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Shock absorbing material on the shoes of long leg braces for paraplegic walking

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Abstract

A study was designed to evaluate if shock absorbing material (ethyl vinyl acetate (EVA)) on the shoes of long leg braces could decrease the accelerations and consequent shock forces transmitted through the leg and brace during paraplegic walking. Six male paraplegics (26-55 years old) took part, four using a "swing-to" and two a "swing-through" technique when walking. Recordings comprised accelerometry of leg and brace, force platform measurement, and still photography of the trajectories of the leg segments. Each experimental condition was tested three times with a coefficient of variation (CV) for the measurements ranging from 5-22%. Compared to hard heels, shoes equipped with 20mm EVA soles decreased the acceleration amplitude in the first 10 msec as well as at maximum for shoe-to-ground contact. With the accelerometer at the malleolus reduction of the amplitude averaged 22% and 12% respectively, and 35% and 21% respectively with the accelerometer on the caliper (p: 0.03-0.1). In a second trial the two "swing-through" walkers had new shoes made with a 10mm thick EVA heel built in. After 3 months of walking with these shoes tests were carried out with the accelerometer attached to the malleolus both when the new and the former shoes were put on the calipers. CV for these measurements were 15-24%. It was found that the new shoes decreased the amplitudes by up to 62% and 26% on average (all $p<0.01$). The experimental subjects indicated that the EVA soles/heels gave a more comfortable and silent walk, e.g. the "bump" transmitted up through the body to the head diminished. In future, shock absorbing material should be built into the heels of shoes provided to long leg braces for paraplegic walking.

Introduction

Shock absorbing soles in shoes have been shown to reduce the shock transmitted up through the legs in walking and running (Bojsen-Møller 1983, Light et al. 1980, Wosk & Voloshin 1985), and furthermore such soles have been found to be of advantage in relation to low back pain, and foot fatigue and stiffness (Dyer 1983, Wosk & Voloshin 1985), and may improve comfort and provide pain relief (Clark et al. 1989).

Paraplegics when walking with long leg braces have a heavy shoe to ground contact. Due to their spinal cord lesion they cannot feel the heel strike in the heel pad and they have no muscular function which can reduce the shock waves up through the body. In addition they have an abnormally low bone mineral content in the long bones of the lower extremities (Biering-Sørensen et al. 1988). These conditions imply that paraplegics are potentially more vulnerable to the heel-strike than normal persons.

The purpose of this study was to evaluate if the shock absorbing material EVA (ethyl vinyl acetate) attached to the shoes of long leg braces can decrease the acceleration and consequent shock forces transmitted up through the leg and long leg braces during paraplegic walking.

Participants and methods

Participants

A total of 6 spinal cord injured patients participated in the study (Table1). They were all fully rehabilitated and trained to use long leg braces and forearm crutches. Participant No. 1

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Table 1. Basic data for the participants.

Participant no.	Age at lesion (years)	Duration since lesion	Cause of lesion	Neurological incomplete	motor level complete	Weight (kg)	Height (cm)
1	18	29 years	Traffic accident	Th 4		62	178
2	21	19 years	Traffic accident	Th 7	Thlo	67	175
3	37	14 months	Fall		Thlo	68	180
4	36	20 years	Traffic accident		Thl2	78	181
5	24	20 months	Falling tree		Thl2	85	180
6	22	17 years	Gun shot	Thl2	L4	50	170

had some spasticity but medical treatment was not needed. The other subjects had flaccid paresis/paralysis of the lower limbs. None of the subjects had other lower limb problems which influenced their paraplegic walking.

Participants No. 1 and 6 used "swing-through" technique while the others used "swing-to" technique when walking. At the test sessions participant No. 3 walked in parallel bars, while the others used their crutches.

Measurements

To detect the accelerations in the legs and long leg braces a Philips PR 9367/20 unidirectional linear accelerations transducer was used. The accelerometer was connected through a 5m shielded cable to a Philips carrier frequency amplifier PR 9340. The cable was held during the experiment by an assistant to decrease movement artifacts and to eliminate interference with the paraplegic walking.

The signals from the amplifier were recorded on paper by a Siemens Mingograf 800 jetrecorder with a paper-speed of 5cm per sec.

