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MORPHOLOGICAL ANALYSIS OF PLANTAR SURFACE DURING A GAIT CYCLE

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ABSTRACT: In this paper we present some theoretical considerations and experimental biomechanical analysis of gait cycle. The theoretical aspects of the gait cycle, parameters and limits defining the gait cycle but also an analysis of gait typologies developed by a healthy subject are presented in the first part of the paper. The principles and methodology for investigating structure of gait cycle vs. morphological modifications of plantar surface, using a pressure plate type RSScan and also some experimental aspects highlighted during the developed analysis are presented in the second part of the paper. In the third part of the paper are presented the results of these analysis and correlation strategies. In the final part of the paper, conclusions of the investigations are set by records analyses. Also are presented the development of biomechanical investigations for comparative evaluations and future directions of the studies.
Keywords: gait cycle, plantar surface biomechanics

1. INTRODUCTION

The morphology of the human body structure is specialized to perform its movements called "loco-motor" and its complex function called "locomotion". In defining human locomotion it is important to start with the more general sense of the term. Locomotion is not only of the body as a whole but also of his segments analyzed separately.

By human locomotion means primarily a movement of the human body to have a foothold above the ground. Secondly locomotion is moving in space of one of its segments inferior to a reference point. Definition locomotion is subject thus defined movements biological structures. In anatomical, human loco-motor apparatus consists of bones, joints, ligaments and muscles. This is the system that forms the basic structure of human locomotion and that gives him the opportunity to travel, to move or themselves position. All elements of morph-functional loco-motor system participate in these actions and disorders manifested must be recognized and rehabilitated to play to the human body the possibility to correctly conduct the locomotion function.

Alignment of bones, muscles, ligaments and tendons in the foot plantar surface formed on a lateral arch (metatarsal) and an arch in length (longitudinal).

During gait cycle these elastic arcades help equal distribution of body weight along each plantar area. Foot arches plays a very important role in gait allowing to the human body to regulate dynamic and continuously its bipodal balance. These plantar surfaces act as a rigid structure for normal mobility. At the same time these areas are elastic and flexible, adapting them to various ground surfaces on moving human subject. Plantar arches fully develop by the age of 12 or 13 years. In some cases, plantar arches do never develop normally and determine the appearance of morphological forms manifested in different form of gait cycle disorders, posture or local pathologies. [1]

Some human subjects with flat foot forms are likely to develop inflammation and pain in the ligaments of plantar surfaces, Achilean tendonitis, stress fractures, muscle stretching of the calf earlier and hyperkeratosis. In these cases, flat foot can lead to muscle imbalance and joint problems in the ankles, knees, thighs and lower part of the trunk.

Many people with flat feet will have problems of plantar vault as a result of the continue solicitations on foot. Excessive weight, abnormal positions, weakening of supporting tissues or overuse can lead to weakening of ligaments and muscles that support the arch length, leading in time to the "fall" it. Overstress the plantar surface, walking, or performing exercises on hard surfaces, bipodal position can weaken or metatarsal arch flattening of the forefoot. This will increase pressure on nerves and blood vessels in the all surfaces of foot, thus causing pain and irritation. [2]

Figure 1: Flat foot [1]

Figure 2: Hollow foot [1]

Most people have a vault on the surface of the foot, causing a gap between the plantar surface and ground. Some people may have higher than normal plantar arch and this abnormality is called "hollow leg" (Figure 2). Due to these high plantar arches more than normal size during walking or rest a heavy weight is pressing down on the heel and toe.

Hollow leg can cause a variety of symptoms such as pain and postural instability. Shaped hollow leg can develop at any age and can manifest in one leg or both.

Usually hollow foot is an anatomical and hereditary dysfunction, but it can be a neurological dysfunction arising from certain diseases such as Charcot-Marie-Tooth disease, polio, muscular dystrophy or stroke. [3] The vault of a hollow leg will appear high even when standing in foot. In addition, will be present one or more of the following symptoms: fingers bent; pain during walking or rest; postural instability.

