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BIOMECHANICAL ANALYSES OF BODY MOVEMENT AND LOCOMOTION AS AFFECTED BY CLOTHING AND FOOTWEAR FOR COLD WEATHER CLIMATES

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14. ABSTRACT
A study of Army cold weather clothing was conducted to determine effects on soldiers' movements and walking gait of adding layers of clothing to the body. Performance in a temperate duty uniform was also compared with performance in cold weather clothing, and differences in walking gait associated with regular combat boots and with cold weather foot gear were investigated. Study participants, 13 Army enlisted men, were each tested in seven clothing conditions. A video-based motion analysis system and a force plate were used to capture the maximum range of motion in various planes of the body and gait kinematics and kinetics. A total of 104 dependent variables were measured directly or derived. Analyses of variance revealed that adding clothing layers interfered with bending at the waist and moving the upper arm at the shoulder. Compared with the temperate duty uniform, cold weather clothing changed walking patterns; participants leaned further forward and moved the arms less at the shoulders with the multilayered clothing. The cold weather boots also interfered with leg swing, compared with regular combat boots. A principal components analysis yielded factors suggesting simple and complex metrics sensitive to effects of protective clothing on gait characteristics.

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PERFORMANCE CHARACTERISTICS	COMBAT BOOTS	WALKING	ARMY PERSONNEL

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Table of Contents

Table of Contents (continued)

Figures

Tables

Preface and Acknowledgements

The work reported here was conducted under U.S. Army Research, Development & Engineering Command (RDECOM), Natick Soldier Center contract DAAD16-03-F-0091 with Geo-Centers, Inc., Newton, MA. The work was performed at the Center for Military Biomechanics Research, Natick Soldier Center, during the period September 2002 to August 2004. Dr. Carolyn K. Bensel of the Center was the project officer for the contract. This project was part of the 6.2 program 1L162723AH98AA — Biomechanical Approach to Soldier-CIE Integration, which was carried out by Dr. Bensel and other members of the Center.

The authors wish to thank the men from the Enlisted Volunteer Platoon of the U.S. Army Soldier Systems Center for their participation in this study; and Dr. Tracey M. Bernard, Department of Occupational Safety and Health, Murray State University, Murray, KY, for assistance in the data-collection phase. The authors also gratefully acknowledge the contributions of Mr. John Redgate, Technical Editor, U.S. Army Soldier Systems Center.

BIOMECHANICAL ANALYSES OF BODY MOVEMENT AND LOCOMOTION AS AFFECTED BY CLOTHING AND FOOTWEAR FOR COLD WEATHER CLIMATES

INTRODUCTION

Military clothing designed for use in low temperature environments utilizes the layer principle, which states that several thin layers of insulation are more effective than one thick layer, and that several light garments are more versatile than a single heavy garment. Layering permits flexibility in response to climatic conditions, degree of exertion and activity, and personal preferences.

However, as layers of clothing increase, the wearer's range of motion may become restricted, and locomotor patterns may be adversely affected by the encumbrance of the garments. Therefore, a layered clothing system must be evaluated not only on how well it performs the intended protective function, but also on whether it impedes military performance by adversely affecting the Soldier's motor activity.

The layer principle is used in the U.S. Army's Extended Cold Weather Clothing System (ECWCS). The ECWCS is an insulating system that is intended to give adequate protection from cold and wet environments through a temperature range of +4.4 °C to -51.1 °C (+40 °F to -60 °F). The ECWCS system can be adjusted in accordance with temperature and weather conditions, activity levels, and individual preferences. It is designed to provide the appropriate amount of insulation while minimizing weight and bulk. It includes: 1) an inner layer for wicking moisture away from the skin; 2) an intermediate layer for thermal insulation, with primary and secondary subcomponents; and 3) an outer layer for protection against wind and exogenous moisture. Each clothing layer consists of an upper and a lower garment. Previous studies of the mobility effects of ECWCS have been based largely upon subjective ratings from Soldiers wearing the system in the field. Results indicate that the Soldiers are somewhat satisfied with the mobility allowed by ECWCS. With respect to freedom of movement, on a 7-point scale where a rating of "7" corresponded with "very good", ECWCS was given a mean rating of between 5 and 6 (Niro, 1994; Shearer & Peters, 1992). However, the mobility restrictions of ECWCS have apparently never been studied quantitatively.

Although a quantitative study of freedom of movement allowed by the various layers of the ECWCS and by the system as a whole has not been undertaken, such research has been done on the U.S. Army cold weather clothing system that the ECWCS replaced. Bensel, Bryan, and Mellian (1977) and Lockhart and Bensel (1977) tested the effects of the older system on simple body movements of men and women. They found that, as layers were added, there were significant decreases in flexion at the waist and in the extent of arm and leg movements in various planes of the body. The studies also revealed that some layers had a greater negative impact on performance than others, apparently due to differences among the layers in design and material composition.

The methods employed by Bensel et al. (1977) and by Lockhart and Bensel (1977) involved the performance of gross motor activities and the quantification of the maximum extent of movement about joints of the body. The tests they used have metrics that were established previously and that were found to be sensitive to the effects of clothing (Dusek, 1958; Dusek & Teichner, 1956; Saul & Jaffe, 1955). The methods have been applied in a number of studies conducted to quantify the restrictions imposed by various items of military clothing and individual equipment (Bensel, Fink, & Mellian, 1980; Bensel & Lockhart, 1975; Bensel, Teixeira, & Kaplan, 1987; McGinnis, 1972). The tests of gross motor performance differ somewhat in how they are carried out, but each yields a quantitative measure of the maximum extent of movement about joints of the body (Saul & Jaffe). The measurements are usually taken via gravity goniometers (Leighton, 1942).

Recently, the availability of computer-assisted motion analysis systems has extended the types of body movements that can be quantified. With these systems, test participants perform various movements while their activity is recorded using one or more cameras; multiple cameras allow for analysis of movement in three dimensions. Specialized software is used to examine the recordings, to locate and identify predefined points on the body, and to calculate the coordinate positions of the points in a calibrated spatial volume. In this way, a digital representation of the movement of the body's limbs and joints across time is obtained. From these kinematic data, numerous measures can be derived, such as linear and angular displacements, velocities, and accelerations.

There are several advantages to motion capture over older, goniometric techniques that have been used to measure the extent of rotational movement (Laubach, 1978; Leighton, 1942; Woods, Polcyn, O'Hearn, Rosenstein, & Bensel, 1997). Motion capture techniques are not limited to movements that are carried out in a vertical plane, as is the case when a gravity goniometer is used (Leighton). Motion capture allows an individual's uninterrupted motion to be quantified after it has occurred, which is expeditious and minimally intrusive; older methods require the participant to pause after each movement so that measurement devices can be read and reset before the participant continues. Motion capture also permits the study of continuous, repetitive, or cyclic movements, such as walking, crawling, and running, which is not possible using goniometric techniques. Analysis of naturalistic movements provides important insight into the way the clothing or equipment will behave on the Soldier in the field.

An additional technology often used in conjunction with kinematic analysis of motion involves acquisition of kinetic data, in the form of ground reaction force, by use of a force plate. A force plate is a rectangular device, with a flat rigid surface, upon which a participant stands or walks. The force plate typically incorporates either piezo-electric or strain gauge technology. It is used to measure the forces and moments exerted between a participant's body and the floor. In analyzing locomotion, ground reaction force is generally decomposed into three orthogonal components. The directions of the components, which are at right angles to each other, are vertical, antero-posterior, and medio-lateral. From the ground reaction force can be derived the movement of the center of mass of individuals (including their clothing and equipment) as they cross the plate.

This information, in turn, can be used to measure the relative efficiency of an individual's movement in various clothing and equipment conditions. In addition, the combination of kinetic data from the force plate and kinematic data from the camera system can be used to estimate the moments acting at various anatomical joints as an individual traverses the force plate.

The present study used kinematic and kinetic analysis to quantify the mobility effects of various configurations of the ECWCS system. Teitlebaum and Goldman (1972) found that walking in multilayered clothing resulted in energy expenditures beyond that due to the weight of the clothing itself. They recorded metabolic rates of men walking on a level treadmill at a velocity of 5.6 km/h (1.5 m/s) while wearing a five-layer cold weather clothing system weighing approximately 11 kg, and while wearing a work shirt and trousers and carrying the equivalent weight in a belt around the waist. Comparing metabolic rates under the two conditions, Teitlebaum and Goldman found an 18% increase in energy expended during walking with the layered clothing system. They attributed the increased energy cost in the multilayer garments to frictional resistance between layers and to the hobbling effect, or the interference with joint movements, due to clothing bulk. However, Teitlebaum and Goldman did not assess the effects that adding layers of clothing to the body had on range of motion about body joints or on the biomechanics of walking. In the present study, combinations of the ECWCS garments were used to examine the effects on kinematic and kinetic measures of adding clothing layers to the body.

A control condition consisting of the U.S. Army's temperate duty uniform was included in the present study. In their investigation of the predecessor clothing system to the ECWCS, Bensel et al. (1977) and Lockhart and Bensel (1977) confined their investigations to cold weather clothing items. They did not acquire control data on body movement capabilities with a regular duty uniform for temperate environments. Therefore, in the present study, participants were tested in the temperate battle dress uniform (TBDU) and combat boots, as well as in the ECWCS, in order to assess the extent to which cold weather clothing components restrict movements compared with the minimally encumbering TBDU.

There have been modifications in ECWCS components from the time of the initial introduction of the system into Army use. Some of these modifications have been focused on reducing the bulk of components. For purposes of the present study, it was determined that ECWCS items likely to impose constraints on movement would be used. Thus, the ECWCS items described in Appendix A were the cold weather clothing items used in this study.

The number of clothing layers worn was varied in the Bensel et al. (1977) and the Lockhart and Bensel (1977) studies, but the type of footwear worn was kept constant: All participants used athletic shoes throughout testing. In the present study, both torso clothing and footwear were varied. Participants were tested in the standard combat boots that are issued for temperate climates, as well as in the standard boots issued for cold weather use. Research has found an increase in the energy cost of walking when cold weather footwear is used, a finding ascribed to the mass of the footwear (Armor, Vogel, & Worsley, 1973; Soule & Goldman, 1969). The effects cold weather footwear may have on walking gait have not been investigated. The present study examined both simple, stylized movements performed discretely, which were used to identify any restrictions imposed by the garments at particular body locations, as well as the naturalistic, complex, and continuous movement of locomotion, which was used to identify changes in movement patterns caused by the footwear and by the ECWCS system.

The present study was carried out for four purposes. One was to determine the effects on performance of simple body movements and locomotor activities of adding layers of cold weather clothing. The second was to compare performance in the temperate duty uniform with performance in layers of the cold weather clothing. The third purpose was to examine the extent to which execution of simple body movements and locomotor activities differs as a function of the type of insulating liner material used. The fourth purpose was to contrast cold weather footwear and combat boots with respect to parameters of walking gait.

METHOD

Participants

Participants were 13 U.S. Army enlisted men assigned to Headquarters and Headquarters Detachment, U.S. Army Soldier Systems Center, Natick, MA. Summary statistics on the physical characteristics of the men are presented in Table 1.

In accordance with Army Regulation 70-25 (Use of Volunteers as Subjects of Research), potential volunteers were asked to participate after being informed of the purpose of the study, the nature of the test conditions, the risks associated with the study, all procedures affecting a volunteer's well-being, and a volunteer's right to discontinue participation at any time without penalty. Those who agreed to participate in the study expressed their understanding by signing a Volunteer Agreement Affidavit (DA Form 5303-R). The policies prescribed in Army Regulation 70-25 were followed throughout the study.

Table 1. *Anthropometric Measures and Garment Sizes of the Study Participants*

No.	Stature (mm)	Weight (kg)	Chest Circ. (mm)	Waist Circ.[a] (mm)	Crotch Ht. (mm)	Garment Sizes Worn		Boot Size
1	1802	100.7	1135	989	847	Extra Large	Long	10
2	1712	89.1	1110	925	757	Large	Regular	10
3	1757	96.0	1110	1000	870	Large	Regular	8
4	1835	99.5	1118	954	840	Large	Long	11
5	1712	61.3	915	672	751	Small	Regular	9
6	1859	90.3	1080	990	875	Large	Long	10
7	1808	85.4	1012	837	814	Medium	Long	10
8	1813	75.1	937	786	836	Medium	Long	9
9	1749	79.8	1015	840	784	Medium	Regular	10
10	1788	83.8	1102	835	806	Large	Regular	10
11	1687	81.7	1045	843	757	Medium	Regular	9
12	1729	69.1	915	835	785	Small	Regular	9
13	1877	82.4	984	791	896	Medium	Long	12
M	1780	84.2	1033	868	815	Medium[b]	Regular[b]	(10)[c]
SD	58	11.5	78	93	47			(1)[c]

[a]Measured at omphalion. [b]Average nominal values are those derived from the mean anthropometric values. [c]Because boot size is not a linear scale, the median and interquartile range here replace the mean (9.7) and standard deviation (1.0), respectively.

Clothing

Seven clothing conditions were tested in the study. Each condition was a different configuration of clothing items. The following components of the ECWCS were used: the polypropylene wicking layer worn next to the skin; the fiberpile insulating layer worn over the polypropylene items; the quilted insulating liners; the outer shell parka and trousers; and the insulated vapor barrier (VB) boots. Descriptions of the items are presented in Appendix A. In addition to these ECWCS garments, participants wore garments of their own, consisting of TBDUs, undergarments, socks, and combat boots. The combat boots had been broken in by the participants who owned them, whereas the VB boots were new.

Apparatus

Motion Capture Equipment

The participants' movements were recorded using a video-based motion analysis system from Peak Performance Technologies, Inc. (Centennial, CO). Three genlocked VHS video cameras and associated VCRs were used to record the motion. Three 650-W lamps, one adjacent to each camera, were used to illuminate the participant. Matte black backdrops were used for background portions of the test area. One camera was positioned to the rear of the participant, and the others at approximately 45° and 90° to the participant's sagittal plane on the right side of the body. The sampling frequency of the cameras was 60 Hz. Three time-code generators were used to encode the videotape.

Force Plate

The force plate measured 1.2 m × 0.6 m. It was manufactured by Advanced Mechanical Technology, Inc. (Watertown, MA). The force plate was situated upon a resin-leveled substrate in a pit in a concrete floor. The upper surface of the force plate was level with the floor. The force plate was used to measure ground reaction forces as the participant stepped on the plate. Force plate output was recorded for approximately 3 s at a sampling frequency of 1000 Hz.

The three video cameras were set up in the area of the force plate to record participants' movements as they walked across the force plate. An event synchronization unit was used to trigger the recording of the force plate outputs. At the time of triggering, the unit also emitted a signal that was recorded on the audio track of the videotapes. In this way, the collection of force plate and video data was linked in time.

Procedure

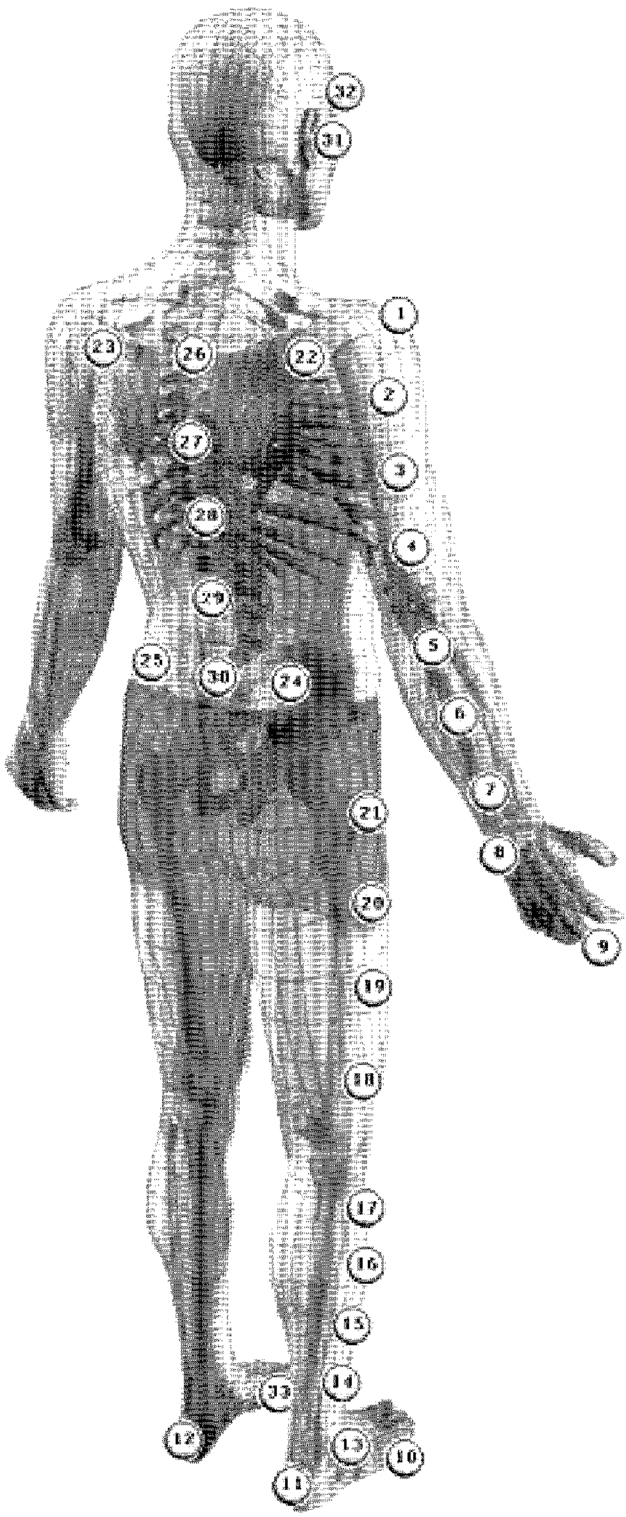
All phases of the experiment took place in the Center for Military Biomechanics Research at the U.S. Army Soldier Systems Center, Natick, MA. During data collection, ambient temperature was maintained at approximately +22 °C (+72 °F) for the comfort of the participants.

