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THE EFFECT OF FOOTWEAR ON THE MOVEMENT OF THE FOOT DURING WALKI--ETC(U)
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THE EFFECT OF FOOTWEAR ON THE MOVEMENT OF THE FOOT DURING WALKING

by

M.M. Dewar and R.M. Crow



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OF THE FOOT DURING WALKING.

10 by
M.M./Dewar R.M./Crow
Environmental Protection Section
Protective Sciences Division

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ABSTRACT

↘ This preliminary investigation found that various types of footwear had very little effect of the movement of the foot during walking. The movement of bare feet and feet shod in CF Arctic mukluks appeared to be similar, as were the movements of feet shod in CF dress shoes and CF combat boots. ↙

RÉSUMÉ

Cette étude préliminaire a démontré que les divers types de chaussures n'influaient guère sur le mouvement du pied en cours de marche. Le mouvement au niveau du pied de sujets marchant pieds nus était semblable à celui de sujets chaussés de mukluks utilisés dans l'Arctique par les Forces armées canadiennes. De plus, aucune différence n'a été observée entre le mouvement du pied de sujets portant des souliers réglementaires des FAC et le mouvement du pied de sujets portant les bottes militaires dont se servent les Forces armées canadiennes.

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INTRODUCTION

This work was undertaken in support of a project on the design of improved Arctic footwear. The purpose of the study was twofold; firstly, to review how the foot moves during walking and secondly, to conduct a preliminary investigation on the effects of footwear, varying in weight and heel height, on this movement.

A literature search revealed that methods of studying foot movements have been established, the details of foot movement during walking have been determined and that normal gait has been compared with abnormal gait. However, no pertinent work is available on the effect of footwear on foot movement.

EXPERIMENTAL PROCEDURE

Of the various methods described in the literature to determine the movement of the foot during walking (1, 2, 3), the method selected for the present study was one in which a cine-camera was used to record, on film, a subject walking on a treadmill. This method was selected because of its technical advantages and reproducibility (1).

Typical photographs obtained from the cine-frames are shown in Figure 1. The subject was an active young male member of the CF/DREO Test Team who had prior experience walking on treadmills. For all runs, he wore combat dress, with the trouser legs rolled up in such a way that they did not restrict his leg movement. Films were made of him walking on the treadmill with:

1. Bare feet
2. CF dress shoes
3. CF boot, combat; socks, grey, woollen
4. CF mukluk ensemble, Arctic; socks, grey, woollen

The footwear worn by the subject was from his personal kit and so was well broken in and comfortable. The heel and sole height and footwear weights are given in Table I.

TABLE I

Particulars of Footwear

	Weight (g)	Heel Height (cm)	Sole Height (cm)
Shoe	527	2.4	1.0
Boot	920	3.1	1.3
Mukluk	1346	4.4	2.9

Since the treadmill was only accessible from one side, the subject was filmed walking toward the left so that the inside of the right foot and the outside of the left foot were exposed to view. Four round adhesive markers were placed on the exposed side of each foot (Figure 1). One marker was placed at the heel and another at the point of greatest protusion of the ankle bone on each foot. On the right foot, markers were placed at the tip and at the base of the large toe and on the left foot, at the tip and at the base of the small toe. When the subject wore footwear, markers were placed at corresponding points on the outside of the footwear. Where necessary, these positions were determined by affixing small pieces of cork to the foot at the selected points, and determining, by feel, the corresponding points on the outside of the footwear. Each point was verified by measuring the distance between it and a reference point previously marked on the leg of the subject. For suitable contrast on the film, black markers were used on the bare feet and on the mukluks, and white markers on the shoes and boots.

It is noted that, in this study, movement of the foot inside the footwear has not been taken into account. Therefore, the resulting loci traced out by the markers are those of points on the outside of the footwear. An exception to this is the locus of the ankle for the dress shoe.