Using the paper recordings the accelerations were described for every step by the maximum amplitude measured within the first 10 msec., i.e. corresponding to the heel-strike, and the overall maximum amplitude for the complete shoe to ground contact.

In one patient (No. 6) light emitting diodes (LED) (Bojsen-Møller 1983) and still photography were used in combination with accelerometry and a force-time recording from a force-platform (AMTI^{R}). Both feet were placed on the platform while the crutches were outside. The LEDs were positioned on the leg brace at mid shank, at the heel and at the forefoot. The diodes were fed by a 50 Hz signal from which, however, one impulse was omitted each second. The 50 Hz signal was further registered on the oscillogram together with the signal from the accelerometer with the missing flash forming an exact time link between the recordings and the photography (Fig. 4, left and top right).

Procedures

Sole trial – EVA soles of 20mm thickness were taped to the subjects normal shoes.

The accelerometer was first taped to the medial malleolus of the right leg in a holder of plaster (Fig. 1) with a thin shell which fitted the malleolus to create the best possible contact to the skeletal system without using invasive techniques.

The participants were allowed 5 min. to get

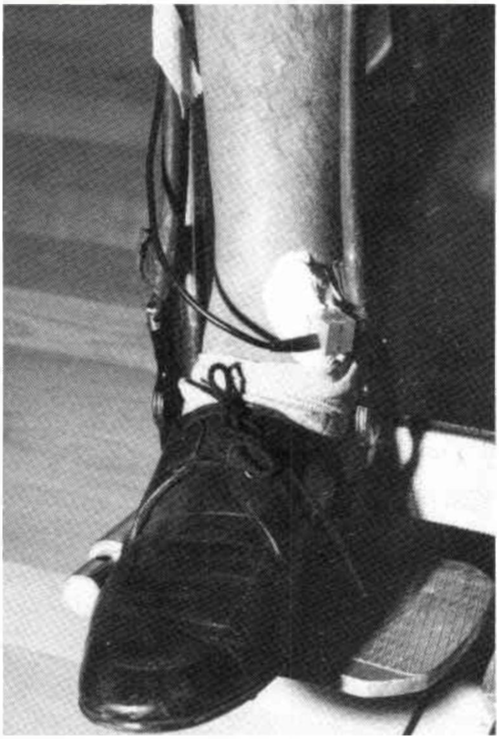

Fig. 1. Accelerometer fixed in a plaster holder and taped to the medial malleolus of the right leg, to create bony contact.

Fig. 2. Paraplegic walking with long leg braces and forearm crutches along a wooden walkway during an experiment with accelerometer attached to the medial malleolus.

used to the equipment. They were then asked to take four consecutive steps three times along a wooden walkway (Fig. 2) with the EVA soles on their shoes, and then three times four steps without the EVA soles.

Afterwards the accelerometer was taped to the long leg brace at the level of the right medial malleolus and the same walking procedure with and without the EVA soles was carried out.

In each of these experiments the accelerometer recording from step No. 2 was used for the analyses. Step No. 2, and not No. 1, was used to ensure that the participant had come into his usual gait pattern.

Heel trial – for participants Nos. 1 and 6, shoes were produced with 10mm EVA sandwiched into the heels (Fig. 3). The participants used these shoes for 2 to 3 months before they were re-tested with the accelerometer taped to the right medial malleolus. First they were tested four times with their new shoes with the 10mm sandwiched into the heels. Afterwards four times with the shoes they used previously.

The test procedure was otherwise the same as described above, except that the accelerometer

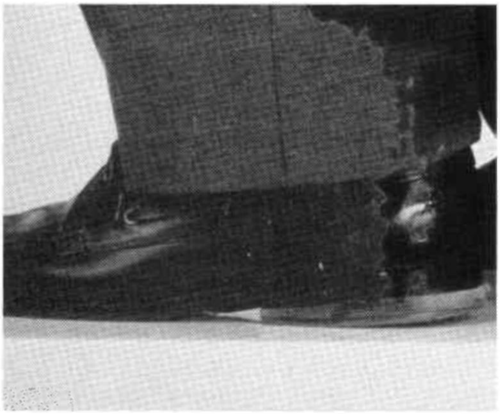

Fig. 3. Shoe with 10mm ethyl vinyl acetate sandwiched into the heel.

recordings for steps Nos. 2, 3 and 4 were utilized in the analyses. More steps were used in this procedure because it was possible in practice with these two "swing-through" walkers to obtain more data for analyses.