Each participant attended one orientation session, followed by four testing sessions. At the orientation session, body measurements were taken and participants were fitted with the clothing and footwear to be worn during testing (Table 1). In fitting the clothing, the sizes tried on first by the participants were determined by participants' body dimensions and Army sizing guidance. With the exception of one participant, this approach resulted in fits that were acceptable to the experimenters and to the participants. The body dimensions of one man were close to the top of the range for a size medium. The experimenters and the participant agreed that a size large rendered a better fit and that was the size used by the participant during the study.

During the orientation session, information on locations of anatomical landmarks was acquired for each participant. With the participant wearing only shorts, several anatomical landmarks on the right side of the body were located by palpation and marked; these were acromion, trochanterion, olecranon, radial styloid process, anterior superior iliac spine, lateral epicondyle, mid-patella, and lateral malleolus. The participant then put on combat boots and remained stationary in a relaxed standing posture while an anthropometer was used to measure height from the standing surface to the level of each landmark. These measurements were recorded and the process was repeated with the participant wearing vapor barrier boots. The landmark heights related to each footwear type were marked on a long and wide sheet of paper affixed to a wall. The participant stood next to the paper diagram wearing combat boots and vapor barrier boots while checks were made to insure that the marks on the diagram were aligned with the participant's anatomical landmarks. Subsequently, locations of equal-interval points along body segments were added to the diagram.

Each participant was also instructed to walk back and forth along a straight walkway, 9 m in length with a 0% grade. The gait velocity and the number of steps taken per minute were calculated. An auditory cadence signal was then introduced, which was at a temporal interval estimated to produce a walking speed of 5.6 km/h (1.5 m/s) for that individual. The participant walked following this cadence, and the gait velocity was calculated. Depending on the resulting velocity, the cadence was then made faster or slower. This process was reiterated until the cadence consistently produced a velocity within ±10% of the target 5.6 km/h (1.5 m/s). The temporal interval of the cadence was then recorded for use during the testing sessions.

At each of the next three sessions, the participants were tested in two of the seven clothing conditions and, at the fourth and final session, the participants were tested in one of the seven clothing conditions. Testing consisted of performance of simple body movements, from which range of motion (ROM) was measured, and walking along a walkway with a 0% grade. At a testing session, the participant was outfitted in the first clothing condition to be tested and reflective markers were placed on the clothing and the skin. The markers served to expedite processing of the videotaped movements. The simple movements and the walking trials were then carried out. When these were completed, there was a rest break and the procedure was repeated for the next clothing condition to be tested.



1) acromion
2) upper arm I
3) upper arm II
4) upper arm III
5) lower arm I
6) lower arm II
7) lower arm III
8) wrist stylion
9) fingertip
10) right toe
11) right heel
12) left heel
13) ankle
14) lower leg IV
15) lower leg III
16) lower leg II
17) lower leg I
18) upper leg IV
19) upper leg III
20) upper leg II
21) upper leg I
22) right shoulder back
23) left shoulder back
24) right hip back
25) left hip back
26) back I
27) back II
28) back III
29) back IV
30) back V
31) tragion
32) temple
33) left toe

Figure 1. Locations of the 33 reflective markers used for motion capture.

Marker Set

The reflective markers used varied in diameter from 15 to 25 mm, depending on their location. Figure 1 depicts the location of the markers. Although most of the markers were attached to the outer clothing, their locations are described in terms of body features.

For placing the markers, the participant stood in a relaxed posture with his back close to a wall. On the wall was the diagram depicting the vertical elevations and lateral displacements of the anatomical landmarks of that individual and the locations of equal-interval points along body segments. Using this scheme to locate body landmarks, markers were placed as follows:

Right arm and hand (9 markers). One marker was placed on the acromion process, three on the upper arm, three on the forearm, one on the wrist stylion, and one on the terminus of the middle finger (dactylion III). The upper and lower arm sets were placed equidistantly in straight lines along the lateral sides of the limb segments with respect to a relaxed standing posture.

Right foot (3 markers). One marker was placed at the location on the boot corresponding to the medial heel point at the rear of the foot, with the participant in a standing posture. One marker was placed corresponding to the lateral malleolus and one to the fifth metatarsophalangeal protrusion.

Left foot (2 markers). One marker was on the medial heel point and another was placed at the fifth metatarsophalangeal protrusion.

Right leg (8 markers). Four markers were placed equidistant from each other on the thigh and another four on the lower leg. Each set of markers was located in a straight line along the lateral surface.

Shoulders (2 markers). A pair of markers was placed on the back of the shoulders, at the points of maximum dorsal protuberance of the right and the left scapulas.

Hips (2 markers). A pair of markers was placed on the dorsal surface at points posterior to the locations of the left and the right anterior superior iliac spine. For clothing conditions that included the ECWCS parka, the markers were placed on a nylon web belt, 145 mm wide, which ensured that the markers would remain visible and in their intended locations.

Spine (5 markers). Five markers were placed equidistantly along the spine, with the superior at the level of the pair of markers on the shoulders and the inferior at the level of the pair of hip markers.

Head (2 markers). Two markers were placed on the right side of the head. One was placed on the tragion, and the other on the temple at a 45° angle to the tragion relative to the Frankfurt plane.

For purposes of efficient processing of the videotapes, olive-green camouflage paint was placed on exposed skin. This served to reduce skin highlights and to increase the contrast between the reflective markers and the participant's skin. The VB boots were also partly covered with olive-green tape in order to provide a dark, contrasting background for the reflective markers.

Testing of ROM and Walking Gait

Immediately before beginning execution of the ROM and the walking activities, the participant stood on the force plate and the weight of the participant plus the clothing comprising the condition being tested was measured. This value was used in the calculation of the kinetic variables that were expressed in Newtons per kilogram. The participant then performed eight ROM tasks. These were followed by two walking activities.

ROM testing. For the ROM activities, the participant was instructed to stand in a particular location with feet aligned to indicator lines on the floor, facing the appropriate direction. These instructions, which varied slightly among ROM activities, were intended to aid in stylizing the movement and to optimize the views of the video cameras. The experimenter gave the particular instructions for each movement, and the participant executed a movement five times in succession before performing the next movement. Three trials (trials 2, 3, and 4) were selected from the five for use in subsequent analyses. Each ROM activity is described in Appendix B.

Unpaced and paced walking. Walking gait was tested in two modes, unpaced and paced. For both modes, a participant walked along a level walkway, about 9 m long. The force plate was mounted flush with the walkway about 6 m along its length. The starting line for the walking was varied somewhat from trial to trial to insure that the participant's right foot completely contacted the force plate and the left foot did not make contact with the plate. Participants were instructed not to look at the force plate or to attempt to target it, and to continue walking for about 1.5 m after crossing it. The force plate was manually triggered by an experimenter as the participant entered the spatial volume calibrated for motion capture, approximately 0.5 s prior to initial heel contact.

For the unpaced trials, participants were instructed to walk along the walkway in a natural manner. This was done until five trials had been completed in which the right foot completely contacted the force plate. The unpaced trials were followed by paced trials. For this, the participant was instructed to follow the cadence of an audio pacing signal, which was generated on a PC. The audio signal was a tone following a marching cadence of the pattern: left, (pause), left, (pause), left, right, left. The pacing signal was set for each participant, based on the number of steps taken per minute during the orientation session, to achieve a walking speed of 5.6 km/h (1.5 m/s). The paced walking trials were executed until five trials had been completed which satisfied the criteria that: a) the participant kept the pace; b) the right foot completely contacted the force plate; and c) the left foot did not contact the force plate. Three unpaced and three paced trials were selected for use in subsequent analyses. Descriptions of the dependent measurements made on the walking activities are presented in Appendix C.

Study Design

Clothing Conditions

Table 2 defines the seven experimental conditions used in the study. The conditions varied by the number of clothing layers worn, and, within a given number of layers, by the components worn to comprise the layers. As indicated in Table 2, VB boots were used in all conditions in which cold weather clothing was worn.

The experimental conditions were chosen to permit the extraction of effects associated with: the number of layers of cold weather clothing used; the wearing of cold weather clothing versus a regular duty uniform; and the use of cold weather footwear versus regular combat boots. Also examined were the effects of insulation type, number of clothing layers, and the interaction between these variables.

Table 2. *Components of the Seven Clothing Conditions*

Condition 1: **Control, With Combat Boots**
- TBDU Coat/TBDU Trousers
- Combat Boots

Condition 2: **Control, With Vapor Barrier Boots**
- TBDU Coat/TBDU Trousers
- Vapor Barrier Boots

Condition 3: **2-Layer ECWCS**
- Polypropylene Undershirt/Polypropylene Drawers
- Cold Weather Parka/Cold Weather Field Trousers
- Vapor Barrier Boots

Condition 4: **3-Layer ECWCS, With TBDU**
- Polypropylene Undershirt/Polypropylene Drawers
- TBDU Coat/TBDU Trousers
- Cold Weather Parka/Cold Weather Field Trousers
- Vapor Barrier Boots

Condition 5: **3-Layer ECWCS, With Fiberpile**
- Polypropylene Undershirt/Polypropylene Drawers
- Fiberpile Shirt/Fiberpile Overalls
- Cold Weather Parka/Cold Weather Field Trousers
- Vapor Barrier Boots

Condition 6: **4-Layer ECWCS, With TBDU**
- Polypropylene Undershirt/Polypropylene Drawers
- TBDU Coat/TBDU Trousers
- Parka Liner/Field Trouser Liner
- Cold Weather Parka/Cold Weather Field Trousers
- Vapor Barrier Boots

Condition 7: **4-Layer ECWCS, With Fiberpile**
- Polypropylene Undershirt/Polypropylene Drawers
- Fiberpile Shirt/Fiberpile Overalls
- Parka Liner/Field Trouser Liner
- Cold Weather Parka/Cold Weather Field Trousers
- Vapor Barrier Boots

Each participant was tested in all seven clothing conditions. The order in which conditions were tested across participants was determined by a digram-balanced Latin square.

Dependent Variables

There was a single dependent variable for each ROM activity. The variable was the angular or linear range associated with the particular movement. The variables are described in Appendix B. For unpaced and paced walking, numerous kinematic and kinetic variables were obtained. The same variables were used to describe both modes of walking. The dependent variables for walking are described in Appendix C.

Statistical Analyses

Before the data were analyzed, they were examined for outliers. There were some trials of unpaced and paced walking in which outliers and spurious data were identified. In the case of five participants, questionable data were identified on one or more trials and the data of these participants were dropped from further analyses. The number of participants included in the analyses of the ROM activities was 13 and the number included in the unpaced and the paced walking was eight.

A number of repeated-measures analyses of variance (ANOVAs) were carried out on the dependent measures. The raw data for a measure that were entered into the analyses were the means of each participant's three trials on a given activity under a clothing condition. One-way repeated-measures ANOVAs were performed to analyze the following effects: the number of layers of cold weather clothing (two, three, and four layers; clothing conditions 3, 5, and 7, respectively); layers of cold weather clothing versus the temperate uniform (two, three, and four layers of cold weather clothing and control; clothing conditions 3, 5, 7, and 1, respectively); and footwear type (combat boots and vapor barrier boots; clothing conditions 1 and 2, respectively). A two-way repeated-measures ANOVA was carried out to examine the effects of insulation type (fiberpile and TBDU) and number of cold weather clothing layers (three and four layers). Clothing conditions 4 through 7 were included in this analysis.

The statistical analyses were accomplished using SPSS for Windows 10.0.5. Significance levels for all ANOVAs were set at $p < .05$. In those instances in which an ANOVA yielded a significant main effect or interaction effect, post-hoc analyses in the form of paired t tests were carried out, with appropriate adjustments being made to the alpha levels by use of a sliding-scale Bonferroni procedure. Correlations in the form of Pearson product-moment correlation coefficients (r) were also calculated between all dependent measures, and a principal components analysis was performed upon the unpaced and paced gait variables.

RESULTS AND DISCUSSION

Summary statistics for the dependent measures associated with the ROM activities, unpaced walking, and paced walking are provided in Appendix D. Following are the results of the analyses of the effects of the number of layers of cold weather clothing, the effects of layers of cold weather clothing versus the temperate uniform control, the layer by liner factorial, and the effects of footwear type. Within each of these analyses, results are presented separately for the ROM data, the unpaced gait data, and the paced gait data.

Effects of the Number of Layers of Cold Weather Clothing

The effects of wearing two, three, or four layers of cold weather clothing were examined using the data for clothing conditions 3, 5, and 7, respectively. The components comprising each condition are listed in Table 3. The results of the ANOVAs performed on the dependent variables are summarized in Appendix E for those variables that yielded significant effects. One of the analyses done on the ROM activities yielded a significant layer effect, as did several of the analyses of the unpaced and the paced gait variables. The means for the variables found to be significantly affected by the number of clothing layers are presented in Table 4.

Table 3. *Components of the Conditions Analyzed to Examine Effects of Layers of Cold Weather Clothing*

	Condition						
Component	1	2	3	4	5	6	7
Vapor barrier boots			■		■		■
Polypropylene layer (undershirt & drawers)			■		■		■
Fiberpile layer (shirt & overalls)			--		■		■
Liner layer (parka & trouser liners)			--		--		■
Outer shell layer (parka & field trousers)			■		■		■
	Control		2 Layers	3 Layers		4 Layers	

Note. Bullets (■) indicate components worn within a condition.

Table 4. *Mean Comparisons for Variables Reflecting a Significant Effect of Layers of Cold Weather Clothing*

	Dependent Variable	Two Layers	Three Layers	Four Layers
	Range of Motion			
R1	Standing trunk flexion (m)	0.695_{A} (0.072) 11	0.656_{B} (0.085) 13	0.641_{C} (0.094) 12
	Unpaced Gait			
UA5	Hip abduction (deg)	-0.2_{A} (5.26) 8	3.8_{B} (4.74) 8	5.4_{B} (2.98) 8
UA11	Ankle varus/valgus (deg)	43.6_{A} (10.5) 8	51.2_{AB} (16.4) 8	58.4_{B} (23.1) 8
UA12	Trunk tilt (deg)	-2.3_{A} (5.39) 8	-0.6_{AB} (4.46) 8	0.8_{B} (4.19) 8
UA16B	Shoulder range, sagittal (deg)	32.7_{A} (11.5) 8	29.5_{AB} (11.5) 8	22.9_{B} (11.2) 8
UX4	Amplitude of maximum propelling force (N/kg)	2.55_{A} (0.333) 8	2.34_{B} (0.258) 8	2.51_{AB} (0.398) 8
	Paced Gait			
PA16	Shoulder extension (deg)	19.1_{AB} (8.9) 8	23.5_{A} (11.6) 8	12.4_{B} (5.3) 8
PA16B	Shoulder range, sagittal (deg)	32.1_{A} (13.5) 8	30.1_{A} (12.3) 8	19.9_{B} (5.4) 8
PZ2	Amplitude of 1^{st} force peak (N/kg)	11.3_{A} (0.64) 8	11.5_{A} (0.61) 8	11.1_{B} (0.83) 8

Note. For each dependent variable, means that do not share the same subscript were significantly different ($p < .05$) on post-hoc tests. The *SD* and the *n* appear below each mean.

ROM Results

There was a significant decrement in standing trunk flexion (R1) at each level of increase in the number of layers, that is, going from two layers to three layers by adding the fiberpile layer, and going from three layers to four layers by adding the quilted liners to the parka and field trousers (Table 4). Adding the third layer resulted in a 6% decrement in the extent of flexion at the waist, and adding the fourth layer resulted in an additional decrement of 2%.

Unpaced Gait Results

None of the temporal variables (UT1-UT12) for unpaced gait were significantly affected by the number of layers worn, and only one of the kinetic variables yielded significant findings (Table 4). This was the amplitude of maximum propelling force (UX4). The maximum force did not change directly with the number of clothing layers; rather the largest force values were associated with the two and the four layer conditions. Thus, going from two layers to three was associated with a decrease in the force amplitude. This is the reverse of what was predicted. Although the one-tailed probability (.011) is significant, the two-tailed probability is not. Given that four layers did not differ significantly from two layers, and that this dependent variable did not manifest a significant interaction effect in the layers-by-insulation factorial (presented below), the omnibus F result cannot be considered meaningful.

Increasing the number of layers from two to either three or four was associated with a significant increase in hip abduction (UA5) during unpaced walking. On the remaining variables found to be significantly affected by the number of layers (UA11, UA12, UA16B), the extreme conditions, the two and the four layers, differed significantly, but the three-layer condition did not differ from the other two (Table 4). For the remaining variables, as layers were added, the range of ankle varus/valgus (UA11) increased, the sagittal range of movement of the arm at the shoulder (UA16B) decreased, and trunk tilt (UA12) increased, with the angle of the trunk changing from slightly negative with two layers of clothing to a slight forward lean with four layers.

Paced Gait Results

Again, none of the temporal gait variables (PT1-PT12) were significantly affected by the number of layers worn and only one of the kinetic variables yielded significant findings (Table 4). In the case of paced gait, the kinetic variable was amplitude of the first vertical force peak (PZ2). For this variable, both two and three layers differed significantly from four layers in a one-tailed test, but in the opposite direction from that predicted. The highest force value was obtained under the three-layer condition and the lowest under the four-layer; the value for the two-layer condition was intermediate to these. Going from three to four layers resulted in a 3% decrease in the amplitude of the first vertical force peak and going from three to two layers resulted in a 2% decrease.

Shoulder extension (PA16) during paced gait was significantly affected by the number of layers (Table 4). Like the findings for the first vertical force peak, shoulder extension did not vary directly with the number of layers. The highest value, indicating greater backward rotation of the arm at the shoulder in the sagittal plane, was achieved when the three-layer condition was worn, and the lowest with the four-layer condition. The values for these conditions differed significantly. The intermediate value, that of the two-layer condition, did not differ significantly from either of the extreme values. Shoulder range of motion in the sagittal plane (PA16B) decreased as the number of layers increased. The two- and the three-layer conditions did not differ significantly. The four-layer condition resulted in values that were significantly lower than those for the other conditions and reflected a substantial reduction in range of motion of the arm at the shoulder. The range of motion was reduced by more than 32% when the fourth layer was worn, relative to the two- and the three-layer conditions.