Figure 1

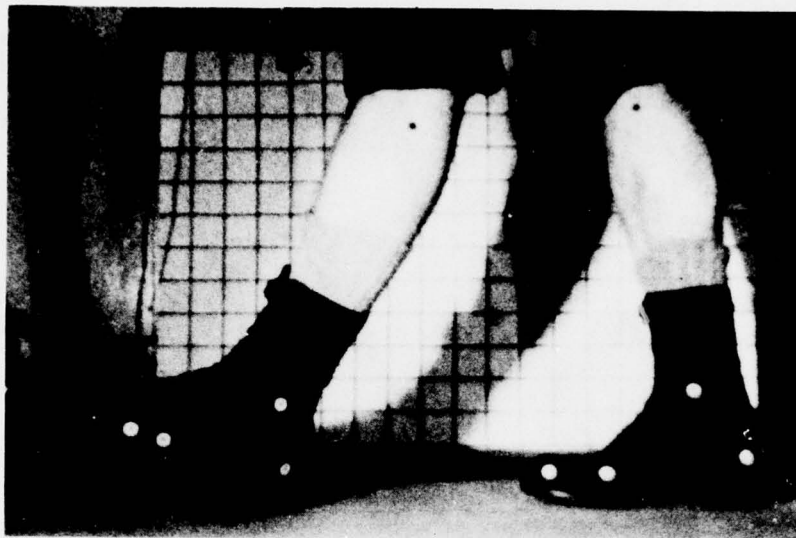
*Photographs of Cine-Frames Showing Markers and Types of Footwear Worn
By Subject Walking on the Treadmill.*



Bare Feet



Dress Shoes



Combat Boots



Arctic Mukluks

Films were taken with a "Cine-Kodak Special II" 16-mm movie camera with a 15-mm lens using "Dupont 931A High Speed Rapid Reversal Film."

After initial experiments, a treadmill speed of 0.7 m/s was selected. It was found that a treadmill speed of 1.6 m/s, the normal walking speed, gave a blurred image on the film and it was impossible to establish the positions of the markers accurately.

To determine the locus of each marker, the film was viewed in a Vanguard Motion Analyser (Model M-16C) which was equipped with a crosshair assembly. The basic method used was to record the coordinates for each marker on the foot at intervals for one cycle of the walking motion and to join them with a smooth curve. This gives the locus of one point on the foot during one pace. A scale factor, the actual object size compared to the viewed image size, was calculated using a grid of five-centimeter squares placed behind the subject and the Analyser crosshair assembly. To ensure that the results for the motion of the feet were consistent, data for each marker were collected from six separate paces.

A certain error due to parallax is inherent in this method. This error would be greater for the left foot than the right since it is farther from the grid. However, it was not felt that this error would materially affect the shape of the reproduced loci. Also, since this study is a comparison of different types of footwear rather than a comparison between right and left feet, this parallax error has been ignored.

RESULTS AND DISCUSSION

Basic Pattern of Movement During Walking

Typical graphs of the loci of the four points marked on the foot are shown in Figures 2 and 3. The closed loci in Figure 2 are those of the marked points on the foot as seen by the camera. Translated into a more normal situation where the subject is walking at a constant speed on a level stationary surface, these are the loci which would be seen by a camera moving at a fixed distance from the subject and at the same rate of speed as the subject. The loci in Figure 3 were derived from those in Figure 2 and are those of the marked points on the foot with reference to a fixed point on the treadmill surface. Again, translating to a more normal situation, these are the loci which would be seen by a camera at a fixed position as the subject walked past it.

