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Comparison of Test Methods to Quantify Shock Attenuating Properties of Athletic Footwear

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Abstract

The purpose of the presented study was to compare the results of ASTM F 1614 Procedure A, Procedure B and the HIT method to quantify the shock attenuating properties of 29 commercially available running shoes. The performed tests revealed a different behavior of the three procedures regarding loading time (ASTM-A: material depending, \bar{x} = 16 ms ± 2; ASTM-B: 20 ms; HIT: 35 ms) and peak force (ASTM-A: material depending, \bar{x} = 992 N ± 92; ASTM-B: material depending, \bar{x} = 985 N ± 110; HIT: 1500 N). Because of viscoelastic material behavior those test methods resulted in different ratings regarding the shock absorbing abilities of the investigated samples.

© 2010 Published by Elsevier Ltd. Open access under [CC BY-NC-ND license](http://creativecommons.org/licenses/by-nc-nd/3.0/).*Keywords:* ASTM F 1614; Mechanical Testing; Running Shoes; Hydraulic Impact Test

1. Introduction

Mechanical testing is a commonly used tool of R&D in the field of sports engineering [1]. Especially for athletic footwear several approaches exist to quantify major properties of the equipment. One of the key features of a running shoe is the ability to reduce impact shock during the first phase of the heel strike, even if the role of cushioning has nowadays been reduced to possible effects on comfort and fatigue instead of injury prevention [2]. However, there are testing standards like ASTM F 1614 or DIN EN 12743 that describe the methodology to determine the shock attenuating properties of footwear. On the other hand, several approaches for designing mechanical test procedures can be found which aim to replicate the biomechanical loads during heel strike more accurately regarding the load-time-regime.

The aim of this project was to perform cushioning tests on a wide variety of running shoes by using three different test methods and, based on the comparison of the results, draw conclusions for future mechanical tests.

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2. Methods

2.1. ASTM F 1614

ASTM F 1614 [3] covers three different procedures to perform the rapid rate force application simulating the human heel strike during running, i.e. Procedure A for falling weight impact machines, Procedure B for compression force controlled machines, and Procedure C for compression displacement controlled machines. The standard value for the reference maximum energy applied by these procedures is 5.0 J using a flat stamp of 45 mm diameter (Fig. 1). Procedure A and Procedure B were chosen representing a gravity driven open loop load-displacement (Procedure A) and a closed loop hysteresis (Procedure B). Procedure C was excluded from this study due to its similarity to Procedure B.

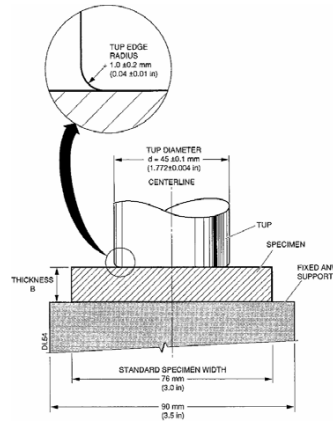


Fig. 1. Dimensions of stamp [3]

2.1.1. ASTM F 1614 Procedure A

The testing device consists of a support frame (weight >400 kg), a ground plate onto which the sample is fixed, and the gravity driven assembly (Fig. 2). This assembly (weight 8.51 kg) is lifted by an electric drive to 50 mm above the heel part of the shoe and released for a free fall. The position of the falling weight is sensed by a LVDT sensor (MTN/IEIR-75; Monitran Ltd.; High Wycombe, UK) while the impact shock is detected by a ± 35 g single axis acceleration sensor (ADXL78; Analog Devices Inc.; Norwood, USA). For data collection ($f=2$ kHz) the sensors are connected to a 16-bit measurement amplifier (CS7008; IMC Messsysteme GmbH; Berlin, Germany).

As required in ASTM F 1614 data was collected for load cycles #26 to #30. According to the test standard, the parameters peak force (F_{\max}), maximum deformation (def_{\max}) and absolute absorbed energy (E_{abs} , Eq. 1) were normalized to an energy input (E_{input}) of 5 J. Furthermore, relative absorbed energy (E_{rel} , Eq. 2) was calculated and time of def_{\max} ($t_{def_{\max}}$) was obtained to calculate deformation velocity (v_{def} , Eq. 3). The general characteristics of these parameters are displayed in Fig. 3.