Statistical methods

The coefficient of variance was calculated to determine the reproducibility of the acceleration recordings.

To investigate possible significant differences in acceleration amplitude when the participants walked with or without EVA soles or heels, the data from the sole trial were treated with Wilcoxon signed-rank test (Kraft & van Eeden, 1968) on the differences of the means. One-tailed p-values were calculated. The data from the heel trials were tested by Mann-Whitney rank sum tests for each person separately.

Results

Figure 4 (bottom right) shows the parameters measured during foot to ground contact for participant No. 6, while walking with long leg braces and forearm crutches on the force platform. Peak deceleration is 4-5g with no anticipation of the touch down registered here or by the light tracks. Peak force is 160 N. From the trajectory of the heel the impacting velocity is found to be 0.4-0.5 m/s.

With 20mm EVA soles fixed to the shoes of the long leg braces there was found to be a decrease in the mean acceleration amplitude of 22% in the first 10 msec and of 12% of the maximum amplitude when recorded with the accelerometer attached to the right medial malleolus. With the accelerometer attached to the right medial malleolus. With the accelerometer attached to the long leg brace the mean decrease in acceleration amplitude was 35% in the first 10 msec and 21% of the maximum amplitude (Table 2).

With 10mm EVA sandwiched into the heels of the shoes and with the accelerometer attached to the right medial malleolus there was a mean decrease in acceleration amplitude of 62% in the first 10 msec and 26% of the maximum amplitude (Table 3). For both participants the decreases were found to be

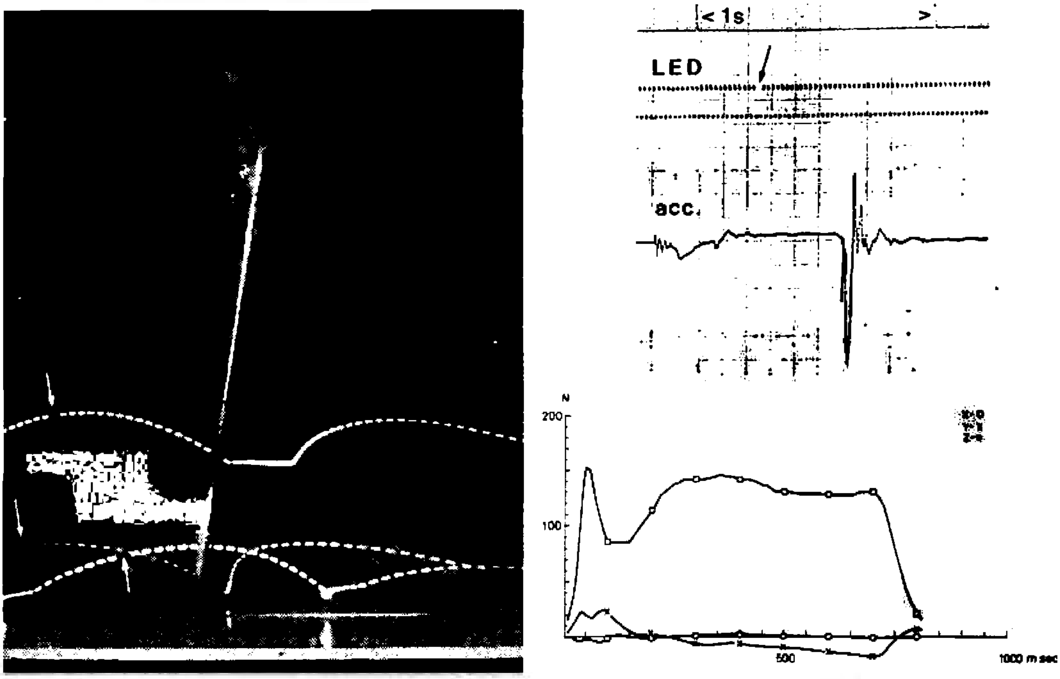

Fig. 4. Left, still photo of paraplegic walking on a walk way with built in force-platform. Light emitting diodes from three light tracks showing the trajectory of the shank, the heel, and the forefoot. Arrows indicate the missing signal and thereby the time link between the three tracks. Top right, oscillogram showing the 50Hz signal for the light emitting diodes (LED) and the accelerometry (acc.) from the same step as Fig. 4, left. Arrow indicates the missing signal. The record is significant in the absence of any anticipation of the impact. Bottom right, force-time curve from force-platform. Same step as in Fig. 4, left and top right. The z-curve (vertical force) shows the impact, but lacks a hump for the push off.