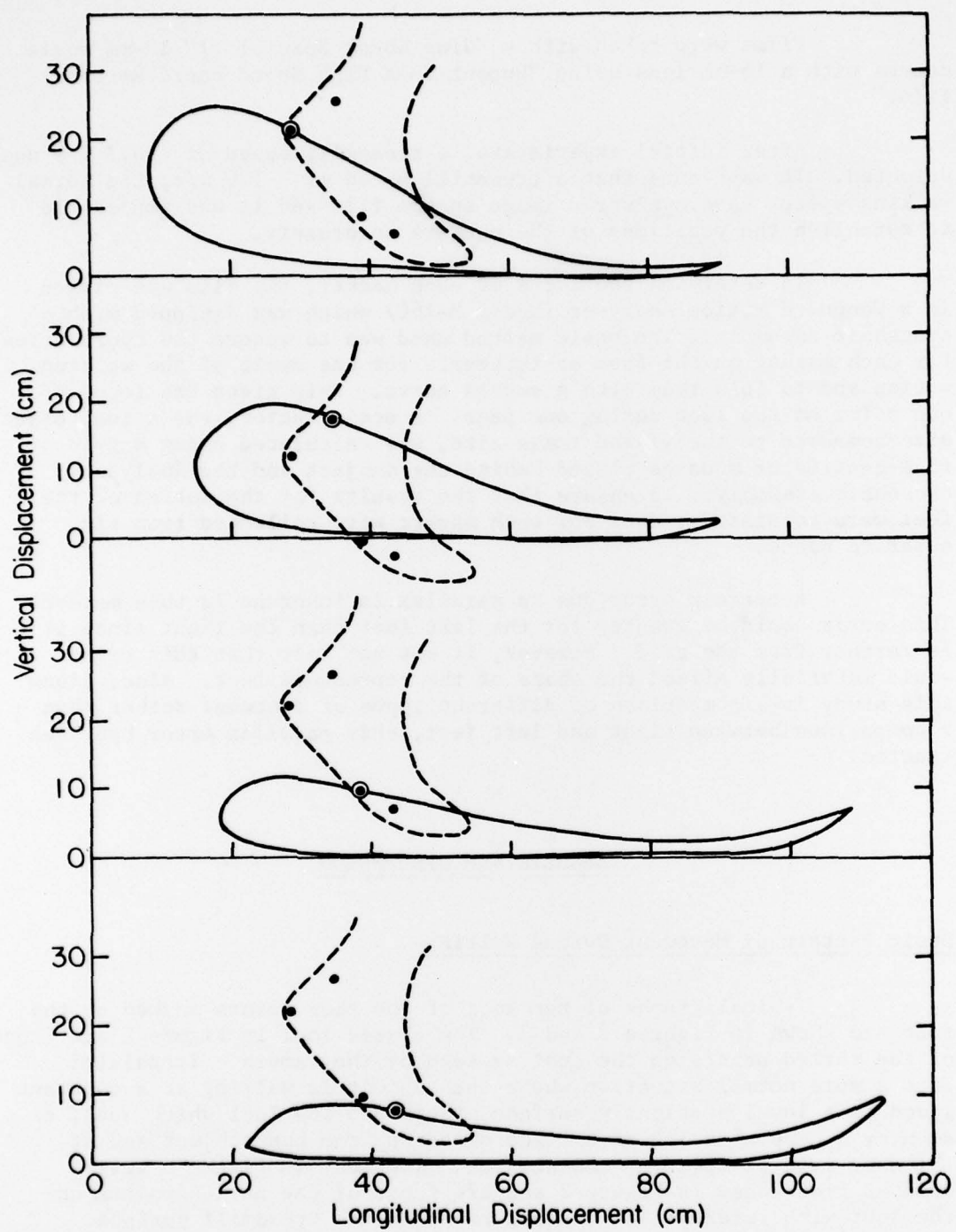


Figure 2. Loci of four markers on left foot of subject walking on treadmill.