Some people may feel the foot or ankle muscles loosen resulting in dragging of the foot during walking. Another range of disorders that can lead to deficiencies of walking, posture and morphological structure are neurological pathologies (Parkinson's disease, stroke etc.) or trauma (fractures of the ankle or toes, tearing ligaments etc.).[4,5]

2. EXPERIMENTAL SETUP

To conduct this research was designed and developed a methodology for selection, acquisition, evaluation and analysis of morphological structures of planting area from a sample of 10 subjects (7 men and 3 women) aged between 22 and 24 years.

In the first phase, each subject was conducted anthropometric measurements (Figure 3 and 4) of the legs. All these numerical values were then analyzed (table 1).

Table 1 [9]. Numerical values

Nr.sample	Foot	1	2	3	4	5	6	7	8	9	10
L [cm]	left	25.8	22.3	22.4	26.3	26.9	25.2	28.3	29.1	25.3	23.3
	right	25.8	22.1	22.5	24.5	27.1	26	28.3	29.1	25.3	23.3
D [cm]	left	26	22.5	22.5	26.7	27.1	25.6	28.5	30	25.5	23.6
	right	26	22.5	22.5	26.7	27.1	25.6	28.5	31	25.5	23.6
t [cm]	left	9.5	8.9	8.5	9.6	9.6	9.1	9.1	10	8.8	8.1
	right	9.5	8.9	8.5	9.5	9.6	9.1	9.3	10	8.8	8.2
a [cm]	left	3	3.9	3	2.8	0	3.6	3	4	5.4	2.2
	right	3.2	3.9	3	2.8	3.6	3.8	3.2	4.2	4.5	2
α	left	7	10	2	12	11	11.5	5	13	5	11
	right	10	5	1	24	14	5	15	15	6	15
β	left	45	51	37	56	52	60.5	40	29	36	39
	right	46	42	35	66	55	40	35	25	40	20
b [cm]	left	6.7	5	5	7	7	6.9	6.8	7	7.1	5
	right	6.7	5	5	7	7.2	6.9	6.9	7	7.1	5
G [cm]	left	43.5	35.2	35.2	45.4	41.2	39	40.6	48	40	35
	right	43.5	35	35	45.7	41.2	39	40.6	48	41	35
c [cm]	left	35.2	33.4	33.4	34.5	36.6	34	37	38	35.1	32
	right	35.6	35.1	31.7	34.3	36	35.2	37	39	35.1	32.2
S [cm]	left	36.7	33	34.4	40	42.2	35.2	40.4	42	34	33
	right	36.7	33.8	34.3	40	42.2	35.2	40.3	42	34.1	33.1
Sex	[M/F]	M	F	F	M	M	M	M	M	M	F
Age	[years]	23	22	22	22	22	24	22	22	22	22
Height	[cm]	174	156	158	181	174	168	182	180	171	150
Weight	[Kg]	63	57	47	65	68	64	75	85	60	40

Each subject was instructed to stand in a relaxed position for measurements the components of loco-motor system. Anthropometric measurement tools used were: anthropometric rapporteur goniometrical, roulette and graduated ruler.

Anthropometric measurements were performed on human subjects and variation of all values is within limits of +/- 25% so subjects can fit in the same percentile group.

Also the values of variation (left/right) measured the subjects in the sample falling below 1% which means that they are not different anatomical structures on each topic on the right side to the left. (Figure 5)

In conclusion subjects of the sample present symmetry of anthropometric values of the same dimensional range and a state of normal health, without excesses of behavior or sportive activities.

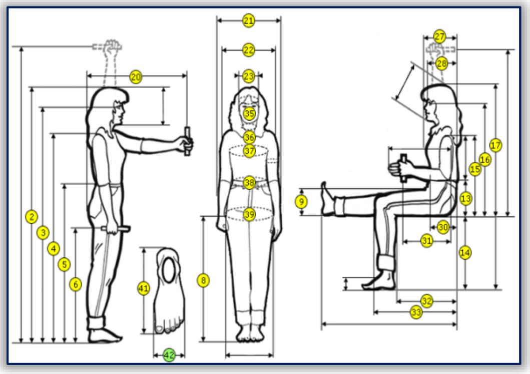


Figure 3: Anthropometrical dimensions for human body [8]

