EXPERIMENTAL DETERMINATIONS OF THE ROUND REACTION FORCE DEPENDING ON THE CHARACTERISTICS OF SOLE MATERIALS AND GROUND SURFACE

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Abstract: Forta de reactiune a solului ocupa un loc important in contextul general al analizei miscarii umane. Reactia corpului la modificarile incaltamintei – fie ele modificari si insertii ale incaltamintei, fie corectii ortopedice ale piciorului – depinde de intervalul de timp in care se utilizeaza un anumit tip de incaltaminte. De fapt, efectele biomecanice ale modificarilor incaltamintei trebuie sa fie diferentiate in functie de timpul necesar pentru adaptarea corpului la aceste modificari.

Scopul acestui studiu a fost de a determina forta de reactiune a solului in functie de caracteristicile materialelor utilizate pentru talpa la mersul normal pe diferite tipuri de suprafete ale solului.

Ground reaction force occupies an important place in the overall context of human motion analysis. The body's reaction to changes in footwear – whether they are shoe modifications and inserts or orthopedic corrections – depends on the time period within which a particular type of footwear is used. In fact, the biomechanical effects of changes in footwear must be differentiated according to the time needed for the body to adapt to these changes.

The purpose of this study was to determine the ground reaction force depending on the characteristics of the materials used for the sole in normal gait on different types of ground surfaces.

Keywords: Ground reaction, Force plate, Biomechanics, Footwear

1. Introduction

Research conducted in recent decades on the ground reaction force during walking has examined how these forces affect the body and the factors that influence them, such as style of walking, stepping surfaces and footwear type. It was found that the body is subjected to dynamic forces 1.1 to 1.3 times the body weight while walking. Also, the role of footwear in sports activities was studied in order to reduce stress, avoid the foot injuries, and to improve performances. It

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must be taken into account that the feet are among the most stressed body parts and that they unfortunately receive only a small part of our daily attention. This is why a lot of people find, sometimes too late, that they have a number of health problems in their feet.

Shoes that do not provide adequate support can lead to an imbalance of the whole body. Proper footwear commands static and dynamic balance of feet, and consequently, a correct center of gravity shift, resulting in balancing the whole body.

Increased interest in studying human movement required to design and develop techniques and equipment to record it. These have enabled to analyze the movement in terms of quality (appearance of movement) or quantity (speed, acceleration, force), significantly contributing to the understanding of basic mechanisms underlying human motion.

Of the kinetic-dynamic parameters that characterize human gait, ground reaction force is of particular relevance. Studies have already established the approximate shape of the variation curve during walking, specific for its components and whose parameters vary from individual to individual, body weight also playing an important role.

Measurement of ground reaction is carried out using force plates. Force plates have been used since the late 1890s. Initially, force platforms were used to measure the vertical component of ground reaction force (GRF). Since 1970, the GRF data obtained have been used to determine the forces acting on the body during walking. Mitigating the dynamic ground reaction force is a constant concern in the manufacture of footwear.

The purpose of this study is to compare the horizontal components of ground reaction force for various kinds of shoes with soles made of different materials, on different types of ground surfaces. The test was attended by volunteers using the same types of shoes on the same types of surfaces. The types of shoes used were: sandals, shoes, leisure shoes, and boots.

2. Experimental

2.1 Equipment

Force determination was carried out using an AMTI force plate and a plate made at the Faculty of Mechatronics and Precision Mechanics of “Politehnica” University of Bucharest (UPB).

The AMTI´s AccuGait System force plate presented in (Fig. 1) was set up in a special walking track. It should be noted that the force plate system of use includes hardware, the analogue / digital converter and data analysis software entitled AccuGait, using NetForce and NetForce / BioAnalysis components.

Fig. 1. AMTI force plate

Each analysis module is designed and developed to provide an integrated, unique solution, for biomechanical analysis activities. Bioanalysis comes with a set of graphic tools.