Discussion

The decrease in the extent of standing trunk flexion can be attributed to the additional bulk of the garments as the number of layers increased. It appears that, when the wearer bent at the waist, the garments compressed until they were more resistant than the body's soft tissue, at which point the fabric of the garments occupied intra-angular space that the soft tissue would otherwise be displaced into. The ability to bend was then impeded because the compressed garments effectively got in the way; the angle could not decrease because the compressed garments were inside of it. It does not appear that trunk flexion was constrained by any failure of the garments to stretch or shift; the polypropylene underwear stretched and the other layers shifted quite freely. A similar effect of the bulkiness of the layers seems to have been manifested in the increased hip abduction during unpaced walking: The thickness of the layers at the crotch and thighs caused the legs to be held further apart because it was effortful to adduct them against the resistance of the garments.

Considering the findings from analyses of unpaced and paced walking, the gait patterns seem more labored as the number of clothing layers increased from two to four, with participants leaning the body forward more and swinging the arms less. This is a less efficient gait than evidenced when only two clothing layers were worn, as manifested by the decreased propelling force and the sharper initial vertical amplitude spike. The increased ankle varus/valgus with an increasing number of clothing layers may reflect a stabilizing compensation to the forward lean, and may also follow from the forced hip abduction as the increasing number of layers induced a somewhat waddling gait.

Effects of Layers of Cold Weather Clothing versus the Temperate Uniform

Performance in the TBDU (control, clothing condition 1) was compared with performance in two, three, and four layers of cold weather clothing (clothing conditions 3, 5, and 7, respectively). The components comprising the clothing conditions are listed in Table 5. Appendix E contains the results of the ANOVAs for the dependent measures that yielded significant effects. The results of contrasts between the mean for the TBDU condition and the means for each of the three cold weather clothing conditions are provided in Table 6 for those variables associated with significant ANOVA findings.

Table 5. *Components of the Conditions Analyzed to Examine Effects of Cold Weather Clothing Layers vs. Temperate BDU Control*

	Condition						
Component	1	2	3	4	5	6	7
Combat boots	■		--		--		--
Temperate BDU (coat & trousers)	■		--		--		--
Vapor barrier boots	--		■		■		■
Polypropylene layer (undershirt & drawers)	--		■		■		■
Fiberpile layer (shirt & overalls)	--		--		■		■
Liner layer (parka & trouser liners)	--		--		--		■
Outer shell layer (parka & field trousers)	--		■		■		■
	Control		2 Layers	3 Layers		4 Layers	

Note. Bullets (■) indicate components worn within a condition.

Table 6. *Mean Comparisons for Variables Reflecting a Significant Effect of Cold Weather Clothing Layers vs. TBDU Control*

	Dependent Variable	TBDU Control	Two Layers	Three Layers	Four Layers
	Range of Motion				
R1	Standing trunk flexion (m)	0.673_A (0.065) 13	0.695 (0.072) 11	0.656_B (0.085) 13	0.641_B (0.094) 12
R2	Unilateral upper arm abduction (deg)	172_A (13.4) 13	172 (14.2) 10	166_B (18.7) 12	162_B (19.5) 11
R5	Bilateral upper arm forward extension (deg)	164_A (12.5) 13	161 (13.4) 11	152_B (17.3) 13	151_B (22.9) 12
R8	Pack reach (m)	0.400_A (0.064) 9	0.430_B (0.068) 6	0.477_B (0.075) 9	0.474_B (0.085) 11

Table 6. (*Continued*)

	Dependent Variable	TBDU Control	Two Layers	Three Layers	Four Layers
		Unpaced Gait			
UA11	Ankle varus/valgus (deg)	42.8 (12.5) 8	43.6 (10.5) 8	51.2 (16.4) 8	58.4 (23.1) 8
UA12	Trunk tilt (deg)	-2.8_A (4.34) 8	-2.3 (5.39) 8	-0.6_B (4.46) 8	0.8_B (4.19) 8
UA14B	Shoulder range, coronal (deg)	17.8_A (5.11) 8	17.9 (5.93) 8	14.5_B (4.72) 8	13.1_B (4.30) 8
UA15	Shoulder flexion (deg)	-14.5_A (8.51) 8	-13.2 (10.21) 8	-5.9_B (7.20) 8	-8.0_B (9.49) 8
UA16B	Shoulder range, sagittal (deg)	34.7_A (13.7) 8	32.7 (11.5) 8	29.5_B (11.5) 8	22.9_B (11.2) 8
		Paced Gait			
PA12	Trunk tilt (deg)	-3.1_A (3.69) 8	-1.7 (5.17) 8	0.0_B (3.62) 8	2.1_B (6.78) 8
PA14	Shoulder adduction (deg)	2.7_A (5.59) 8	7.2 (5.55) 8	9.6_B (2.80) 8	8.8_B (3.86) 8
PA15	Shoulder flexion (deg)	-14.3_A (7.74) 8	-13.1 (10.36) 8	-6.6_B (5.81) 8	-7.5 (8.29) 8
PA16	Shoulder extension (deg)	20.2 (11.8) 8	19.1 (8.9) 8	23.5 (11.6) 8	12.4 (5.3) 8
PA16B	Shoulder range, sagittal (deg)	34.5_A (11.2) 8	32.1 (13.5) 8	30.1 (12.3) 8	19.9_B (5.4) 8

Note. For each dependent variable, layer conditions with subscripts differed significantly ($p < .05$) from the TBDU condition on post-hoc tests. The *SD* and the *n* appear below each mean.

ROM Results

The three-layer condition and the four-layer condition each differed significantly from the TBDU control condition on several of the range of motion variables. The two-layer condition differed from the TBDU on only one dependent measure (Table 6). On each variable for which a significant difference was obtained, the TBDU control was associated with a greater range of motion compared with the cold weather clothing condition.

Relative to the TBDU, the three- and the four-layer conditions resulted in decreases in standing trunk flexion (R1) of 2.5% and of 4.75%, respectively. Unilateral upper arm abduction (R2) decreased in the three-layer condition by 3.4%, and in the four-layer condition by 6%, compared with the TBDU. Bilateral upper arm forward extension (R5) decreased by 7% with three layers, and by 8% with four layers.

For the pack reach measure (R8), all cold weather clothing conditions differed significantly from the TBDU control (Table 6). Higher values on this measure indicate more limited pack reach. With two layers of cold weather clothing, the extent of the arm reach was reduced by about 8% relative to the TBDU condition; the reduction for the three- and the four-layer conditions was about 20%.

Unpaced Gait Results

None of the temporal variables (UT1-UT12) or the kinetic variables for unpaced gait differed between the control and the layered conditions. Several angular variables showed significant differences for three layers and for four layers of cold weather clothing compared with the TBDU control condition. There were no instances in which the two-layer condition and the TBDU differed significantly (Table 6).

For trunk tilt (UA12), wearing the third or the fourth layer of cold weather clothing significantly increased the trunk tilt forward from a negative angle relative to the vertical for the control condition to a positive angle for the four-layer condition. Three shoulder angle variables revealed significant differences between the TBDU control and the cold weather clothing (Table 6). For coronal shoulder range (UA14B), three layers decreased the range of movement between maximum shoulder adduction and abduction by 3 degrees; wearing the fourth layer decreased the range further, to a 5-degree decrement from the control. The extent of shoulder flexion (UA15) and of range of movement of the arm at the shoulder in the sagittal plane (UA16B) both reflected reductions for the three- and the four-layer conditions relative to the TBDU condition. Shoulder flexion was reduced by 60% and by 45% with the three- and the four-layer conditions, respectively. For range of shoulder movement, the reductions were 15% and 34%, respectively.

Although the omnibus F-value for ankle varus/valgus range (UA11) was significant, the mean comparisons were not (Table 6). However, the range was greater for the three- and the four-layer conditions compared with the TBDU control.

Paced Gait Results

As for unpaced gait, none of the temporal or the kinetic variables were affected. Further, there were again no instances in which the two-layer condition and the TBDU differed significantly. The effects for trunk tilt (PA12) were similar to those in unpaced gait, and were greater in magnitude. The three-layer condition differed significantly from the control by tilting the trunk slightly forward of the vertical. With the four-layer condition, the extent of forward trunk tilt was further increased (Table 6).

As in the unpaced gait, effects on some shoulder movements were found, but they did not manifest as strongly as in unpaced gait. Shoulder adduction (PA14) increased significantly in the three- and the four-layer conditions, relative to the TBDU control (Table 6). Shoulder flexion (PA15) showed a significant difference from the TBDU only in the three-layer condition, and the extent of flexion was reduced by about 50% relative to that with the TBDU. The sagittal shoulder range of movement (PA16B) was significantly less than the range with the TBDU only when four layers of cold weather clothing were worn. There was a reduction of 42% with the four layers.

Although the omnibus F was significant for shoulder extension (PA16), none of the layered conditions were found in mean contrasts to differ significantly from the control.

Discussion

With regard to unpaced and paced walking, the effects of the clothing layer conditions, as compared to the effects of the relatively unencumbered control condition, appear to be a constrained gait. This was manifested in an essentially vertical or forward lean position of the trunk with the arms down at the sides of the body and somewhat adducted. It was also found that, when the encumbering layers were worn, the arms were not moved in the sagittal plane to as great an extent as they were when the layers were not being worn. The arms might have been positioned in this manner to aid in maintaining body stability, given that trunk angle differed between the unencumbered TBDU condition and the layer conditions.

The range of motion activities reflected a constraining of arm movements at the shoulder when layers of cold weather clothing were worn, compared with the movements when the body was not encumbered in the clothing layers. This raises the possibility that the reduced extent of arm movements during walking is attributable to constraints at the shoulder imposed by the clothing layers, rather than to a postural adaptation to maintain body stability.

Insulation Type by Cold Weather Clothing Layers Factorial

In the data for the two series of analyses presented previously, the type of insulating material was limited to the fiberpile. A factorial analysis was performed for the purpose of examining any effects of the type of insulating material (fiberpile and TBDU), and to determine whether or not the effects of material type differed as a function of the number of layers (three or four layers) of cold weather clothing worn. The data for clothing conditions 4 through 7 were included in this series of analyses. Table 7 is a list of the components comprising each of the conditions. Appendix E lists the results of the factorial ANOVAs for each dependent variable that yielded a significant main effect or a significant interaction. Results for the main effect of number of layers are not of interest in these analyses and will not be discussed here, but the data are included for completeness. Means and standard deviations for variables that yielded a significant main effect of insulation type or layers are presented in Table 8; means and standard deviations for variables yielding a significant interaction are in Table 9.

Table 7. *Components of the Conditions Analyzed in the Insulation Type by Cold Weather Clothing Layers Factorial*

	Condition						
Component	1	2	3	4	5	6	7
Vapor barrier boots				■	■	■	■
Polypropylene layer (undershirt & drawers)				■	■	■	■
TBDU Layer (coat & trousers)				■	--	■	--
Fiberpile layer (shirt & overalls)				--	■	--	■
Liner layer (parka & trouser liners)				--	--	■	■
Outer shell layer (parka & field trousers)				■	■	■	■
	Control		2 Layers	3 Layers		4 Layers	

Note. Bullets (■) indicate components worn within a condition.

ROM Results

Insulation type significantly affected the extent of upper leg flexion (R6), but not in the direction expected. Relative to the TBDU, range of movement was greater, by about 6%, when the fiberpile was used (Table 8). No other ROM variables yielded a significant main effect of insulation type.

There was a significant interaction between insulation type and number of layers on only one ROM activity, lateral waist flexion (R7). The significant interaction was attributable to the fact that, when the TBDU was used, the extent of flexion was less with four than with three clothing layers, whereas the opposite was the case when the fiberpile was used. The findings from the contrasts among the means for waist flexion were opposite to the direction expected (Table 9). That is, the extent of waist flexion was significantly greater with the four-layer fiberpile than with the three-layer fiberpile or the four-layer TBDU. There is no obvious explanation for this result.

Table 8. *Means (and Standard Deviations) for Variables Yielding a Significant Main Effect of Insulation Type or Number of Cold Weather Clothing Layers in the Type by Layers Factorial Analyses*

		Insulation Type		Number of Layers	
		TBDU	Fiberpile	Three	Four
	Dependent Variable	(Conds. 4 & 6)	(Conds. 5 & 7)	(Conds. 4 & 5)	(Conds. 6 & 7)
	Range of Motion				
R2	Unilateral upper arm abduction (deg)	--	--	167.4 (16.04)	166.9 (16.21)
R6	Upper leg flexion (deg)	70.14 (12.49)	74.86 (13.64)	--	--
	Unpaced Gait				
UT1	Stride length (m)	--	--	1.71 (0.089)	1.65 (0.070)
UT12	Gait velocity (m/s)	--	--	1.38 (0.185)	1.28 (0.105)
UA2	Pelvic obliquity (deg)	--	--	7.92 (2.189)	9.06 (2.694)
UA13	Shoulder abduction (deg)	--	--	24.74 (4.095)	21.01 (4.298)
UA14B	Shoulder range, coronal (deg)	--	--	16.38 (5.17)	13.62 (3.96)
UA16	Shoulder extension (deg)	--	--	24.53 (10.11)	15.22 (7.54)
UA16B	Shoulder range, sagittal (deg)	--	--	31.91 (11.14)	23.19 (10.13)

Table 8. (*Continued*)

	Dependent Variable	Insulation Type: TBDU (Conds. 4 & 6)	Insulation Type: Fiberpile (Conds. 5 & 7)	Number of Layers: Three (Conds. 4 & 5)	Number of Layers: Four (Conds. 6 & 7)
		Paced Gait			
PT1	Stride length (m)	--	--	1.74 (0.105)	1.64 (0.095)
PA2	Pelvic obliquity (deg)	--	--	8.15 (2.43)	9.54 (3.71)
PA16	Shoulder extension (deg)	--	--	25.7 (11.5)	14.5 (9.0)
PA16B	Shoulder range, sagittal (deg)	31.04 (13.42)	25.02 (10.58)	33.80 (12.68)	22.26 (8.91)
PZ6	Amplitude of 2^{nd} force peak (N/kg)	11.97 (0.93)	12.34 (1.26)	--	--

Note. Dashes indicate a nonsignificant main effect ($p > .05$).

Unpaced Gait Results

The two insulation conditions did not differ significantly on any of the variables for unpaced gait (Table 8). However, there was one significant interaction, and it occurred on the pelvic obliquity variable (UA2; Table 9). With the TBDU as the insulating layer, range of movement changed little as clothing layers were increased from three to four. When the fiberpile served as the insulation, range of movement was greater with four than with three clothing layers. Contrasts among the means indicated that pelvic obliquity was greater in the four-layer fiberpile condition than in either of the three-layer conditions. There was not a significant difference between the fiberpile and the TBDU when four layers of clothing were used (Table 9).

Paced Gait Results

A significant main effect of insulation type was found on two variables for paced walking (Table 8). When compared to the TBDU, the fiberpile garments produced a significant decrease in shoulder range of motion in the sagittal plane (PA16B) of about 19%. One kinetic variable was affected: Relative to the TBDU, fiberpile insulation was accompanied by a 3% increase in the amplitude of the 2^{nd} vertical force peak (PZ6).

Analyses of the paced walking data yielded four significant interactions between the type of liner and the number of clothing layers (Table 9). Among these were the variables stride period (PT2) and gait velocity (PT12). When the TBDU was used, stride period was shorter and gait velocity higher with four than with three clothing layers. With the fiberpile insulation, stride period was longer and velocity lower when four layers were worn, compared with three. Contrasts of the means for stride period (PT2) indicated that the shortest stride period was for the TBDU four-layer condition. The value for this condition differed significantly from those for the TBDU three-layer and the fiberpile four-layer conditions (Table 9). Gait velocity (PT12) was significantly slower for the fiberpile four-layer condition than for the other three conditions.

Table 9. *Mean Comparisons for Variables Reflecting a Significant Interaction Effect in the Type of Insulation by Clothing Layers Factorial Analyses*

Dependent Variable		Three Layers TBDU	Three Layers Fiberpile	Four Layers TBDU	Four Layers Fiberpile
		Range of Motion			
R7	Lateral waist flexion (m)	0.234_{AB} (0.053) 11	0.217_{A} (0.059) 11	0.226_{A} (0.038) 11	0.237_{B} (0.048) 12
		Unpaced Gait			
UA2	Pelvic obliquity (deg)	8.20_{A} (2.50) 8	7.64_{A} (1.95) 8	8.10_{AB} (1.85) 8	10.02_{B} (3.17) 8
		Paced Gait			
PT2	Stride period (s)	1.32_{A} (0.156) 8	1.28_{AB} (0.241) 8	1.21_{B} (0.094) 8	1.38_{A} (0.245) 8
PT12	Gait velocity (m/s)	1.35_{A} (0.157) 8	1.38_{A} (0.256) 8	1.39_{A} (0.139) 8	1.20_{B} (0.202) 8
PA9	Ankle plantarflexion (deg)	18.0_{A} (4.79) 8	14.0_{AB} (4.89) 8	14.2_{B} (6.07) 8	18.2_{AB} (8.02) 8
PZ2	Amplitude of 1st force peak (N/kg)	11.4_{AB} (0.64) 8	11.5_{A} (0.61) 8	11.5_{A} (0.70) 8	11.1_{B} (0.83) 8

Note. For each dependent variable, means that do not share the same subscript were significantly different ($p < .05$) on post-hoc tests. The *SD* and the *n* appear below each mean.

