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The Evaluation of Ground Reaction Force (GRF) Graphics Acquired During Some Daily Activities

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Due to the gravity, we constantly maintain contact with the ground, and in this process, interactions occur between the body and the ground. According to Newton's 3rd Law of Motion (Law of Reaction), for every action, there is an equal and opposite reaction. The reaction force exerted to the body by ground is specifically called the ground reaction force (GRF). Measuring the GRF with insole mats is more useful and objective than the force platforms. In this method, it is possible to get data from more than one step in one single trial.

Our purpose in this study was to demonstrate the gait graphics taken from some daily activities and to evaluate the GRF during stair ascent and descent.

The data taken from the measurements of 10 subjects' (5 males, 5 females) stair ascent and descent were analyzed and discussed.

Key words: ground reaction force, stair ascent, descent.

Introduction

Walking is one of the complex movements of human and its basic component is gait. In last twenty years, gait analysis has become a method of diagnosis and follow up for patients with gait disorders. In the meantime, gait analysis has developed with kinematics and kinetics. Kinematics means the science of movement. In this kind of analysis you can measure positions, velocities, and accelerations of body segments. In another words, angular displacements of the joints can be measured. In kinetic analysis, force measurements are possible. According to Newton's 3rd Law of Motion (Law of Reaction), for every action, there is an equal and opposite reaction. When a human body is contact with the ground, a force is exerted to the body as a reaction by the ground. Due to the gravity, we constantly maintain contact with the ground, and in this process, interactions occur between the body and the ground. The reaction force supplied by the ground is specifically called the ground reaction force (GRF), which is basically the reaction to the force the body exerts on the ground [1, 5]. The GRF, along with the weight, is an important external force. When a person stands still, this ground reaction force is equal to the person's mass multiplied by the gravitational acceleration (F = m.g). For a typical person of 80 kg weight, this reaction will be (80 x 10) 800 N. GRF has three component vectors in vertical, medial-lateral and ante-

rior-posterior planes. Vertical force is generated by the vertical acceleration of the body and is of highest magnitude. The GRF is commonly measured by force-platforms and insole mats. Force platforms are more common in movement laboratories but they have some disadvantages that patients must target the platform and they have to place the foot only once in one trial. Otherwise, it is hard to get clear data. The second method is the insole mats, which can be set into a shoe or a booty-like shoe. In measurement of GRF with insole systems, there is no constraint on foot placement and it is possible to measure several consecutive strides during gait and it provides detailed information specific to each region of the foot sole. So, it is more objective than the force platforms.

In this study, our purpose is to demonstrate the gait graphics taken from some daily activities and to evaluate the GRF during stair ascent and descent.

Materials and Methods

Five males (mean age 20.4 ± 2.1 yr; mean mass 73.6 ± 8.7 kg) and five females (mean age 19.8 ± 0.8 yr; mean mass 54.2 ± 4.4 kg) were informed about the procedure and accepted to participate in this study. They were all right-handed. Subjects wore boot-like designed flat shoes of Zebris© with insole-mats inserted in it and were required to ascend and then descend the 4 steps stair model at natural speed. After a few trials of familiarization, the ground reaction forces were recorded from both sides by Zebris 3D Motion Analysis System©. This system has insole mats connected to an analog digital converter by a cable adaptor. Its sampling rate was 60 Hz. Data converter was connected to a PC to enable the time versus force graphics to be seen while the subject was walking. Data from heel (1), midfoot (2), forefoot lateral side (3), and forefoot medial side (4) were recorded separately in the same steps. The heel was from 0% to 30% and midfoot from 30% to 60% to foot length. The forefoot was from 60% to 100% and this part was divided into the lateral and medial forefoot regions equally. Each of these areas is represented with a time versus force graphic in the report paper. The peak forces (Fmax1, Fmax2, Fmax3, and Fmax4) are the maximum force values normalized by dividing with body weight in each corresponding area. The time between reaching the peak force and initial contact in each corresponding area (Tmax1, Tmax2, Tmax3, and Tmax4) were recorded for every step on stairs in milliseconds (ms).

In statistical analysis, Man - Whitney U test was applied for gender differences. And Kruskal — Wallis test was applied to test the differences between the steps.

Results

The mean fmax and tmax values of all steps during stair ascent and descent were given in table 1 and table 2 (Tables 1, 2). And in Table 3, mean values of fmax and tmax for all 40 steps were presented (Table 3). The differences between the stair ascent and descent were found for Fmax1, Tmax1, Fmax2, Tmax2, Tmax3 and Tmax4 values. In this comparison we did not find any differences in between Fmax3 and Fmax 4 values. Again, during stair ascent only Fmax3 values were different ($p<0,05$) and during stair descent Tmax3 and Tmax4 values were different ($p<0,05$).