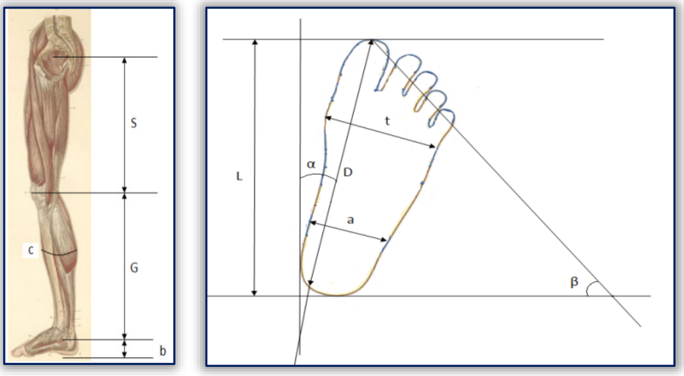


Figure 4: Calf and plantar surface size [8]

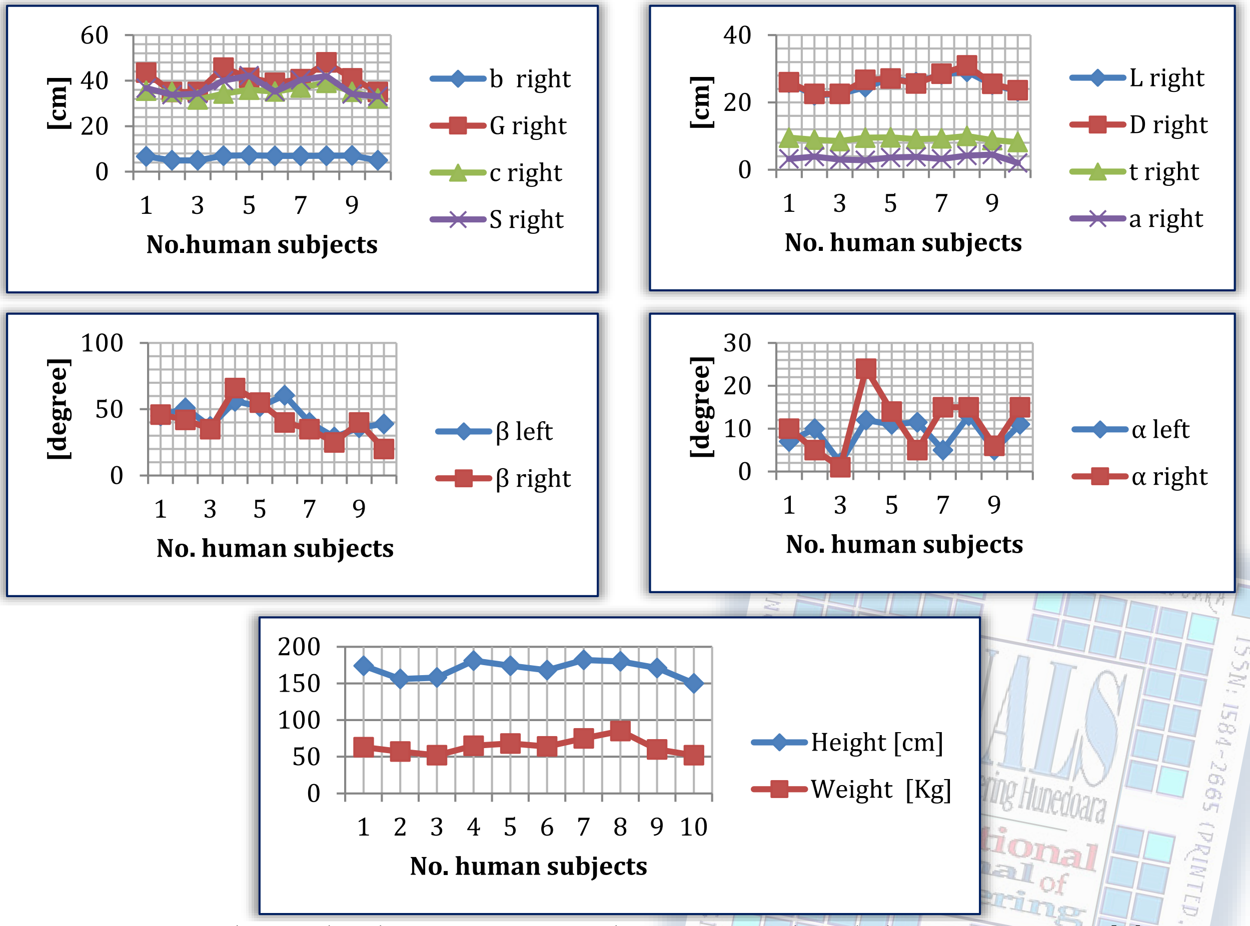
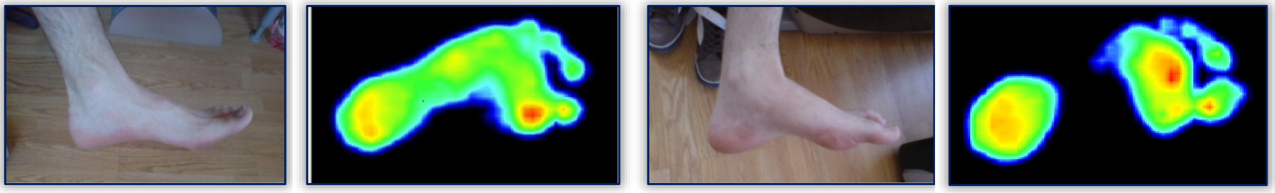