Another of the significant interactions in the analyses of the paced walking data was for the ankle plantarflexion measure (PA9). On this measure, the TBDU was associated with a decrease in plantarflexion and the fiberpile with an increase as the number of layers was increased from three to four. The TBDU three-layer condition had the highest mean value and the TBDU four-layer condition the lowest on the ankle plantarflexion measure. Contrasts of the means indicated that the value for the TBDU three-layer condition differed significantly only from the value for the TBDU four-layer condition (Table 9). The fourth variable for which a significant interaction was obtained in analyses of paced walking was the amplitude of the 1st force peak (PZ2). When the TBDU was worn, there was little difference between the amplitudes in the three- and the four-layer conditions; but, when the fiberpile was worn, the amplitude was lower for the four- than for the three-layer condition (Table 9). The fiberpile four-layer condition was also associated with the lowest amplitude for the 1st force peak. The mean for this condition differed significantly from both the mean of the fiberpile three-layer and the mean of the TBDU four-layer conditions.

Discussion

It was expected that any differences obtained on the ROM activities as a function of insulation type would favor the TBDU; the fiberpile is thicker, less compressive, and less flexible than the nylon/cotton material of which the TBDU is made. However, use of the TBDU limited upper leg flexion compared with use of the fiberpile. The means for the individual clothing conditions (Appendix D) indicated that both conditions in which the TBDU was incorporated (conditions 4 and 6) resulted in more limited upper leg flexion than the parallel conditions in which the fiberpile was incorporated (conditions 5 and 7). As part of the design of the ECWCS, the fiberpile layer was dimensioned to be worn directly over the polypropylene underwear. The TBDU, on the other hand, was sized to be worn over regular underwear shorts and a T-shirt. It is possible that the underlying polypropylene layer resulted in a tight fit of the TBDUs and, thus, the greater constraint on leg flexion with the TBDUs than with the fiberpile.

The finding from the paced walking data that shoulder range of motion in the sagittal plane differed with insulation type was in the expected direction: Shoulder range of motion was more restricted with the fiberpile than with the TBDU liner. The reason for the attenuated amplitude on the 2nd vertical force peak under the fiberpile compared with the TBDU condition during paced walking is not clear, but suggests that kinetic variables be investigated further for their sensitivity to material differences.

Some of the effects of insulation type and garment layers manifested only in certain combinations, hence the significant interaction effects on some variables. Stride period for paced walking was longest when four layers of clothing were worn and the insulating material incorporated in the layers was fiberpile. The slowest paced gait velocity was also achieved under this combination, as were the largest plantarflexion angle and the lowest amplitude of 1st peak force during paced walking. It would appear that some characteristics of the four-layer/fiberpile combination, including possibly the general bulkiness of it, resulted in a gait pattern that differed somewhat from the pattern with the other insulating material and layer combinations.

Effects of Footwear Type

For this analysis, the unpaced and the paced walking variables were analyzed. The clothing conditions included were conditions 1 and 2 (Table 10). The TBDU was the torso clothing worn with both boot types. The results of the ANOVAs in which significant effects were obtained are presented in Appendix E.

Table 10. *Components of the Conditions Analyzed to Examine Effects of Footwear Type*

	Condition						
Component	1	2	3	4	5	6	7
Combat boots	■	--					
Vapor barrier boots	--	■					
Temperate BDU (coat & trousers)	■	■					
	Control		2 Layers	3 Layers		4 Layers	

Note. Bullets (■) indicate components worn within a condition.

Unpaced Gait Results

Use of the VB boots resulted in a significant delay in the time to maximum braking force (UX2), which was increased by 9.6% compared with the value for the combat boots. This temporal measure is expressed as a percentage of the gait cycle. When combat boots were worn, the maximum braking force occurred at an average proportion of 16.6% of the gait cycle; when VB boots were worn, it occurred at an average of 18.2% of the gait cycle (Appendix D). Although analyses of stride period and gait velocity did not yield significant differences between footwear types, the mean value of stride period for the VB boots exceeded that for the combat boots by about 5%, and gait velocity for the VB boots was about 3% slower (Appendix D).

Paced Gait Results

Hip flexion (PA3) increased significantly, by 6.4 degrees, when VB boots were worn (Appendix D). No other variables were significantly affected by footwear during paced gait.

Discussion

The VB boots are thick and extremely bulky; it is likely that the increased hip flexion resulted from a style of gait in which the feet are not so much swung forward, but rather lifted and planted. The delay in maximum braking force associated with the VB boots, compared with the combat boots, is likely due to the fact that the VB boots are less stable. The fit characteristics of the VB boots are such that the foot tends to move within the boots in the transverse plane relative to the sole.

Intervariable Correlations and Principal Components Analysis

Including the ROM activities, unpaced walking, and paced walking, 104 dependent variables were analyzed in the present study. Correlation coefficients were calculated to examine the relationships between all variables. The unpaced and paced gait variables were also included in a principal components analysis.

Intervariable Correlations

A graphic depiction of the magnitude of correlations between all the dependent variables, arranged by category, is presented in Figure 2. The triangular region represents the elements below the main diagonal in a symmetric matrix. The large number of variables precluded text labeling of the axes; categorical labels were used instead. The labels are located along the diagonal. Because the directional relationships of many of the variables are arbitrary, the magnitude of r is plotted, rather than the r value itself; this presentation was chosen to facilitate graphic interpretation. Each plotted cell represents the absolute value of the correlation between the variable located on the diagonal vertically above the cell and the variable located on the diagonal horizontally to the right of the cell. Within the categories along the diagonal, variables appear in the order in which they are listed in Appendices B and C.

It can be seen in Figure 2 that the kinetic variables tended to be highly correlated within both the unpaced and the paced gait conditions (dark regions along the border) and between the unpaced and the paced conditions (dark square region at bottom center). The temporal variables also showed high correlations within the paced and the unpaced conditions (dark regions along the border). However, the temporal variables for the unpaced data were not highly correlated with those for the paced data. The non-temporal kinematic metrics correlated highly between the unpaced and the paced data (the dark diagonal band).

Principal Components Analysis

A principal components analysis was conducted on the gait data with the intent of elucidating any emergent properties that would better characterize gait than the unitary metrics used in the present study. The possibility of reducing, in future studies of torso clothing, the number of dependent variables measured directly or derived was also a consideration in carrying out the principal components analysis.

A Varimax rotation using Kaiser normalization converged in 33 iterations. Smith and Miao (1994) reported that, based on simulation studies, eigenvalues of less than 1.4 are effectively no better than random. Use of this criterion retained a set of 17 factors, which captured 89.3% of the variance. Factor loadings of the dependent variables appear in Table 11.

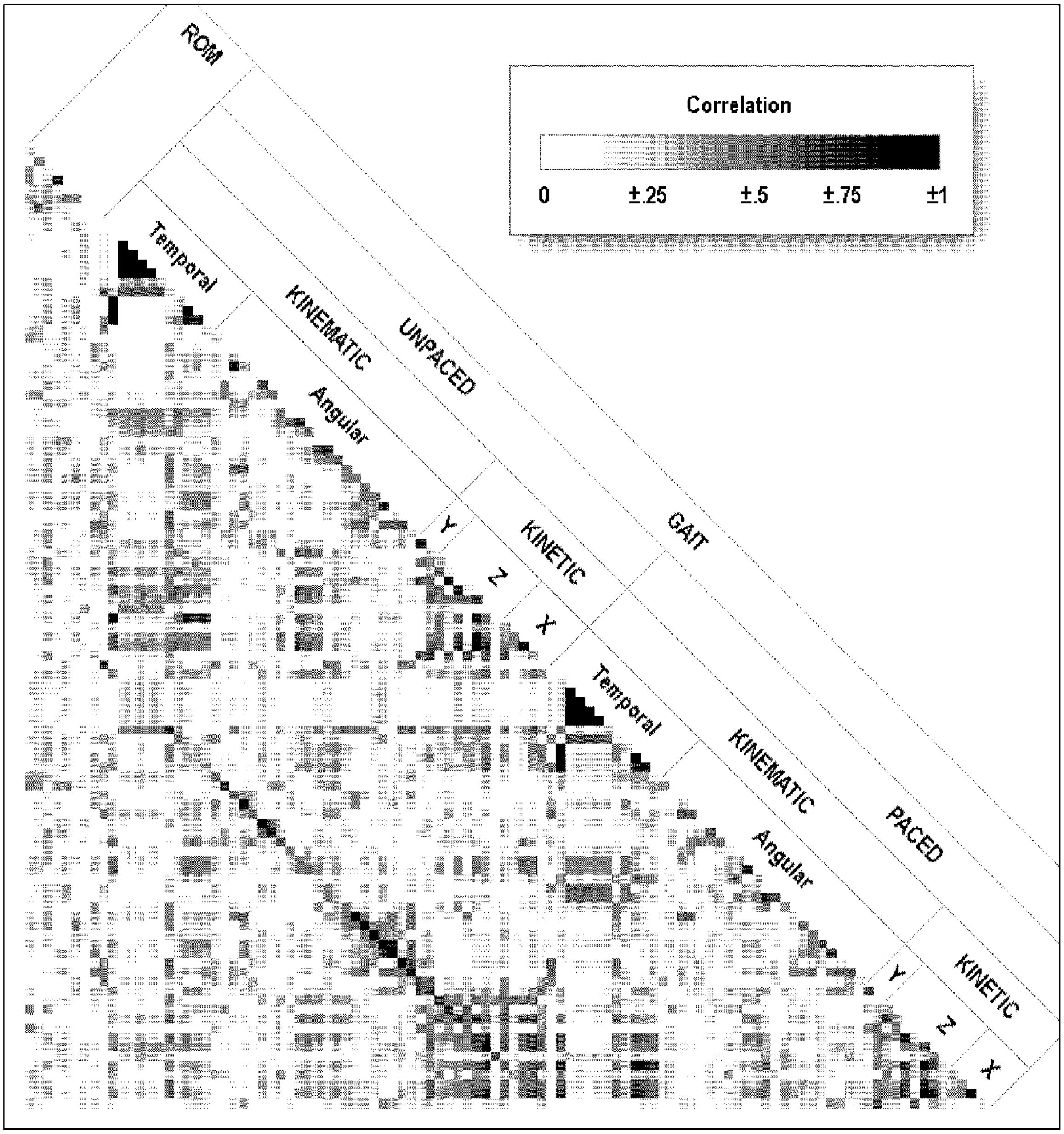


Figure 2. Correlational matrix of the 104 dependent variables. Absolute magnitudes of *r* are depicted. (See text for further description.)

Table 11. *Principal Component Factors and Loadings of Dependent Variables*

Dependent Variable Code	Name	Factor Loading
	Factor 1: Eigenvalue 12.4, Variance 13.0%	
UZ5	Time to 2nd force peak	0.864
PZ3	**Time to minimum force peak**	**0.860**
UX4	**Amplitude of maximum propelling force**	**0.853**
PZ5	Time to 2nd force peak	0.843
PX4	Amplitude of maximum propelling force	0.837
UX3	Time to transition force	0.795
PZ1	Time to 1st force peak	0.762
UZ6	Amplitude of 2nd force peak	-0.751
UZ3	Time to minimum force peak	0.746
PX3	Time to transition force	0.703
UZ1	Time to 1st force peak	0.638
PZ6	**Amplitude of 2nd force peak**	**-0.593**
PX2	Time to maximum braking force	0.571
UT8	Stance width	-0.493
UA8	Knee flexion, maximum	-0.481
PT8	Stance width	-0.469
	Factor 2: Eigenvalue 7.9, Variance 8.1%	
PT5	Stance/swing ratio	0.964
PT4	Swing phase	-0.960
PT6	Double support	0.958
PT7	Single support	-0.956
PT3	Stance phase	0.953
PA10	Ankle dorsiflexion	0.699
PT9	Step length	-0.652
PA8	Knee flexion maximum	0.497
PA8B	Knee range, sagittal	0.480
	Factor 3: Eigenvalue 7.2, Variance 7.5%	
PA15	**Shoulder flexion**	**0.894**
UA15	**Shoulder flexion**	**0.889**
PA14B	Shoulder range, coronal	-0.833
UA14B	**Shoulder range, coronal**	**-0.809**
UA4	Hip extension	0.565
	Factor 4: Eigenvalue 7.1, Variance 7.4%	
UT6	Double support	-0.957
UT4	Swing phase	0.956
UT3	Stance phase	-0.931
UT7	Single support	0.922
UT5	Stance/swing ratio	-0.896
UT9	Step length	0.658
UZ7	Average vertical force	0.646

Table 11. (*Continued*)

Dependent Variable		Factor Loading
Code	Name	
	Factor 5: Eigenvalue 6.9, Variance 7.2%	
PA16	**Shoulder extension**	**0.848**
UA16	**Shoulder extension**	**0.844**
PT1	**Stride length**	**0.797**
UA16B	**Shoulder range, sagittal**	**0.748**
PA16B	**Shoulder range, sagittal**	**0.717**
PA1	Pelvic rotation	0.660
UT1	**Stride length**	**0.646**
UA1	Pelvic rotation	0.642
UA10	Ankle dorsiflexion	-0.445
	Factor 6: Eigenvalue 6.4, Variance 6.7%	
UY2	Force excursions, 0–30%	0.789
UX5	Time to maximum propelling force	0.745
UZ4	Amplitude of minimum force peak	-0.718
UX1	Amplitude of maximum braking force	-0.717
UY4	Force excursions, 0–100%	0.703
UZ2	Amplitude of 1st force peak	0.690
PZ4	Amplitude of minimum force peak	-0.658
PY2	Force excursions, 0–30%	0.614
PZ2	**Amplitude of 1st force peak**	**0.565**
PX1	Amplitude of maximum braking force	-0.559
PY4	Force excursions, 0–100%	0.552
	Factor 7: Eigenvalue 5.5, Variance 5.8%	
UT11	Cadence	0.872
UT10	Step period	-0.814
UT2	Stride period	-0.807
UT12	**Gait velocity**	**0.731**
	Factor 8: Eigenvalue 4.5, Variance 4.7%	
PA14	**Shoulder adduction**	**0.852**
UA14	Shoulder adduction	0.814
PA13	Shoulder abduction	0.797
UA13	**Shoulder abduction**	**0.774**
PA12	**Trunk tilt**	**0.481**
	Factor 9: Eigenvalue 4.0, Variance 4.1%	
UA2	**Pelvic obliquity**	**0.892**
PA2	**Pelvic obliquity**	**0.886**
UA6B	Hip range, coronal	0.678
PA6B	Hip range, coronal	0.549

Table 11. (*Continued*)

Dependent Variable		Factor Loading
Code	Name	
	Factor 10: Eigenvalue 3.7, Variance 3.9%	
UA5	**Hip abduction**	**0.861**
PA5	Hip abduction	0.857
UA6	Hip adduction	0.728
PA6	Hip adduction	0.713
	Factor 11: Eigenvalue 3.6, Variance 3.7%	
PA7	Knee flexion, minimum	-0.851
UA7	Knee flexion, minimum	-0.828
UA8B	Knee range, sagittal	0.499
PA3	**Hip flexion**	**0.450**
	Factor 12: Eigenvalue 3.0, Variance 3.2%	
UA3	Hip flexion	-0.829
UA4B	Hip range, sagittal	0.789
UA12	**Trunk tilt**	**0.466**
	Factor 13: Eigenvalue 3.0, Variance 3.1%	
PT10	Step period	0.770
PT11	Cadence	-0.685
PT2	**Stride period**	**0.626**
PT12	**Gait velocity**	**-0.552**
	Factor 14: Eigenvalue 3.0, Variance 3.1%	
UA10B	Ankle range, sagittal	0.799
UA9	Ankle plantarflexion	0.684
UA11	**Ankle varus/valgus**	**0.573**
PA11	Ankle varus/valgus	0.501
	Factor 15: Eigenvalue 2.6, Variance 2.7%	
PA4B	Hip range, sagittal	0.774
PA4	Hip extension	0.580
	Factor 16: Eigenvalue 2.5, Variance 2.6%	
PZ7	Average vertical force	-0.698
UX2	**Time of maximum braking force**	**0.521**
	Factor 17: Eigenvalue 2.4, Variance 2.5%	
PA9	**Ankle plantarflexion**	**0.694**
PA10B	Ankle range, sagittal	0.612
PX5	Time to maximum propelling force	0.550

Note. Variables that showed significant effects of clothing condition are printed in bold.

The patterns of loadings of the dependent variables on the principal component factors in many cases suggest not only quantitative patterns, but also certain qualitative aspects of gait, both global and localized, that were observed during the experiment. Some factors can be interpreted clearly; others are ambiguous. There is no guarantee that the particular factor pattern that emerges from such an analysis will be unambiguous. Nevertheless, examination of these factors is useful in determining which variables should be retained in future research, and what sort of new, derived, or higher-order variables might be developed to try to capture some of the global properties of gait that are not amenable to analysis using the unitary measurement of individual angles or body parts in isolation. An attempt follows to interpret the 17 factors in terms of meaningful aspects of unpaced and paced gait.

Factor 1 is multifaceted, but appears to be capturing an energetically inefficient ground contact, probably associated with the VB boot. The boot tends to roll during initial contact with the ground, rather than to strike the ground. In addition, the fit characteristics of the VB boot are such that the foot can move around within the boot. The first factor has heavy loadings on variables related to the temporal aspects of the ground reaction forces, particularly the time subsequent to initial contact of the foot with the ground. This factor may be primarily reflecting the difference between the combat boot and the VB boot.

Factor 2 and Factor 4 are complementary. Both have heavy loadings on temporal gait variables. Factor 2 appears to describe a short-stepped, plodding gait when walking to the external pacing signal. The gait pattern is defined by an increased stance and a decreased swing phase and an increase in the proportion of the stride spent in double support. There is also greater flexion at the knee and the ankle. Factor 4 is the opposite. It describes an unpaced gait, with longer steps and a longer swing phase. The proportion of the stride spent in double support is decreased and the proportion spent in single support is increased. It can be speculated that Factor 2 manifests when the external pace is ill suited to the individual, resulting in an unnatural gait that is consciously maintained to follow the pacing signal.

Factor 3 has strong loadings on both unpaced and paced gait variables related to movement of the arm at the shoulder. This factor appears to describe a gait in which the arms are held forward of the trunk, and move less in the coronal plane. This arm placement was observed during testing as a tendency for participants to hold their arms such that the hands were anterior to the body and at about waist level. This arm placement seemed to be associated with a participant consciously attending to placement of the foot, possibly due to the encumbrance of the clothing. The arm placement manifested as a sort of rhythmic transverse punching movement of the alternate arms, rather than a sagittal swinging.

