volunteers filled out a questionnaire concerning boot comfort (Appendix A).

EXPERIMENTAL DESIGN AND ANALYSIS

A balanced-order experimental design was used to ensure that none of the boots was more likely than any of the others to be tested earlier or later in the subjects' multi-week testing period, thereby avoiding order effects due to learning, physical conditioning, fatigue, boredom, etc. The statistical analysis for each variable involved a 2-way ANOVA that looked at the main effects of boot (12 levels) and load (2 levels), as well as boot-load interaction. When an ANOVA identified a boot main effect, a Duncan post-hoc test was performed to identify significant differences between boots.

ENVIRONMENTAL IMPACT

Testing and training for this study were conducted indoors and outdoors at USARIEM, USASSC, and on Natick public streets, roads, and recreational land, after securing permission from town authorities. The study involved little or no airborne emission, waterborne effluent, external radiation, outdoor noise, or solid bulk waste disposal, thereby complying with existing federal, state, and local laws and regulations (AR 200-2 Categorical Exclusion A-11).

The field tests and road marches were conducted with 14 military and civilian volunteers from USARIEM and USASBCC. All lived at the existing barracks at USASSC or in their habitual residences in and around the town of Natick, MA. Neither the living arrangements nor the experimental activities had a significant impact on the environment (AR 200-2 Categorical Exclusion A-19).

RESULTS

In all the tables in this section, statistically significant differences between the boots are indicated by superscripted letters. Variable means for boots not superscripted with the same letter are significantly different. This notation does not apply to differences across conditions, as in walking in the loaded vs. unloaded condition.

PHYSICAL PERFORMANCE

Timed 400 m Grass Runs

Table 4 shows that, on the straight grass 400 m course, there was no significant difference among the boots as to run time without a load. While means differed by as much as 5%, the standard deviations were too large for the differences to be significant. However, there were significant differences in run time when the 60 lb backpack was carried. Boot 3 produced the fastest mean time, while boots 5, 7, 8, 11, and 12 produced the slowest times.

Table 4. Run times (s) for 400 m straight grass course, mean (SD)

Boot number	With no load	With 60 lb backpack
1	98.38 [a] (10.29)	128.30 [a,b] (12.16)
2	99.16 [a] (8.63)	130.92 [a,b] (9.83)
3	97.74 [a] (9.42)	125.45 [b] (10.79)
4	96.57 [a] (9.52)	128.18 [a,b] (10.41)
5	97.13 [a] (5.70)	131.20 [a] (10.58)
6	99.69 [a] (9.02)	129.46 [a,b] (11.14)
7	99.15 [a] (5.67)	132.5 [a] (8.87)
8	100.68 [a] (7.57)	131.31 [a] (6.96)
9	98.16 [a] (9.57)	128.22 [a,b] (10.16)
10	99.25 [a] (9.30)	128.08 [a,b] (10.52)
11	98.87 [a] (9.19)	132.32 [a] (11.40)
12	98.59 [a] (8.03)	131.50 [a] (9.07)

different letters indicate significant ($p \leq 0.05$) differences between boots

On the 400 m zigzag course (Table 5), there were no significant run time differences among the boots when the 60 lb pack was carried. However, without the pack, boots 5 and 12 produced the fastest run times, while boot 6 produced the slowest times. There was a significant boot by load interaction because not all of the boots the same run time increases when the load was added. Boots 3 and 9 showed the smallest run time increases when the load was added.

Table 5. Run times (s) for 400 m zigzag grass course, mean (SD)

Boot number	With no load	With 60 lb backpack
1	116.93 [a,b] (6.86)	148.80 [a] (10.74)
2	119.20 [a,b] (7.12)	150.86 [a] (8.20)
3	118.66 [a,b] (7.11)	143.84 [a] (10.92)
4	116.97 [a,b] (5.94)	150.12 [a] (12.52)
5	116.29 [b] (6.00)	148.02 [a] (14.44)
6	121.05 [a] (5.65)	148.67 [a] (9.97)
7	118.63 [a,b] (8.71)	148.29 [a] (10.83)
8	120.07 [a,b] (6.3)	149.38 [a] (10.29)
9	118.74 [a,b] (6.12)	146.16 [a] (9.51)
10	118.84 [a,b] (7.43)	147.12 [a] (11.41)
11	120.06 [a,b] (7.09)	150.3 [a] (10.11)
12	116.74 [b] (6.25)	147.89 [a] (10.65)

Different letters indicate significant ($p \leq 0.05$) differences between boots.
There was a significant ($p \leq 0.05$) boot by load interaction.

PHYSIOLOGY

Rate of Oxygen Consumption

There were significant differences among the boots as to rate of oxygen consumption relative to body mass during unloaded walking, walking with the 60 lb pack, and unloaded running (Table 6). For unloaded walking, boot 10 produced the lowest rate of oxygen consumption, while boot 5 produced the highest rate of oxygen consumption. For walking with the 60 lb backpack, boot 12 produced the lowest rate of oxygen consumption, while boot 5 again produced the highest rate of oxygen consumption. For unloaded running, boot 12 again produced the lowest rate of oxygen consumption, while boot 6 produced the highest rate of oxygen consumption.

Table 6. Rate of oxygen consumption relative to body mass (ml/kg/min), mean (SD)

Boot number	Unloaded walking at 3.0 mph	Walking with 60 lb backpack, at 3.0 mph	Unloaded running at 6.0 mph
1	15.96 [a,b] (1.77)	22.05 [a,b] (3.61)	40.99 [a,b,c] (1.88)
2	15.73 [a,b,c] (1.79)	21.77 [a,b] (3.51)	40.77 [a,b,c] (2.35)
3	15.44 [c,d,e] (1.83)	21.05 [c] (3.13)	40.48 [c] (2.25)
4	15.73 [a,b,c] (2.08)	21.79 [a,b] (3.41)	41.39 [a,b,c] (1.75)
5	16.05 [a] (1.88)	22.26 [a] (3.28)	41.5 [a,b] (2.56)
6	15.69 [a,b,c] (1.84)	21.41 [b,c] (3.40)	41.67 [a] (2.19)
7	15.99 [a,b] (1.87)	21.96 [a,b] (3.60)	41.00 [a,b,c] (1.95)
8	15.70 [a,b,c] (1.91)	21.51 [b,c] (3.52)	41.12 [a,b,c] (2.38)
9	15.14 [d,e] (1.96)	20.92 [c] (3.02)	40.9 [a,b,c] (2.56)
10	15.06 [e] (1.58)	21.01 [c] (3.19)	40.60 [b,c] (2.49)
11	15.53 [b,c,d] (1.60)	20.89 [c] (3.20)	40.69 [a,b,c] (2.60)
12	15.15 [d,e] (1.85)	19.98 [d] (3.63)	38.78 [d] (2.7)

Different letters indicate significant ($p \leq 0.05$) differences between boots
There was a significant ($p<0.05$) boot by load interaction for the walking conditions.

Table 7 shows the rate of oxygen consumption relative to body-plus-load mass during unloaded walking, backpack load carriage, and unloaded running. The similarity in the means between the unloaded and loaded walking conditions show that the increase in oxygen consumption during load carriage is in direct proportion to the increase in load above body weight. In the previous table, rate of oxygen consumption was divided by body mass of the volunteer with shorts and T-shirt but no shoes. In this table, rate of oxygen consumption is divided by mass of the body-plus-load, including clothing and footwear. That is why the values for unloaded walking and running in this table are slightly less than in the previous table. For unloaded walking, boot 10 produced the lowest rate of oxygen consumption relative to body-plus-load mass, while boot 5 produced the highest rate of oxygen consumption. For walking with a 60 lb backpack, boot 12 produced the lowest rate of oxygen consumption relative to body-plus-load mass, while boot 5 produced the highest rate of oxygen consumption. For unloaded running, boot 12 produced the lowest rate of oxygen consumption relative to body-plus-load mass, while boot 6 produced the highest rate of oxygen consumption.

Table 7. Rate of oxygen consumption relative to body-plus-load mass (ml/kg/min), mean (SD)

Boot number	Unloaded walking at 3.0 mph	Walking with 60 lb backpack at 3.0 mph	Unloaded running at 6.0 mph
1	15.63 [a] (1.73)	15.74 [a,b] (2.43)	40.14 [a,b] (1.80)
2	15.41 [a,b] (1.73)	15.55 [a,b] (2.35)	39.94 [b] (2.28)
3	15.14 [b,c] (1.77)	15.04 [c] (2.07)	39.70 [b] (2.20)
4	15.44 [a,b] (2.01)	15.57 [a,b] (2.24)	40.64 [a,b] (1.63)
5	15.71 [a] (1.83)	15.89 [a] (2.18)	40.63 [a,b] (2.46)
6	15.36 [a,b] (1.75)	15.28 [b,c] (2.24)	40.89 [a] (2.12)
7	15.69 [a] (1.82)	15.70 [a,b] (2.46)	40.21 [a,b] (1.86)
8	15.36 [a,b] (1.84)	15.34 [b,c] (2.40)	40.24 [a,b] (2.26)
9	14.84 [c] (1.90)	14.98 [c] (2.04)	40.09 [a,b] (2.49)
10	14.79 [c] (1.53)	15.03 [c] (2.16)	39.86 [b] (2.39)
11	15.15 [b,c] (1.55)	14.87 [c,d] (2.05)	39.77 [b] (2.48)
12	14.86 [c] (1.79)	14.41 [d] (2.37)	38.37 [c] (1.94)

Different letters indicate significant ($p \leq 0.05$) differences between boots

BIOMECHANICS

In-Shoe Pressure Sensing During Walking With and Without a Load

In regard to maximum pressures on the rear medial foot (Table 8), the results for unloaded and loaded walking at 3.5 mph were similar. Boot 7 produced the lowest pressures, while boots 10 and 12 produced the highest pressures. The significant boot by load interaction occurred because, when the load was added, not all the boots increased maximum pressure on the rear medial foot equally.

Table 8. Maximum pressure (psi) on rear medial foot during a full stride (psi), and its time of occurrence (% of stride) while walking at 3.5 mph, mean (SD)

Boot number	No load		60 lb load	
	psi	% of stride	psi	% of stride
1	40.3 ^{f} (8.2)	18.4 ^{b,c,d} (4.6)	38.2 ^{e,d} (6.8)	20.0 ^{c,d} (5.1)
2	43.4 ^{e,f} (11.1)	18.9 ^{a,b,c} (4.5)	41.2 ^{c,d} (10.7)	20.5 ^{b,c,d} (3.9)
3	42.6 ^{e,f} (11.3)	17.4 ^{d,e} (5.1)	40.8 ^{c,d} (9.7)	22.1 ^{a} (9.2)
4	42.1 ^{e,f} (10.2)	19.1 ^{a,b} (4.2)	37.6 ^{d,e} (8.8)	21.0 ^{a,b,c,d} (3.4)
5	40.6 ^{f} (11.6)	18.0 ^{b,c,d,e} (3.4)	38.9 ^{d} (10.4)	20.4 ^{b,c,d} (3.8)
6	41.3 ^{e,f} (14.4)	18.0 ^{b,c,d,e} (5.2)	41.4 ^{c,d} (13.8)	20.2 ^{c,d} (3.8)
7	36.3 ^{g} (12.7)	17.0 ^{e} (4.2)	35.2 ^{,e} (9.8)	20.6 ^{b,c,d} (4.0)
8	50.0 ^{b,c} (13.7)	17.6 ^{c,d,e} (2.7)	47.4 ^{b} (9.8)	19.6 ^{d} (3.6)
9	45.5 ^{d,e} (15.0)	17.6 ^{c,d,e} (3.7)	43.9 ^{c} (12.8)	20.3 ^{c,d} (4.2)
10	53.6 ^{a,b} (14.5)	17.6 ^{c,d,e} (4.0)	53.6 ^{a} (11.8)	21.0 ^{a,b,c,d} (4.0)
11	49.4 ^{c,d} (17.3)	17.3 ^{d,e} (3.7)	48.1 ^{b} (14.2)	21.5 ^{a,b,c} (5.1)
12	54.9 ^{a} (21.4)	20.0 ^{a} (5.0)	50.9 ^{a,b} (18.5)	21.9 ^{a,b} (3.9)

Different letters indicate significant ($p \leq 0.05$) differences between boots
There was a significant ($p \leq 0.05$) boot by load interaction for both maximum pressure and the time of occurrence

In regard to maximum pressures on the rear lateral foot (Table 9), boots 1 and 2 produced the lowest pressures without a load, while boots 8, 10 and 12 produced the highest pressures. During loaded walking, boots 1, 2, 4, and 7 produced the lowest pressures, while boot 10 produced the highest pressures. The significant boot by load interaction occurred because, when the load was added, not all the boots increased maximum pressure on the rear lateral foot equally.

Table 9. Maximum pressure (psi) on the rear lateral foot during a full stride (psi), and its time of occurrence (% of stride) while walking at 3.5 mph, mean (SD)

Boot number	No load		60 lb load	
	psi	% of stride	psi	% of stride
1	39.3 [d] (9.8)	18.1 [a,b,c] (5.4)	36.9 [e] (7.6)	20.3 [a,b,c] (4.5)
2	39.7 [d] (10.5)	17.7 [b,c] (4.5)	37.2 [e] (10.8)	20.8 [a,b,c] (8.6)
3	44.2 [b,c] (11.6)	16.8 [c] (4.7)	41.7 [c,d] (10.1)	21.8 [a,b] (9.3)
4	41.9 [c,d] (11.1)	18.7 [a,b] (4.5)	36.8 [e] (9.7)	20.5 [a,b,c] (3.8)
5	41.1 [c,d] (11.3)	17.9 [b,c] (4.1)	38.8 [d,e] (9.0)	20.2 [b,c] (3.5)
6	41.3 [c,d] (13.5)	17.3 [b,c] (5.5)	41.8 [c,d] (13.4)	19.6 [b,c] (4.0)
7	40.8 [c,d] (11.9)	17.3 [b,c] (5.9)	38.2 [e] (9.0)	22.8 [a] (15.4)
8	49.4 [a] (13.1)	17.6 [b,c] (2.6)	46.4 [a,b] (9.2)	19.3 [b,c] (3.7)
9	46.9 [a,b] (13.8)	17.0 [c] (3.6)	44.7 [b,c] (11.4)	18.6 [c] (4.5)
10	50.6 [a] (11.1)	17.3 [b,c] (3.7)	49.2 [a] (8.1)	19.8 [b,c] (4.2)
11	48.0 [a,b] (20.0)	16.8 [c] (3.7)	45.7 [b] (16.2)	21.9 [a,b] (10.0)
12	49.2 [a] (15.9)	19.4 [a] (4.9)	44.3 [b,c] (12.0)	21.0 [a,b,c] (5.1)

Different letters indicate significant ($p \leq 0.05$) differences between boots
There was a significant ($p \leq 0.05$) boot by load interaction for maximum pressure

In regard to maximum pressures on the mid medial foot (Table 10), boot 6 produced the lowest pressures without a load, while boot 12 produced the highest pressures. During loaded walking, boot 3 produced the lowest pressures, while boots 4, 7, 11, and 12 produced the highest pressures. The significant boot by load interaction occurred because, when the load was added, not all the boots increased maximum pressure on the mid medial foot equally.