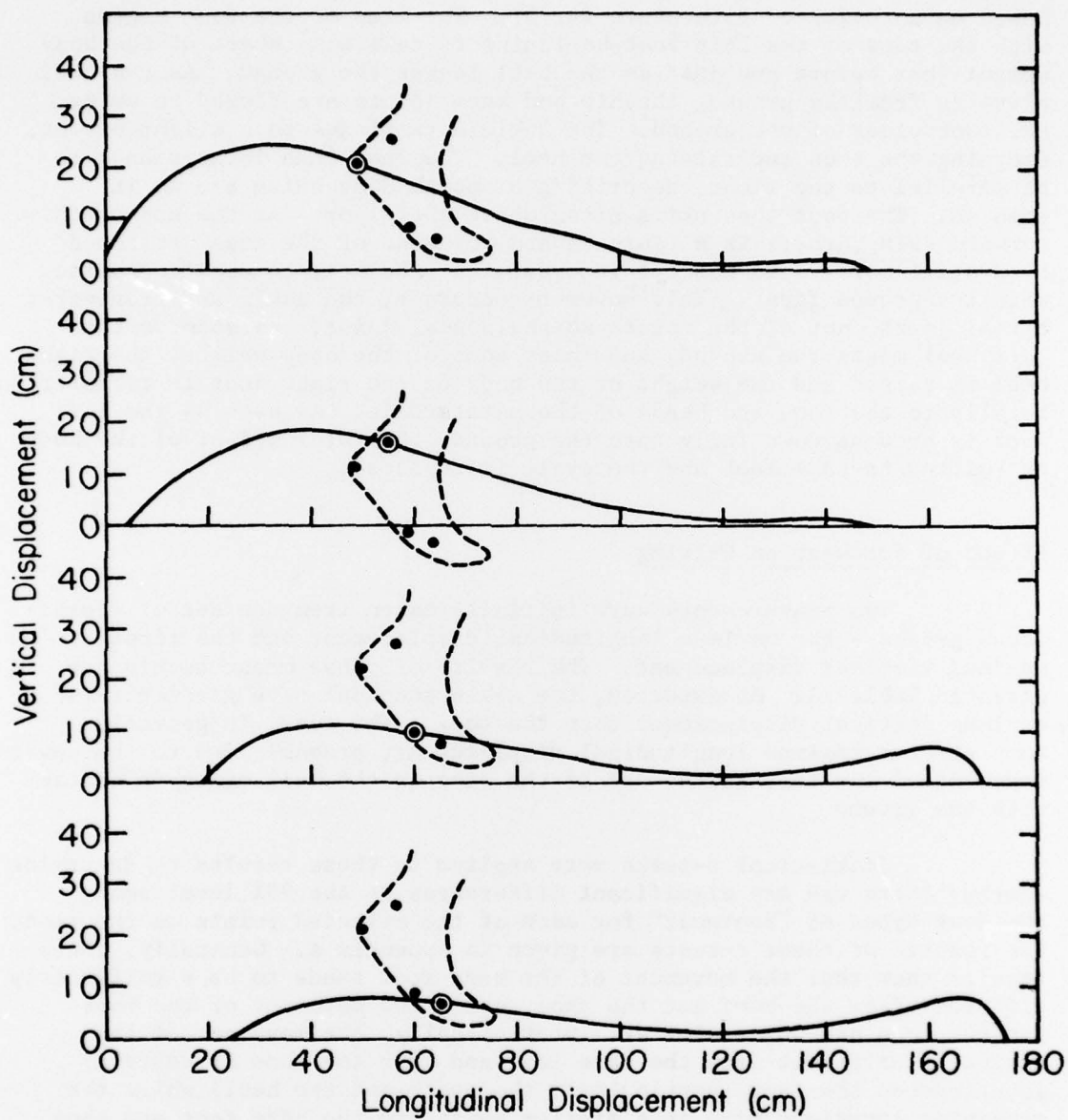


Figure 3. Loci of four markers on left foot with reference to a fixed point on the treadmill.

For the sake of completeness, the following description of a step includes information other than that provided by these graphs, based on a review of literature (4, 5). The step of the foot begins with the toes of the left foot beginning to take some share of the body weight just before and just as the heel leaves the ground. As the heel elevates from the ground, the hip and knee joints are flexed to swing the foot clear of the ground. The ankle dorsiflexes to a slight extent, dropping the toes and raising the heel. The foot then rotates back to be parallel to the floor, describing a smooth descending arc as it does so. The foot then skims along above the floor. At the end of this forward swing, there is a rapid upward movement of the toes, followed by a still more rapid descent in order that the heel comes into contact with the ground first. This movement occurs at the ankle and transverse tarsal joint, not at the metatarso-phalangeal joint. As soon as the left heel meets the ground, and takes some of the body weight, the right heel is raised and the weight of the body on the right foot is transferred totally to the toes and heads of the metatarsals. As soon as the left foot is brought down fully onto the ground, the total weight of the body is shifted to this foot and the cycle is repeated.