Table 2. Accelerometer-recordings (measured in G) from the long leg brace and the right medial malleolus from six paraplegics walking with and without 20mm EVA-soles attached to the shoes of their long leg braces. The coefficient of variation (CV) is given.

	Maximum amplitude within first 10msec.				Maximum amplitude for complete shoe to ground contact			
	CV	Mean	Range	P-value	CV	Mean	Range	P-value
Accelerometer attached to medial malleolus								
Without EVA soles	11.1%	1.2	0.7–1.6	0.109	22.3%	3.7	1.3–6.0	0.109
With EVA soles	19.9%	1.0	0.3–2.8		21.2%	3.2	1.0–4.8	
Accelerometer attached to caliper								
Without EVA soles	5.6%	4.9	3.6–6.5	0.031	4.8%	5.0	3.6–6.5	0.078
With EVA soles	20.9%	3.2	0.2–5.5		14.2%	4.0	2.0–5.5	

Each CV and mean is calculated on the basis of three trials for each participant, i.e. 18 measurements.

Table 3. Accelerometer-recordings (measured in G) from the right medial malleolus from two paraplegics walking with and without 10mm EVA sandwiched into the heels of the shoes of their long braces. The coefficient of variation (CV) is given.

	Maximum amplitude within first 10msec.			Maximum amplitude for complete shoe to ground contact		
	CV	Mean	Range	CV	Mean	Range
Without 10mm EVA	24.7%*	1.9	0.6–3.2	17.6%	2.4	1.6–3.2
With 10mm EVA	18.3%	0.7	0.4–1.0	15.3%	1.8	1.2–2.2

Each CV and mean is calculated on the basis of 12 steps for each participant, i.e. 24 measurements.
*excluding one outlier: CV=16.0%.

significant (in all instances $p<0.01$).

In addition to the recorded accelerometer signals the subjects indicated that the EVA soles and heels gave a more comfortable and silent walk. The "bump" up through the body to the head was said to be diminished.

Discussion

The walking patterns used by paraplegics expose the heels and legs to an impact which they feel is uncomfortable and which may be harmful. The present investigation indicated that the paraplegic leg when walking on hard surfaces in the "swing-to" as well as in the "swing-through" technique is exposed to 3-4g at each touch down. However, placing the accelerometer on the skin although with a snug fit around the prominent malleolus rather than directly to the skeleton introduces an uncertainty and the deceleration may be even greater than that measured. This deceleration will produce a skeletal load which must be considered excessive especially for their fragile bones.

The lack of anticipation of the impact is noteworthy. Normally adjustments of muscle activity, joint position, and velocity of the heel are seen in the last 10-20 msec before heel contact. The paraplegics seem unable to perceive the shocks and to protect themselves against them. The reduction by 33% of the peak load by sandwiching a 10mm thick sheet of EVA foam into the heels of the shoes is one important result of this study.

A somewhat lesser reduction of the accelerations in the sole trial compared with the heel study was found. This might partly be due to the fact that the soles were externally taped to the shoes making them 20mm thicker in the soles. This can well have changed the pattern of walking, while in the heel study the normal walking pattern was possible.

Considering the sole trial with the major reductions in accelerations registered at the caliper it is noticeable how large were the reductions found in the accelerations recorded from the medial malleolus in the EVA heel study. Thus the results indicate that an even larger reduction in accelerations up through the long leg braces might be obtained by building EVA into the heels.

In addition to the significant reductions in accelerations the participating paraplegics claimed that the EVA soles/heels gave them a more comfortable walk.

Therefore the authors suggest it is justified to propose that all shoes for long leg braces for paraplegic walking in the future should have shock absorbing material built into the heels.

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