Factor 5 describes a loose, swinging gait, independent of pace. From the variables on which this factor has heavy loadings, the factor can be characterized by a backward arm swing and greater pelvic rotation, resulting in an increase in stride length. This gait style would be induced if the trunk were held unnaturally upright, or if an attempt were made to tilt the trunk backward; however, this factor is independent of trunk tilt per se.

Factor 6 has heavy loadings on variables related to the magnitudes of the ground reaction forces, particularly those forces occurring early in the stance phase. This factor may reflect a lateral shifting of the heel within the VB boot, resulting in an inefficient stance. Both unpaced and paced walking variables load strongly on this factor; it may be hazarded that the effects of the VB boot mask the effects of other sources of variation, such as the external pacing of gait. This factor may, in fact, largely be reflecting the difference between the combat boot and the VB boot.

Factor 7 refers to temporal aspects of unpaced gait. This factor in particular is likely reflective of clothing conditions and of differences among the participants in body measurements and proportions.

Factor 8 refers to the extrema of upper arm position in the coronal plane, independent both of angular range and of external pacing. It is doubtless an effect of the upper-body clothing.

Factor 9 describes movement of the pelvis in the coronal plane. It encompasses variables for both unpaced and paced gait. By itself, this factor is difficult to interpret, but likely reflects individual differences in body dimensions, differences associated with footwear, or both.

Factor 10 refers to the extrema of hip abduction and adduction, independent of whether or not gait was externally paced. Variables associated with hip movement in the sagittal plane do not load on this factor. This factor appears to describe a positioning of the upper legs with respect to the midline of the body, but it does not indicate the extent of variation from that position over a stride. This factor likely reflects both differences in body dimensions among participants and differences between the combat boots and the VB boots.

Factor 11 has heavy loadings on minimum knee flexion angle for both unpaced and paced gait. This factor probably reflects individual anthropometric differences more than anything else.

Factor 12 seems paradoxical: It refers to an increase in hip range of motion in the sagittal plane, but to an increase that is not associated with increased hip flexion and that does not manifest when gait is externally paced. Such results could be produced if there was an increase in variability of the extrema of hip flexion and a greater increase in the variability of hip extension. This factor probably reflects clothing effects, as well as body dimensional differences among participants.

Factor 13 is weighted heavily on variables related to the temporal aspects of paced gait. This factor is the counterpart of Factor 7, which was heavily loaded on the same variables for unpaced gait, with the signs of the variables reversed. Factor 13 is likely reflective of clothing effects, body dimension differences among participants, and ability of participants to follow the external pacing signal.

Factors 14 and 17 distinguish between unpaced and paced gait in terms of movement at the ankle joint, but these factors, along with Factors 15 and 16, are of small magnitude and are too simple to interpret further. These four factors cannot, in and of themselves, be associated with any garment effects or with a particular gait characteristic.

GENERAL DISCUSSION

The most extreme clothing conditions contrasted in the present study were the TBDU, a regular duty uniform, and four layers of cold weather clothing. The analyses contrasting the TBDU with four layers of cold weather clothing, as well as analyses contrasting the TBDU with three clothing layers, yielded a number of significant differences in angular variables, principally related to shoulder movements. Differences related to shoulder movements were obtained for range of motion activities, unpaced gait, and paced gait. The findings indicated that, when three or four layers of cold weather clothing were worn, participants moved and walked differently than they did when they were relatively unencumbered. The added bulk of the cold weather garments appears to interfere with the ability to bend at the waist and to move the upper arms at the shoulders. When walking, participants tended to lean forward, holding the arms forward and down, and the arms moved less at the shoulders, compared with walking gait with the TBDU. It is noteworthy that comparisons between the TBDU and two layers of cold weather clothing did not indicate significant differences. Thus, the range of motion and walking measures for the unencumbered body, the TBDU condition, were not substantially different from those for the body clothed in winter underwear, a loose fitting parka, and loose fitting trousers.

Although the gait appeared to be more labored with the three and the four layers of cold weather clothing, compared with the TBDU, temporal and kinetic gait variables did not manifest significant differences between the duty uniform and up to four layers of cold weather clothing. These measures may not be sensitive enough to reflect changes in gait; or it may be that the gait changes observed were adaptive rather than detrimental. That is, adopting a more forward leaning posture with restrained arm movement when wearing layers of cold weather clothing may have been an adjustment that allowed the gait to remain similar in other respects to gait when the body was unencumbered.

Manipulation of the type of insulating material used indicated that the fiberpile, being bulkier and less compressive, restricted a few movements to a greater extent than did the TBDU when used as an insulating material. The significant interactions between the number of layers and the type of insulation revealed that some of the effects of the two different insulating materials manifested only when a certain number of layers of cold weather clothing were worn. The use of fiberpile insulation in combination with four layers of cold weather clothing yielded results that were somewhat distinctive from the results for the other combinations of insulation and clothing layers. During paced gait, the fiberpile/four-layer clothing combination was associated with a relatively long stride period, a shorter stride length, a lower gait velocity, and a lower amplitude of peak force at heel contact. The fiberpile/four clothing layer combination was the bulkiest of the clothing combinations tested. This characteristic may have resulted in the fiberpile/four clothing layer combination distinguishing itself from the others.

When two, three, and four layers of cold weather clothing were compared with each other, both the unpaced and the paced gait data revealed increasing reductions of arm movement at the shoulder in the sagittal plane as the number of clothing layers was increased. The other variables for which a significant layer effect was obtained differed between unpaced and paced walking. The measures that were significant for either mode of walking did not include any temporal gait variables.

The only range of motion activity significantly affected by the number of layers of cold weather clothing worn was standing trunk flexion. The extent of this movement decreased as the number of layers increased. In their studies of the effects on range of motion of a U.S. Army cold weather clothing system (the predecessor to the clothing system in the present study), Bensel et al. (1977) and Lockhart and Bensel (1977) found that trunk flexion decreased with the number of layers worn. These researchers also reported that abduction and extension of the arm at the shoulder were increasingly constrained by the addition of clothing layers. Although each layer did not result in statistically significant reductions in the movements, the extreme conditions did differ significantly. The findings from the present study were similar, in that maximum abduction and forward extension of the arm were generally more limited with four layers of clothing than with two. The fact that, in the present study, there were no statistically significant differences on these range of motion activities involving upper arm abduction and forward extension may indicate that the U.S. Army cold weather clothing ensemble in use today is an improvement over its predecessor in terms of the body mobility afforded the wearer.

Comparisons between combat and VB boots on the variables for unpaced walking gait revealed several differences. Time to maximum braking force was proportionally later in the gait cycle with the VB boots. Stride period was somewhat longer and gait velocity somewhat slower with the VB boots as well, although the differences were not significant. Paced walking revealed a significant difference between footwear types only for the hip flexion measure. The difference may be attributable to a tendency for the foot to be lifted and then planted on the ground when the VB boots were used, whereas there was a normal leg swing when the combat boots were worn.

Some general findings can be drawn from the four analyses of cold weather clothing. One of these is that the fiberpile, which was added to two layers of cold weather clothing to comprise a three-layer system, adversely affected motion because it did not compress sufficiently at the joints or regions of bodily flexion. The result was a direct limitation in the ranges of movement as the fiberpile filled in a portion of the space into which the body segment would otherwise enter. Because of its bulk, the fiberpile also occupied spaces that the body segments would normally occupy at rest or during normal gait. This was manifested at the axillary regions and at the crotch and medial surfaces of the thighs. The wearer had to either constantly exert pressure against the garments in order to maintain a normal posture or assume an adaptive posture. The impact of the fiberpile tended to affect gait, which in turn precipitated further postural adaptations.

Quilted nylon liners were added to three-layers of clothing to comprise a four-layer clothing system. The addition of the nylon liners did not result in the same of degree of restriction as resulted from the addition of the fiberpile layer. Although this was due in part to the fact that the quilted liners are thinner than the fiberpile, they are also more compressible. It appears as well that the quilted liners have the advantage of less interlayer friction than the fiberpile, such that adding the quilted liners as a fourth layer might, in some cases, increase mobility. This effect would be obtained if the detrimental impact of the added bulk of the liners was less than the beneficial effect of counteracting the friction associated with the fiberpile layer. It may be concluded that an insulating layer should have the requisite insulating properties, but not add bulk to the body. Insulating material should compress easily and have the ability to slide easily against overlying and underlying layers of material.

It is clear that different configurations of cold weather clothing impose restrictions on the body in different ways and to varied degrees. It is therefore important to evaluate the choice of a configuration carefully. It may be that one configuration is optimal for the environmental conditions, but imposes unacceptable movement restriction; another configuration, one that is only slightly less effective given the same environmental conditions, might impose much less movement restriction. The latter would be the preferred choice, given consideration of both the particular environment and the particular activity to be engaged in within that environment.

Teitlebaum and Goldman (1972) reported that layers of cold weather clothing imposed adverse effects on locomotion, with the result that the metabolic cost of walking in the layered system increased beyond that due to the weight change of adding the clothing to the body. They proposed that the multilayered clothing created a hobbling effect, restricting movement at the joints and thereby increasing the metabolic cost of walking. The findings from the present study indicate that the wearing of layers of cold weather clothing does affect gait biomechanics. This study suggests that several different patterns of effects are produced by cold weather garments. These effects do not occur uniformly, but manifest in response to the specific number of layers worn, the particular type of insulating material used, the particular combinations of garments, and the difference between walking ad lib and walking in synchrony with an external cadence cue.

The findings from this study also suggest how adaptations to restrictive garments may lead to gait modifications and, from these modifications, to tertiary consequences. In other words, the ultimate effect of restrictive garments upon gait must be seen not as a direct adverse consequence, but as the end of a causal chain of adaptations to restrictions and the consequences of these adaptations.

The principal components analysis of the gait variables reflected global gait characteristics that corresponded to observations made by the experimenters in the study. It also captured localized effects involving particular joints, and it was sensitive to the difference between unpaced and paced gait conditions. Further research should concentrate on the development of an orthogonal set of dependent variables designed to be more sensitive to global characteristics of gait. The principal component factors appear to have captured the essence of what these dependent metrics might consist of. They might be relatively simple measures, similar to the variables used in the present study, or complex metrics derived from them in linear or weighted combinations. It might also be possible for the gait characteristic of interest to be obtained directly by calculation from the multidimensional kinematic/kinetic dataset.

Future studies should utilize a smaller set of carefully chosen dependent measures than were used in the present study, with the goal not only of describing the effects of protective garments upon gait, but of explaining these effects in terms of adaptation and of local and global causality; this is the next logical step towards developing a predictive model of the effects of restrictive garments upon gait.

In attempting to describe global characteristics of gait, it will be important to distinguish between: a) those characteristics that are associated with individual differences or with an individual's physical state and b) those that are resultant from the clothing, footwear, or equipment that is being worn. The interaction of these two sources must also be addressed; it might be the case that a particular restrictive item has a somewhat different effect on a tall thin individual than on a short heavy one. Using cold weather clothing as an example, the noncompressability of the fiberpile layer in the axillary regions may have little effect on the range of motion of an individual who is thin and broad-shouldered, and more effect on an individual who is narrow-shouldered and heavy and/or muscular.

The pattern of results obtained in the principal components analysis for this study suggests the retention of some of the simple measures, among them spatial and temporal gait parameters, including stance/swing ratio, shoulder adduction and abduction, pelvic obliquity, and hip abduction. Suggested measures that are derived or conditional include: increase of the extension portion of sagittal shoulder range; forward position of the arms accompanied by decreased coronal shoulder range; a change in the upper arm coronal position without a change in range; a change in the upper leg coronal position without a change in range; and a shift in the centroid of area under the vertical force curve that is simultaneously towards the abscissa and away from the ordinate.

Ideally, both the simple and complex metrics would be refined by controlling for the effects of individual variation. One way to do this is to initially use anthropometric variables as predictive covariates, and then examine only those variables that significantly account for the remaining variance. Additional measures of physiological activity, such as energy cost, could help to distinguish between those effects of clothing that are merely adaptive without being detrimental and those effects that are actually detrimental to individual performance.

CONCLUSIONS

The major conclusions from this study of cold weather clothing are:

- Bulky clothing not only constrains movement, it affects the resting posture.
- Bulky clothing can induce altered gait patterns, which are adaptive and are not necessarily inefficient.
- A salient adaptation to wearing layers of cold weather clothing is decreased arm movement during gait.
- Vapor barrier boots per se induce gait adaptations, which may exacerbate the effects of cold weather clothing.
- Similar levels of clothing protection may differ in mobility restrictions, resulting in a trade-off between protection and mobility.
- Kinematic and kinetic analyses combined reveal global gait characteristics in response to clothing.
- Future research should utilize complex orthogonal factors to capture global characteristics, rather than simple unitary variables.

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APPENDIX A

DESCRIPTION OF COLD WEATHER CLOTHING SYSTEM COMPONENTS

APPENDIX A

DESCRIPTION OF COLD WEATHER CLOTHING SYSTEM COMPONENTS

The various items in the ECWCS system are intended to be used in climatic categories C-1, C-2, and C-3.

Underwear, Extended Cold Weather, Polypropylene. The polypropylene underwear layer is worn next to the skin, and acts as a moisture-wicking layer to draw moisture away from the body towards the outer layers of the system. This underwear is made of a knitted, brushed, multifilament polypropylene. The shirt has long sleeves, a mock turtleneck, wrist cuffs, and a partial front zipper extending to the middle of the chest for ventilation. The drawers cover the lower extremities and have an elasticized waist and elasticized ankle cuffs. The undershirt weighs 0.31 kg and the drawers weigh 0.37 kg.

Shirt, Polyester, Fiberpile, Extended Cold Weather; Overall, Bib, Cold Weather, Fiberpile. The fiberpile layer is intended for use at temperatures at and below –32 °C (-25 °F). The fiberpile shirt acts as the primary insulating layer on the upper body. It is constructed of a knitted 9–11 oz/yd^2 polyester fiberpile. The shirt has reinforced shoulder and elbow patches, a mock turtleneck collar, front slide fastener, elastic drawcord waist, hook-and-pile cuff tabs, two chest cargo style pockets, and two lower handwarmer pockets. The shirt weighs 0.59 kg. The overalls are intended to serve as the primary insulating layer for the lower torso and appendages. They are constructed of a brown, knitted 10 oz/yd^2 polyester fiberpile. They are bib type overalls with adjustable elasticized suspenders equipped with quick-release buckles, full-length slide fasteners on the sides, and a two-way slide fastener on the crotch. The overalls weigh 0.73 kg.

Liner, Cold Weather, Coat; Liner, Cold Weather, Trousers, Field. The coat and trouser liners are intended to serve as an additional insulating layer on both the upper and lower body, to be added in extreme cold. The liners are quilted and made of polyester batting filler with a green, ripstop nylon outer layer. The liners can be worn independently of the coat and trousers, to which they attach via buttons and buttonholes on the coat front and on the outer seams of the trousers.

Parka, Extended Cold Weather, Woodland Camouflage. The parka is constructed from a three-layer nylon and polytetrafluorethylene laminate, in a woodland camouflage pattern. The material has the property of being able to repel water while allowing perspiration to evaporate. This layer is intended to be used as an outer windproof and waterproof layer. The parka has an integral hood, a two-way full front zipper for full-face protection with only the eyes exposed, an inside wind barrier at the waist, an elastic drawcord at the hem, axillary ventilation zippers, and hook-and-pile closures at the wrist tabs. It features inside map pockets accessible without unzipping the parka, two breast pockets, two large lower cargo pockets, and a rank tab at center chest. The parka weighs 0.84 kg.

Trousers, Cold Weather, Field, Woodland Camouflage Pattern. The trousers are intended to serve as a durable insulting layer over the liners. They are constructed of a 289 g/m^2 nylon/cotton wind-resistant, water-repellant sateen with a woodland camouflage pattern. They include front slash pockets, flapped rear pockets, side cargo pockets, adjustable waist tabs, and drawcords at the cuffs. The trousers weigh 1.8 kg.

Boots, Extreme Cold Weather, Insulated, White. The boots are constructed of rubber, latex, nylon tricot, and polyester, with a polyurethane sole. The insulation consists of three layers of needle-punched polyester foam hermetically sealed between an outer and inner layer of rubber. They provide protection against environmental hazards down to -40 °C (-40 °F) when stationary and down to -51 °C (-60 °F) when active. The boots are secured with six pairs of eyelets. They feature pressure release valves to adjust internal air pressure at high altitudes. Tabs on the heel permit attachment of cross-country skis. The boots are approximately 28.75 cm high. A size nine pair of boots weighs 2.81 kg. They are known also as vapor barrier (VB) boots.

Other items in the ECWCS system that were not used include a balaclava, insulated hood, fur hood ruff, glove liners, gloves, over-mittens, and a white nylon camouflage overgarment.

APPENDIX B

DESCRIPTION OF RANGE OF MOTION ACTIVITIES AND DEPENDENT MEASURES

APPENDIX B
DESCRIPTION OF RANGE OF MOTION ACTIVITIES AND DEPENDENT MEASURES

The eight ROM tasks are described in the order in which they were performed.

1. Standing trunk flexion. From a standing position, the participant bends at the waist and reaches for the floor with both hands while keeping the knees straight. A linear measurement is made vertically from the right middle fingertip (dactylion III) to the floor. (See Figure B-1.)

2. Unilateral upper arm abduction. While standing up straight with the arms straightened at the elbow and the palms facing forward, the participant raises the right arm up and out to the side as far as possible. All movement is in the sagittal plane. (See Figure B-2.)

3. Bilateral upper arm abduction. While standing up straight and keeping the arms straightened at the elbow and the palms facing forward, the participant raises both arms out to the side and up as far as possible. All movement is in the sagittal plane. (See Figure B-2.)

4. Unilateral upper arm forward extension. While standing up straight and keeping the right arm stiff at the elbow with the palms facing the legs, the participant extends the right arm forward and then up as far as possible. All movement is in the sagittal plane. (See Figure B-3.)