Figure 5: The graphical representation of the variation calf and plantar surface size [9]

Forms of plantar surfaces records for each subject were performed using a pressure plate type RSScan with a set of about 16,000 sensors on an area of 1.2 m² (2 x 0.6). This equipment allows recording plantar surface behavior during the gait cycle with a length of 1.85 m and a maximum frequency of 500 Hz.

3. RESULTS

After recording the behavior of the subjects were highlighted two special cases of plantar surfaces - flat foot and leg hollow (subject 5 to 9 in table 1).



Flat foot (FF) RSScan mark of FF Hollow foot (HF) RSScan mark of HF

Figure 6: Images with hollow and flat foot, also the RSScan marks of them [9]

For plantar surface morphology analysis were established, according to the procedure, following areas: (1) big finger (2) fingers 2-5 (3) metatarsus 1-5 (4) mid sole (5) medial heel (6) lateral heel (figure 7).

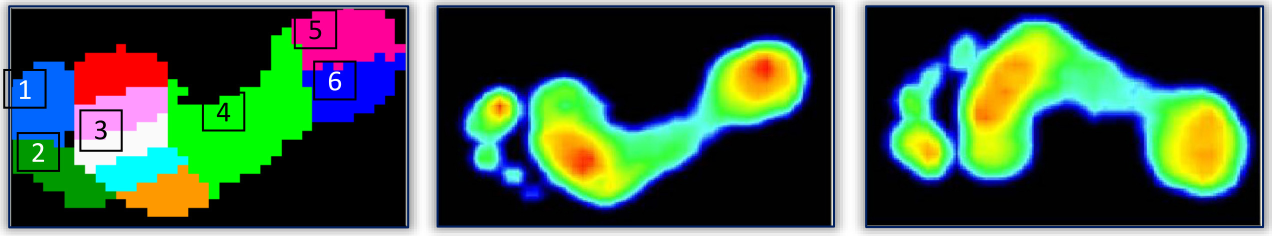


Figure 7: Representing areas of foot analysis and sensory mark on pressure plate (left / right) [9]

Each subject was instructed to walk with both feet on the pressure plate type RSSscan for 7 variants gait: normal walking (a), crawling, walking added, walking marching, walking right leg stuck (d), walking with eyes closed in step marching with arms outstretched (c) in front and rear gait (b) (figure 8). For each drive were performed 3 tests with each subject separately. A total of 210 tests were performed on the pressure plate RSScan. Frequency of the plate was set to 100 Hz.