Table 10. Maximum pressure (psi) on the mid medial foot during a full stride (psi), and its time of occurrence (% of stride) while walking at 3.5 mph, mean (SD)

Boot number	No load		60 lb load	
	psi	% of stride	psi	% of stride
1	$4.90^{c,d,e,f}$ (8.3)	$15.8^{e,f}$ (17.7)	$5.05^{b,c}$ (5.1)	$25.3^{d,e,f}$ (21.7)
2	$2.94^{e,f}$ (4.4)	$15.7^{e,f}$ (19.9)	$3.92^{b,c}$ (4.1)	$23.7^{e,f,g}$ (19.0)
3	$2.63^{e,f}$ (3.3)	12.9^{f} (16.7)	2.91^{c} (2.8)	17.0^{g} (15.2)
4	$8.64^{a,b}$ (8.6)	$24.9^{b,c,d}$ (15.3)	8.12^{a} (6.2)	$27.3^{c,d,e,f}$ (17.2)
5	$5.16^{c,d,e}$ (6.7)	$32.8^{a,b}$ (35.0)	$5.20^{b,c}$ (3.4)	43.4^{a} (33.8)
6	2.44^{f} (4.5)	12.3^{f} (19.5)	$4.18^{b,c}$ (8.4)	$19.1^{f,g}$ (20.8)
7	$7.33^{b,c}$ (10.1)	$30.7^{a,b}$ (28.5)	8.05^{a} (9.6)	$35.2^{b,c}$ (27.6)
8	$4.03^{e,f}$ (7.1)	$19.6^{d,e,f}$ (25.0)	$5.40^{b,c}$ (6.8)	$32.7^{b,c,d}$ (29.9)
9	$4.74^{d,e,f}$ (4.6)	$28.5^{a,b,c}$ (22.7)	5.70^{b} (4.4)	$32.6^{b,c,d}$ (22.5)
10	$3.40^{e,f}$ (3.6)	$21.0^{c,d,e}$ (20.5)	$3.60^{b,c}$ (3.3)	$26.8^{d,e,f}$ (22.7)
11	$6.60^{b,c,d}$ (7.2)	$25.9^{b,c,d}$ (19.3)	8.62^{a} (11.2)	$29.5^{c,d,e}$ (18.2)
12	10.06^{a} (14.2)	34.2^{a} (32.6)	8.13^{a} (11.8)	$40.4^{a,b}$ (30.7)

Different letters indicate significant ($p \leq 0.05$) differences between boots
There was a significant ($p \leq 0.05$) boot by load interaction for both maximum pressure and its time of occurrence

In regard to maximum pressures on the mid lateral foot (Table 11), boot 6 produced the lowest pressures without a load, while boot 8 produced the highest pressures. During loaded walking, boot 4 produced the lowest pressures, while boot 2 produced the highest pressures. The significant boot by load interaction occurred because, when the load was added, not all the boots increased maximum pressure on the mid lateral foot equally.

Table 11. Maximum pressure (psi) on the mid lateral foot during a full stride (psi), and its time of occurrence (% of stride) while walking at 3.5 mph, mean (SD)

Boot number	No load		60 lb load	
	psi	% of stride	psi	% of stride
1	16.4 [d,e] (6.6)	48.5 [c,d] (20.9)	14.2 [d,e] (6.1)	57.0 [b,c] (21.9)
2	20.3 [b] (12.4)	41.3 [d] (19.9)	20.5 [a] (11.5)	50.1 [c,d] (24.0)
3	16.2 [d,e] (7.7)	47.3 [c,d] (23.0)	14.0 [d,e] (6.6)	52.3 [c,d] (24.4)
4	16.1 [d,e] (7.8)	33.8 [e] (18.3)	12.3 [e] (5.2)	34.6 [e] (22.2)
5	17.1 [c,d,e] (6.9)	49.3 [c] (22.7)	15.1 [d] (7.3)	53.7 [c,d] (24.7)
6	14.6 [e] (6.1)	50.6 [b,c] (20.3)	13.2 [d,e] (5.4)	47.6 [d] (22.4)
7	16.7 [d,e] (9.1)	45.3 [c,d] (22.0)	15.3 [d] (8.5)	50.8 [c,d] (22.4)
8	23.3 [a] (9.9)	57.8 [a] (20.5)	20.3 [a,b] (7.0)	63.0 [a,b] (20.3)
9	19.1 [b,c,d] (9.0)	50.2 [b,c] (20.4)	17.9 [c] (8.3)	50.5 [c,d] (25.3)
10	17.2 [c,d,e] (7.8)	57.2 [a,b] (20.8)	15.2 [d] (6.4)	64.6 [a] (18.0)
11	19.7 [b,c] (10.4)	50.3 [b,c] (23.7)	18.2 [b,c] (6.5)	61.2 [a,b] (20.9)
12	20.9 [a,b] (10.9)	63.0 [a] (23.0)	19.5 [a,b,c] (10.9)	66.0 [a] (21.5)

Different letters indicate significant ($p \leq 0.05$) differences between boots
There was a significant ($p \leq 0.05$) boot by load interaction for both maximum pressure and the time of occurrence

In regard to maximum pressures on the medial fore-foot (Table 12), boot 1 produced the lowest pressures without a load, while boot 2 produced the highest pressures. During loaded walking, boot 1 produced the lowest pressures, while boot 12 produced the highest pressures. The significant boot by load interaction occurred because, when the load was added, not all the boots increased maximum pressure on the medial fore-foot equally.

Table 12. Maximum pressure (psi) on the medial fore-foot during a full stride (psi), and its time of occurrence (% of stride) while walking at 3.5 mph, mean (SD)

Boot number	No load		60 lb load	
	psi	% of stride	psi	% of stride
1	49.0 [f] (12.2)	89.2 [a,b,c] (4.0)	46.0 [e] (10.8)	88.7 [b,c] (4.5)
2	64.5 [a] (22.9)	90.8 [a] (4.8)	55.0 [a,b,c] (15.6)	89.8 [a,b] (4.6)
3	58.7 [a,b,c] (14.9)	88.3 [b,c,d] (7.5)	52.3 [b,c,d] (11.6)	88.8 [b,c] (6.2)
4	55.1 [c,d,e] (16.6)	87.3 [d] (4.7)	51.5 [b,c,d] (14.1)	87.5 [c,d] (5.0)
5	52.3 [d,e,f] (15.8)	88.3 [b,c,d] (4.8)	48.8 [d,e] (14.3)	88.8 [b,c] (4.8)
6	57.3 [b,c,d] (16.5)	87.6 [c,d] (6.3)	55.8 [a,b] (13.5)	86.3 [d] (5.3)
7	59.7 [a,b,c] (17.0)	88.1 [c,d] (5.0)	55.5 [a,b] (14.2)	88.1 [b,c] (4.7)
8	55.3 [c,d,e] (24.8)	90.1 [a] (4.5)	50.3 [c,d,e] (19.3)	88.3 [b,c] (8.5)
9	55.4 [c,d,e] (18.8)	90.8 [a] (4.8)	55.5 [a,b] (19.7)	90.8 [a] (4.6)
10	52.6 [d,e,f] (18.0)	89.9 [a,b] (3.8)	54.1 [a,b,c] (15.5)	89.8 [a,b] (3.7)
11	49.5 [e,f] (17.3)	89.1 [a,b,c] (7.1)	47.7 [d,e] (14.9)	89.1 [b,c] (4.6)
12	62.3 [a,b] (29.4)	89.8 [a,b] (4.3)	57.8 [a] (21.3)	89.6 [a,b] (4.6)

Different letters indicate significant ($p \leq 0.05$) differences between boots
There was a significant ($p \leq 0.05$) boot by load interaction for both maximum pressure and the time of occurrence

In regard to maximum pressures on the lateral fore-foot (Table 13), boot 8 produced the lowest pressures without a load, while boots 3, 4, and 6 produced the highest pressures. During loaded walking, boot 8 again produced the lowest pressures, while boot 6 produced the highest pressures. The significant boot by load interactions occurred because, when the load was added, not all the boots increased maximum pressure on the lateral fore-foot equally.

Table 13. Maximum pressure (psi) on the lateral fore-foot during a full stride (psi), and its time of occurrence (% of stride) while walking at 3.5 mph, mean (SD)

Boot number	No load		60 lb load	
	psi	% of stride	psi	% of stride
1	41.5 [c,d] (11.5)	83.0 [e,f] (5.2)	39.1 [e] (9.0)	84.1 [b,c] (4.0)
2	43.1 [b,c] (13.0)	84.5 [c,d,e] (4.5)	40.3 [d,e] (10.3)	83.7 [b,c] (4.7)
3	52.1 [a] (15.7)	83.1 [e,f] (4.1)	46.8 [b] (12.8)	83.0 [c] (8.1)
4	51.8 [a] (16.0)	85.0 [b,c] (3.9)	46.6 [b,c] (12.4)	84.4 [b,c] (4.1)
5	46.2 [b] (14.9)	84.4 [c,d,e] (3.1)	43.0 [c,d] (13.5)	84.5 [b,c] (3.4)
6	51.4 [a] (16.0)	82.6 [f] (4.8)	50.8 [a] (14.9)	83.5 [b,c] (4.0)
7	46.7 [b] (19.6)	83.2 [d,e,f] (5.2)	46.8 [b] (17.0)	84.0 [b,c] (4.8)
8	34.0 [f] (10.5)	83.6 [c,d,e,f] (5.6)	32.8 [f] (9.8)	84.1 [b,c] (5.2)
9	40.1 [c,d,e] (12.6)	87.2 [a] (4.1)	40.2 [d,e] (11.7)	86.6 [a] (3.3)
10	38.2 [d,e] (15.8)	86.1 [a,b] (5.4)	37.3 [e] (13.2)	86.5 [a] (3.6)
11	36.5 [e,f] (14.3)	84.2 [c,d,e] (4.8)	37.5 [e] (11.3)	84.1 [b,c] (4.4)
12	44.0 [b,c] (17.0)	84.7 [b,c,d] (4.0)	46.1 [b,c] (17.3)	84.6 [b] (4.0)

Different letters indicate significant ($p \leq 0.05$) differences between boots
There was a significant ($p \leq 0.05$) boot by load interaction for both maximum pressure and the time of occurrence.

Table 14 shows the maximum sum of the Tekscan® pressure readings at all of the measurement points on the sensor pad beneath the heel (includes medial and lateral rear-foot regions), as an indication of the total force on the heel. Boots 6 and 7 produced the lowest sum-of-pressures without a load, while boots 4 and 9 produced the highest sum-of-pressures. During loaded walking, boot 7 produced the lowest sum-of-pressures, while boots 4 and 9 again produced the highest sum-of-pressures.

Table 14. Maximum sum-of-pressure (psi) and time to maximum sum-of-pressure (% of stride) at the heel while walking at 3.5 mph, mean (SD)

Boot number	No load		60 lb load	
	Peak Pressure	% of Stride	Peak Pressure	% of Stride
1	4856.0 [b,c,] (748.8)	23.0 [a,b] (3.1)	4960.0[b,c] (590.6)	24.2 [a,b] (2.9)
2	5127.3[b] (1036.1)	22.4 [a,b,c,d] (3.0)	5261.1 [a,b] (1034.2)	23.4 [b,c] (2.3)
3	4831.1[,b,c] (906.3)	22.1 [b,c,d] (3.0)	5000.7 [b,c] (824.5)	23.8 [b,c] (3.0)
4	5535.3 [a] (1316.9)	22.5 [a,b,c,d] (3.6)	5515.6[a] (1255.3)	23.8 [b,c] (2.2)
5	4947.7 [b,c] (1018.6)	23.2 [a] (2.9)	5117.5[b,c] (1178.4)	23.9 [b,c] (2.2)
6	4644.7 [c] (1074.6)	21.7 [d] (4.3)	5048.2 [b,c] (1217.6)	23.1 [c,d] (3.5)
7	4639.5 [c] (1362.1)	22.8 [a,b,c] (4.2)	4812.1 [c] (1182.1)	24.3 [a,b] (2.6)
8	4955.5 [b,c] (690.7)	21.5 [d] (2.7)	4986.4 [b,c] (621.7)	22.3 [d] (3.2)
9	5526.0 [a] (1227.8)	21.9 [b,c,d] (2.9)	5527.5 [a] (1162.2)	23.0 [c,d] (3.1)
10	4780.6 [b,c] (755.8)	21.9 [c,d] (3.7)	5017.4 [b,c] (640.6)	23.9 [b,c] (2.0)
11	5046.0 [b] (1174.1)	22.0 [b,c,d] (3.1)	5246.9 [a,b] (1237.6)	23.5 [b,c] (3.0)
12	4981.2 [b,c] (1663.6)	22.3 [a,b,c,d] (3.9)	5182.7 [b] (1319.5)	24.8 [a] (2.4)

Different letters indicate significant ($p \leq 0.05$) differences between boots

Table 15 shows the maximum sum of the Tekscan® pressure readings at all of the measurement points on the sensor pad beneath the fore-foot (includes medial and lateral fore-foot regions), as an indication of the total force on the fore-foot. Boots 2, 3, 8, 9, 10, and 11 produced the lowest sum-of-pressures on the fore-foot without a load, while boot 5 produced the highest sum-of-pressures. During loaded walking, boots 8 and 10 produced the lowest sum-of-pressures, while boots 4, 5, and 12 produced the highest sum-of-pressures.