5. Bilateral upper arm forward extension. While standing up straight and keeping the arms stiff at the elbow with the palms facing the legs, the participant extends both arms forward and then up as far as possible. All movement is in the sagittal plane. (See Figure B-3.)

6. Upper leg flexion. While standing up straight and grasping an upright support, the participant raises the right upper leg as far as possible, letting the lower leg bend freely at the knee. All movement is in the sagittal plane. (See Figure B-4.)

7. Lateral waist flexion. Starting from a straight, standing position with the arms at the sides, the participant bends to the right as far as possible without any twisting motion. All movement is in the coronal plane. (See Figure B-5.)

8. Pack reach. While standing up straight, the participant lifts the right arm out to the side and up and then, bending the elbow, reaches as far behind the opposite shoulder as possible. A linear measurement is made from the right middle fingertip (dactylion III) to a point on the back near the fifth thoracic vertebra (T5). Movement is primarily in the coronal plane. (See Figure B-6.)

Table B-1 contains a definition of the measurement made on each ROM task.

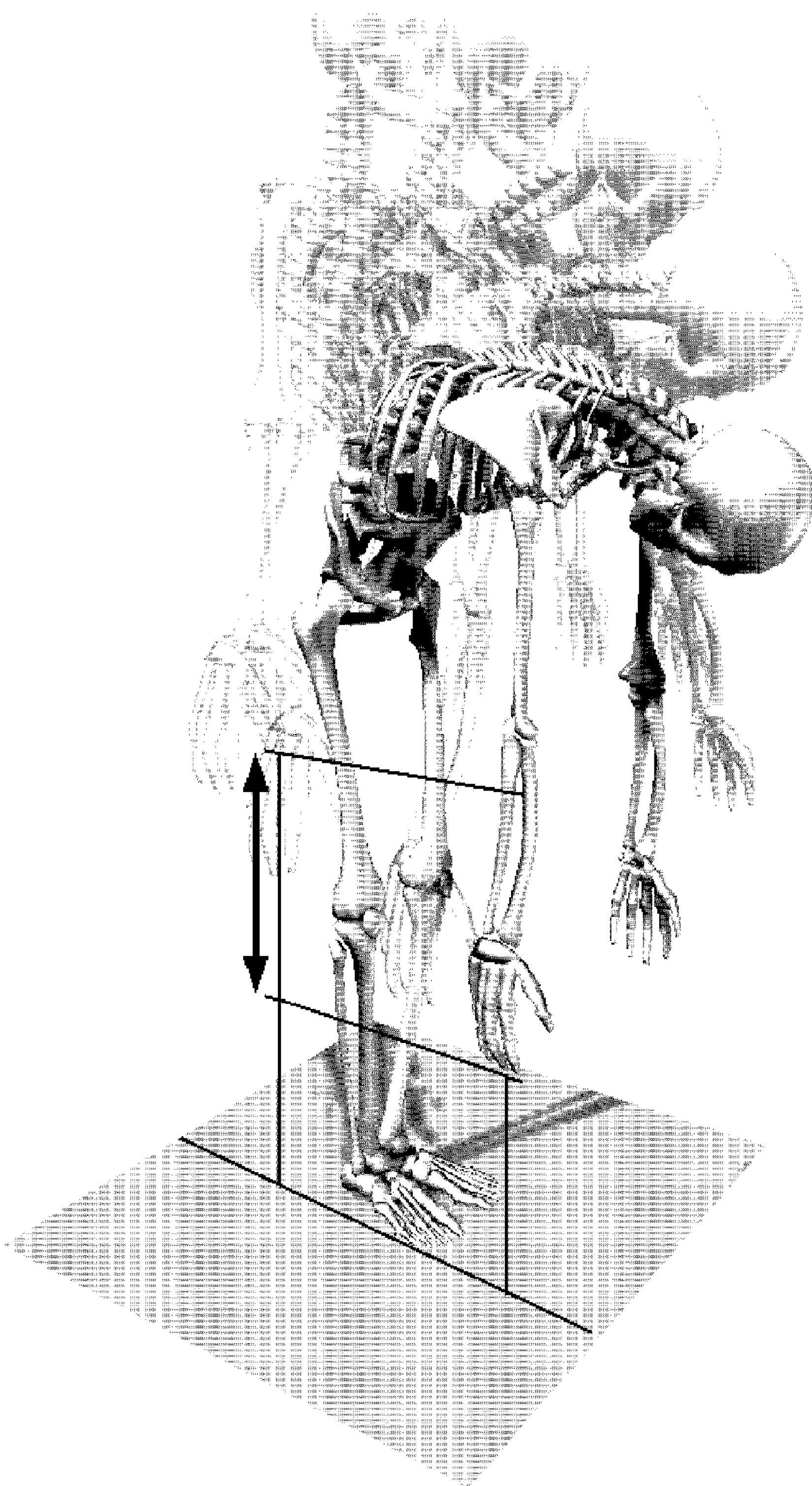

Figure B-1. Standing trunk flexion, measured by the vertical difference between the middle fingertip in the resting and the flexed positions.

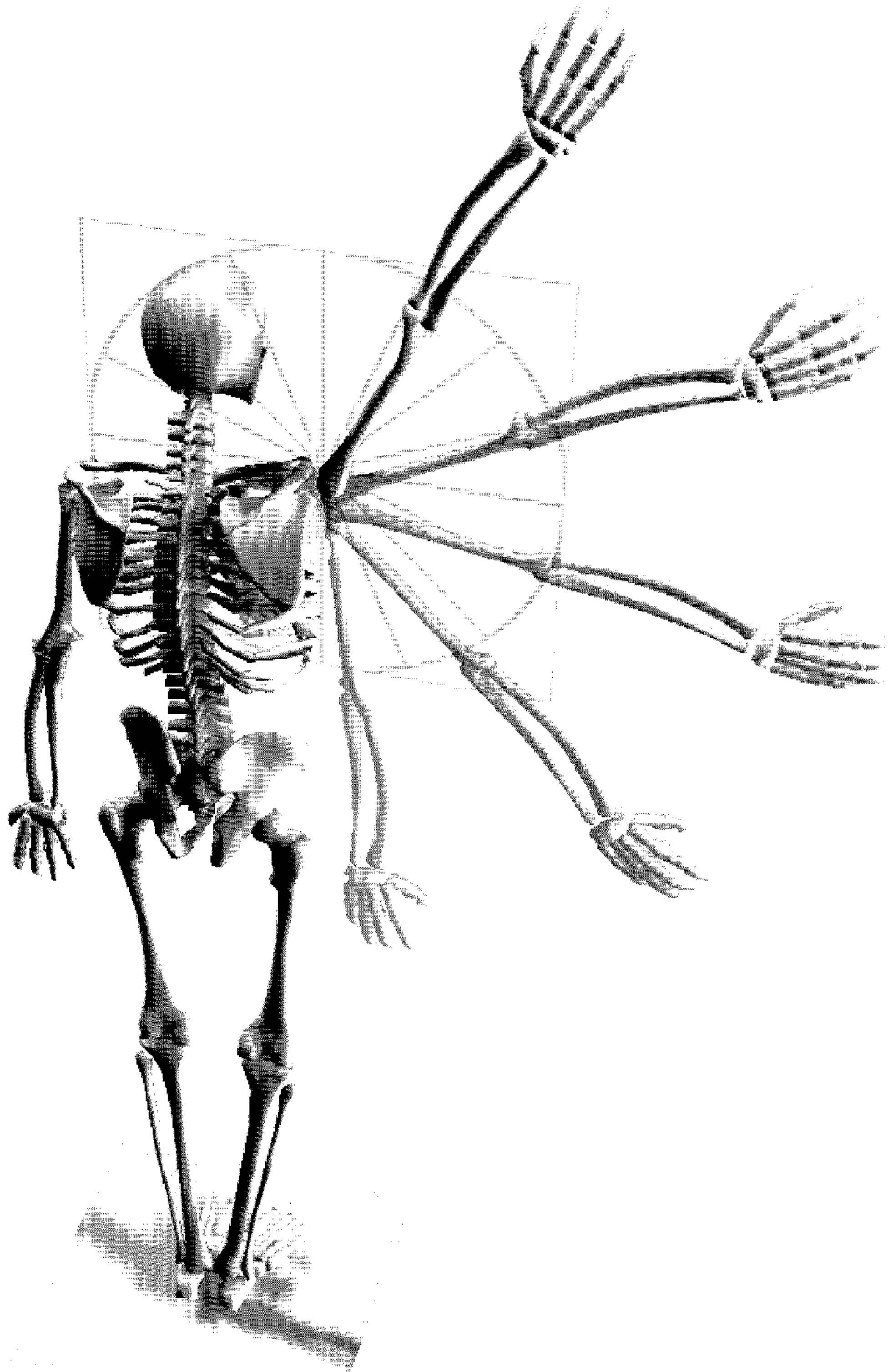

Figure B-2. Upper arm abduction, measured as an angle in the coronal plane. This was performed both unilaterally (depicted) and bilaterally.

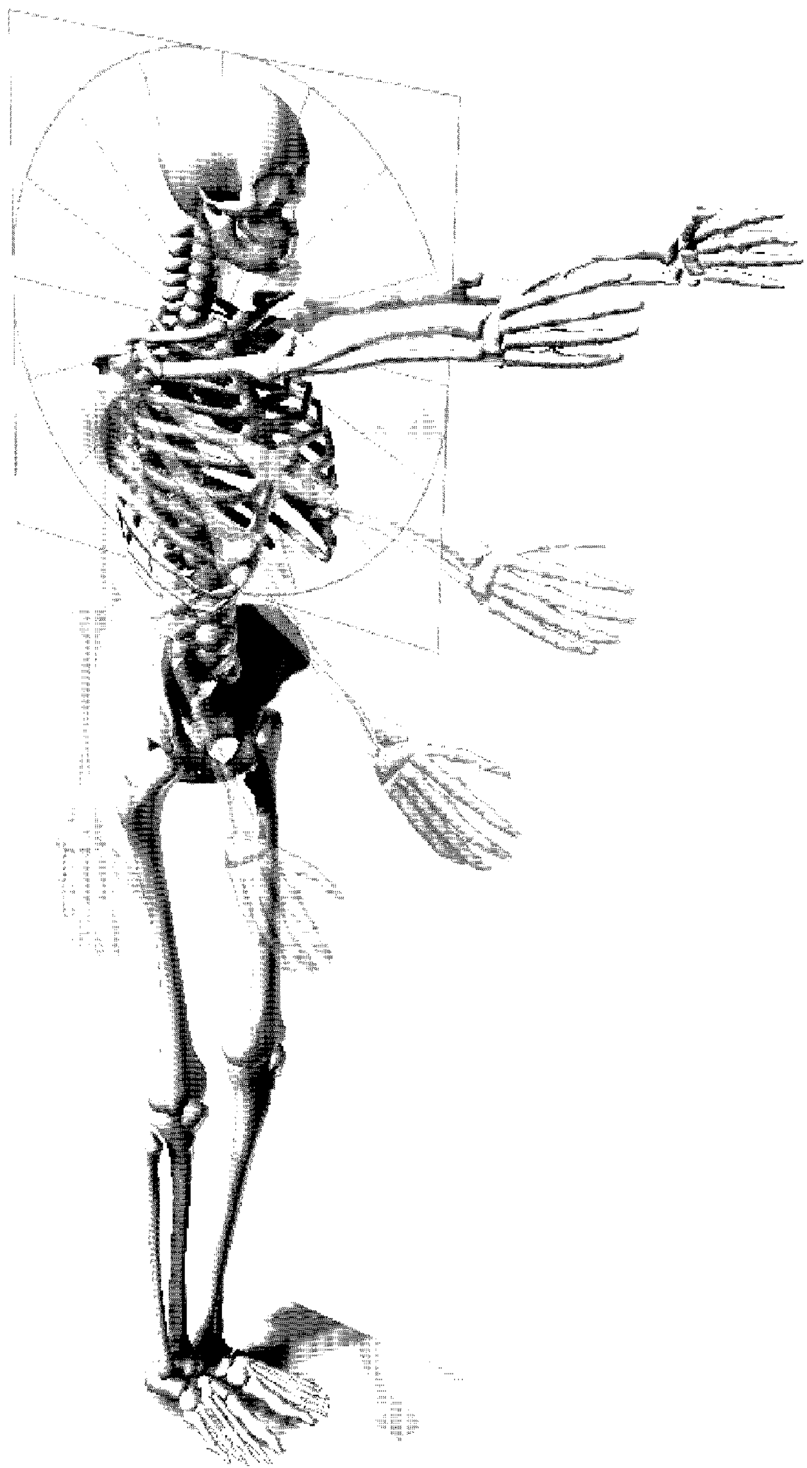

Figure B-3. Upper arm forward extension, measured as an angle in the sagittal plane. This was performed both bilaterally (depicted) and unilaterally.

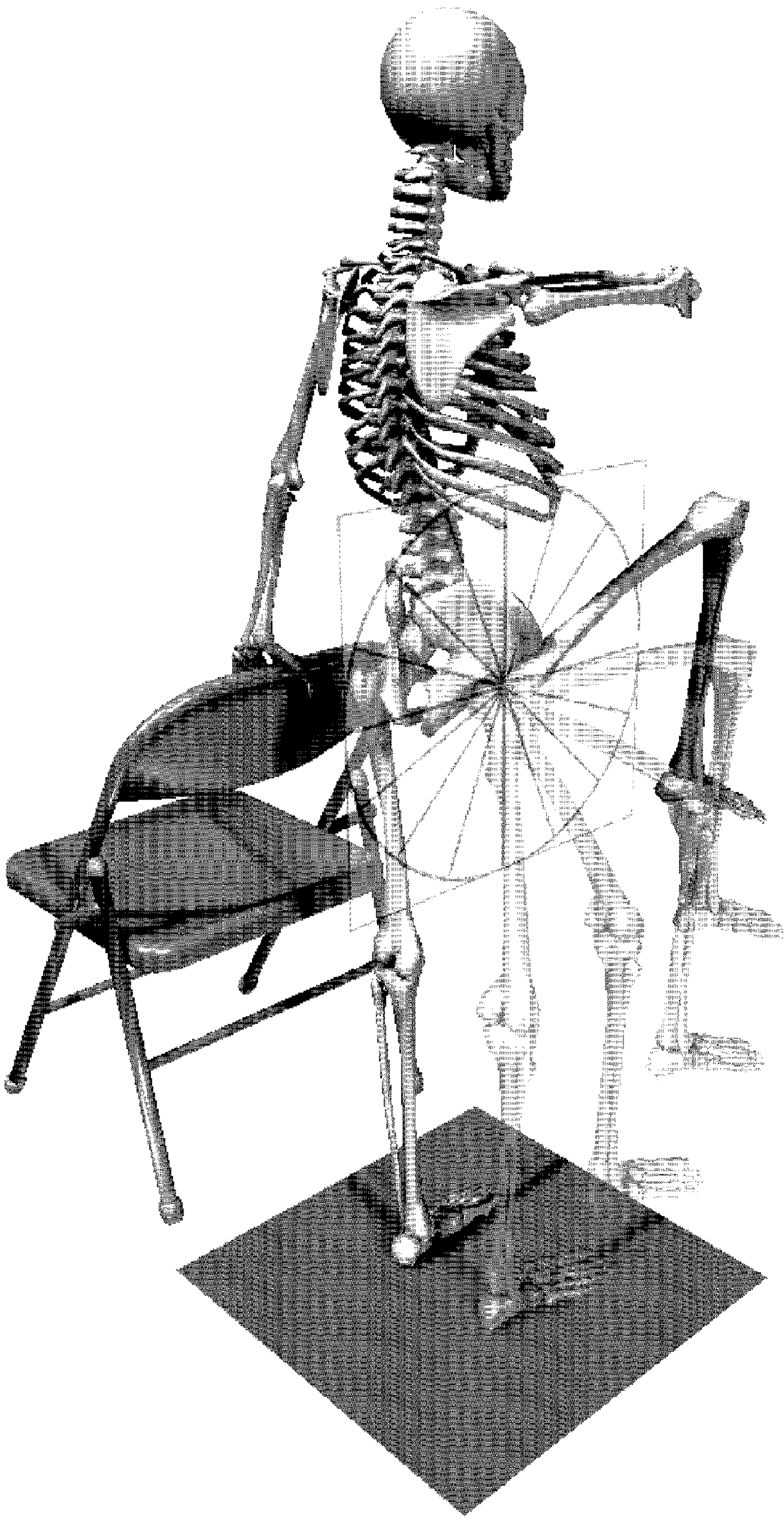

Figure B-4. Upper leg flexion, measured as an angle in the sagittal plane.