$$E_{\text{abs}} = E_{\text{input}} - E_{\text{return}} \quad (1)$$

$$E_{\text{rel}} = \frac{E_{\text{abs}}}{E_{\text{input}}} \cdot 100 \quad (2)$$

$$v_{\text{def}} = \frac{def_{\max}}{t_{def_{\max}}} \quad (3)$$



Fig. 2. Apparatus Procedure A

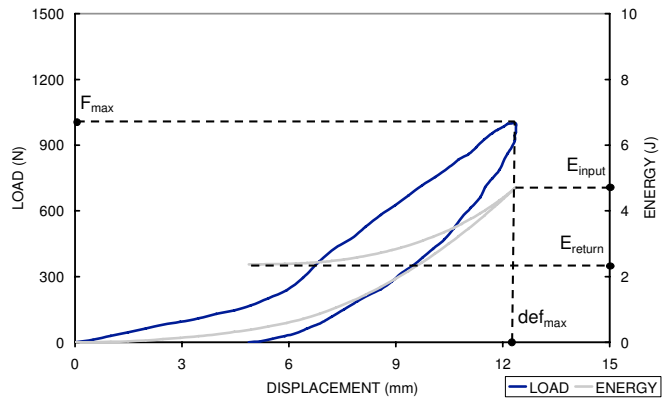


Fig. 3. Calculated parameters Procedure A

2.1.2. ASTM F 1614 Procedure B

The requirements described in ASTM F 1614 Procedure B are implemented using a servohydraulic testing device (HC10; Zwick GmbH & Co. KG; Ulm, Germany, Fig. 4). In a force controlled test mode a load equivalent to an energy input of $5 \text{ J} \pm 0.5$ is transferred onto the heel part of the samples in 20 ms with an interval of 2 s.

Load and displacement were sampled for cycles #26 to #30 using integrated sensors (sampling rate $f=1 \text{ kHz}$). Based on this data, the parameters F_{\max} , def_{\max} , v_{def} , E_{input} , E_{abs} and E_{rel} were calculated (Fig. 5).



Fig. 4. Apparatus Procedure B

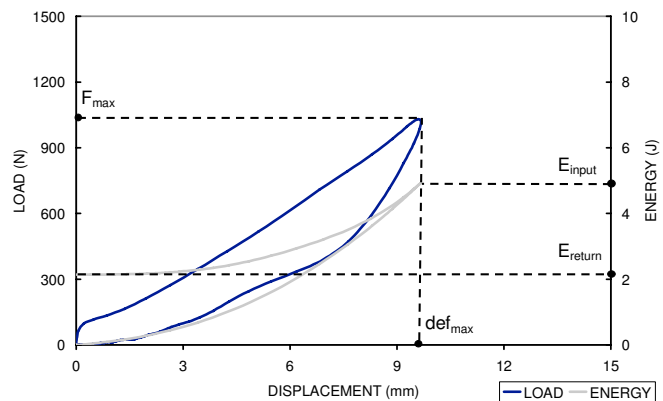


Fig. 5. Calculated parameters Procedure B

2.2. HIT

In contrast to this constant energy based testing approach of ASTM F 1614, a Hydraulic Impact Test with a characteristic load-time relationship which was derived from biomechanical measurements is used at Chemnitz University of Technology [4]. By means of a force controlled servohydraulic machine (cf. Procedure B) a peak force of 1500 N is applied to the heel part of a running shoe within 35 ms resulting in a constant loading rate of approximately 43 kNs^{-1} . In comparison to ASTM F 1614 the stamp is larger (diameter 50 mm) and has a spherical contact area (Fig. 6). After 100 ms the specimen is fully unloaded again. Furthermore, time between impacts is 0.7 s representing step time while running.

The parameters F_{\max} , def_{\max} , v_{def} , E_{input} , E_{abs} and E_{rel} were calculated based on the load and displacement data sampled for cycle #100 using integrated sensors (sampling rate $f=1 \text{ kHz}$, Fig. 7).



Fig. 6. Stamp HIT

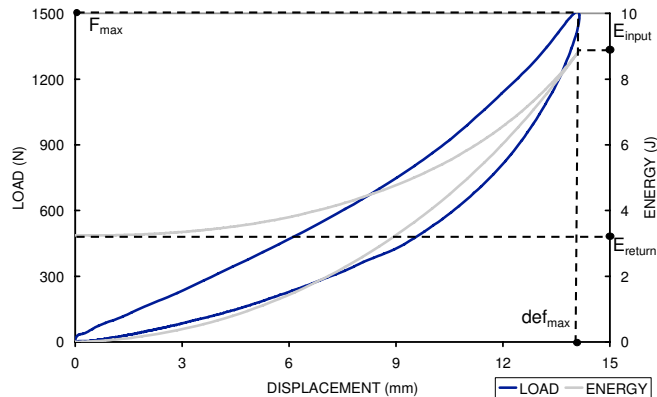


Fig. 7. Calculated parameters HIT

2.3. Test samples, conditions and data processing

29 running shoes (weight: $\bar{x}=304 \text{ g} \pm 41$, size UK8) of five major brands were tested by applying the test procedures described above in a randomized order. Ambient temperature during all tests was 23°C . To compare the investigated test procedures, the arithmetic mean of each parameter was calculated and Pearson's correlation coefficient (r) of each combination of two procedures was determined.

For a final evaluation of the shock attenuating properties of the tested footwear a ranking was created for parameter E_{rel} indicating highest amount as rank #1 and lowest as rank #29 as it is done in consumer tests. Furthermore, the rank in the ASTM measurements of each shoe was compared to the ranking of the HIT. Thus, the greatest deviations in positive and negative direction as well as the average deviation (root mean square) were determined.