Table 15. Maximum sum-of-pressure (psi) and time to maximum sum-of-pressure (% of stride) at the toe while walking at 3.5 mph, mean (SD)

Boot number	No load		60 lb load	
	Peak Pressure	% of Stride	Peak Pressure	% of Stride
1	4785.3[a,b] (1018.2)	73.8[a] (16.3)	4917.5[a,b] (843.5)	77.7[a,b] (9.1)
2	4716.7[b] (1299.1)	73.9[a] (15.3)	4951.6[a,b] (1095.6)	76.6[a,b] (9.4)
3	4699.9[b] (1251.8)	70.0[a] (17.8)	4891.0[a,b] (1043.5)	74.0[b,c] (12.5)
4	5052.7[a,b] (1638.2)	70.3[a] (19.1)	5185.5[a] (1247.8)	77.7[a,b] (8.3)
5	5212.6[a] (1283.2)	75.0[a] (14.4)	5229.9[a] (1159.1)	79.3[a] (3.1)
6	5008.6[a,b] (1371.7)	73.0[a] (17.6)	4957.8[a,b] (1411.7)	74.3[b,c] (12.7)
7	5012.1[a,b] (1402.1)	73.1[a] (17.1)	4962.8[a,b] (1230.6)	74.5[b,c] (13.0)
8	4707.0[b] (1341.8)	74.9[a] (14.9)	4644.8[b] (1094.8)	72.1[c] (16.2)
9	4637.0[b] (1364.9)	75.7[a] (13.7)	5019.1[a,b] (1279.6)	75.6[a,b,c] (14.3)
10	4672.2[b] (1061.6)	70.8[a] (20.6)	4738.5[b] (973.3)	76.9[a,b] (9.4)
11	4672.7[b] (1274.0)	72.7[a] (17.2)	4968.3[a,b] (1240.9)	75.0[b,c] (14.8)
12	4917.0[a,b] (1586.3)	70.4[a] (19.9)	5159.3[a] (1345.2)	76.4[a,b] (11.1)

Different letters indicate significant ($p \leq 0.05$) differences between boots

Center of pressure is the defined as the x and y coordinates on the force-platform's surface of a hypothetical point at which the actual force of the foot on the ground could be exerted and produce the torque about the platform origin actually produced by the forces of the foot distributed over its entire ground contact surface. For someone walking at a given speed, a faster peak velocity of the foot center of pressure suggests that the boot makes the foot plantarflex rapidly, with the sole slapping the ground. Therefore, a faster peak velocity of the foot center of pressure may be considered less desirable. Table 16 shows that for unloaded walking at 3.5 mph, peak velocity of the foot center of pressure was lowest for boots 5, 7, 8, 10, 11, and 12, and highest for boots 2 and 3. For walking with the 60 lb load, peak velocity of the foot center of pressure was lowest for boot 7, and highest for boots 2, 3, and 4.

Table 16. Peak velocity (m/s) of foot center of pressure while walking at 3.5 mph, mean (SD)

Boot no.	No load	60 lb load
1	$0.780^{b,c}$ (0.273)	$0.745^{b,c}$ (0.210)
2	0.885^{a} (0.354)	0.814^{a} (0.253)
3	0.922^{a} (0.391)	0.831^{a} (0.300)
4	$0.865^{a,b}$ (0.288)	0.834^{a} (0.263)
5	0.728^{c} (0.309)	$0.704^{b,c,d}$ (0.212)
6	$0.867^{a,b}$ (0.448)	$0.771^{a,b}$ (0.282)
7	0.729^{c} (0.256)	0.658^{d} (0.181)
8	0.759^{c} (0.303)	$0.696^{c,d}$ (0.212)
9	$0.779^{b,c}$ (0.279)	$0.740^{b,c}$ (0.189)
10	0.724^{c} (0.293)	$0.727^{b,c}$ (0.222)
11	0.701^{c} (0.190)	$0.693^{c,d}$ (0.165)
12	0.730^{c} (0.231)	$0.703^{b,c,d}$ (0.174)

Different letters indicate significant ($p \leq 0.05$) differences between boots

Motion Analysis of Unloaded and Loaded Walking

Kinematics. Greater vertical and front-back acceleration of the body center-of-mass while walking (Table 17) is likely less desirable because it reflects jarring of the body and is usually associated with higher forces on the body. In regard to vertical acceleration during unloaded walking, boot 1 produced the lowest vertical maximum acceleration, while boot 6 produced the highest. As to front-back acceleration during unloaded walking, boots 5 and 7 produced the lowest acceleration, while boot 6 produced the highest. Looking at vertical acceleration of the body during carriage of a 60 lb backpack, boot 11 produced the lowest acceleration while boots 6 and 7 produced the highest. There was no difference among the boots as to front-back acceleration during walking while carrying a load.

Table 17. Maximum vertical and front-back acceleration (m/s^2) of the body center-of-mass while walking at 3.5 mph, mean (SD)

Boot number	No load		60 lb load	
	Vertical	Front-back	Vertical	Front-back
1	5.79^{c} (1.61)	$4.51^{a,b}$ (1.92)	$6.58^{a,b}$ (3.92)	3.61^{a} (1.09)
2	$6.56^{a,b,c}$ (3.11)	$4.20^{a,b}$ (1.94)	$5.77^{a,b}$ (2.08)	3.71^{a} (1.37)
3	$6.27^{a,b,c}$ (2.51)	$3.99^{a,b}$ (1.27)	$5.72^{a,b}$ (2.43)	3.88^{a} (1.41)
4	$6.19^{a,b,c}$ (1.64)	$4.09^{a,b}$ (1.54)	$5.52^{a,b}$ (1.57)	4.29^{a} (1.94)
5	$6.81^{a,b,c}$ (3.82)	3.87^{b} (1.43)	$5.87^{a,b}$ (1.83)	4.29^{a} (2.07)
6	7.82^{a} (4.28)	5.11^{a} (1.95)	6.91^{a} (3.64)	4.49^{a} (1.81)
7	$7.59^{a,b}$ (4.14)	3.82^{b} (1.33)	6.79^{a} (3.34)	4.25^{a} (2.13)
8	$6.42^{a,b,c}$ (3.54)	$4.69^{a,b}$ (2.72)	$6.30^{a,b}$ (5.12)	4.42^{a} (1.61)
9	$6.81^{a,b,c}$ (3.15)	$4.56^{a,b}$ (4.37)	$5.58^{a,b}$ (1.66)	4.50^{a} (2.54)
10	$6.09^{b,c}$ (2.55)	$3.99^{a,b}$ (1.44)	$6.71^{a,b}$ (4.63)	4.31^{a} (1.68)
11	$6.34^{a,b,c}$ (3.43)	$4.30^{a,b}$ (2.96)	5.23^{b} (1.16)	3.86^{a} (1.26)
12	$6.30^{a,b,c}$ (2.21)	$4.79^{a,b}$ (3.61)	$5.51^{a,b}$ (1.48)	4.02^{a} (2.37)

Different letters indicate significant ($p \leq 0.05$) differences between boots

It is difficult to place a value judgement on stride length during walking at 3.5 mph (Table 18). While a greater stride length can contribute to a higher top speed, there is no apparent advantage of a longer stride length during walking at submaximal speed. During the tests of unloaded walking, boot 4 produced the longest stride length, while boot 7 produced the shortest stride length. Under the 60 lb backpack load, boots 10 and 11 produced the longest stride length, while boot 5 produced the shortest stride length.

Table 18. Stride length (m) while walking at 3.5 mph, mean (SD)

Boot number	No load	60 lb load
1	1.60[a,b,c] (0.15)	1.58[a,b,c] (0.11)
2	1.61[a,b,c] (0.10)	1.59[a,b,c] (0.08)
3	1.60[a,b,c] (0.08)	1.60[a,b] (0.08)
4	1.63[a] (0.09)	1.59[a,b,c] (0.11)
5	1.59[a,b,c] (0.12)	1.55[c] (0.21)
6	1.59[a,b,c] (0.09)	1.59[a,b,c] (0.11)
7	1.58[c] (0.08)	1.58[a,b,c] (0.09)
8	1.58[b,c] (0.09)	1.58[a,b,c] (0.13)
9	1.61[a,b,c] (0.09)	1.60[a,b] (0.10)
10	1.62[a,b] (0.10)	1.61[a] (0.10)
11	1.60[a,b,c] (0.09)	1.61[a] (0.09)
12	1.61[a,b,c] (0.10)	1.56[b,c] (0.16)

Different letters indicate significant ($p \leq 0.05$) differences between boots

Generally, the percentage of the stride under double support (Table 19) usually increases with the amount of weight carried (Martin and Nelson, 1986). This means that both feet are concurrently on the ground a greater percentage of the time. The adjustment is considered desirable because double support spreads the load over two feet, thereby improving balance and reducing the forces and torques experienced by each leg individually. On the other hand, increased time in double support generally means a shorter stride and greater energy cost. These linked phenomena are evidenced by the fact that boots 1 and 7, which produced the greatest time in double support without a load, also produced high rates of oxygen consumption (Table 6), while boot 10, which produced the lowest double support percentage, evidenced the lowest rate of oxygen consumption.

A similar pattern emerged for walking with the 60 lb backpack. Boot 5, which produced the greatest time in double support, evidenced both the shortest stride length (Table 18) and the highest rate of oxygen consumption. Boot 9, which produced the least time in double support, also evidenced a relatively long stride length and low rate of oxygen consumption.

Table 19. Double support duration (% of stride) while walking at 3.5 mph, mean (SD)

Boot number	No load	60 lb load
1	13.3[a] (6.6)	14.9[a,b] (2.5)
2	12.9[a,b] (2.1)	14.7[a,b,c] (2.1)
3	12.1[a,b,c] (1.8)	13.8[b,c] (2.1)
4	12.5[a,b,c] (1.8)	14.4[b,c] (2.0)
5	12.9[a,b] (2.7)	15.8[a] (5.7)
6	12.8[a,b] (2.1)	14.6[b,c] (2.7)
7	13.4[a] (2.1)	14.8[a,b,c] (2.1)
8	12.5[a,b,c] (2.6)	14.6[b,c] (3.3)
9	11.6[b,c] (1.6)	13.6[c] (2.09)
10	11.3[c] (1.8)	13.9[b,c] (2.3)
11	12.2[a,b,c] (1.9)	13.9[b,c] (1.7)
12	12.2[a,b,c] (1.4)	14.9[a,b] (3.9)

Different letters indicate significant ($p \leq 0.05$) differences between boots

It is interesting to note in Table 20 that boot 4 produced the lowest values for both minimum and maximum knee angles during both unloaded and loaded walking. That means that the knee was never fully straightened and went through the stride in a more bent position. In addition, for both loaded and unloaded walking, boot 4 showed the greatest knee range of motion. These phenomena together suggest somewhat of a "Groucho" walk. The knees bent to the least extent in boots 9 and 10 under both the unloaded and loaded conditions. The knees straightened the most in boots 2, 3, and 5 for unloaded walking and in boots 5, 7, and 11 during loaded walking.

Table 20. Knee angle (deg) while walking at 3.5 mph, mean (SD)

	No load			60 lb load		
Boot no.	Minimum	Maximum	Range	Minimum	Maximum	Range
1	112.8^{b} (5.3)	$175.7^{a,b}$ (3.1)	$62.8^{b,c}$ (5.0)	$112.4^{d,e}$ (4.4)	$175.0^{a,b,c}$ (2.8)	$62.6^{a,b}$ (4.5)
2	$114.3^{a,b}$ (6.8)	176.0^{a} (2.4)	$61.6^{c,d,e}$ (5.8)	$114.1^{a,b,c,d}$ (7.1)	$175.5^{a,b}$ (2.5)	$61.3^{b,c}$ (5.6)
3	$113.9^{a,b}$ (7.3)	176.1^{a} (2.4)	$62.1^{c,d}$ (5.9)	$113.7^{b,c,d}$ (7.2)	$175.5^{a,b}$ (2.5)	61.8^{b} (5.9)
4	108.7^{d} (4.2)	173.1^{e} (2.8)	64.3^{a} (3.5)	108.0^{f} (4.4)	172.3^{d} (2.5)	64.3^{a} (4.1)
5	$113.9^{a,b}$ (5.5)	176.0^{a} (2.7)	$62.1^{c,d}$ (4.9)	$114.2^{a,b,c,d}$ (5.7)	175.6^{a} (2.8)	$61.4^{b,c}$ (5.2)
6	110.5^{c} (3.3)	$174.3^{c,d}$ (3.0)	$63.8^{a,b}$ (2.4)	111.6^{e} (4.6)	$174.8^{a,b,c}$ (3.0)	$63.1^{a,b}$ (3.7)
7	113.4^{b} (4.3)	175.9^{a} (3.3)	$62.5^{c,d}$ (4.0)	$113.0^{c,d,e}$ (4.5)	175.7^{a} (3.7)	$62.7^{a,b}$ (4.9)
8	$114.5^{a,b}$ (6.3)	$175.0^{a,b,c,d}$ (3.5)	$60.5^{e,f}$ (4.9)	$114.8^{a,b,c}$ (7.4)	$173.4^{c,d}$ (10.6)	58.6^{d} (11.7)
9	115.7^{a} (5.4)	$174.5^{b,c,d}$ (2.8)	58.8^{g} (4.4)	$115.4^{a,b}$ (5.1)	$174.6^{a,b,c}$ (2.8)	59.2^{d} (4.4)
10	115.7^{a} (3.3)	$175.0^{a,b,c,d}$ (2.4)	$59.4^{g,f}$ (3.8)	116.0^{a} (3.8)	$175.1^{a,b,c}$ (2.6)	59.1^{d} (3.6)
11	$113.9^{a,b}$ (4.6)	$175.3^{a,b,c}$ (2.3)	$61.4^{d,e}$ (4.0)	$113.7^{b,c,d}$ (4.8)	175.7^{a} (2.5)	62.0^{b} (4.8)
12	$114.2^{a,b}$ (5.1)	$173.9^{d,e}$ (2.4)	$59.7^{g,f}$ (5.0)	$114.1^{a,b,c,d}$ (4.8)	$173.6^{b,c,d}$ (2.9)	$59.4^{c,d}$ (4.5)

Different letters indicate significant ($p \leq 0.05$) differences between boots

Table 21 shows that the ankle angle during unloaded walking closed down the most (became smallest) for boot 11 and closed down the least for boots 1, 3, 7, and 8. During loaded walking, the ankle angle closed down the most (became smallest) for boot 12 and closed down the least for boots 1, 3, 4, and 8. The range of ankle motion during unloaded walking was the smallest for boot 8 and the largest for boots 6 and 9. During loaded walking, the range of ankle motion was the smallest for boot 8 and the largest for boots 7 and 9.