Effect of Footwear on Walking

Two measurements were initially taken from each set of closed-locus graphs - the maximum longitudinal displacement and the first maximum vertical displacement. The results of these measurements are given in Table II. As expected, the ankle and heel have greater first maximum vertical displacement than the toes. The toes, in general, have greater maximum longitudinal displacement, probably due to the upward movement of the toes at the end of the step as the heel comes in contact with the ground.

Statistical t-tests were applied to these results to determine whether there was any significant differences at the 99% level among the four types of "footwear" for each of the selected points on the foot. The results of these t-tests are given in Appendix A. Generally, these results show that the movement of the bare foot tends to be significantly different from the boot and the shoe, while the movement of the boot and the shoe are quite similar. Statistically, the movement of the mukluk is different from the bare foot and from the shoe at certain locations on the foot (particularly the ankle and the heel) while the remaining locations move in a similar manner to the bare foot and shoe (e.g. the toes).

The displacement results for the four locations on each foot were plotted against the heel height and footwear weight, as shown in Figures 4 and 5 respectively. Sole height has not been included in

TABLE II

Maximum Displacements of Foot During Walking With Different FootwearMaximum Longitudinal Displacement (cm)

Type of Footwear	Left Foot				Right Foot			
	Ankle	Heel	Toe Base	Toe Tip	Ankle	Heel	Toe Base	Toe Tip
Bare								
$\bar{x}$ *	76	82	91	92	70	79	85	82
cv **	1	1	1	1	2	2	2	3
Shoe								
$\bar{x}$	80	88	98	100	72	83	89	89
cv	3	3	3	2	3	3	3	3
Boot								
$\bar{x}$	82	89	98	100	85	75	90	90
cv	3	3	4	3	2	2	2	2
Mukluk								
$\bar{x}$	83	90	97	98	88	82	90	87
cv	4	4	5	5	5	5	4	4

Vertical Displacement, First Maximum (cm)

Bare								
$\bar{x}$	20	25	12	9	14	21	8	13
cv	4	4	3	6	17	13	5	8
Shoe								
$\bar{x}$	23	30	16	12	17	29	11	13
cv	1	1	2	2	2	1	1	2
Boot								
$\bar{x}$	22	29	16	12	16	26	10	15
cv	3	2	2	2	3	1	7	5
Mukluk								
$\bar{x}$	22	27	14	13	20	25	11	14
cv	4	3	4	2	4	4	9	5