3. Results

Peak force of ASTM F 1614 compliant tests was approximately 1 kN (66 % of the maximum load in the HIT, Table 1). This partially explains the higher energy input of 8.11 J±1.03 onto the heel part of the running shoes in the HIT. The arithmetic mean of def_{max} in Procedure A was comparable to the HIT even under the lower loading mentioned above while def_{max} in Procedure B was approximately 20 % lower. On the other hand, the Pearson correlation coefficients of def_{max} for HIT vs. Procedure B ($r=.83$) and Procedure A vs. Procedure B ($r=.84$) were higher than for HIT vs. Procedure A ($r=.63$). The velocity of midsole deformation v_{def} was highest in Procedure A and lowest in HIT. A systematic interrelation in this parameter was detected only for HIT vs. Procedure B ($r=.80$). ASTM F 1614 Procedure A exhibited the highest E_{rel} . This parameter revealed a high correlation between the three test methods: Procedure A vs. Procedure B ($r=.99$) HIT vs. Procedure A ($r=.94$), HIT vs. Procedure B ($r=.95$).

Table 1. Arithmetic mean and standard deviation of the calculated parameters

Test Method	F_{max} (N)		def_{max} (mm)		v_{def} (mm/s)		E_{input} (J)		E_{abs} (J)		E_{rel} (%)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Procedure A	992	92	12.4	1.1	719	15	5.00	0.00	2.51	0.23	50.1	4.6
Procedure B	985	110	9.9	1.0	483	25	5.00	0.00	2.21	0.25	44.2	4.9
HIT	1500	0	12.4	1.7	282	33	8.11	1.03	3.01	0.40	37.4	4.1

The ranking of E_{rel} for each testing procedure is shown in relation to the ranking in the HIT (Fig. 8). Three (Procedure A) respectively five (Procedure B) shoes are matching HIT. Detailed information about the comparison of the different rankings is given in Table 2.

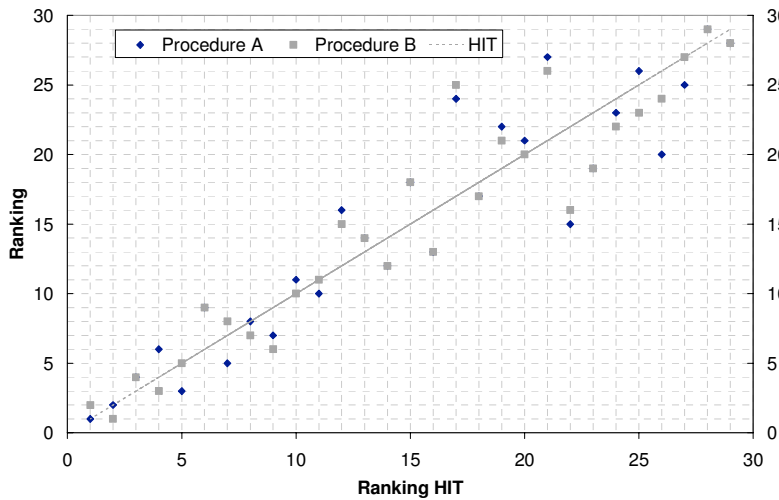


Fig. 8. Ranking of shock attenuation properties (E_{rel})

Table 2. Comparison of rankings

Method 1	Comparison Method 2	Maximum negative deviation	Maximum positive deviation	Average deviation
		(lower ranks in method 1)	(higher ranks in method 1)	(RMS)
Procedure A	Procedure B	-4	3	±1.0
HIT	Procedure A	-7	7	±2.3
HIT	Procedure B	-8	6	±2.0

4. Discussion

This study investigated three different test methods that aim to obtain the shock attenuating properties of running footwear. These procedures differed in the general approach of the controlled parameter as well as in load-time relationship, stamp shape and impact frequency. Peak forces in ASTM based tests were in accordance with the findings of Mills [5] and hence below the typical peak vertical ground reaction forces during passive peak in heel-toe running [6] which are considered as 1.5- to 3-times body weight. Interestingly, comparable values of F_{\max} in Procedure A and Procedure B resulted in different def_{\max} . On the other hand, there was a similarity in def_{\max} between Procedure A and HIT. Thus, mechanical energy as the product of force and displacement was absorbed by the same shoe in a different manner dependent on the used test procedure. Even if there was a correlation of $r=.94$ up to $r=.99$ in the parameter E_{rel} representing a match of 88 % up to 98 %, the proposed ranking revealed huge individual differences in the evaluation of a single shoe especially in between the HIT and the ASTM based tests.

5. Outlook

To simulate human heel strike during running a test method different to ASTM F 1614 is needed because of the significantly lower contact forces measured in Procedure A and Procedure B. For instance, in durability tests the application of realistic forces is essential to predict the long term behavior of the tested materials.

Researchers at Chemnitz University of Technology work on the biomechanical evaluation of the HIT durability test [4]. First results of that study show a realistic reduction of the shock attenuating properties during mechanical testing compared to shoes that were worn by recreational runners for 600 km.

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