Table 21. Ankle angle (deg) while walking at 3.5 mph, mean (SD)

Boot number	No load		60 lb load	
	Minimum	Range	Minimum	Range
1	107.7[a] (4.79)	24.6[b,c] (4.4)	107.5[a] (4.70)	26.0[a,b,c] (4.1)
2	106.8[a,b,c] (6.07)	23.9[b,c,d] (3.8)	105.8[a,b,c] (7.54)	26.9[a,b] (5.6)
3	108.7[a] (6.10)	24.1[b,c,d] (5.6)	107.3[a] (6.02)	26.5[a,b,c] (4.3)
4	107.2[a,b] (5.84)	25.2[a,b] (3.4)	108.1[a] (5.84)	25.6[b,c] (3.2)
5	106.8[a,b,c] (6.89)	23.9[b,c,d] (5.8)	106.9[a,b] (6.75)	24.8[c,d] (5.0)
6	106.6[a,b,c] (3.08)	26.5[a] (4.4)	106.8[a,b] (2.73)	27.4[a,b] (4.0)
7	108.5[a] (3.88)	25.3[a,b] (4.2)	107.2[a,b] (3.25)	27.6[a] (3.6)
8	108.3[a] (5.33)	22.7[d] (3.3)	108.0[a] (5.47)	23.8[d] (3.3)
9	105.1[b,c] (4.70)	26.4[a] (4.1)	104.6[b,c,d] (4.85)	27.7[a] (4.3)
10	106.7[a,b,c] (5.96)	23.9[b,c,d] (2.5)	106.5[a,b,c] (5.90)	25.0[c,d] (3.8)
11	104.6[c] (4.09)	23.3[c,d] (3.4)	104.2[c,d] (4.46)	26.5[a,b,c] (3.0)
12	104.8[b,c] (6.00)	24.5[b,c] (5.3)	103.2[d] (7.45)	27.1[a,b] (6.8)

Different letters indicate significant ($p \leq 0.05$) differences between boots

Forces and Torques. It is apparent that higher forces on the body during walking are more likely to produce injury than lower forces. Therefore, the forces experienced by the major lower body joints are an important measure of a boot's effectiveness. Table 22 shows the maximum forces on the ankle, knee and hip while walking at 3.5 mph both with and without a load. During unloaded walking, boot 8 produced the lowest forces on all 3 joints, and boot 4 the highest forces. During walking with the 60 lb backpack, boots 1 and 8 produced the lowest joint forces, while boot 11 produced the highest joint forces.

Table 22. Maximum force (N) on the ankle, knee and hip while walking at 3.5 mph, mean (SD)

	No load			60 lb load		
Boot no.	Ankle	Knee	Hip	Ankle	Knee	Hip
1	982.4^{b,c} (86.3)	948.0^{a,b,c} (101.0)	872.6^{a,b,c} (107.9)	1306.9^{d} (71.4)	1267.3^{d} (68.7)	1192.6^{c} (69.4)
2	989.2^{a,b,c} (97.0)	949.9^{a,b,c} (95.6)	875.3^{a,b,c} (98.7)	1330.9^{a,b,c,d} (88.0)	1290.0^{a,b,c,d} (87.0)	1209.0^{a,b,c} (87.9)
3	975.5^{c} (89.7)	935.0^{c} (87.6)	862.2^{b,c} (83.6)	1328.3^{a,b,c,d} (97.4)	1289.4^{a,b,c,d} (97.9)	1208.1^{a,b,c} (99.4)
4	1003.0^{a} (98.3)	967.9^{a} (97.7)	902.1^{a} (100.3)	1319.8^{b,c,d} (107.1)	1283.3^{b,c,d} (106.1)	1211.6^{a,b,c} (104.4)
5	970.0^{c} (73.1)	931.5^{c} (72.9)	850.4^{c,d} (128.6)	1341.8^{a,b,c} (62.1)	1302.0^{a,b,c} (61.4)	1230.9^{a,b} (74.2)
6	973.8^{c} (79.1)	933.0^{c} (80.1)	859.2^{b,c} (77.2)	1316.3^{c,d} (76.1)	1276.4^{b,c,d} (72.7)	1200.0^{b,c} (71.2)
7	969.5^{c} (81.1)	930.2^{c} (79.9)	859.4^{b,c} (74.8)	1310.5^{c,d} (74.0)	1271.4^{c,d} (70.1)	1195.7^{c} (65.9)
8	947.1^{d} (68.4)	907.9^{d} (67.8)	826.5^{d} (62.4)	1310.0^{c,d} (62.0)	1268.3^{d} (57.6)	1182.5^{c} (52.7)
9	976.5^{c} (83.9)	938.0^{b,c} (80.2)	871.0^{a,b,c} (102.6)	1329.4^{a,b,c,d} (88.6)	1288.2^{a,b,c,d} (84.0)	1213.9^{a,b,c} (83.7)
10	970.9^{c} (101.7)	934.8^{c} (98.6)	858.9^{b,c} (95.2)	1334.7^{a,b,c,d} (104.0)	1296.0^{a,b,c,d} (101.8)	1211.1^{a,b,c} (96.2)
11	983.0^{b,c} (99.0)	948.5^{a,b,c} (103.8)	892.9^{a,b} (151.7)	1359.1^{a} (98.1)	1319.4^{a} (98.5)	1235.9^{a} (92.6)
12	997.4^{a,b} (94.3)	958.1^{a,b} (97.9)	878.0^{a,b,c} (106.9)	1350.1^{a,b} (101.2)	1306.6^{a,b} (98.5)	1227.2^{a,b} (102.7)

Different letters indicate significant ($p \leq 0.05$) differences between boots

During walking, the heel is the foot's first point of contact with the ground (Chan and Rudins, 1994; Hughes and Jacobs, 1979). The forces transmitted from the ground to the body at heel-strike are typically the highest forces on the body during the entire stride, and are transmitted up the body through the skeletal system. Therefore, an important measure of a boot's effectiveness is the degree to which it can attenuate the forces at heel-strike. Table 23 shows maximum heel-strike forces during walks at 3.5 mph both with and without a load. It can be seen that the vertical forces are much higher than the braking forces, and are thus more relevant to the issue of a boot's effectiveness for preventing injury. During unloaded walking, boot 8 produced the lowest vertical heel-strike forces, as it did for forces at the ankle, knee, and hip described above; boots 4 and 12 produced the highest vertical heel-strike forces. During walking with the 60 lb backpack, boots 1 and 6 produced the lowest vertical heel-strike forces, while boot 11 produced the highest vertical heel-strike forces, just as it produced the highest forces at the ankle, knee, and hip described above.

Table 23. Maximum heel-strike force (N) while walking at 3.5 mph, mean (SD)

Boot number	No load		60 lb load	
	Vertical Force	Braking Force	Vertical Force	Braking Force
1	965.5^{b,c,d} (84.5)	183.2^{a,b} (29.7)	1274.8^{d} (76.4)	254.0^{a} (42.2)
2	980.7^{a,b} (102.4)	183.4^{a,b} (30.6)	1304.7^{a,b,c,d} (87.9)	260.6^{a,b,c} (47.3)
3	963.9^{b,c,d} (95.0)	178.0^{a} (26.9)	1292.7^{b,c,d} (105.4)	273.2^{b,c,d} (38.6)
4	991.3^{a} (103.8)	195.0^{b} (38.8)	1298.4^{a,b,c,d} (111.5)	265.0^{a,b,c,d} (50.8)
5	967.2^{b,c,d} (73.3)	179.8^{a} (28.6)	1321.9^{a,b} (75.9)	268.0^{a,b,c,d} (46.2)
6	947.1^{d,e} (81.8)	181.3^{a} (31.3)	1278.3^{d} (77.5)	273.7^{b,c,d} (41.4)
7	956.8^{c,d,e} (76.9)	176.3^{a} (27.5)	1281.9^{c,d} (70.1)	256.7^{a,b} (39.9)
8	937.4^{e} (70.4)	179.9^{a} (27.7)	1285.5^{c,d} (69.2)	268.8^{a,b,c,d} (33.2)
9	967.9^{b,c,d} (89.0)	184.3^{a,b} (33.8)	1295.2^{a,b,c,d} (95.1)	273.9^{b,c,d} (48.4)
10	960.7^{b,c,d} (103.5)	174.7^{a} (28.6)	1314.4^{a,b,c} (101.7)	282.5^{d} (40.8)
11	971.5^{a,b,c} (101.3)	180.9^{a} (32.6)	1327.0^{a} (105.6)	278.3^{c,d} (36.6)
12	991.4^{a} (94.7)	186.3^{a,b} (31.8)	1305.8^{a,b,c,d} (91.7)	257.3^{a,b} (48.1)

Different letters indicate significant ($p \leq 0.05$) differences between boots

It is more difficult to place a value-judgement on maximum push-off force (Table 24) than on maximum heel-strike force. It is clear that lower heel-strike force is desirable because it results in less shock to the body as the heel strikes the ground. However, low push-off force may not be as desirable because it translates into reduced acceleration. Thus the benefit of lower maximum push-off force is reduced force transmitted through the musculoskeletal system, but the drawback may be reduced ability to accelerate the body. Under the no-load condition, boot 8 produced the lowest maximum vertical push-off forces, while boots 4, 6, and 12 produced the highest such forces. Under the 60 lb backpack load, boots 4, 8, and 10 produced the lowest maximum vertical push-off forces, while boots 6 and 12 produced the highest such forces. As to propulsive forces, under the no-load condition, boot 8 again produced the lowest maximum push-off forces, while boot 4 produced the highest such forces. Under the 60 lb backpack load, boot 8 again produced the lowest maximum propulsive push-off forces, while boots 3-7 produced the highest such forces.

Table 24. Maximum push-off force (N) while walking at 3.5 mph, mean (SD)

Boot number	No load		60 lb load	
	Vertical Force	Propulsive Force	Vertical Force	Propulsive Force
1	925.7[a,b,c] (102.5)	174.7[b,c] (25.7)	1241.8[b,c,d,e] (104.0)	233.8[a,b] (32.8)
2	920.6[a,b,c] (95.5)	174.5[b,c] (24.8)	1236.3[d,e] (101.3)	231.2[a,b] (33.9)
3	923.3[a,b,c] (88.5)	171.7[b,c,d] (25.2)	1261.0[a,b,c] (97.3)	234.7[a] (27.7)
4	936.2[a] (94.2)	182.5[a] (30.8)	1230.9[e] (93.0)	236.8[a] (29.6)
5	921.8[a,b,c] (83.3)	173.9[b,c] (26.6)	1240.8[c,d,e] (97.4)	236.7[a] (39.9)
6	931.7[a] (105.8)	176.2[a,b] (27.9)	1269.8[a] (92.0)	239.0[a] (25.4)
7	928.7[a,b] (101.6)	173.0[b,c] (28.6)	1257.0[a,b,c,d] (112.7)	236.1[a] (30.1)
8	874.2[d] (84.5)	141.2[g] (22.9)	1227.0[e] (95.1)	200.0[d] (28.5)
9	909.3[c] (90.4)	168.5[c,d,e] (17.2)	1247.5[b,c,d,e] (99.0)	232.0[a,b] (20.0)
10	912.2[b,c] (101.3)	163.2[e,f] (19.6)	1227.4[e] (105.1)	216.8[c] (33.2)
11	912.0[b,c] (113.0)	159.6[f] (29.1)	1262.8[a,b] (118.6)	219.6[c] (32.9)
12	934.8[a] (99.9)	165.5[d,e,f] (30.3)	1271.6[a] (121.7)	225.0[b,c] (44.1)

Different letters indicate significant ($p \leq 0.05$) differences between boots

Rear-foot Angular Motion. Excess rear-foot motion during walking is considered undesirable because when the ankle pronates or supinates excessively, potentially injurious torques in the frontal plane are transmitted up the leg to the knee and hip. Table 25 shows that boots 1, 3, 9, and 12 did not produce any supination at all during unloaded walking, while boot 5 produced the most supination. During loaded walking, only boots 1 and 9 did not produce any supination, while boot 5 again produced the most supination.

Table 25. Minimum rear-foot angle (deg) while walking at 3.5 mph, mean (SD)

Boot number	No load	60 lb load
1	1.77[a] (5.20)	0.29[a,b] (7.20)
2	-3.81[d,e] (10.23)	-2.17[a,b,c] (11.06)
3	1.20[a,b] (4.35)	-1.02[a,b] (4.98)
4	-0.35[a,b,c,d] (5.60)	-2.62[b,c] (4.45)
5	-5.54[e] (6.62)	-4.86[c] (6.42)
6	-2.03[b,c,d] (6.08)	-2.89[b,c] (8.49)
7	-2.56[c,d,e] (7.23)	-1.45[a,b,c] (4.85)
8	-1.25[a,b,c,d] (7.46)	-0.64[a,b] (8.26)
9	1.90[a] (4.91)	1.22[a] (3.14)
10	-0.10[a,b,c] (5.98)	-0.04[a,b] (5.99)
11	-1.57[a,b,c,d] (6.21)	-1.46[a,b,c] (6.01)
12	1.18[a,b] (8.67)	-2.34[a,b,c] (9.48)

Different letters indicate significant ($p \leq 0.05$) differences between boots
A negative angle indicates supination, while a positive angle indicates pronation

Excessive pronation during walking or running is considered a major risk factor for lower extremity injury. Table 26 shows that during unloaded walking, boots 4 and 5 produced the least pronation, while boot 8 produced the most. During loaded walking, boot 5 produced the least pronation, while boot 8 produced the most.