* $\bar{x}$ is the mean of six readings of the displacement

** cv is the coefficient of variation in x in %.

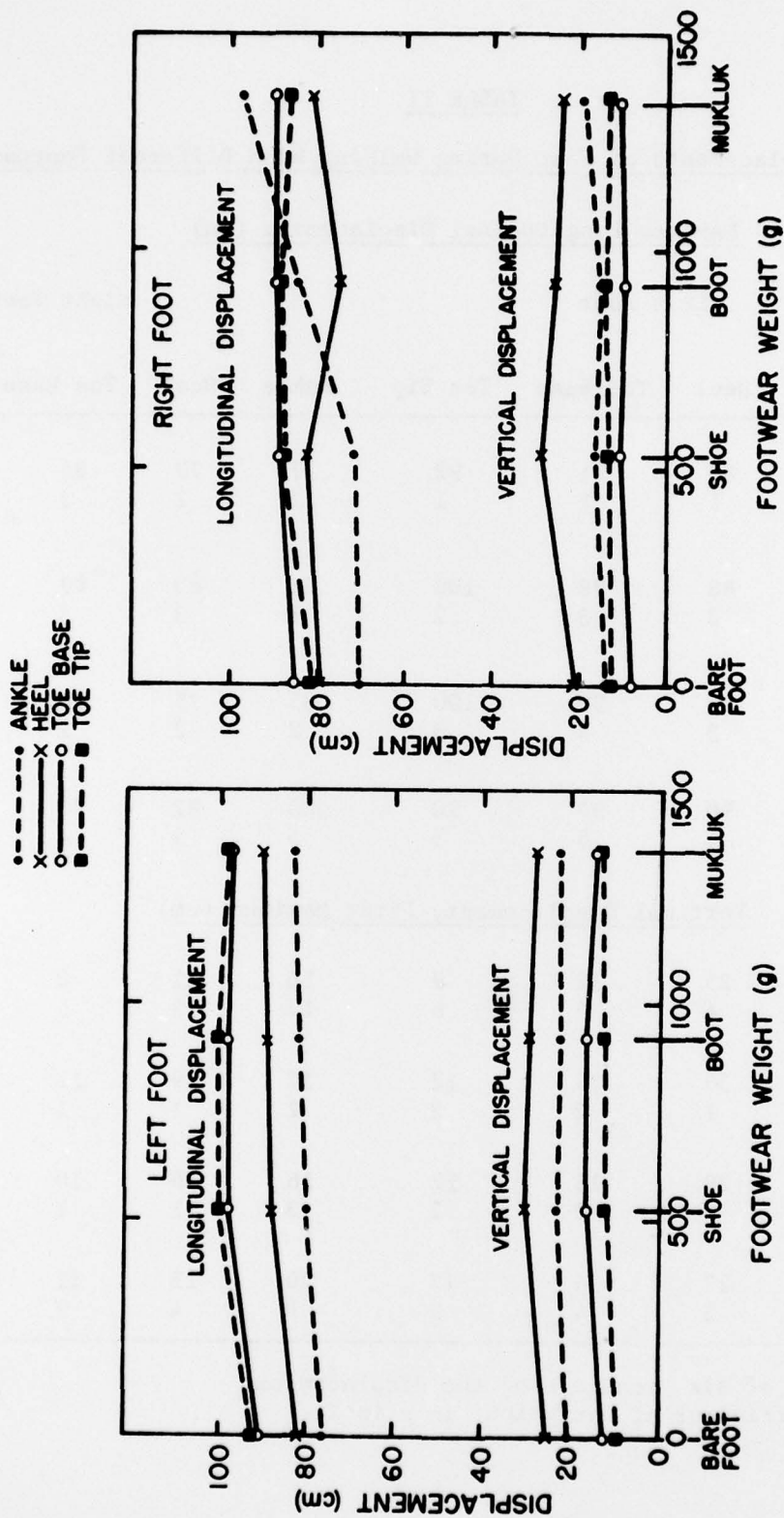


Figure 4. Plot of footwear weight and maximum longitudinal and vertical (first) displacement.