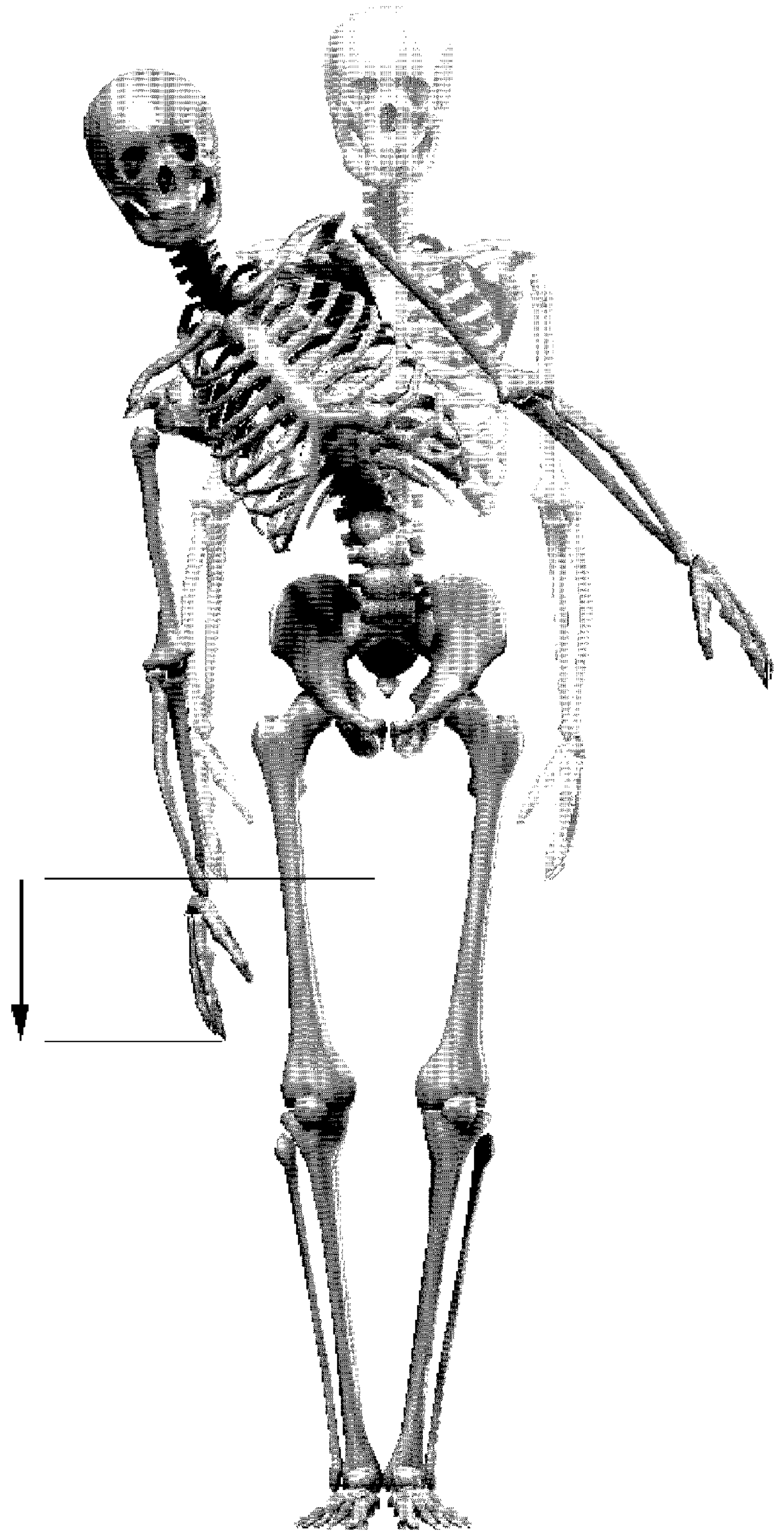

Figure B-5. Lateral waist flexion, measured by the vertical difference between the middle fingertip in the resting and the flexed positions.

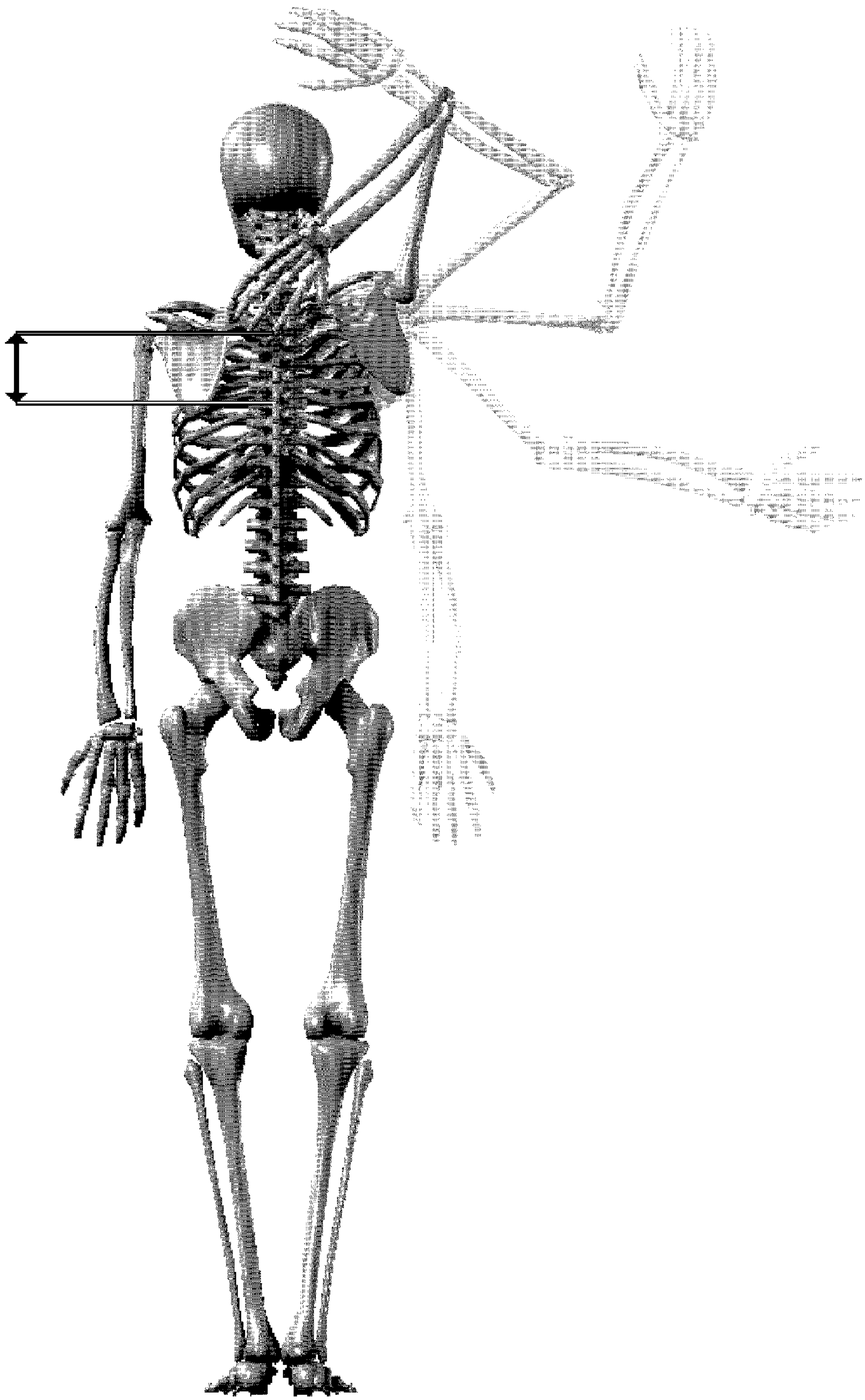

Figure B-6. Pack reach, measured in the reaching position by the vertical distance from the middle fingertip to the superior back marker (not depicted).

Table B-1. *Dependent Variables for ROM Activities, With Reference Codes and Measurement Definitions*

Code	Variable (scale)	Definition
R1	Standing trunk flexion (m)	Difference between the vertical elevation of the right middle fingertip (dactylion III) in the neutral posture and in the maximum flexion position. Larger values indicate greater flexion.
R2	Unilateral upper arm abduction (deg)	Difference in coronal angle of the right upper arm between the neutral posture and maximum abduction. Larger values indicate greater abduction.
R3	Bilateral upper arm abduction (deg)	Difference in coronal angle of the right upper arm between the neutral posture and maximum abduction. Larger values indicate greater abduction.
R4	Unilateral upper arm forward extension (deg)	Difference in sagittal angle of the right upper arm between the neutral posture and maximum extension. Larger values indicate greater extension.
R5	Bilateral upper arm forward extension (deg)	Difference in sagittal angle of the right upper arm between the neutral posture and maximum extension. Larger values indicate greater extension.
R6	Upper leg flexion (deg)	Difference in sagittal angle of the right upper leg between the neutral posture and maximum flexion. Larger values indicate greater flexion.
R7	Lateral waist flexion (m)	Difference between the vertical elevation of the right middle fingertip (dactylion III) in the neutral posture and in the maximum flexion position. Larger values indicate greater flexion.
R8	Pack reach (m)	Vertical distance between the right middle fingertip (dactylion III) and the superior back marker while in the reaching position. Smaller values indicate greater reach.

APPENDIX C

DESCRIPTION OF DEPENDENT MEASURES FOR UNPACED AND PACED WALKING

APPENDIX C
DESCRIPTION OF DEPENDENT MEASURES FOR UNPACED AND PACED WALKING

The same dependent measures were used to describe unpaced and paced walking. The measures are listed and defined in Table C-1. Figures C-1 through C-3 are schematic depictions of the dependent variables derived from the vertical, antero-posterior, and medio-lateral ground reaction forces, respectively. For those measures expressed in Newtons per kilogram, the value in the denominator was clothed body mass for the particular clothing condition being tested.

Table C-1. *Dependent Variables for Unpaced and Paced Walking, With Reference Codes and Measurement Definitions*

Code	Variable (scale)	Definition
T1	Stride length (m)	Horizontal distance between the right heel at initial contact with the ground and the right heel when it again contacts the ground.
T2	Stride period (s)	Time from initial contact of the right heel with the ground until the right heel again contacts the ground.
T3	Stance phase (%)	Percentage of stride that the right foot is in contact with the ground.
T4	Swing phase (%)	Percentage of stride that the right foot is not in contact with the ground.
T5	Stance/swing ratio (ratio scale)	Stance phase of the right foot divided by the swing phase of the right foot.
T6	Double support (%)	Percentage of stride that both feet are in contact with the ground.
T7	Single support (%)	Percentage of stride that the right foot only is in contact with the ground.
T8	Stride width (m)	Maximum side to side distance between the feet measured at the midpoint of the heels.
T9	Step length (m)	Horizontal distance between the right heel at initial contact with the ground and the left heel at initial contact.
T10	Step period (s)	Time between initial contact of the right heel with the ground and initial contact of the left heel.

Table C-1. (*Continued*)

Code	Variable (scale)	Definition
T11	Cadence (steps/min)	Number of steps per minute.
A1	Pelvic rotation (deg)	Range of movement of the interhip segment in the transverse plane.
A4B	Hip range, sagittal (deg)	Total angle between maximum hip flexion and extension.
A5	Hip abduction (deg)	Position of maximum outward rotation of the thigh about the hip in the coronal plane.
A6	Hip adduction (deg)	Position of maximum inward rotation of the thigh about the hip in the coronal plane.
A6B	Hip range, coronal (deg)	Total angle between maximum hip adduction and abduction.
A7	Knee flexion, minimum (deg)	Smallest value of the angle formed between the upper and lower leg with the vertex at the knee. Nominally coded as negative, increasingly negative values indicate less flexion.
A8	Knee flexion, maximum (deg)	Greatest value of the angle formed between the upper and lower leg with the vertex at the knee. Larger positive values indicate greater flexion.
A8B	Knee range, sagittal (deg)	Total angle between minimum and maximum knee flexion.
A9	Ankle plantarflexion (deg)	Maximum value of the angle of the foot relative to the lower leg in the sagittal plane, minus 90 degrees.
A10	Ankle dorsiflexion (deg)	Minimum value of the angle of the foot relative to the lower leg in the sagittal plane, subtracted from 90 degrees.
A10B	Ankle range, sagittal (deg)	Sum of ankle plantarflexion and dorsiflexion.

Table C-1. (*Continued*)

Code	Variable (scale)	Definition
A12	Trunk tilt (deg)	Maximum value, across the gait cycle, of the forward sagittal deviation from vertical of a line formed by acromion and trochanterion.
A13	Shoulder abduction (deg)	Maximum upward rotation of the upper arm about the shoulder in the coronal plane.
A14	Shoulder adduction (deg)	Maximum inward rotation of the upper arm about the shoulder in the coronal plane.
A14B	Shoulder range, coronal (deg)	Angle between maximum shoulder adduction and maximum shoulder abduction.
A15	Shoulder flexion (deg)	Maximum forward rotation of the upper arm about the shoulder in the sagittal plane. Larger negative values indicate greater flexion.
A16	Shoulder extension (deg)	Maximum backward rotation of the upper arm about the shoulder in the sagittal plane. Larger positive values indicate greater extension.
A16B	Shoulder range, sagittal (deg)	Angle between maximum shoulder extension and maximum shoulder flexion.
Y2	Force excursions, 0-30% (N)	Force excursions over the first 30% of the force-time curve.
Y4	Force excursions, 0-100% (N)	Force excursions over 100% of the force-time curve.
Z1	Time to 1st force peak (%)	Time to the first force peak, from contact to maximum, as a percentage of total contact time.
Z2	Amplitude of 1st force peak (N/kg)	Amplitude value at the first peak in the force-time curve.
Z3	Time to minimum force peak (%)	Time from contact to the minimum force, as a percentage of total contact time.

Table C-1. (*Continued*)

Code	Variable (scale)	Definition
Z4	Amplitude of minimum force peak (N/kg)	Amplitude at the lowest point in the trough between force peaks in the force-time curve.
Z5	Time to 2^{nd} force peak (%)	Time to the second force peak, from contact to maximum, as a percentage of total contact time.
Z6	Amplitude of 2^{nd} force peak (N/kg)	Amplitude value at the second peak in the force-time curve.
Z7	Average vertical force (N/kg)	Sum of all forces sampled during contact divided by the number of samples.
X1	Amplitude of maximum braking force (N/kg)	Amplitude of the largest negative force peak.
X2	Time of maximum braking force (%)	Time from initial contact to largest negative force peak, as a percentage of total contact time.
X3	Time to transition force (%)	Time from initial contact to where the force-time curve crosses the abscissal zero-value.
X4	Amplitude of maximum propelling force (N/kg)	Amplitude of the largest positive force peak.
X5	Time to maximum propelling force (%)	Time from contact to the largest positive force peak, as a percentage of total contact time.

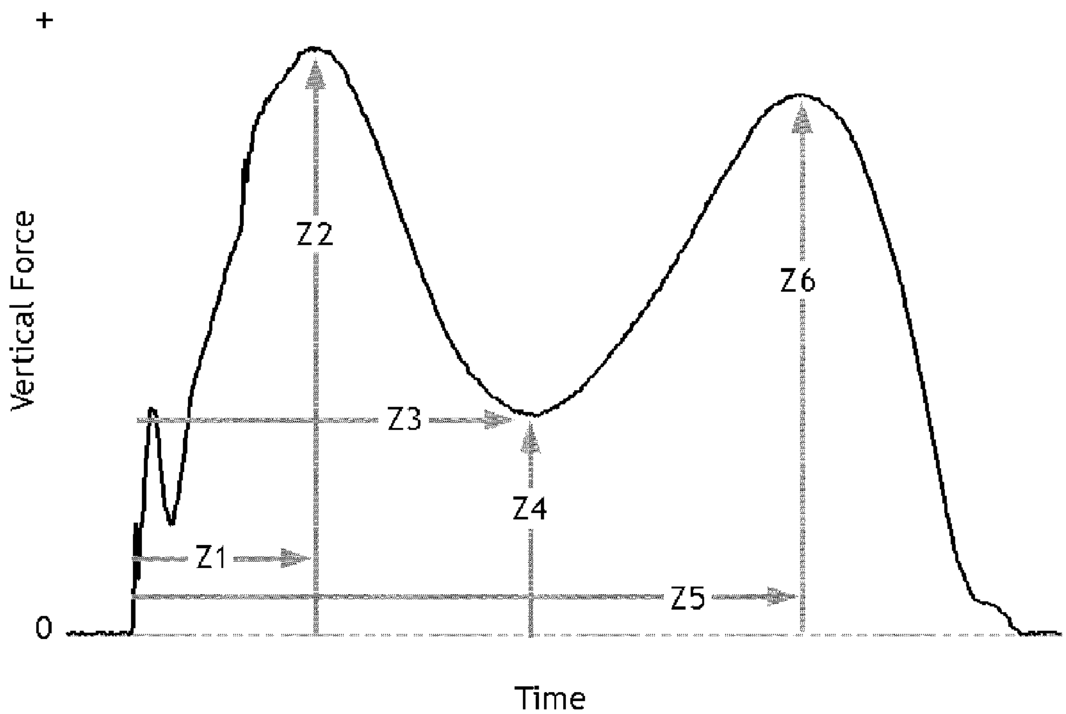

Figure C-1. Schematic depiction of the dependent variables derived from vertical kinetic force. These variables were obtained from both non-paced and paced gait.

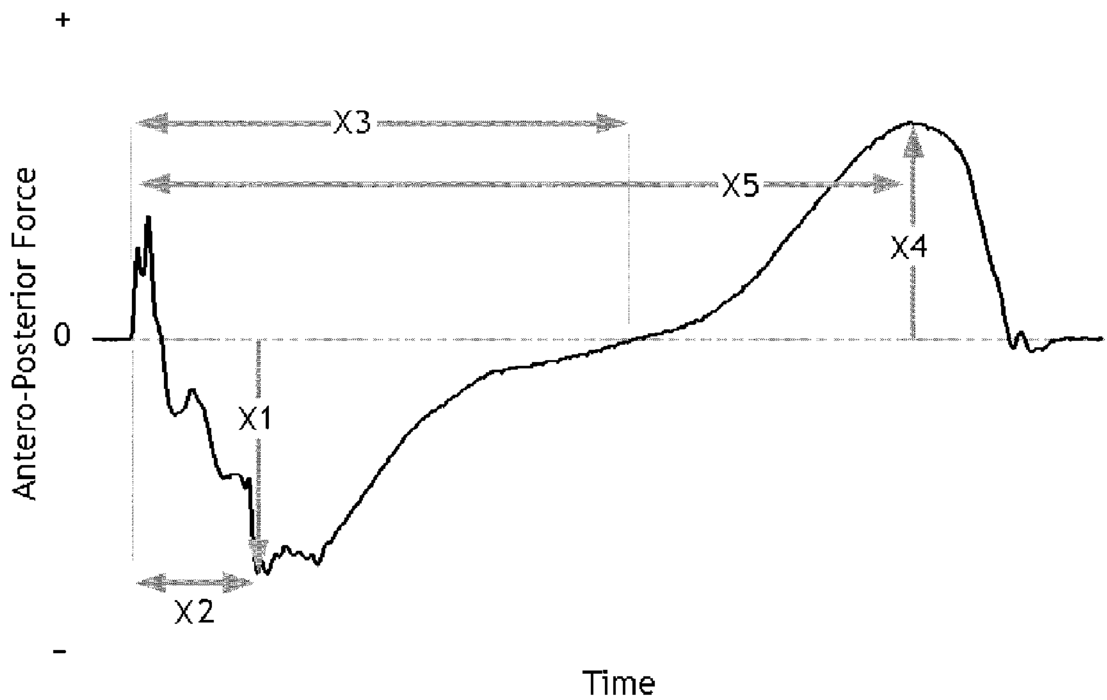

Figure C-2. Schematic depiction of the dependent variables derived from antero-posterior kinetic force. These variables were obtained from both non-paced and paced gait. X2 and X3 begin at the initiation of contact; X3 ends at the time of transition at the zero-crossing.