Graphic bioanalysis shows various parameters of gait, balance and power which are most commonly used in the field, namely: Fx, Fy, Fz, GRF in 3D, the center of pressure, Mx, My, Mz moments.

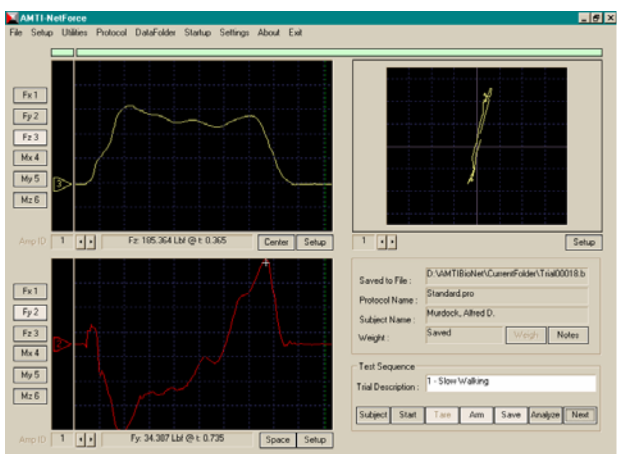

Fig. 2. Display of obtained experimental data

The force plate made by UPB is presented in (Fig. 3)

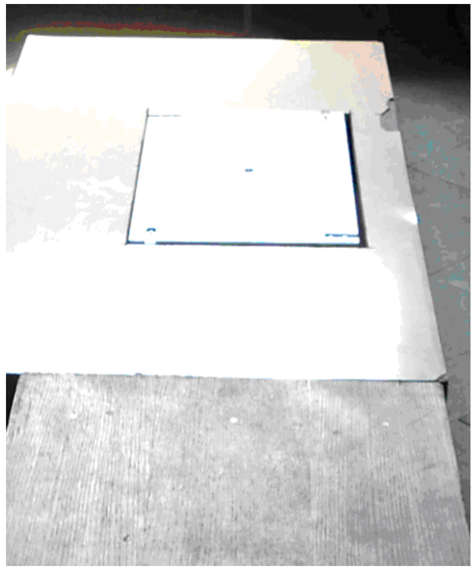

Fig. 3. Force plate made at UPB.

This plate allows simultaneous measurement of the three components of ground reaction force (Fig.4).

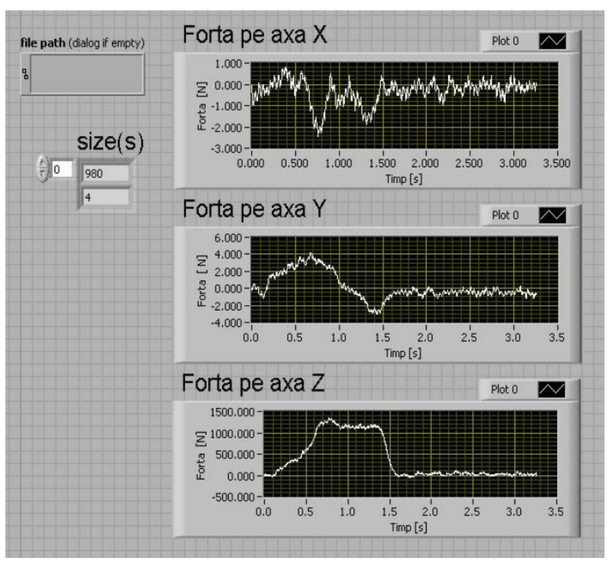

Fig. 4. Display of obtained experimental data

2.2 Subjects

Three healthy female volunteers aged 50 ÷ 52, weighing 69 ÷ 72 kg have participated in the tests. They have expressed their consent prior to participating in this experiment.

2.3 Procedure

Subjects walked on the track where the force plate was introduced, each wearing seven different kinds of shoes. Walking was done on seven different areas applied on the platform. Only studies in which the right foot landed fully on the plate were valid. The analyzed shoes had different heel heights, ranging from 0.5 to 7 cm, width between 2 and 6 cm, made of various materials: polyurethane, rubber, PVC, ABS. Walking surfaces used in the study were as follows: metal, linoleum, parquet, carpet, rubber, asphalt, stone tile.