Table 26. Maximum rear-foot angle (deg) while walking at 3.5 mph, mean (SD)

Boot number	No load	60 lb load
1	15.06[b,c] (5.37)	14.93[a,b,c] (5.71)
2	15.48[a,b,c] (9.19)	15.89[a,b] (11.02)
3	13.03[c,d] (6.56)	13.49[a,b,c,d] (7.01)
4	11.10[d] (6.46)	10.61[d,e] (7.57)
5	11.24[d] (4.48)	9.869[e] (3.27)
6	13.34[a] (8.59)	12.21[c,d,e] (5.70)
7	13.80[c,d] (6.29)	12.54[b,c,d,e] (5.75)
8	18.39[a] (8.82)	16.47[a] (8.11)
9	17.12[a,b] (8.11)	15.84[a,b] (7.89)
10	15.30[a,b,c] (6.19)	14.95[a,b,c] (6.95)
11	13.01[c,d] (5.39)	12.60[b,c,d,e] (5.54)
12	14.39[b,c,d] (6.67)	14.42[a,b,c] (7.46)

Different letters indicate significant ($p \leq 0.05$) differences between boots
A negative angle indicates supination, while a positive angle indicates pronation

Table 27 shows the average rear-foot angle during walking. Because a positive angle means pronation, and a negative angle supination, it can be seen that, on average, the foot was in a pronated position. However, during both loaded and unloaded walking, the foot was least pronated in boot 5, less than 1 degree. The foot was most pronated, about 7 degrees, in boots 8 and 9.

Table 27. Average rear-foot angle (deg) while walking at 3.5 mph

Boot number	No load	60 lb load
1	6.41[a,b,c] (3.97)	5.49[a,b,c] (4.79)
2	5.00[b,c,d] (7.23)	4.91[a,b,c,d] (9.372)
3	5.30[a,b,c,d] (4.406)	4.07[c,d] (4.08)
4	4.28[c,d] (5.038)	2.63[d,e] (4.74)
5	0.69[e] (4.22)	0.61[e] (4.30)
6	3.62[d] (4.534)	3.79[c,d] (4.456)
7	3.86[d] (4.35)	3.63[c,d] (4.14)
8	6.94[a,b] (5.14)	6.916[a] (5.996)
9	7.23[a] (5.59)	6.71[a,b] (4.816)
10	5.46[a,b,c,d] (4.46)	5.51[a,b,c] (5.103)
11	4.28[c,d] (4.33)	4.31[b,c,d] (4.05)
12	6.35[a,b,c] (5.09)	4.44[a,b,c,d] (5.52)

Different letters indicate significant ($p \leq 0.05$) differences between boots

Excessive rear-foot motion during walking is not considered desirable. The standard deviation of rear-foot angle provides a measure of the variability of the rear-foot angle. Table 28 shows that all of the boots produced standard deviations of rear-foot angle of about 3-5 degrees. Boots 3 and 4 produced the smallest standard deviations of rear-foot motion during both loaded and unloaded walking, while boot 2 produced the largest standard deviations.

Table 28. Within trial standard deviation of rear-foot angle while walking at 3.5 mph, mean (SD)

Boot number	No load	60 lb load
1	3.23[c] (1.30)	3.48[a,b] (2.13)
2	4.87[a] (3.86)	4.36[a] (2.41)
3	2.80[c] (1.462)	3.25[b] (1.58)
4	2.85[c] (1.29)	3.13[b] (1.38)
5	3.76[b,c] (1.80)	3.53[a,b] (1.42)
6	3.25[c] (1.574)	3.493[a,b] (2.382)
7	3.78[b,c] (1.52)	3.53[a,b] (1.29)
8	4.34[a,b] (2.037)	4.05[a,b] (2.35)
9	3.79[b,c] (2.53)	3.63[a,b] (2.208)
10	3.66[b,c] (1.60)	3.48[a,b] (1.917)
11	3.551[b,c] (1.615)	3.39[a,b] (1.439)
12	3.338[b,c] (2.200)	4.18[a,b] (2.922)

Different letters indicate significant ($p \leq 0.05$) differences between boots

Range of rear-foot angular motion is another measure of how much frontal plane ankle motion the boots allowed. Table 29 shows that the boots produced rear-foot ranges of motion between 11 and 19 degrees. During unloaded walking, boots 3 and 4 produced the smallest range of rear-foot motion, just as they produced the smallest standard deviations of rear-foot angle, while boot 8 produced the largest range of rear-foot motion. During loaded walking, boot 4 produced the smallest range of rear-foot motion, while boot 2 produced the largest range of rear-foot motion, just as it had produced the largest standard deviations.

Table 29. Range of rear-foot motion (deg) while walking at 3.5 mph, mean (SD)

Boot number	No load	60 lb load
1	13.29[c,d] (5.01)	14.63[a,b] (7.26)
2	19.29[a,b] (12.63)	18.06[a] (9.69)
3	11.83[d] (5.48)	14.51[a,b] (6.67)
4	11.45[d] (4.75)	13.23[b] (5.20)
5	16.79[a,b,c] (7.24)	14.73[a,b] (6.35)
6	15.37[b,c,d] (10.63)	15.10[a,b] (7.46)
7	16.36[a,b,c] (7.98)	13.99[a,b] (4.61)
8	19.64[a] (12.10)	17.10[a,b] (10.79)
9	15.22[b,c,d] (8.13)	14.62[a,b] (8.31)
10	15.40[b,c,d] (6.90)	14.99[a,b] (7.74)
11	14.58[c,d] (5.76)	14.07[a,b] (5.17)
12	13.21[c,d] (8.93)	16.76[a,b] (10.52)

Different letters indicate significant ($p \leq 0.05$) differences between boots

Kinematics and Kinetics of Jump Landing

When landing on the ground from a jump, effective shock absorption by a boot is critical for avoiding injury. Table 30 shows peak landing power and force values when jumping off a 24 inch high platform. Lower values indicate better shock absorption, and higher values, poorer shock absorption. It can be seen that boot 11 produced the lowest power and force values, and a longer time to reach peak power and force, showing that the shock absorption delayed and attenuated force and power peaks. Boots 7 and 8 produced the highest force and power peaks. It can be seen that peak force and power occurred almost immediately upon landing, about 3 hundredths of a second after initial contact.

Table 30. Peak landing power and force values when jumping off a 24 inch high platform, mean (SD)

Boot number	Peak Value		Time of peak value (ms)	
	Power (W)	Force (N)	Power	Force
1	$17735^{a,b}$ (4404)	$5584^{d,e}$ (1604)	$31.15^{c,d}$ (7.63)	$32.36^{c,d}$ (7.87)
2	$17775^{a,b}$ (3781)	$5597^{d,e}$ (1293)	$31.44^{b,c,d}$ (5.88)	$32.78^{b,c,d}$ (5.73)
3	$17969^{a,b,c}$ (4225)	$5774^{b,c,d,e}$ (1393)	$31.53^{b,c,d}$ (6.00)	$32.62^{b,c,d}$ (6.08)
4	$17838^{a,b}$ (3772)	$5666^{c,d,e}$ (1300)	$33.55^{a,b}$ (5.08)	$34.73^{a,b}$ (4.94)
5	$18785^{b,c,d}$ (3481)	$6063^{a,b,c,d}$ (1246)	$32.24^{b,c,d}$ (5.03)	$33.39^{b,c,d}$ (4.96)
6	$19204^{c,d}$ (4170)	$6126^{a,b,c}$ (1489)	$33.0^{a,b,c}$ (5.77)	$33.91^{a,b,c}$ (5.73)
7	19869^{d} (4113)	6310^{a} (1450)	$33.03^{a,b,c}$ (4.28)	$34.06^{a,b,c}$ (4.59)
8	19506^{d} (4193)	6369^{a} (1521)	$30.91^{c,d}$ (6.45)	$31.82^{c,d}$ (6.41)
9	$17979^{a,b,c}$ (3498)	$5792^{b,c,d,e}$ (1183)	30.44^{d} (4.94)	31.47^{d} (4.99)
10	19298^{d} (3666)	$6205^{a,b}$ (1194)	$32.06^{b,c,d}$ (4.96)	$32.97^{b,c,d}$ (5.08)
11	17376^{a} (4078)	5543^{e} (1364)	34.57^{a} (5.47)	35.59^{a} (5.56)
12	$18802^{b,c,d}$ (4625)	$6132^{a,b,c}$ (1810)	$31.22^{d,c}$ (5.94)	$32.54^{b,c,d}$ (5.59)

Different letters indicate significant ($p \leq 0.05$) differences between boots

Looking at average landing power and force after jumping off a 24 inch high platform (Table 31), it can be seen that boot 11 again showed its superiority in best attenuating force and power peaks. Boot 5 was the least capable in this regard.

Table 31. Average landing power (W) and force (N) after jumping off a 24 inch high platform, mean (SD)

Boot number	Power	Force
1	2669[a,b] (1043)	1005[b,c] (507)
2	2676[a,b] (817)	983[b,c] (373)
3	2727[a,b,c] (802)	1021[a,b,c] (376)
4	2730[a,b,c] (768)	1004[b,c] (364)
5	2948[c] (814)	1126[a] (396)
6	2773[a,b,c] (930)	1033[a,b,c] (443)
7	2738[a,b,c] (865)	1008[b,c] (430)
8	2857[b,c] (862)	1091[a,b] (417)
9	2758[a,b,c] (817)	1031[a,b,c] (399)
10	2739[a,b,c] (740)	1010[b,c] (346)
11	2611[a] (767)	953[c] (350)
12	2783[a,b,c] (856)	1055[a,b,c] (410)

Different letters indicate significant ($p \leq 0.05$) differences between boots

Table 32 shows that peak landing acceleration after jumping off a 24 in high platform was in the 68-78 m/s^2 range, equivalent to 7-8 g's. In keeping with its lower peak force and power values, boot 11 produced the lowest landing accelerations, along with boot 2. Just as they produced the highest force and power peaks, boots 7 and 8 produced the highest peak accelerations.

Table 32. Peak landing acceleration (m/s^2) and velocity (m/s) after jumping off a 24 inch high platform, mean (SD)

Boot number	Peak Value		Time of peak value (ms)	
	Acceleration	Velocity	Acceleration	Velocity
1	$70.00^{b,c}$ (18.50)	3.482^{d} (0.011)	$32.36^{c,d}$ (7.87)	$4.727^{b,c,d}$ (1.51)
2	68.57^{c} (10.40)	3.482^{d} (0.012)	$32.78^{b,c,d}$ (5.73)	$5.027^{b,c}$ (2.02)
3	$70.52^{b,c}$ (13.05)	3.472^{b} (0.007)	$32.62^{b,c,d}$ (6.08)	$3.647^{e,f}$ (2.03)
4	$69.17^{b,c}$ (11.37)	3.487^{e} (0.013)	$34.72^{a,b}$ (4.94)	5.272^{b} (1.86)
5	$74.47^{a,b,c}$ (13.58)	3.482^{d} (0.011)	$33.39^{b,c,d}$ (4.96)	$4.697^{b,c,d}$ (1.63)
6	$75.29^{a,b}$ (16.63)	3.480^{d} (0.012)	$33.91^{a,b,c}$ (5.74)	$4.303^{c,d,e}$ (1.69)
7	77.19^{a} (14.90)	3.489^{e} (0.012)	$34.06^{a,b,c}$ (4.59)	5.969^{a} (2.09)
8	77.95^{a} (16.10)	$3.470^{a,b}$ (0.008)	$31.82^{c,d}$ (6.41)	$3.242^{f,g}$ (1.64)
9	$71.69^{a,b,c}$ (12.77)	3.467^{a} (0.004)	31.47^{d} (4.99)	2.333^{h} (0.68)
10	76.74^{a} (13.07)	$3.471^{a,b}$ (0.004)	$32.97^{b,c,d}$ (5.08)	$3.167^{f,g}$ (0.73)
11	68.19^{c} (12.52)	3.476^{c} (0.007)	35.59^{a} (5.56)	$4.216^{d,e}$ (1.34)
12	$75.35^{a,b}$ (19.29)	$3.469^{a,b}$ (0.007)	$32.54^{b,c,d}$ (5.59)	$2.865^{g,h}$ (1.36)

Different letters indicate significant ($p \leq 0.05$) differences between boots

Kinetics of Running at 6.5 mph

The first force peak during running occurs just after the foot makes contact with the ground. Table 33 shows that the peak was reached 12%-16% into the stride. During non-sprint running, as at 6.5 mph, the heel is the foot's first point of contact with the ground for a vast majority of runners. The forces transmitted from the ground to the body at heel-strike are usually quite high, and are transmitted up the body through the skeletal system. Therefore, an important measure of a shoe or boot's effectiveness during running is the degree to which it can attenuate the forces at heel-strike. Looking at the force magnitude as a percentage of body weight, it can be seen that the first force peak is in the vicinity of 47%-79% above body weight. Boot 1 produced the lowest force, while boot 9 produced the highest force.