Table 1. Mean values of fmax and tmax for all areas and for both sex during stair ascent. Tmax2 in step I and fmax2, tmax2, and fmax3 in step II differs ($p<0,05$)

			StepI		StepII		StepIII		StepIV	
	sex	*n*	mean	std	mean	std	mean	std	mean	std
fmax1	f	5	4.95	1.68	4.01	0.96	3.96	1.21	3.17	1.58
	m	5	3.08	2.06	4.27	2.74	2.82	2.11	2.21	1.44
tmax1	f	5	0.27	0.09	0.23	0.14	0.25	0.16	0.4	0.22
	m	5	0.17	0.05	0.22	0.14	0.29	0.19	0.31	1.23
fmax2	f	5	1.22	0.4	**1.41**	0.50	0.91	0.50	1.05	0.36
	m	5	0.8	0.56	**0.66**	0.23	0.85	0.55	0.72	0.50
tmax2	f	5	**0.67**	0.18	**0.55**	0.24	0.55	0.20	0.59	0.28
	m	5	**0.31**	0.15	**0.29**	0.15	0.21	0.03	0.54	0.22
fmax3	f	5	3.13	1.02	**3.50**	1.26	2.59	0.90	2.09	1.35
	m	5	2.39	0.66	**1.89**	.95	1.71	0.79	0.93	0.83
tmax3	f	5	0.8	0.22	0.70	0.21	0.68	0.24	0.66	0.24
	m	5	0.56	0.19	0.58	0.12	0.55	0.23	0.63	0.30
fmax4	f	5	1.87	0.69	2.53	1.33	2.27	0.96	2.62	1.37
	m	5	1.96	0.86	2.25	1.06	2.34	1.20	1.28	0.61
tmax4	f	5	0.73	0.19	0.62	0.28	0.64	0.20	0.51	0.19
	m	5	0.59	0.17	0.51	0.27	0.56	0.24	0.37	0.31

Table 2. Mean values of fmax and tmax for all areas and for both sex during stair descent, there are no statistically differences between female and male data

			StepI		StepII		StepIII		StepIV	
	sex	*n*	mean	std	mean	std	mean	std	mean	std
fmax1	f	5	2.43	0.78	3.05	1.29	2.74	2.31	1.82	1.21
	m	5	1.90	1.35	2.50	2.14	1.45	1.42	1.69	1.40
tmax1	f	5	0.14	0.05	0.17	0.10	0.14	0.03	0.18	0.16
	m	5	0.18	0.07	0.18	0.05	0.16	0.04	0.23	0.20
fmax2	f	5	1.28	0.58	1.55	0.44	1.11	0.51	1.47	0.51
	m	5	0.86	0.39	1.47	0.93	1.07	0.44	1.31	0.96
tmax2	f	5	0.13	0.03	0.11	0.03	0.18	0.13	0.11	0.02
	m	5	0.19	0.05	0.14	0.04	0.15	0.34	0.17	0.15
fmax3	f	5	2.11	0.82	2.56	0.93	2.40	0.59	2.74	0.75
	m	5	2.12	0.72	2.30	0.69	2.66	0.40	2.05	0.76
tmax3	f	5	0.38	0.24	0.19	0.17	0.19	0.28	0.15	0.21
	m	5	0.37	0.24	0.26	0.29	0.22	0.25	0.07	0.04
fmax4	f	5	2.47	0.42	2.80	1.44	2.69	0.73	2.51	1.71
	m	5	3.08	1.04	3.01	1.01	3.12	1.36	1.62	0.48
tmax4	f	5	0.59	0.11	0.33	0.24	0.27	0.28	0.15	0.04
	m	5	0.56	0.23	0.32	0.28	0.38	0.26	0.16	0.15

Table 3. Mean values of fmax and tmax for all areas and for all steps

	During	*n*	Mean	Std
fmax1	ascent	40	3.56	1.84
	descent	40	2.20	1.51
tmax1	ascent	40	0.27	0.15
	descent	40	0.17	0.1
fmax2	ascent	40	0.95	0.49
	descent	40	1.27	0.61
tmax2	ascent	40	0.46	0.24
	descent	40	0.15	0.07
fmax3	ascent	40	2.28	1.19
	descent	40	2.37	0.7

Продължение на табл. 3

tmax3	ascent	40	0.65	0.22
	descent	40	0.23	0.23
fmax4	ascent	40	2.14	1
	descent	40	2.55	1.1
tmax4	ascent	40	0.57	0.24
	descent	40	0.35	0.25

Discussion and Conclusion

There are statistically differences of Tmax2 values in step 1 and Fmax2, Tmax2, Fmax3 values in step 2 between female and male subjects. There are no differences in all other data. As a conclusion, kinetic characteristics of men and women gait according to GRF are similar to each other. As expected, most of the values are different between stair ascent and descent [2, 3]. Because, during ascent, the gait starts with the heel contact, then continues with midfoot and forefoot. But during stair descent, it starts with the forefoot and continues with midfoot and heel.

Comparing the steps gives more evidence for the neuromuscular control of the gait and the characteristics of exceeding an obstacle [4, 7]. In our study we used a wooden model of standard home stairs including 4 steps. The surfaces of the steps are natural and not slippery. It is seen that, while subjects ascend the stairs, the fmax1 values tend to decrease from 1st step to 4th step. This means heel contact is getting slighter as the subjects repeat the movement. In another words, contractions of the muscles which provide the stability of body against GRF during the contacts with the ground were regulated in optimum level. This is one of the most important components of gait control. In a neuromuscular problem such as diabetes mellitus or neuropathies, it would be difficult to resist the GRF and regulate the muscle contractions especially for the braking mechanism in gait. Beside this, it is also known that the peak forces are higher in climbing an obstacle than level walking [6].

If we compare all the steps during ascent and descent together, it is seen that Fmax1 is the highest and then Fmax3, Fmax4 and Fmax2 are in sequence. It means that, the highest force is exerted on the heel, then in sequence, on the lateral forefoot, medial forefoot and midfoot. These results are also same with the level walking.

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