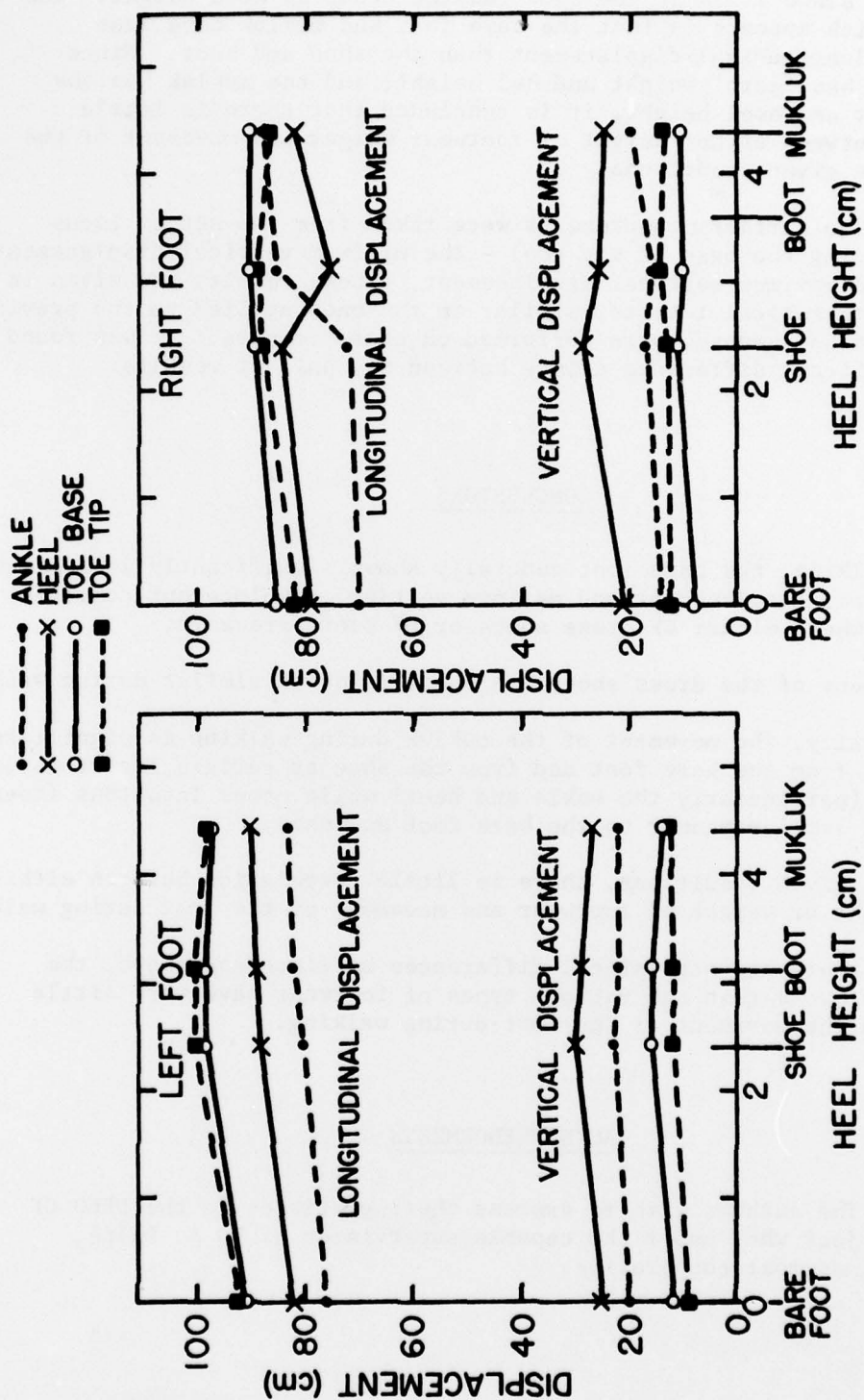


Figure 5. Plot of heel height and maximum longitudinal and vertical (first) displacement.

these Figures since it is in the same ranking order as heel height. The only trend which appears is that the bare foot and mukluk have less vertical and longitudinal displacement than the shoe and boot. Since the bare foot has "zero" weight and heel height, and the mukluk has the maximum weight and heel height, it is concluded that there is little correlation between either height or footwear weight and movement of the foot under the given conditions.

Two further measurements were taken from the set of locus graphs (excluding the base of the toe) - the minimum vertical displacement and the second maximum vertical displacement. These results are given in Table III. Statistical t-tests, similar to the ones applied to the previous displacement measurements, were performed on these results. It was found that no significant difference exists between any pair of results.

CONCLUSIONS

1. During walking, the bare foot generally shows significantly less maximum longitudinal displacement and maximum vertical displacement compared to cases where either CF dress shoes or CF boots are worn.
2. The movement of the dress shoes and boots is quite similar during walking.
3. Statistically, the movement of the mukluk during walking is significantly different from the bare foot and from the shoe at certain locations on the foot (particularly the ankle and heel) while other locations (toes) move in a similar manner to the bare foot and shoe.
4. Under the given conditions, there is little correlation between either heel height or weight of footwear and movement of the foot during walking.
5. Although there are statistical differences as discussed above, the overall view is that the various types of footwear have very little effect on the movement of the foot during walking.

ACKNOWLEDGEMENTS

The authors wish to express their gratitude to the DREO CF Test Team subject who, under the capable supervision of WO A. Dalpé, was at all times most cooperative.