Table 33. Variables relating to first force peak while running at 6.5 mph, mean (SD)

Boot number	Magnitude (N)	Time (% of stride)	Magnitude (% body weight)
1	1142.05 [e] (260)	12.9 [d,c] (4.2)	146.68 [e] (33.48)
2	1248.91 [d,c] (285.12)	14.97 [a,b] (2.56)	157.91 [c,d,e] (32.91)
3	1257.2 [b,c,d] (301.05)	13.1 [b,c,d] (4.28)	159.38 [c,d] (37.20)
4	1218.39 [d,e] (286.68)	11.7[d] (2.65)	153.32 [d,e] (33.02)
5	1278.46 [b,c,d] (348.86)	14.03 [a,b,c] (2.82)	160.10 [c,d] (37.74)
6	1322.94 [a,b,c,d] (382.63)	13.04 [d,c] (5.65)	165.08 [b,c,d] (40.00)
7	1325.95 [a,b,c] (365.48)	13.19 [b,c,d] (4.59)	166.72 [a,b,c] (42.83)
8	1415.3 [a] (398.22)	15.16 [a] (2.34)	176.86 [a,b] (42.49)
9	1421.14 [a] (356.14)	14.73 [a,b,c] (4.13)	178.99 [a] (37.47)
10	1296.08 [b,c,d] (241.60)	14.53 [a,b,c] (3.51)	164.65 [b,c,d] (31.24)
11	1358.15 [a,b] (281.07)	15.81 [a] (3.99)	173.71 [a,b] (36.53)
12	1337.53 [a,b,c] (279.68)	15.38 [a] (4.19)	169.87 [a,b,c] (38.59)

Different letters indicate significant ($p \leq 0.05$) differences between boots

There is a low point in force on the foot between the heel-strike and push-off peaks. The force at that low point ranges from 31%-42% above body weight (Table 34). The force was lowest for boot 6 and highest for boots 2 and 9.

Table 34. Variables relating to force low point between the heel-strike and push-off peak forces when running at 6.5 mph, mean (SD)

Boot number	Magnitude (N)	% of Stride	% of body weight
1	1017.71 [b] (238.16)	16.79 [c] (4.78)	130.60 [a,b] (29.68)
2	1119.20 [a] (199.91)	18.81 [a,b] (3.48)	141.73 [a] (23.14)
3	1064.64 [a,b] (215.85)	18.00 [a,b,c] (3.42)	134.82 [a,b] (26.16)
4	1038.74 [a,b] (255.43)	16.74 [c] (3.29)	130.71 [a,b] (29.74)
5	1107.39 [a,b] (238.33)	18.31 [a,b,c] (3.86)	138.87 [a,b] (24.81)
6	1033.81 [a,b] (295.45)	17.80 [b,c] (5.60)	129.39 [b] (33.17)
7	1065.83 [a,b] (285.51)	18.11 [a,b,c] (4.95)	133.37 [a,b] (30.80)
8	1104.70 [a,b] (250.32)	19.73 [a] (2.99)	138.06 [a,b] (24.90)
9	1124.61 [a] (214.65)	19.36 [a,b] (3.86)	141.95 [a] (22.26)
10	1086.98 [a,b] (190.48)	18.63 [a,b,c] (2.57)	137.98 [a,b] (24.16)
11	1101.52 [a,b] (213.93)	19.88 [a] (3.82)	140.18 [a,b] (23.84)
12	1080.01 [a,b] (161.93)	19.56 [a,b] (3.41)	137.00 [a,b] (22.78)

Different letters indicate significant ($p \leq 0.05$) differences between boots

The second peak force during running occurs as the runner pushes off the ground. Table 35 shows that the magnitude of that peak ranged from 134%-144% above body weight. Boots 4 and 6 produced the lowest forces, while boots 8 and 12 produced the highest peak forces.

Table 35. Variables relating to the second force peak when running at 6.5 mph, mean (SD)

Boot number	Magnitude (N)	% of Stride	% of body weight
1	1845.80 [e] (209.10)	44.22 [a] (5.87)	236.86 [b,c,d] (27.13)
2	1915.74 [a,b,c] (200.66)	45.71 [a] (3.33)	242.85 [a,b] (24.06)
3	1875.30 [b,c,d,e] (174.85)	44.29 [a] (3.87)	237.77 [a,b,c,d] (20.96)
4	1861.97 [c,d,e] (219.28)	44.29 [a] (4.70)	234.28 [d] (22.35)
5	1886.58 [a,b,c,d,e] (214.25)	45.19 [a] (4.81)	238.08 [a,b,c,d] (28.62)
6	1855.76 [d,e] (177.49)	44.33 [a] (4.36)	234.18 [d] (23.64)
7	1873.10 [c,d,e] (206.30)	44.58 [a] (4.91)	236.82 [b,c,d] (31.72)
8	1935.83 [a] (180.79)	45.83 [a] (3.34)	243.85 [a] (19.37)
9	1849.82 [e] (170.72)	45.89 [a] (3.72)	235.37 [d,c] (28.89)
10	1907.17 [a,b,c,d] (175.95)	45.33 [a] (4.17)	241.91 [a,b,c] (21.81)
11	1870.05 [c,d,e] (196.32)	45.88 [a] (3.16)	238.79 [a,b,c,d] (24.25)
12	1927.30 [a,b] (187.35)	46.02 [a] (6.15)	243.98 [a] (25.73)

Different letters indicate significant ($p \leq 0.05$) differences between boots

Comfort and Injury Prevention

It is important to note that, for boots 1, 2, 5, 6, 7, 11, and 12, there was one less 6-mile hike than for boots 3, 4, 8, 9, and 10. This could have caused a minor reduction in the frequencies of both positive and negative responses listed in the tables below.

Tables 36-40 show the number of volunteers that made positive comments about various aspects of the boots. Table 36 shows the number of volunteers that cited various aspects of the toe box as among the best boot features. Boot 5 received 2 favorable comments about the toe box, while boots 1, 4, 10, and 11 each received 1 favorable comment about the toe box. The remainder of the boots received no favorable comments about the toe box.

Table 36. Number of volunteers that cited various aspects of the toe box as among the best boot features

Boot number ➡	1	2	3	4	5	6	7	8	9	10	11	12
High toe box			1							1		
Snug toe box					1							
Wide toe box				1								
Good toe box					1						1	

Table 37 shows the number of volunteers that cited various aspects of the sole as among the best boot features. Boots 2 and 4 received the most positive comments about the sole, while boot 12 received the fewest positive comments.

Table 37. Number of volunteers that cited various aspects of the sole as among the best boot features

Boot number ➡	1	2	3	4	5	6	7	8	9	10	11	12
Traction	5	3	3	2	2	1	3	1	5	5	2	1
Thick sole	1			1		1	1					
Cushion	1	2		2								
Insole				3	1							
Soft/comfortable		3						1	1	1		
Liked sole		2	1	1	2						1	
Good shock absorption				1								
Ridged sole								1				
Tread					1		1					
TOTAL	7	10	4	10	6	2	5	3	6	6	3	1

Table 38 shows the number of volunteers that cited various aspects of the uppers as among the best boot features. Boot 12 received the most positive comments about the uppers, while boots 2 and 6 were the only boots to receive no positive comments about the uppers.

Table 38. Number of volunteers that cited various aspects of the uppers as among the best boot features

Boot number ➡	1	2	3	4	5	6	7	8	9	10	11	12
Flexibility							1					
Support	1		1					3	1	1	2	6
Stiff												1
Height				1	1							

Table 39 shows the number of volunteers that cited miscellaneous aspects as among the best boot features.

Table 39. (Part I) Number of volunteers that cited miscellaneous aspects as among the best boot features

Boot number ➡	1	2	3	4	5	6	7	8	9	10	11	12
Lightweight				1			2		1			1
Comfortable	1		3	3				5	6	2	4	2
Sturdy								2				
No answer / no positive attributes	3	2	5	2	5	5	6	1	1			
Flexibility		1	1	1		2			1			1
Support	1		1	1				1	2	1	1	
No blisters									1	1		
Stiff support										1		2
Flexible uppers												1
Overall boot					1			1	1		1	
Soft								1				
Fit			1	1		1	1		1			1
Very stable												1

Table 39. (Part II) Number of volunteers that cited miscellaneous aspects as among the best boot features

Boot number ➡	1	2	3	4	5	6	7	8	9	10	11	12
Stability												1
Nice and roomy											1	
Easy to break in											1	
Good easy laces								1				
Conformed to foot												1
Pliable leather					1							
Well weighted						1						
Protected foot						1						
Rigid										1		
Solid boot, nothing special						1						
Snug over most of foot							1		1			
Light and easy to maneuver										1		
Heel support		1										

Table 40 shows the total number of positive comments for each boot, ranging from a low of 8 for boot 6 to a high of 21 for boot 9. Of the prototype boots (numbers 1-5), boot 4 received the greatest number of positive comments at 19. Current-issue Army boots (numbers 6 and 7) received only 8-10 positive comments. The number of positive comments for the commercial hiking boots (numbers 8-12) ranged from 14-21.

Table 40. Total number of positive comments for each boot

Boot number ➡	1	2	3	4	5	6	7	8	9	10	11	12
Number of positive comments	10	12	12	19	11	8	10	17	21	15	14	19

Tables 41 to 45 show the number of volunteers that cited various aspects of the boot as among the worst boot features. Complaints about the toe box are shown in Table 41. There were no toe box complaints for boots 4, 7, and 11, while the highest number of toe box complaints were registered for boots 5 and 10, each of which tallied 5 complaints.

Table 41. Number of volunteers that cited various aspects of the toe box as among the worst boot features

Boot number ➡	1	2	3	4	5	6	7	8	9	10	11	12
Narrow toe box										3		
Sliding in toe area								1				
Big toe box		1			1							
Low toe box					1							
Small toe box			1		3	2		1	2	2		
Not well cushioned												2
Toe box	1											
No cushion in toes												2
Toes went numb			1									

Complaints about the sole are shown in Table 42. There were no sole complaints for boots 2 and 8, while the highest number of complaints about the sole were registered for boot 6, which tallied 4 complaints.

Table 42. Number of volunteers that cited various aspects of the sole as among the worst boot features

Boot number ➡	1	2	3	4	5	6	7	8	9	10	11	12
Traction	1		1		1	1	1		2		1	
Not flexible			1									
cushion			1									1
Uncomfortable insole				2		1						
Sole						1				1		
Tread						1						
No sole							2					
Stiff sole									1	2		1

Complaints about the uppers are shown in Table 43. Boot 12 was the only boot that did not produce any complaints about the uppers. The highest number of upper complaints was registered for boots 2 and 7, each of which tallied 6 complaints.

Table 43. Number of volunteers that cited various aspects of the uppers as among the worst boot features

Boot number ➡	1	2	3	4	5	6	7	8	9	10	11	12
Support		5	2	4	2	5	6	2	1	1		
Binding on ankles	1										1	
Rigid upper								3				
Could be higher									1			
Comment	2				1					1		
Loose around ankle		1										
Uppers stiff											1	

Complaints about the heel are shown in Table 44. There were no toe box complaints for boots 2, 7, 8, 9, and 12, while the highest number of heel complaints were registered for boot 1, which tallied 5 complaints, mainly for rubbing.

Table 44. Number of volunteers that cited various aspects of the heel area as among the worst boot features

Boot number ➡	1	2	3	4	5	6	7	8	9	10	11	12
Rubbed heel	4		1		1							
Stretchy heel area	1		1									
Heels too high				1								
Blister on heel					1					1		
Plastic heel											1	
Heel box				1		1						

Complaints about miscellaneous factors are shown in Table 45. All of the boots produced some complaints.

Table 45 (Part I). Number of volunteers that cited miscellaneous factors as among the worst boot features

Boot number ➡	1	2	3	4	5	6	7	8	9	10	11	12
Rubbing on foot		1										
Too tight						2						
Poor arch support			1		1			1				
No answer / no positive attributes	3	4	3	4	1		2	3	5	3	4	5
Flexibility	1							1	1			
Support		1										
Minimal upper padding			1									
Too loose, too big		1										
Feel rock through sole				1								
Overall boot				1	1							
Too long	1											
Lack of ventilation								1	1		1	

Table 45 (Part II). Number of volunteers that cited miscellaneous factors as among the worst boot features

Boot number ➡	1	2	3	4	5	6	7	8	9	10	11	12
Not very light				1				1			1	
Too hard						1						
Too small									1	1		
Bulky											1	
Wore too much the balls on feet											1	
Wrong size											1	
Hard to lace quickly												1
Feet overheated												1
Narrow mid foot												1
Soft sides												1
Sharp edges in boot						1						
Ridged line across upper arch								1				

Table 46 shows the total number of negative comments for each boot. The highest number of negative comments were for boot 6, the standard-issue Army combat boot, while the lowest number of negative comments were for boots 7 and 11, the current-issue Army jungle boot and a commercial boot, respectively. The prototype boots (numbers 1-5), all received about the same number of negative comments, ranging from 10 to 13, similar to the number of negative comments for the commercial hiking boots (boots 8-12) which ranged from 9-12 negative comments.

Table 46. Total number of negative comments for each boot

Boot number ➡	1	2	3	4	5	6	7	8	9	10	11	12
Number of negative comments	12	10	11	11	13	16	9	12	10	12	9	10

Table 47 shows the number of injuries to different regions of the foot subsequent to the 6-mile hike with a 60-lb backpack. The only injuries evidenced during the study were friction-related ones, including chafing, hot-spots, and blisters. The fewest injuries occurred for boot 8, while the most injuries occurred with boot 5, a prototype Army boot.

Table 47. Number of injuries* to different regions of the foot subsequent to a 6-mile hike with 60-lb backpack.

Boot number ➡	1	2	3	4	5	6	7	8	9	10	11	12
Total	47	22	20	29	69	54	51	15	30	34	20	22
Inferior Aspect	18	10	5	7	13	24	9	8	22	14	5	18
Forefoot: Superior Aspect	4	1	1	8	21	18	20	1	6	10	2	3
Heel: Posterior, Medial, Lateral	20	5	9	5	31	8	11	3	0	7	3	1
Ankle: Medial & Lateral	2	0	2	2	2	0	1	0	0	0	5	0
Lateral Aspect of Foot	3	2	3	4	1	4	2	2	1	2	2	0
Medial Aspect of Foot	0	4	0	3	1	0	8	1	1	1	3	0

* The only injuries evidenced during the study were friction-related ones, including chafing, hot-spots, and blisters.

As seen in Table 48, boots 8, 9, and 12 produced the fewest reports of foot or ankle pain, soreness, or discomfort subsequent to the march, while boot 5 produced the most, in keeping with its high rate of injury production seen in the previous table.

Table 48. Number of volunteers reporting foot or ankle pain, soreness, or discomfort subsequent to the march

Boot number	Number of volunteers
1	9
2	9
3	6
4	6
5	11
6	9
7	9
8	4
9	4
10	9
11	6
12	4

All of the boots were men's size 9. However, not all nominal size 9's actually have the same inside length. Table 49 shows that boots 4 and 8 produced no complaints about being too short or too long. All the other boots produced some complaints, but no more than 3 of the 14 volunteers complained about the length of any particular boot. Ideally, boots that are too short or too long would not be a problem in the Army as long as recruits are given the opportunity to try boots on and pick from a range of sizes.

