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GAIT SYMMETRY ANALYSIS IN MULTIPLE SCLEROSIS

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Abstract: *Gait analysis is a challenge. The aim of the paper is to analysis the asymmetry of kinematic gait parameters, using the cyclograms and symmetry indexes (SI,R,GA), for patients affected by multiple sclerosis (MS) evaluate using EDSS scale. The research try to analysis the evolution of possible gait disorders. The results demonstrate that in case of MS patients are semnificative decrease (50%) of angle amplitude of knee and ankle. Also the symmetry indexes have high values and these are more obvious during heel attack, swing phase and single support phases of gait. Evolution of kinematic parameters and symmetry indexes lead to the conclusion about development of control motor lacj of lower limb.*

Key words: *gait symmetry, multiple sclerosis, EDSS score, symmetry index.*

1. PROBLEM DESCRIPTION

For the researchers and in clinical field, gait analysis remains a challenge as there is no precise definition of what normal gait means. The human gait is still a subject of study that try to define the more complex relation of the nervous system and how the control over what the myoartrokinetic system is realised. The process is complex and use tools that are capable to measure the mechanics and activities of the components of the human body [1]. In the recent years, gait biomechanical analysis has seen an important development, based on optoelectronic and kinematic systems and kinetic analysis systems that were developed mainly in the field of computer vision and entertainment industries, using markers for the anatomical landmarks which allows precision in assessment and in the kinematic interpretation [2], [3], [4].

One of the pathologies that are disabling for the locomotor system by creating significant disabilities that are difficult to predict is multiple sclerosis that determine a progressive process of axonal demyelization with consequences on the gait [5], [6].

Gait variability, parameters variation during a gait cycle or variation between steps are prevalent characteristics to the persons with multiple sclerosis this is way the analysis and realization of evolution prediction for this parameters represent an important objective of biomechanical analysis.

However, the great majority of studies refer to spatiotemporal parameters (like step length, duration, gait phases). The results are extremely diverse and also in contradiction failing to provide accurate results, most of the results demonstrating just the existence of small differences between groups of healthy people and people suffering from multiple sclerosis.

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By using new technologies for measuring and gait parameters evaluation will allow the identification of the risks that disabilities persons present in sense of mobility limitation, falling risk/risk of falls, but also in realisation of study trials in order to realise some therapeutically intervention procedures [8]. In the situation when it is present a diminution of plantar flexion, the persons with MS develop a gait patterns that are characterised by falling of foot when foot landing. This joint position can determine the involvement of foot dorsiflexors group muscles and implicitly the realisation of motor control for the foot in the initial phase of the gait, more precisely during the initial stance phase.

In the same time, gait disturbance in SM are associated with decreased muscle strength and the presence of the spasticity (sometimes this can be imperceptible in the absence of gait analysis), instability or balance changes, significant sensorial impairment [9].

In the same context of using the technologies in gait assessment, there are studies suggestions regarding the use like an alternative the treadmill for gait analysis. This approach offer the possibility to track the parameters for a longer period of time, on a longer distance, with the possibility to change the speed and inclination degree all of that put the MS subject in a situation close to the normal walking condition.

However, what is deficient in this type of evaluation is the fact that only the spatiotemporal parameters are analysed and an association with kinematic results is also required.

Therefore, the majority of the studies are based on the analysis of temporo-spatial parameters, the kinematic ones are missing, which limits an early detection of gait disorders in people with MS in the early stages of the disease thus limiting the therapeutic intervention.

2. APPLICATION FIELD

In this moment, statistical data spoke about more then 2,5mil people diagnosed with multiple sclerosis (MS). The movement variability is associated with specific status of human body systems, and could be consider a marker of motor control. For this reason know the movement variability is a way for have a image of MS impairments.

The features of movement are more important, for development the therapeutic intervention mechanic assistive device then know the speed movement. Know the kinetic parameters in relationship with clinical evolution of gait, allows a good understanding of MS progression; also could have contribution to a classification of neuromuscular changes and adaptation that involve gait pattern changes from the mechanic point of view.

3D analysis of gait gives information needed for rehabilitation. In MS kinetic analysis of gait could give a lot of contributions for early diagnostic of gait disorders in MS even if this is not evident on clinical examination. In this context is important to analysis the symmetry and understand the motor control during gait for development the assistive device [10].

Practical application of gait analysis in MS is based on analysis of 21 de parameters with max rotation produced 6 orthogonal domains of gait (pace, rhythm, variability, asymmetry, anteo-posterior dynamic asymmetry, medio-lateral dynamic symmetry).

3. RESEARCH STAGES - STATE OF THE ART IN BIOMECHANIC ASSESSMENT

Socie et al in their paper speak about the great variability of kinetic parameters at MS people, compare with healthy people, referees to strike duration, length strike [11].

In the last 10 years the technology for gait analysis has a lot of change, a high accuracy and sensitivity regarding how is possible to use the information in pathology [8] allows to analysis the lower limb parameters: angles, speed, accelerations, force and moment. Also the technology includes non-wearable and wearable gait analysis systems.

Non – wearable gives information with high accuracy but needs laboratory environment and are expensive [12], [13].

Three main non-wearable technologies are as follows: optical motion capture systems, force platforms/balance boards, and instrumented walkway mats.

Wearable sensors are use for data collect in daily activity. They could be use for any part of the human body. The most useful sensors are isoinertial sensors and pressure sensors

In spatial clinic gait evaluation uses scales like Kurtzke Disability Scale (EDSS), but they gives information about disability level, but not about the gait quality, associated movements. The quantitative assessment could give information about mechanic joint process [14].