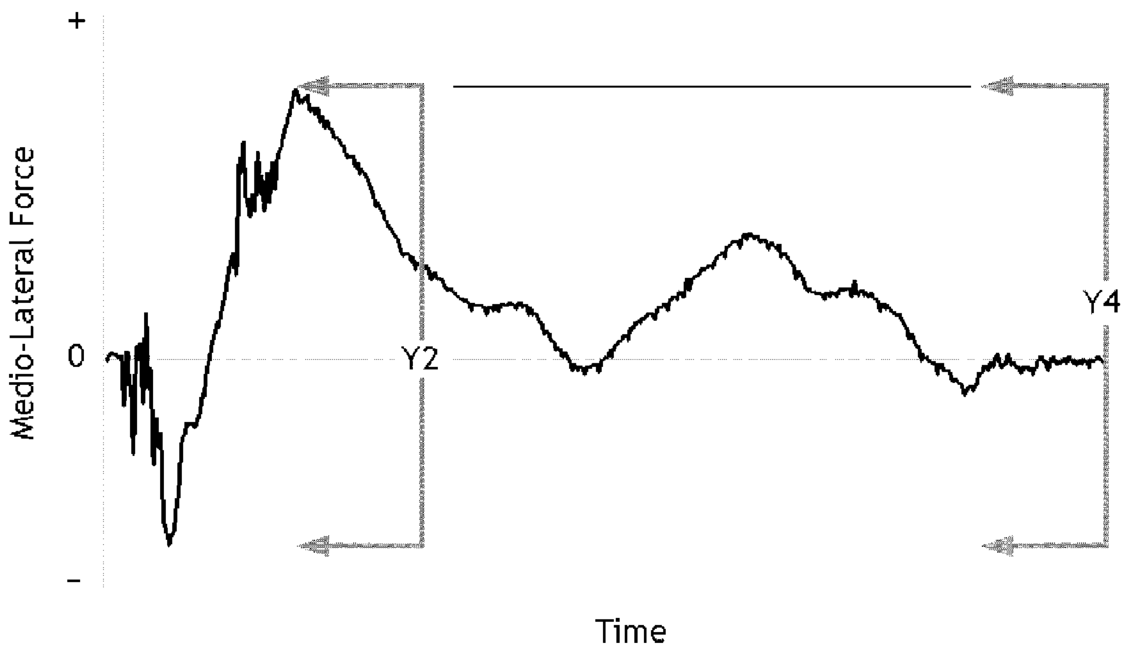

Figure C-3. Schematic depiction of the dependent variables derived from medio-lateral kinetic force. These variables were obtained from both non-paced and paced gait.

APPENDIX D

SUMMARY STATISTICS FOR THE DEPENDENT MEASURES

APPENDIX D
SUMMARY STATISTICS FOR THE DEPENDENT MEASURES

Table D-1. *Descriptive Statistics for the Range of Motion Variables in the Seven Clothing Conditions*

Dependent Variable	Plot of Condition 2-7 Means Relative to Condition 1 Mean[a]	*M*	*SD*	*n*
R1	Standing trunk flexion (m)			
	1	0.673	0.065	13
	2	0.684	0.094	12
	3	0.695	0.072	11
	4	0.649	0.092	12
	5	0.656	0.085	13
	6	0.673	0.067	11
	7	0.641	0.094	12
R2	Unilateral upper arm abduction (deg)			
	1	172	13.4	13
	2	174	7.3	12
	3	172	14.2	10
	4	169	13.3	11
	5	166	18.7	12
	6	171	11.4	11
	7	162	19.5	11
R3	Bilateral upper arm abduction (deg)			
	1	174	12.7	12
	2	174	8.8	12
	3	176	13.6	11
	4	175	10.4	11
	5	167	17.2	13
	6	166	21.0	9
	7	176	22.3	11
R4	Unilateral upper arm forward extension (deg)			
	1	168	7.5	12
	2	161	16.0	12
	3	161	13.4	11
	4	156	24.2	12
	5	155	14.8	12
	6	157	11.9	12
	7	155	17.8	11

Table D-1. (*Continued*)

Dependent Variable	Plot of Condition 2-7 Means Relative to Condition 1 Mean[a]	*M*	*SD*	*n*
R5	Bilateral upper arm forward extension (deg)			
	1	164	12.5	13
	2	158	16.6	11
	3	161	13.4	11
	4	160	19.1	11
	5	152	17.3	13
	6	156	12.6	12
	7	151	22.9	12
R6	Upper leg flexion (deg)			
	1	98	50.6	12
	2	93	18.7	11
	3	81	15.3	11
	4	70	13.0	11
	5	74	15.7	12
	6	70	12.6	12
	7	76	11.8	12
R7	Lateral waist flexion (m)			
	1	0.224	0.043	13
	2	0.229	0.045	12
	3	0.230	0.043	10
	4	0.234	0.053	11
	5	0.217	0.059	11
	6	0.226	0.038	11
	7	0.237	0.048	12
R8	Pack reach (m)			
	1	0.400	0.064	9
	2	0.393	0.070	9
	3	0.430	0.068	6
	4	0.420	0.081	7
	5	0.477	0.075	9
	6	0.457	0.086	9
	7	0.474	0.085	11

[a] The bars represent only the differences between means; the horizontal scale is unique to each variable. Entries to the left of the vertical line indicate values less than and those to the right indicate values greater than the value for condition 1. These plots are intended to facilitate interpretation of the mean contrast analyses.

Table D-2. *Descriptive Statistics for the Unpaced Gait Variables in the Seven Clothing Conditions*

Dependent Variable		Plot of Condition 2-7 Means Relative to Condition 1 Mean[a]	*M*	*SD*	*n*
UT1	Stride length (m)				
		1	1.67	0.095	8
		2	1.69	0.075	8
		3	1.73	0.112	8
		4	1.72	0.075	8
		5	1.70	0.105	8
		6	1.67	0.092	8
		7	1.64	0.035	8
UT2	Stride period (s)				
		1	1.29	0.139	8
		2	1.33	0.098	8
		3	1.31	0.266	8
		4	1.22	0.096	8
		5	1.29	0.198	8
		6	1.29	0.113	8
		7	1.30	0.119	8
UT3	Stance phase (%)				
		1	59.3	1.44	8
		2	57.4	2.73	8
		3	57.6	2.04	8
		4	59.3	1.85	8
		5	58.5	0.83	8
		6	58.0	4.17	8
		7	60.4	4.83	8
UT4	Swing phase (%)				
		1	40.7	1.44	8
		2	42.6	2.73	8
		3	42.4	2.04	8
		4	40.9	1.34	8
		5	41.5	0.83	8
		6	41.2	3.40	8
		7	39.6	4.83	8
UT5	Stance/swing ratio (ratio scale)				
		1	1.47	0.095	8
		2	1.37	0.155	8
		3	1.36	0.106	8
		4	1.42	0.061	8
		5	1.43	0.053	8
		6	1.47	0.318	8
		7	1.61	0.433	8

Table D-2. (*Continued*)

Dependent Variable		Plot of Condition 2-7 Means Relative to Condition 1 Mean[a]	*M*	*SD*	*n*
UT6	Double support (%)				
		1	18.7	2.89	8
		2	14.9	5.45	8
		3	15.1	4.09	8
		4	17.5	1.83	8
		5	17.1	1.65	8
		6	17.2	6.97	8
		7	20.8	9.67	8
UT7	Single support (%)				
		1	81.3	2.89	8
		2	85.1	5.45	8
		3	84.9	4.09	8
		4	83.1	2.34	8
		5	82.9	1.65	8
		6	83.7	7.95	8
		7	79.2	9.67	8
UT8	Stride width (m)				
		1	0.35	0.318	8
		2	0.35	0.318	8
		3	0.36	0.352	8
		4	0.70	0.437	8
		5	0.53	0.473	8
		6	0.30	0.241	8
		7	0.42	0.394	8
UT9	Step length (m)				
		1	0.82	0.090	8
		2	0.88	0.091	8
		3	0.87	0.051	8
		4	0.87	0.045	8
		5	0.84	0.090	8
		6	0.84	0.069	8
		7	0.81	0.102	8
UT10	Step period (s)				
		1	0.679	0.056	8
		2	0.695	0.077	8
		3	0.698	0.129	8
		4	0.659	0.052	8
		5	0.685	0.074	8
		6	0.699	0.061	8
		7	0.706	0.057	8

Table D-2. (*Continued*)

Dependent Variable		Plot of Condition 2-7 Means Relative to Condition 1 Mean[a]	*M*	*SD*	*n*
UT11	Cadence (steps/min)				
		1	91.9	8.17	8
		2	89.1	8.47	8
		3	92.1	13.18	8
		4	94.1	6.38	8
		5	91.8	9.68	8
		6	90.5	7.82	8
		7	89.5	7.65	8
UT12	Gait velocity (m/s)				
		1	1.31	0.166	8
		2	1.27	0.076	8
		3	1.35	0.208	8
		4	1.42	0.132	8
		5	1.34	0.228	8
		6	1.30	0.079	8
		7	1.27	0.130	8
UA1	Pelvic rotation (deg)				
		1	21.1	6.51	8
		2	20.1	5.31	8
		3	18.0	4.66	8
		4	18.9	4.09	8
		5	16.1	4.51	8
		6	16.1	4.82	8
		7	16.5	6.42	8
UA2	Pelvic obliquity (deg)				
		1	8.6	1.59	8
		2	9.1	4.32	8
		3	9.3	2.01	8
		4	8.2	2.50	8
		5	7.6	1.95	8
		6	8.1	1.85	8
		7	10.0	3.17	8
UA3	Hip flexion (deg)				
		1	-21.2	9.80	6
		2	-23.7	4.64	8
		3	-19.2	12.22	8
		4	-25.6	5.99	8
		5	-22.9	10.70	8
		6	-23.1	4.19	8
		7	-24.1	5.22	8

Table D-2. (*Continued*)

Dependent Variable		Plot of Condition 2-7 Means Relative to Condition 1 Mean[a]	*M*	*SD*	*n*
UA4	Hip extension (deg)				
		1	17.7	5.76	6
		2	17.3	4.55	8
		3	14.8	8.80	8
		4	16.7	4.83	8
		5	18.4	4.60	8
		6	16.5	2.64	8
		7	16.9	6.45	8
UA4B	Hip range, sagittal (deg)				
		1	38.9	13.77	6
		2	41.0	5.12	8
		3	33.9	11.15	8
		4	42.3	4.68	8
		5	41.2	8.03	8
		6	39.6	3.31	8
		7	41.0	5.58	8
UA5	Hip abduction (deg)				
		1	2.8	1.61	6
		2	1.0	5.20	8
		3	-0.2	5.26	8
		4	4.2	4.25	8
		5	3.8	4.74	8
		6	2.7	3.66	8
		7	5.4	2.98	8
UA6	Hip adduction (deg)				
		1	-9.8	4.74	6
		2	-11.0	4.80	8
		3	-13.4	4.49	8
		4	-8.9	4.63	8
		5	-9.1	3.87	8
		6	-10.5	4.60	8
		7	-10.0	5.03	8
UA6B	Hip range, coronal (deg)				
		1	12.6	4.51	6
		2	12.0	2.72	8
		3	13.3	4.93	8
		4	13.2	3.38	8
		5	12.9	3.39	8
		6	13.1	2.80	8
		7	15.4	3.46	8

Table D-2. (*Continued*)

Dependent Variable		Plot of Condition 2-7 Means Relative to Condition 1 Mean[a]	*M*	*SD*	*n*
UA7	Knee flexion, minimum (deg)				
		1	-10.0	7.53	8
		2	-13.0	6.68	8
		3	-16.2	5.95	8
		4	-19.0	9.88	8
		5	-16.2	10.79	8
		6	-13.4	5.91	8
		7	-11.5	11.08	8
UA8	Knee flexion, maximum (deg)				
		1	33.5	13.9	6
		2	28.0	4.3	8
		3	35.4	13.5	8
		4	31.1	8.8	8
		5	31.3	14.2	8
		6	35.5	8.6	8
		7	36.8	17.4	8
UA8B	Knee range, sagittal (deg)				
		1	43.8	18.0	6
		2	41.0	7.2	8
		3	51.6	15.9	8
		4	50.1	15.9	8
		5	47.4	14.8	8
		6	48.9	10.1	8
		7	48.3	19.9	8
UA9	Ankle plantarflexion (deg)				
		1	13.7	3.25	8
		2	13.1	7.95	8
		3	16.7	5.11	8
		4	15.3	3.75	8
		5	12.6	5.07	8
		6	16.9	8.20	8
		7	14.8	9.16	8
UA10	Ankle dorsiflexion (deg)				
		1	13.7	2.59	8
		2	19.3	11.43	8
		3	12.5	4.49	8
		4	15.5	3.30	8
		5	16.5	5.36	8
		6	16.7	5.39	8
		7	19.9	12.5	8

Table D-2. (*Continued*)

Dependent Variable	Plot of Condition 2-7 Means Relative to Condition 1 Means[a]	*M*	*SD*	*n*
UA10B	Ankle range, sagittal (deg)			
	1	27.4	3.5	8
	2	32.4	10.9	8
	3	29.1	6.8	8
	4	30.8	4.4	8
	5	29.1	5.8	8
	6	33.6	13.2	8
	7	34.8	19.7	8
UA11	Ankle varus/valgus (deg)			
	1	42.8	12.5	8
	2	55.0	20.7	8
	3	43.6	10.5	8
	4	58.4	7.5	8
	5	51.2	16.4	8
	6	52.9	26.4	8
	7	58.4	23.1	8
UA12	Trunk tilt (deg)			
	1	-2.8	4.34	8
	2	-3.1	3.55	8
	3	-2.3	5.39	8
	4	0.4	5.09	8
	5	-0.6	4.46	8
	6	-2.3	4.00	8
	7	0.8	4.19	8
UA13	Shoulder abduction (deg)			
	1	20.5	5.75	8
	2	22.0	4.00	8
	3	23.9	6.87	8
	4	26.1	2.95	8
	5	23.4	4.80	8
	6	22.1	5.26	8
	7	19.9	3.05	8
UA14	Shoulder adduction (deg)			
	1	2.6	5.87	8
	2	6.7	4.57	8
	3	6.0	6.57	8
	4	7.8	5.54	8
	5	8.9	2.36	8
	6	7.9	4.84	8
	7	6.9	3.15	8

Table D-2. (*Continued*)

Dependent Variable	Plot of Condition 2-7 Means Relative to Condition 1 Mean[a]	*M*	*SD*	*n*
UA14B	Shoulder range, coronal (deg)			
	1	17.8	5.11	8
	2	15.4	2.03	8
	3	17.9	5.93	8
	4	18.2	5.19	8
	5	14.5	4.72	8
	6	14.2	3.79	8
	7	13.1	4.30	8
UA15	Shoulder flexion (deg)			
	1	-14.5	8.51	8
	2	-14.5	6.16	8
	3	-13.2	10.21	8
	4	-8.9	10.66	8
	5	-5.9	7.20	8
	6	-7.9	8.99	8
	7	-8.0	9.49	8
UA16	Shoulder extension (deg)			
	1	20.1	11.59	8
	2	16.6	9.04	8
	3	19.5	8.86	8
	4	25.4	10.18	8
	5	23.7	10.67	8
	6	15.6	9.38	8
	7	14.8	5.77	8
UA16B	Shoulder range, sagittal (deg)			
	1	34.7	13.7	8
	2	31.1	7.7	8
	3	32.7	11.5	8
	4	34.3	11.0	8
	5	29.5	11.5	8
	6	23.5	9.7	8
	7	22.9	11.2	8
UY2	Force excursions, 0–30% (N)			
	1	108	24.6	8
	2	102	23.6	8
	3	111	25.1	8
	4	129	30.3	8
	5	115	28.6	8
	6	124	30.1	8
	7	114	20.4	8

Table D-2. (*Continued*)

Dependent Variable	Plot of Condition 2-7 Means Relative to Condition 1 Mean[a]	*M*	*SD*	*n*
UY4	Force excursions, 0–100% (N)			
	1	120	31.7	8
	2	107	23.9	8
	3	117	25.6	8
	4	132	35.9	8
	5	125	25.4	8
	6	129	30.9	8
	7	129	34.5	8
UZ1	Time to 1st force peak (%)			
	1	21.3	2.71	8
	2	21.8	3.14	8
	3	21.6	4.18	8
	4	21.7	2.44	8
	5	22.5	3.95	8
	6	22.0	3.98	8
	7	21.9	4.63	8
UZ2	Amplitude of 1st force peak (N/kg)			
	1	11.6	0.71	8
	2	11.3	0.68	8
	3	11.6	1.15	8
	4	11.5	1.14	8
	5	11.3	0.96	8
	6	11.7	1.32	8
	7	11.4	1.24	8
UZ3	Time to minimum force peak (%)			
	1	45.2	6.20	8
	2	46.6	4.41	8
	3	48.1	7.69	8
	4	48.0	5.11	8
	5	46.1	6.67	8
	6	47.9	4.71	8
	7	47.2	9.41	8
UZ4	Amplitude of minimum force peak (N/kg)			
	1	6.77	0.73	8
	2	6.84	0.85	8
	3	6.56	1.20	8
	4	6.56	0.95	8
	5	6.61	0.76	8
	6	6.52	1.04	8
	7	6.51	0.82	8