Table 49. Number of volunteers reporting the boots either too long or too short

Boot number	Too long	Too short
1	1	1
2	3	0
3	0	1
4	0	0
5	0	2
6	0	1
7	1	1
8	0	0
9	0	2
10	0	2
11	1	0
12	0	1

Table 50 shows the number of volunteers reporting too little or too much width in various segments of the boot. Boot 2 produced 5 complaints about a wide toe box, while boots 5 and 6 each produced 7 complaints of a narrow toe box. Boots 2 and 4 produced the most complaints about a wide fore-foot, while boots 6 and 7 produced the most complaints about a narrow fore-foot. Boot 2 produced 6 complaints about a wide mid-foot. Boots 1 and 5 each produced 4 complaints about a narrow heel.

Table 50. The number of volunteers reporting too little or too much width in various segments of the boot

	Toe Box		Fore-foot		Mid-foot		Heel	
Boot number	Wide	Narrow	Wide	Narrow	Wide	Narrow	Wide	Narrow
1	1	1	1	0	0	0	2	4
2	5	0	4	0	6	0	3	0
3	1	2	2	1	2	0	2	0
4	3	0	4	1	1	0	1	1
5	0	7	1	3	0	2	1	4
6	0	7	0	5	0	2	0	2
7	0	5	0	5	1	2	0	3
8	1	0	0	0	1	0	0	0
9	0	3	0	0	0	1	0	0
10	0	4	0	0	0	0	2	2
11	0	0	1	1	2	1	1	0
12	2	1	1	0	1	1	0	0

Inadequate toe box height can be associated with injury to the toe nails. Table 51 shows that half the volunteers complained that boot 5 had inadequate toe box height. Boots 6 and 7, the current-issue Army boots, also produced a relatively high number of such complaints.

Table 51. Number of volunteers reporting inadequate toe box height

Boot number	frequency
1	1
2	0
3	1
4	1
5	7
6	5
7	5
8	0
9	2
10	1
11	0
12	2

Table 52 shows the number of volunteers reporting pain or soreness in various parts of the leg during the 6-mile 60-lb backpack hike. None of the boots produced exceptionally high or low scores in this regard.

Table 52. Number of volunteers reporting pain or soreness in various parts of the leg during the 6-mile 60-lb backpack hike

Boot number	Pain front lower leg	Pain back lower leg	Pain front knee	Pain front thigh	Pain back thigh
1	0	0	0	1	1
2	0	0	0	1	1
3	1	1	0	1	1
4	1	0	1	0	0
5	0	1	0	0	0
6	0	0	1	0	0
7	1	2	0	1	1
8	1	2	0	1	1
9	1	1	2	1	1
10	0	0	0	1	1
11	0	1	1	1	1
12	1	0	0	0	0

Table 53 shows the number of volunteers reporting they slipped or fell on either rocky surfaces, branches, or roots. In this regard, the commercial hiking boots did very well, producing only 0-1 slips. Boot 7 was the poorest, with 6 slips.

Table 53. Number of volunteers reporting they slipped or fell on either rocky surfaces or branches/roots

Boot number	Rocky Surfaces	Branches/ Roots	Total Slips
1	3	1	4
2	2	1	3
3	1	2	3
4	2	0	2
5	0	3	3
6	1	2	3
7	4	2	6
8	0	1	1
9	1	0	1
10	0	1	1
11	0	1	1
12	0	0	0

Volunteer perceptions of inadequate traction on dirty or wet surfaces are shown in Table 54. The numbers are low for all the boots despite the notable difference in reported slips above.

Table 54. Number of volunteers reporting inadequate traction on dirty or wet surfaces.

Boot number	Dirt	Wet
1	0	0
2	1	0
3	1	1
4	0	1
5	0	0
6	2	1
7	0	1
8	0	1
9	1	2
10	0	0
11	1	0
12	0	0

Some boot tread patterns can trap dirt, mud, or stones. Table 55 shows the number of volunteers reporting collection of dirt, mud or stones in the boot tread. Boot 6 produced no reports at all concerning collection of mud in the tread. Boot 8 produced the most such complaints.

Table 55. Number of volunteers reporting collection of dirt, mud or stones in the boot tread

Boot number	Number of complaints
1	2
2	2
3	2
4	2
5	1
6	0
7	1
8	4
9	1
10	3
11	2
12	1

One of the major functions of hiking boots is to protect the bottom of the foot from point pressures due to rocks and stones. Table 56 shows the number of volunteers reporting they felt rocks and stones through the boot heel or sole while hiking. Again the commercial boots, numbers 8-12, excelled, producing the fewest sensations of objects through the boot.

Table 56. Number of volunteers reporting they felt rocks and stones through the boot heel or sole while hiking

Boot number	Number of complaints
1	5
2	6
3	7
4	9
5	8
6	7
7	6
8	2
9	0
10	1
11	3
12	3

Overall boot discomfort is reported in Table 57. Boot 5 produced reports of excessive discomfort among almost half the volunteers, with boot 7 not far behind. Boots 8, 10, 11, and 12, all commercial, produced no reports of excessive discomfort during the march.

Table 57. Number of volunteers reporting the boots very uncomfortable during the march

Boot number	Very uncomfortable
1	1
2	3
3	2
4	1
5	6
6	3
7	5
8	0
9	2
10	0
11	0
12	0

Lack of boot flexibility can be unpleasant during hiking. Table 58 shows that boots 1, 2, 4, and 5 produced no complaints at all about inflexibility. Boots 6, 8, and 10 each produced 4 complaints about boot sole inflexibility.

Table 58. Number of volunteers reporting the boot soles inflexible

Boot number	Not flexible
1	0
2	0
3	2
4	0
5	0
6	4
7	3
8	4
9	2
10	4
11	1
12	1

Table 59 shows the number of volunteers reporting the boot uppers inflexible. Boots 8, 10, and 11, all commercial, produced the most reports of inflexible uppers, while boots 1, 2, 3, and 5, all military prototypes, produced no reports of boot upper inflexibility.

Table 59. Number of volunteers reporting the boot uppers inflexible

Boot number	Number of complaints
1	0
2	0
3	0
4	1
5	0
6	1
7	1
8	4
9	0
10	2
11	3
12	0

Table 60 shows information that should be considered among the most important in evaluating a boot; that is, the number of volunteers that, based only on comfort and function, would not recommend the boots for use by the Army as field boots. Half of the volunteers would not recommend boots 5, 6, and 7, which notably include the current-issue Army combat boot and jungle boot. Almost as many would not recommend boot 3. All the commercial boots (numbers 8-12), as well as one prototype boot (number 2), fared best in this regard. There were no volunteers who would not recommend boot 12 for use by the Army as field boots.

Table 60. Number of volunteers that, based only on comfort and function, would not recommend the boots for use by the Army as field boots

Boot number	Number of complaints
1	4
2	2
3	6
4	3
5	7
6	7
7	7
8	2
9	2
10	2
11	1
12	0

Friction between the boot lining and the foot can cause discomfort as well as injury to the skin. Table 61 shows that boot 5 produced the most complaints by far, 23 in all. Boot 1 also produced relatively many complaints, a total of 16. Boots 8 and 12, both commercial, produced no chafing complaints at all.

Table 61. The number of volunteers reporting chafing by the boot lining at various parts of the foot.

	Toe box		Fore-foot		Heel		Ankle		
Boot number	Top under surface	Outside surface	Top under surface	Inside surface	Inside Surface	Outside surface	Top under surface	Inside surface	Outside surface
1	1	0	0	0	4	2	2	3	4
2	0	0	0	1	3	0	0	0	0
3	0	1	0	0	1	1	1	0	0
4	0	0	0	0	0	1	0	1	0
5	5	1	0	2	8	4	1	2	0
6	3	1	1	1	2	1	0	0	0
7	2	3	3	0	3	1	1	0	0
8	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	1	0	0	0
10	0	3	0	0	0	1	0	0	1
11	0	0	0	0	0	1	0	1	0
12	0	0	0	0	0	0	0	0	0

A SYSTEM FOR OVERALL BOOT EVALUATION

It is difficult to compare the overall effectiveness of the 12 boots by examining all of the tables presented in the results section. Therefore, a point system was devised in which each boot would receive points for the variables deemed most critical to overall boot evaluation. The selected variables are listed below. The criterion for selection of variables was that a clear value judgement about the effectiveness of the boots could be made based on comparison of variable means. In other words, it had to be clear whether a variable indicated something positive or negative about the boot, and whether a high score or a low score was desirable. For instance, none of the Tekscan® results were used in the point system because they didn't appear to add any evaluative information beyond that produced by the force platform data, the comfort questionnaires, and the injury assessment. Point values were assigned based on the post hoc statistical analysis. To do this, the boots were ranked according to the letters or set of letters assigned to them in the post hoc analysis, where different letters indicates significantly different means. Thus 1 was always the best score. Several of the boots often received the same ranking, so that scores sometimes ranged from 1-3 and other times from 1-8 etc. In order to avoid weighting some of the variables more heavily than others, the rankings were multiplied by an integer such that the scores for each variable had a maximum value of about 20.

To allow space for data in Table 62, which summarizes the overall evaluation, each of the variables in the list below is preceded by a letter that represents that variable in the table.

A. 400 m straight run times without load
B. 400 m straight run times with load
C. 400 m zigzag run times without load
D. 400 m zigzag run times with load
E. Rate of oxygen consumption relative to body mass (ml/kg/min), unloaded walking
F. Rate of oxygen consumption relative to body mass (ml/kg/min), loaded walking
G. Rate of oxygen consumption relative to body mass (ml/kg/min), unloaded running
H. Maximum vertical heel-strike force (N) while walking at 3.5 mph, unloaded
I. Maximum vertical heel-strike force (N) while walking at 3.5 mph, loaded
J. Maximum rear-foot angle (deg) while walking at 3.5 mph, unloaded
K. Maximum rear-foot angle (deg) while walking at 3.5 mph, loaded
L. Range of rear-foot motion (deg) while walking at 3.5 mph, unloaded
M. Range of rear-foot motion (deg) while walking at 3.5 mph, loaded
N. Peak landing force when jumping off a 24 inch high platform
O. Total number of positive comments for each boot
P. Total number of negative comments for each boot
Q. Number of injuries to different regions of the foot subsequent to 6-mile hike

R. Number of volunteers reporting foot or ankle pain, soreness, or discomfort
S. Number of volunteers reporting they slipped or fell
T. Number of volunteers reporting collection of dirt, mud or stones in the boot tread
U. Number of volunteers that felt rocks and stones
V. Number of volunteers reporting the boots very uncomfortable during the march
W. Number of volunteers reporting the boot soles inflexible
X. Number of volunteers reporting the boot uppers inflexible
Y. Number of volunteers that would not recommend the boots
Z. The number of volunteers reporting chafing by the boot

Table 62 shows the points assigned to each boot in the overall evaluation (lower is better). The next to last row in Part II of the table gives the total score for each boot. The last row gives a base_{100} score computed such that the poorest performing boot would score 50 and the best performing boot 100. The calculation used to get the base_{100} score was as follows:

$$\text{base}_{100}\text{ score} = 100 - 50\frac{(\text{individual boot total score - best boot total score})}{(\text{worst boot total score - best boot total score})}$$

$$= 100 - 50(\text{individual boot total score-}184)/(327\text{-}184)$$

It can be seen that boot 12, the Salomon Adventure 9 Ultralight, was the best boot overall, with a base_{100} score of 100. Based on their scores the boots are ranked as follows, from best to worst:

Base_{100} Scores (100 is best, lower scores are not as good)

Rank	Boot	Score
1.	Salomon Adventure 9 Ultralight (boot 12)	100
2.	Raichle Highline (boot 9)	90
4.	Prototype 3 (boot 3)	84
4.	Prototype 4 (boot 4)	84
4.	Asolo Meridian (boot 11)	84
6.	Asolo AFX 535 (boot 10)	73
7.	Prototype 1 (boot 1)	70
8.	Prototype 2 (boot 2)	67
9.	Montrail Moraine (boot 8)	65
10.	Army combat boot (boot 6)	59
11.	Army jungle boot (boot 7)	51
12.	Prototype 5 (boot 5)	50

Table 62 (Part I). Points assigned to each boot in the overall evaluation (lower is better)

	Boot Number											
Variable	1	2	3	4	5	6	7	8	9	10	11	12
A	10	10	10	10	10	10	10	10	10	10	10	10
B	12	12	6	12	18	12	18	18	12	12	18	18
C	12	12	12	12	6	18	12	12	12	12	12	6
D	10	10	10	10	10	10	10	10	10	10	10	10
E	18	15	9	15	21	15	18	15	6	3	12	6
F	16	16	8	16	20	12	16	12	8	8	8	4
G	12	12	6	12	15	18	12	12	12	9	12	3
H	12	18	12	21	12	6	9	3	12	12	15	21
I	3	12	9	12	18	3	6	6	12	15	21	12
J	12	15	6	3	3	6	6	21	18	15	6	9
K	12	14	10	4	2	6	8	16	14	12	8	12
L	6	15	3	3	12	9	12	18	9	9	6	6
M	12	18	12	6	12	12	12	12	12	12	12	12
N	4	4	8	6	10	12	16	16	8	14	2	12

For each variable, each boot was assigned points according to the statistical results, such that lower scores were better and higher scores worse. Scores for each variable were adjusted to fall within an approximate range of 0-20.