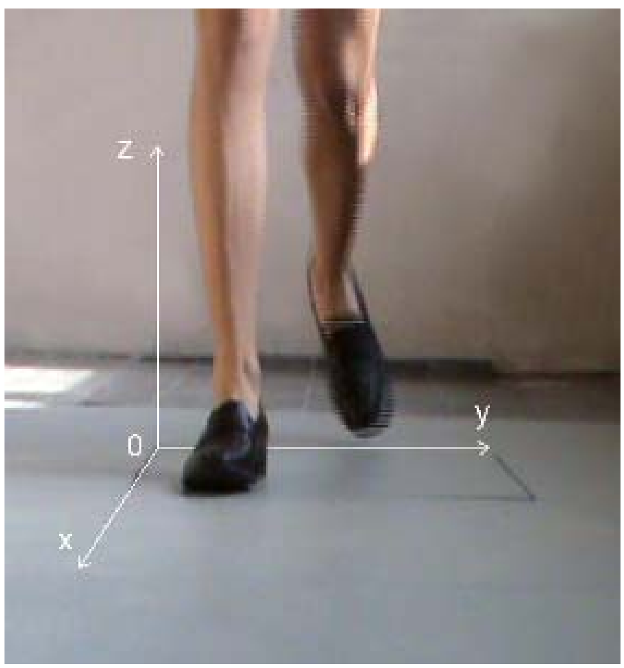

Fig. 5. Manner of stepping on the force plate

3. Results

Ground reaction force is dependent on the mechanical properties (stiffness, adhesion, etc.) of the contact surfaces (in our case shoe soles and support surface). The role of the stepping surface during walking is that of braking, supporting, and pushing.

From the data recorded on the force platform the maxima of the three ground reaction force components were chosen for analysis, namely, the vertical component Fz, the anteroposterior component Fx, and the medio-lateral component Fy.

When there is heel contact between the foot and the floor, the force is zero, as heel strike is defined when contact is generated. In a very short period of time, after heel strike, the force begins to increase rapidly, as the body is supported by the foot. Due to the fact that the center of mass shifts down and with some deceleration, the inertial force must be added to the gravitational force, which means that the vertical force applied through the foot exceeds body weight and reaches the peak, which can be seen in Fig. 6.

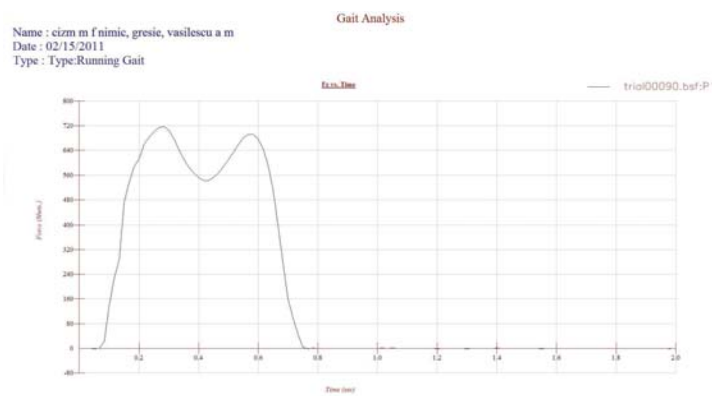

Fig.6. Variation of the Fz vertical component of the ground reaction during normal gait.

During unipodal support, when the heel contacts the ground, there is a rapid deceleration which leads to an increase of ground reaction force which exceeds body weight. Then, the center of mass undergoes a downward acceleration, which will produce an inertial force directed upwards, which will reduce the ground reaction force. When the human body is upright, the vertical component of ground reaction force is equal to the weight of the human body.

In the final stage of the support phase (propulsion) the propulsive action generates greater forces than body weight. The second peak occurs about mid-cycle during walking. As the limb is ready for lift-off, the force quickly reaches zero at the end of support phase.