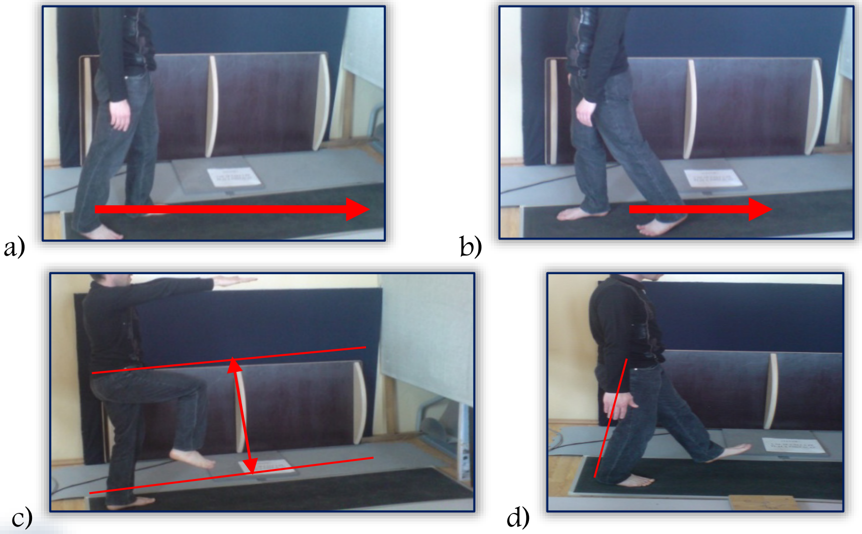


Figure 8: Types walk on RSScan board: a) normal gait; b) backwards gait; c) gait with raised leg and hands in front; d) gait with right leg blocked [9]

For each of the seven variants gait, developed pressures were recorded at each areas level noted on the plantar surface. In the example shown in Figure 9 is the subject with flat-foot.

In normal gait type, plantar pressure on two legs is distributed almost evenly allowing the subject to keep their balance and stability.

Evolution of pressure for each area of the plantar surface is within normal limits. It is observed only a slightly increased pressure on the left leg, in medial heel zone with slight tendencies to solicit the ankle inward and request a larger area of contact with the ground.

For crawling gait the pressure in the metatarsals is distributed more evenly than if normal gait, but the pressure on right foot heel is higher.

In the case of added gait can be seen an increase in plantar pressure in the heels.

In the case of locked right leg gait the pressure is more pronounced on the left leg, the pressure on the right leg is lower and evenly distributed and for the left foot is accentuated in tarsals area.

For the march gait, the distribution analysis can see that in the metatarsals, on both legs, the pressure is the same, and the accented area is in the heels. There is an increased pressure in the toe, heel and metatarsal bones, especially left leg for the gait with eyes closed (the most unstable kind of walk).