TABLE III

Vertical Displacements of Foot During Walking With Different Footwear

		<u>Minimum Vertical Displacement (cm)</u>					
		Left Foot			Right Foot		
Type of Footwear		Ankle	Heel	Toe Base	Ankle	Heel	Toe Base
Bare	$\bar{x}$ *	1	2	1	2	1	2
	cv **	0	0	50	50	50	40
Shoe	$\bar{x}$	2	1	1	3	1	2
	cv	40	0	60	20	60	30
Boot	$\bar{x}$	2	1	2	1	1	2
	cv	40	0	25	60	0	30
Mukluk	$\bar{x}$	2	1	3	2	2	2
	cv	40	60	0	0	30	0
		<u>Vertical Displacement, Second Maximum (cm)</u>					
Bare	$\bar{x}$	2	3	7	3	2	8
	cv	25	20	9	20	30	13
Shoe	$\bar{x}$	3	2	7	3	2	9
	cv	20	25	11	0	30	8
Boot	$\bar{x}$	3	2	9	3	2	10
	cv	20	25	11	0	25	8
Mukluk	$\bar{x}$	4	3	12	4	3	10
	cv	23	30	13	20	17	5

* $\bar{x}$ in the mean of six readings of the displacement

** cv is the coefficient of variation in x in %.

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APPENDIX A

t-Test Results for Comparison of Footwear Parameters

Significance level 99% ($n - 1 = 4.60$)
 Comparisons which have t-test values exceeding 4.60 are significantly different.
 The significantly different values are underlined in the Table.

Footwear Comparison	t Values at given Locations							
	Left Foot				Right Foot			
	Ankle	Heel	Toe Base	Toe Tip	Ankle	Heel	Toe Base	Toe Tip
<u>t values for Maximum Longitudinal Displacement</u>								
Bare Foot - Shoe	<u>6.40</u>	<u>9.19</u>	<u>42.00</u>	<u>8.30</u>	<u>1.40</u>	<u>2.01</u>	<u>3.67</u>	<u>7.28</u>
Bare Foot - Boot	<u>4.43</u>	<u>6.87</u>	<u>12.00</u>	<u>5.79</u>	<u>5.40</u>	<u>6.07</u>	<u>1.77</u>	<u>4.79</u>
Bare Foot - Mukluk	<u>4.87</u>	<u>2.86</u>	<u>4.04</u>	<u>2.58</u>	<u>13.88</u>	<u>7.60</u>	<u>2.23</u>	<u>3.90</u>
Shoe-Boot	<u>2.72</u>	<u>3.20</u>	<u>0.32</u>	<u>0.30</u>	<u>1.43</u>	<u>1.26</u>	<u>0.44</u>	<u>0.26</u>
Shoe-Mukluk	<u>2.58</u>	<u>9.11</u>	<u>3.91</u>	<u>0.04</u>	<u>5.08</u>	<u>5.18</u>	<u>0.96</u>	<u>0.15</u>
Boot-Mukluk	<u>0.16</u>	<u>4.97</u>	<u>6.59</u>	<u>1.63</u>	<u>44.80</u>	<u>3.27</u>	<u>1.23</u>	<u>1.48</u>
<u>t values for Vertical Displacement, First Maximum</u>								
Bare Foot - Shoe	<u>3.72</u>	<u>9.19</u>	<u>41.90</u>	<u>8.63</u>	<u>3.05</u>	<u>7.66</u>	<u>17.10</u>	<u>3.46</u>
Bare Foot - Boot	<u>4.73</u>	<u>6.87</u>	<u>9.59</u>	<u>11.50</u>	<u>3.65</u>	<u>3.83</u>	<u>27.70</u>	<u>5.06</u>
Bare Foot - Mukluk	<u>6.42</u>	<u>2.86</u>	<u>4.04</u>	<u>1.33</u>	<u>3.95</u>	<u>2.47</u>	<u>1.92</u>	<u>2.27</u>
Shoe-Boot	<u>2.72</u>	<u>3.20</u>	<u>0.32</u>	<u>1.33</u>	<u>6.23</u>	<u>11.70</u>	<u>3.95</u>	<u>19.27</u>
Shoe-Mukluk	<u>2.58</u>	<u>9.11</u>	<u>3.91</u>	<u>6.43</u>	<u>5.72</u>	<u>9.72</u>	<u>1.68</u>	<u>4.35</u>
Boot-Mukluk	<u>2.95</u>	<u>4.97</u>	<u>6.59</u>	<u>8.80</u>	<u>10.06</u>	<u>4.42</u>	<u>0.49</u>	<u>1.69</u>

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KEY WORDS

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Foot
Motion

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