In the second half of unipodal phase support, in order to accelerate the body's center of mass forward, the ground applies a forward directed force on the foot. This occurs as a gradual and then rapid increase, followed by a rapid reduction of force.

Anteroposterior reaction force Fx is the horizontal force exerted by the force plate on the foot (Fig. 7), acting in the walking direction of the subject with a lower magnitude than the vertical ground force component of the soil. At first there is a braking force in the mid-stance phase, with the purpose of reducing the speed of the body's center of mass which is then followed by propulsion. Close to the mid-stance phase, Fx becomes positive, which means that the force plate reaction acts forward, while muscle forces push the foot on the plate.

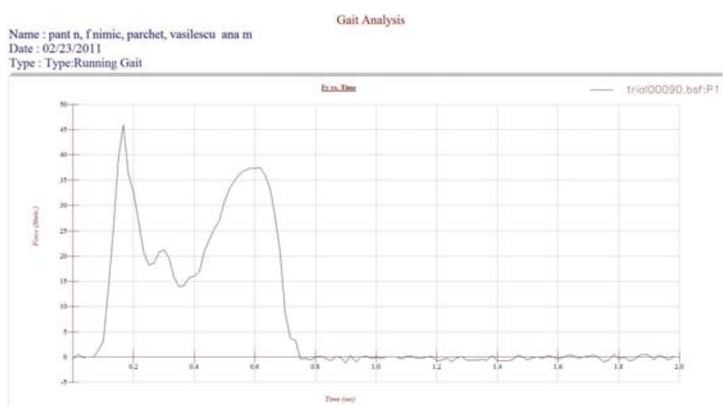

Fig.7. Variation of anteroposterior component Fx of ground reaction force during normal gait

The horizontal component perpendicular to walking direction Fy (Fig. 8) is due to oscillations in the frontal plane with an important role in providing balance in the unipodal support phase. For this, the size of the area of contact with the ground is relevant (for example, walking in high heels, where foot oscillations in the frontal plane are very pronounced).

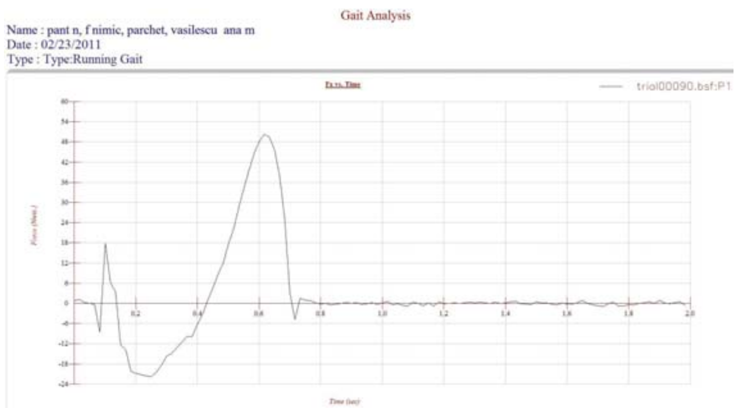

Fig.8. Variation of mediolateral component Fy of ground reaction force during normal gait

Table 1 presents values of the Fz, Fy, Fx components of the ground reaction for shoe sole materials (levicel, polyurethane, leather, thermoplastic rubber, polyvinyl chloride, durocol, dermadur) on contact surfaces (metal, carpet, linoleum, parquet, rubber, asphalt, stone tile) for the two subjects. Subject 1 weighs 72 kg and subject 2 69 kg. The angle between the vertical component Fz and the medio-transverse component Fy was also calculated.