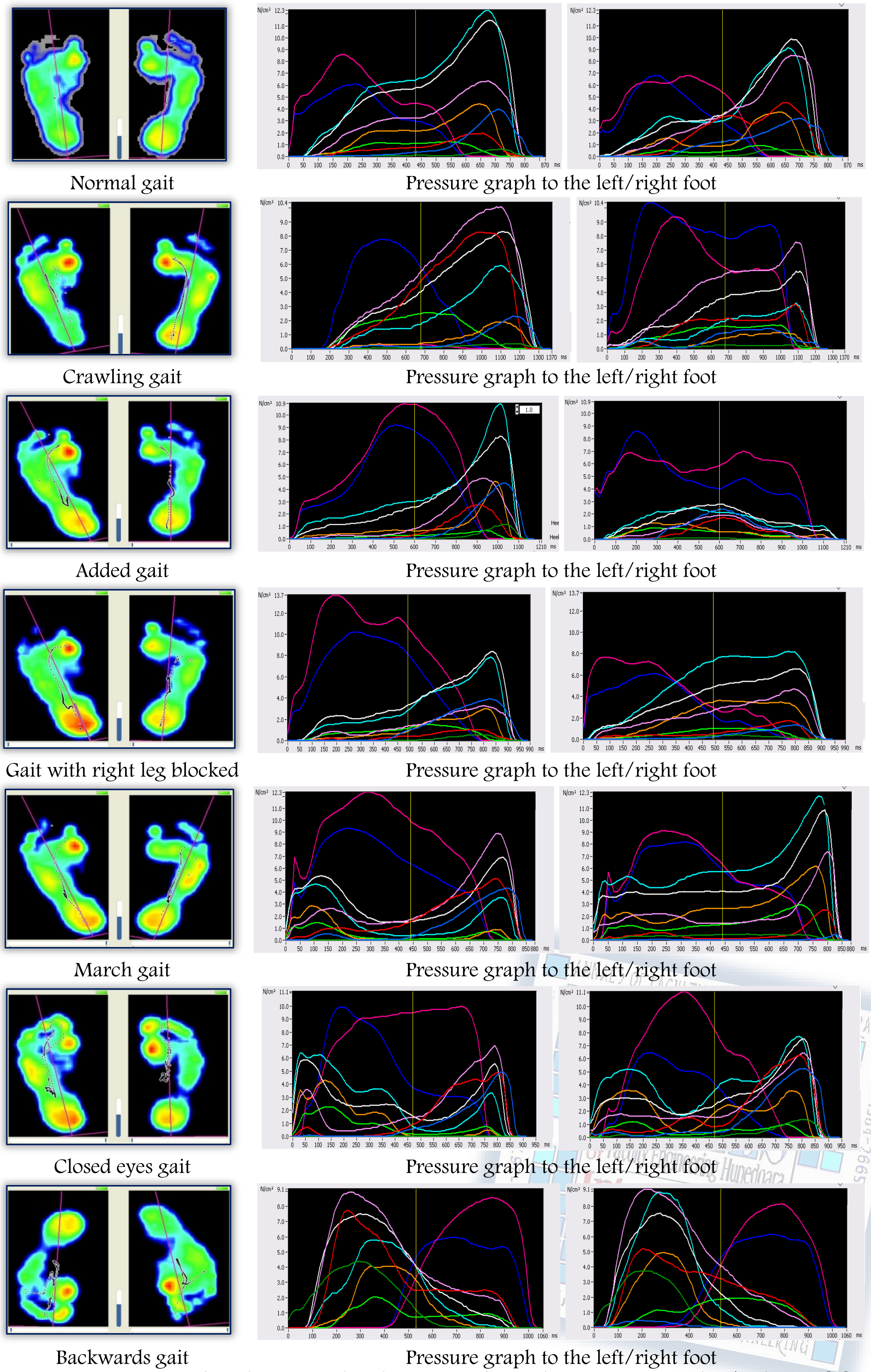


Figure 9: Sensory mark and pressure distribution graphs of plantar surface for left/right foot [9]

In the case of reversing gait, increased pressure can be seen in the right heel and metatarsal bones in the right leg.

4. CONCLUSIONS

In terms of the loco-motor system, the area of plantar surface in contact with the ground is a very important parameter in ensuring bipodal posture and balance in full. Morphological analysis of the subject flat-footed highlights a substantial difference (+ 12.5%) at the distributed forces amount level on the plantar surface in case of walking typology with dynamic aspects (march walking, added gait). In case of dragged gait, the subject with flat-footed shows a smaller force variation (+ 5%) distributed on right/left plantar surfaces, and an increase zonal force on medial heel on the right and on the tarsals on the left foot. Force distribution forms on plantar surfaces can be seen in all variants of flat foot indicating a contact surface between soil and planting areas much larger.

3D model of the corrective insole foot flat — The assembly of flat foot and corrective insole

Figure 10: Plantar surface "supported" by corrective insole [9]

This expansion causes a positional instability on gait cycle, resulting in increased amount of energy consumption for keeping the balance of the human subject.

Therefore, plantar surface with the ground extended contact by plantar vault must be "supported" by a fair and adequate dimensional insole that provides mobility and flexibility.

The corrective insole is made in relation to the anthropometric dimensions of the human subject and gives postural comfort, stability and an even distribution of body weight. [10, 11]

These determinations underlying to further research on insurance postural comfort status by behavioral types of insoles analysis and also develop the studies of plantar pressure distribution in various forms of sports movements (jumping, landing on the ground, spins, etc.).

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