Table 62 (Part II). Points assigned to each boot in overall evaluation (lower is better)

	Boot Number											
Variable	1	2	3	4	5	6	7	8	9	10	11	12
O	12	10	10	3	11	14	12	5	1	7	8	3
P	12	10	11	11	13	16	9	12	10	12	9	10
Q	14	6	6	8	20	16	15	4	9	10	6	6
R	18	18	12	12	22	18	18	8	8	18	12	8
S	12	9	9	6	9	9	18	3	3	3	3	0
T	10	10	10	10	5	0	5	20	5	15	10	5
U	10	12	14	18	16	14	12	4	0	2	6	6
V	3	9	6	3	18	9	15	0	6	0	0	0
W	0	0	10	0	0	20	15	20	10	20	5	5
X	0	0	0	5	0	5	5	20	0	10	15	0
Y	12	6	18	9	21	21	21	6	6	6	3	0
Z	16	4	4	2	23	9	13	0	1	5	2	0
Total	270	277	231	229	327	300	323	283	214	261	231	184
Base 100 Score	70	67	84	84	50	59	51	65	90	73	84	100

For each variable, each boot was assigned points according to the statistical results, such that lower scores were better and higher scores worse. Scores for each variable were adjusted to fall within an approximate range of 0-20.

DISCUSSION

Many significant differences were found between the boots in regard to many variables that reflect the boots' effectiveness in preventing injury to the soldier and enhancing performance. The extensive data produced by the experiment should allow fact-based decisions concerning military boot design.

The variables addressed in this experiment covered most of the three levels of requirements of military boots specified by Hamill and Bensel (6). The 400 m straight and zigzag runs with and without a load addressed the locomotor capabilities of the wearer. The oxygen uptake tests for loaded and unloaded walking, and unloaded running, addressed the efficiency of locomotion. The tabulation of injuries addressed the goal of minimizing the occurrence of lower extremity injury and pain. The requirement of providing comfort was assessed by the questions the volunteers answered about each boot after the 6 mile backpack march. Information was provided, as well, on the weight of the boots and how high they come up the ankle. This study did not address military requirements of water resistance and durability of the uppers or soles, nor maximal unit cost or production factors. Such considerations may impede adaptation of boots or boot features that performed very well on our tests.

Despite the fact that, in their boot materials testing study, Hamill and Bensel (6) found the black leather combat boot and the hot weather jungle boot to show poorer impact attenuation than commercial footwear, as measured by peak deceleration, time to peak deceleration, and peak pressure, we found that these two current-issue boots did not show high foot impact forces during both unloaded and loaded walking. The reason is likely that the walker makes subconscious adjustments in gait in response to the hardness of the footwear. Thus the hard soles of the current-issue military boots likely caused gait adjustments so that the volunteers did not strike the ground forcefully. These results are in contrast to the human testing of Hamill and Bensel (8) in which they found that the jungle and combat boots produced higher peak impact forces than commercial footwear. However, Hamill and Bensel found no difference between the various boots for foot impact force during running, and sometimes lower impact for the military boots.

Hamill and Bensel (9) showed no difference among footwear as to the heart rate or oxygen consumption of males. In contrast, we found a number of significant differences among the boots as to oxygen consumption during unloaded and loaded walking, as well as running.

Just as in the study of Williams et al. (17) who compared current-issue combat and jungle boots to commercially available boots, and a hybrid boot composed of the outer shell of the jungle boot and a non-standard polyurethane sole, we found that, with the exception of prototype boot 5, the prototypes and the commercial boots were superior overall to the standard leather and jungle boots. Their conclusion, that optimal characteristics of commercially available boots can be combined to create a military prototype boot surpassing those in current use, is in keeping with ours.

We observed ground impact landing forces following a jump from a 0.6 m high box to be in the range of 7 times body weight. This is in the general range of the 6 times body weight landing forces observed by McNitt-Gray (13). In contrast to the finding of Hamill and Bensel's (9), the footwear with the highest uppers did not produce the longest times for agility runs. One reason might be that the agility runs were not of the same type. Another reason might be that although the prototype boots were high, they were more flexible than are the current-issue combat boots.

CONCLUSIONS

The boots are discussed below in the order of their rankings, from best to worst:

- The Salomon Adventure 9 Ultralight (boot 12) is the best boot of those tested. It ranked highly as to almost all the critical variables, and was particularly strong as to subjective ratings of the volunteers. It was the only boot that not a single volunteer would not recommend for military use. None of the volunteers found the boot uncomfortable.
- The Raichle Highline (boot 9) was a very good all-around boot. It was excellent as to subjective volunteer ratings, shielding the foot from rocks and stones, boot upper flexibility, and preventing chafing.

<u>The following 3 boots all had the same score</u>

- Prototype 3 (boot 3) was a fairly good boot which performed well as to control of rear-foot motion during unloaded walking, boot upper flexibility, and lack of chafing. Most of its other scores were mid-range.
- Prototype 4 (boot 4) was superior in keeping the foot from pronating. It received a lot of positive comments, had good sole flexibility and didn't chafe. Its weaknesses were high heel-strike force and poor shielding against rocks and stones.
- The Asolo Meridian (boot 11) was also a good all-around boot. It scored very well in minimizing impact in the jump landing, volunteer perceptions of comfort, and lack of chafing. It was generally mid-range for the remaining variables, except for poor showings on the 400 m straight run with a load and heel-strike force while walking with a load.

- The Asolo AFX 535 (boot 10) scored very well as to perceived comfort, prevention of slipping, and rate of oxygen consumption during unloaded walking. It performed poorly at preventing foot or ankle pain, soreness or discomfort and had a stiff sole.
- Prototype 1 (boot 1) scored very well as to flexibility of both the boot uppers and sole, perceived comfort, attenuation of heel-strike force during loaded walking, and attenuation of impact during jump landing. However, it didn't score strongly on most other variables, and produced several reports of foot or ankle pain, soreness, or discomfort.
- Prototype 2 (boot 2) scored very well as to flexibility of both the boot uppers and sole, lack of chafing, and attenuation of impact during jump landing. However, it didn't score strongly on most other variables, and scored poorly as to heel-strike

force during unloaded walking, ankle stabilization, and number of reports of foot or ankle pain, soreness, or discomfort.

- The Montrail Moraine (boot 8) scored very highly as to attenuation of heel-strike force during both unloaded and loaded walking, positive volunteer comments, prevention of foot injuries, prevention of slipping, protection against rocks and stones, perceived comfort, and prevention of chafing. However, the boot had several weak areas and performed poorly on the 400 m straight run with load, control of rear-foot motion, and collection of dirt and stones in the sole. Both the boot uppers and soles were perceived as inflexible.
- The current-issue Army combat boot (boot 6) was third from last as to overall score. It scored well as to attenuation of heel-strike force during walking and prevention of dirt buildup in the boot tread. However, many other scores were fair to poor. The boot garnered its worst scores on the 400 m zigzag run without a load, rate of oxygen consumption during unloaded running, number of reports of foot or ankle pain, soreness or discomfort, and sole stiffness. Fully half of the volunteers said they would not recommend the boot for military use.
- The Army jungle boot (boot 7) scored next to last of the 12 boots. The boot scored well as to prevention of dirt and rock buildup in the sole tread and flexibility of the boot uppers. However, the boot scored poorly on the 400 m straight run with load, rate of oxygen consumption during unloaded walking, number of reports of foot or ankle pain, soreness, or discomfort, and number of slips and falls. Fully half of the volunteers said they would not recommend the boot for military use.
- Prototype 5 (boot 5) was the worst boot of all. While it scored well in prevention of pronation during both loaded and unloaded walking, resistance to collection of dirt and stones in the boot tread, and flexibility of both uppers and soles, it didn't score well on most other tests. Its most outstanding weaknesses were at the 400 m straight run with load; rate of oxygen consumption during unloaded and loaded walking; heel-strike force during loaded walking; number of injuries subsequent to the 6 mile hike; number of reports of foot or ankle pain, soreness, or discomfort; number of reports that the boots were very uncomfortable; and boot chafing. Fully half of the volunteers said they would not recommend the boot for military use.

Knowledge of which boot did the best on each test can help determine which features of each boot may be worth incorporating into a future military boot. Therefore, the best performer on each test is indicated below:

- The 12 boots did not differ as to 400 m straight run time without load.
- Prototype 3 produced the fastest 400 m straight run times with load.
- Prototype 5 and the Salomon boot produced the fasted 400 m zigzag run times without a load.
- The 12 boots did not differ as to 400 m zigzag run times with load.
- The Asolo AFX 535 produced the lowest rate of oxygen consumption for unloaded walking.
- The Salomon boot produced the lowest rate of oxygen consumption for loaded walking.

- The Salomon boot produced the lowest rate of oxygen consumption for unloaded running.
- The Montrail Moraine produced the lowest maximum vertical heel-strike force during unloaded walking.
- Prototype 1 produced the lowest maximum vertical heel-strike force during loaded walking.
- Prototypes 4 and 5 were best at controlling foot pronation during unloaded walking.
- Prototype 5 was best at controlling foot pronation during loaded walking.
- Prototypes 4 and 5 were best at controlling range of rear-foot motion during unloaded walking.
- Prototype 4 was best at controlling range of rear-foot motion during loaded walking.
- The Asolo Meridian was best at attenuating peak landing force when jumping off a 24 inch high platform.
- The Raichle Highline received the greatest number of positive comments.
- The jungle boot and Asolo Meridian received the fewest negative comments.
- The Montrail Moraine produced the lowest number of foot injuries consequent to the 6-mile hike. NOTE: The only injuries evidenced during the study were friction-related ones, including chafing, hot-spots, and blisters.
- The Montrail Moraine, Raichle Highline, and Salomon Adventure produced the fewest complaints of foot or ankle pain, soreness, or discomfort.
- The Salomon boot produced the fewest number of slips or falls (none).
- The Army combat boot produced the least collection of dirt, mud or stones in the boot tread.
- The Raichle Highline provided the best protection against rocks and stones.
- All the commercial boots except the Raichle Highline were best at comfort in producing no complaints of extreme discomfort during the 6 mile march.
- Prototypes 1, 2, 4, and 5 had the most flexible soles.
- Prototypes 1, 2, 3, and 5, as well as the Raichle Highline and Salomon Adventure had the most flexible uppers.
- The Salomon received the most recommendations for use as a military boot.
- The Montrail Moraine and Salomon boots produced the fewest reports of chafing.

RECOMMENDATIONS

Of the prototypes, boots 3 and 4 produced the best overall test results. Because the Solomon boot was so clearly superior to the other boots and the Raichle Highline was a strong second place, some of their features are worthy of consideration for incorporation into a future military boot. However, the fact that these two commercial boots were from non-U.S. manufacturers (Salomon from France and Raichle from Switzerland) may prevent the inclusion of specific proprietary features into U.S. military boots. Licensed manufacture in the U.S. of foreign products or components is a possible solution.

It is important to note that we did not perform some essential off-the-wearer tests on the boots, such as tests for resistance to wear, water, organic liquids, heat, flame, etc. Neither did we test how the boots function after being used for several months. Evidence from such tests should be combined with evidence from our experiments for overall boot evaluation.

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APPENDIX A

Boot Questionnaire and Foot Injury Recording Form

Boot Study Questionnaire

Subject ID #________ DATE:______________

Boot Type:__________

COMFORT/DISCOMFORT RATINGS:

1) Did you experience any pain soreness or discomfort in your feet or ankles during the march?

YES______ NO_______

If NO go on to Question # 2.

If YES answer the following questions.

1A) Were the boots appropriate in length? YES___ NO___

If No were the boots too long? YES___ NO___
If No were the boots too short? YES___ NO___

If the boots were too short:

A) Did you feel that there was not enough room for your toes in the boot? YES___ NO___

B) Did you feel excess pressure on your heels while walking or running? YES___ NO___

1B) Indicate how this pair of boots fits your foot width-wise

	wide	neutral	narrow
Toe box	____	____	____
Forefoot area	____	____	____
Midfoot/instep area	____	____	____
Heel area	____	____	____

1D) Were the toe boxes of the boots high enough inside?

YES____ NO____

1E) Did the inside lining of the boot chafe or otherwise injure you or cause discomfort? YES___ NO___

If YES, where was the problem area:

Toe Box:	Top under surface	______
	Inside surface	______
	Outside surface	______
	Insole	______
Forefoot area:	Top under surface	______
	Inside surface	______
	Outside surface	______
	Insole	______
Midfoot/instep:	Top under surface	______
	Inside surface	______
	Outside surface	______
	Insole	______
Heel area:	Top under surface	______
	Inside surface	______
	Outside surface	______
	Insole	______
Ankle area	achilles area	______
	inner ankle bone	______
	outer ankle bone	______
	under boot laces	______

2. Did you experience any pain or soreness in your legs during the march?

YES_____ NO_____

If YES where did the soreness occur? ______________________

3. Did you slip or fall during the march? YES____ NO_____

If YES what kind of surface were you walking/running on when the slip happened? Paved road____ dirt road____ rock_____ Fallen tree branches_____

4. Indicate your opinion of the traction provided by these boots, (i.e. their ability to grip the ground and prevent you from slipping).

_____ Good traction

_____ Adequate traction

_____ Bad traction

If you found these boots to have inadequate traction what were the surface conditions (dirt, paved, rock, dry, wet, slimy) when you experienced the bad traction? ______________________

5. Did stones or dirt/mud collect in the tread of the heels or soles of these boots?

YES____ NO_____

6. As you walked over rocks and stones could you feel them through the heeals or soles of these boots?

YES____ NO_____

7. How comfortable were these boots to wear during the march?

_____ Very comfortable

_____ Neither comfortable or uncomfortable

_____ Very uncomfortable

8. How flexible were the soles of these boots?

Not flexible at all ____

Moderately flexible ____

Very flexible ____

9\. How flexible were the uppers of these boots?

Not flexible at all ____

Moderately flexible ____

Very flexible ____

10\. In terms of hiking what is the best feature of the boots you wore today?

____

____

11\. In terms of hiking what is the worst feature of the boots you wore today?

____

____

12\. Based only on comfort and function would you reccomend these boots for use by the Army as field boots?

YES____ NO____

If NO, explain why?

____

____

FOOT INJURY DATA FORM

NAME________________________ DATE____________

Total No.	Left Foot	Total No.	Right Foot
______		______	
______		______	
______		______	
______		______	
______		______	
______		______	
______		______	
______		______	

Blisters	(B)
Hot Spots	(HS)
Bruises	(BU)
Abrasions	(A)
Tinea Pedis	(TP)
Metatarsal Pain	(MP)
Dermatitis	(D)
Other____________