Table 1

Values of ground reaction components

Sole material – contact surface	Fz(N) maximum		Fy(N) maximum		Fx(N) maximum		Angle between Fz and Fy (°)	
	A[1]	B[2]	A[1]	B[2]	A[1]	B[2]	A[1]	B[2]
levicel-metal	715	694	24	24	82	82	1,92	1,98
levicel-carpet	719	694	25	26	82	74	1,99	2,14
levicel-linoleum	736	690	16	20	82	82	1,24	1,66
levicel-parquet	736	715	24	24	98	90	1,87	1,92
levicel-rubber	722	720	25	28	102	74	1,98	2,22
levicel-asphalt	736	694	24	24	82	82	1,86	1,98
levicel-stone tile	736	715	24	24	96	90	1,86	1,92
PU-metal	715	694	16	32	65	82	1,28	2,64
PU- carpet	715	694	24	32	82	74	0,033	0,046
PU- linoleum	726	715	24	16	82	82	0,033	0,022
PU- parquet	715	736	24	24	82	90	0,033	0,032

PU-rubber	718	732	16	24	65	80	0,022	0,032
PU-asphalt	736	694	24	16	82	82	0,032	0,023
PU-stone tile	715	694	24	24	90	90	0,033	0,034
leather -metal	736	725	16	22	106	89	0,021	0,030
leather - carpet	700	694	16	16	99	74	0,022	0,023
leather -linoleum	715	673	16	16	90	90	0,022	0,023
leather - parquet	736	736	24	24	98	98	0,032	0,032
leather -rubber	709	719	30	17	117	101	0,042	0,023
leather -asphalt	748	694	24	16	88	90	0,032	0,023
leather - stone tile	736	736	24	24	98	98	0,032	0,032
TR-metal	733	724	32	24	101	97	0,043	0,033
TR- carpet	752	724	22	14	101	97	0,029	0,031
TR- linoleum	742	717	30	21	112	102	0,040	0,029
TR- parquet	730	705	28	22	86	93	0,030	0,031
TR- rubber	709	719	30	17	117	101	0,042	0,023
TR-asphalt	705	730	24	25	110	90	0,034	0,034
TR- stone tile	712	716	29	16	86	99	0,040	0,022
PVC-metal	700	727	19	13	127	83	0,027	0,017
PVC-carpet	718	717	15	19	118	97	0,020	0,026
PVC-linoleum	714	718	25	13	116	100	0,022	0,023
PVC- parquet	729	729	23	16	111	104	0,035	0,021
PVC-rubber	759	713	21	17	133	93	0,027	0,023
PVC-asphalt	759	722	28	23	112	102	0,036	0,031
PVC- stone tile	700	703	14	22	109	74	0,020	0,031
durocol-metal	730	715	20	15	127	98	0,027	0,020
durocol- carpet	726	697	22	18	121	80	0,030	0,025
durocol-linoleum	719	716	25	19	123	89	0,034	0,026
durocol- parquet	722	737	26	27	137	101	0,036	0,036
durocol-rubber	722	713	25	22	122	92	0,034	0,030
durocol-asphalt	701	716	26	17	107	82	0,037	0,023
durocol-stone tile	700	722	18	24	99	86	0,025	0,033
dermadur-metal	733	722	41	45	146	86	0,055	0,055
dermadur-carpet	743	704	30	35	102	102	0,040	0,049
dermadur-linoleum	726	705	31	31	113	92	0,042	0,043
dermadur-parquet	755	697	40	36	113	95	0,052	0,051
dermadur-rubber	739	708	35	40	103	99	0,047	0,056
dermadur-asphalt	724	722	29	26	105	101	0,040	0,036
dermadur-stone tile	718	699	18	39	102	89	0,025	0,055

4. Conclusions

A first conclusion was that the indications of the two plates were very close, which makes the UPB plate more advantageous due to its much lower price.

Tests conducted on the force plates have revealed that the values of ground reaction force components in the three directions (Fz, Fy, Fx) for two subjects of similar weight, wearing the same shoes and walking on the same contact surface are different due to their different walking style.

Values of GRF components vary depending also on the nature of the sole material, and the type of ground surface.

Foot and shoe form an assembly whose characteristics are specific to each individual, and the recommendation is to make custom footwear.

In conclusion, the wrong footwear design and construction leads to additional correction efforts of the whole body.

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