Souza et. al, use the Mircrosoft Kinect R sensor, and make a kinematic analysis of gait and a correlation between gait index and EDSS score [15].

Kinematic asymmetry is presented by Molina-Rueda in his study and the results show an asymmetry in sagittal plane, reduce of hip extension and ROM of hip in stance phase of gait [10].

The same aspect is studied by Pau et al. which observe that patients affected by SM have an increase of hip flexion and decrease of extension during initial contact, follow by decrease of hip extension and plantar flexion during stance phase [16].

Daunoraviciene et.al. [17], discuss about the gait asymmetry for the subjects diagnose with MS by using inertial sensors who performed the heel-to-shin test.

Filli et al. [18] male analysis the difference of range of motion (ROM) between lower limb segments, hip, knee and ankle during gait using optical motion capture system. The conclusion reached regarding the MS gait is that there is a bilateral reduction regarding different gait parameters: length of the step, joints range of motion is still preserve at the level of the hip, but is significantly reduced at the knee and ankle. According to the authors this gait characteristics causes a substantial left-right asymmetry for MS subjects [17]. The variability of the gait is important, while the segmental interco-ordination has small deviations. The analysis of the progression curve of the joint angles allowed the authors to create gait patterns for the studied group that showed a great heterogeneity with a pronounced reduction of the amplitudes of movement and a great instability.

Crenshaw et al. [19] analysed the shape of the sagittal curve for the hip, knee, and ankle movements during the gate to determine symmetry by using the eigenvector approach. Their result showed that there is an important asymmetry related to the state of local and generalized muscle fatigue. Moreover, they demonstrate a correlation between symmetry and gait parameters, which suggest MS progression. In this context the factors that involve MS progression also influence the gait quality, decrease of symmetry index, decrease the gait speed, strike length, increase of support and double stance [19].

The use of inertial sensors validation was also performed by Flachenecker et al. [20] They observed a correlation between the gait parameters provided by the IMU and the severity of the disease assessed by the EDSS scale and they accepted that the IMU allows the detection of differences in these parameters, between people with MS and healthy people, even in the early stages of MS [20].

By analysing the specialized literature the conclusion is that in terms of gait analysis there is no standardization, especially in people with MS. The MS subjects present a great polymorphism of parameters and joint behaviour, which is related to the motor control performance. Also, there still is more shortcomings concern the analysis of gait symmetry for each phase of gait.

When the gait is described the terms symmetry and asymmetry are used alternatively in literature. Asymmetry of gait is due to the deviations from the midline made by the limbs when a subject walks. This adverb describe the variance of the left and right hemi corps or limbs from the midline and it is present in pathological gait and also in normal gait [21].

Variability, complexity, regularity and symmetry or asymmetries are terms used to measured kinematic of human gait routine. They published an extensive review of walking symmetry measures. Since then, new methods of symmetry quantification have emerged, especially recently [22].

In the past, discrete methods and statistical parameters were the only two classes of symmetry quantifiers [23].

4. THE AIM OF THE STUDY

Starting from the analysis of the literature, we noticed that the analysis of gait aimed especially the time-varying parameters (like trajectories, angular amplitudes, muscular forces and moments of force in the/across the joints).

These parameters allow an objective/concrete/ real quantification of gait symmetry, especially when, clinically, the possible asymmetries are not obvious and they cannot be objectified.

5. METHOD

Our study aims to analyse the variability of gait parameters (angular amplitudes at the knee and ankle), comparison for three categories of subjects: healthy subjects, MS subjects with an EDSS score 2 and MS subjects with an EDSS score 4, by establishing the range of values that define gait symmetry and gait pattern identification.

We consider that obtaining this objective information about the magnitude of the asymmetry of movements can contribute to tracking the impact it has on gait as a whole and consequently can help to establish a customised rehabilitation program or can help to design personalised assistance systems.

In each category, dates from 4 subjects were included, groups characterization can be found in Table 1.

Table 1

Average anthropometric characteristics - average values (± SD).

Subjects	Healthy	MS with an EDSS score 2	MS with an EDSS score 4
Age [years]	57.5 (±4.54)	45.7 (±1.92)	53.7 (±3.03)
Weight [Kg]	62.75 (±3.11)	75.75 (±1.92)	73.75 (±3.031)
Height [cm]	161.25 (±6.45)	175.5 (±1.5)	172.75 (±1.92)

6. EQUIPMENTS AND SOFTWARES

Kinematic analysis of gait parameters, has been made using the VICON system for movement capture, from Bioengineering Laboratory (www.incesa.ro). The system included 14 infrared cameras, the frequency is 200 Hz.

For recording the movement the system uses software NEXUS, and a special skeleton model named Plug-in–Gait is associated with each subject. The subject wears a black suit which has 39 reflective markers, 14mm diameter (Fig.1). Markers position are in according to the protocol described by Davis et al. [25].

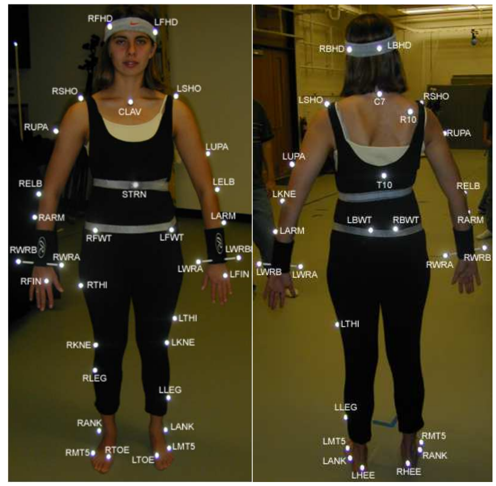

Fig. 1. Vicon marker setup [26]

Using the software we made the movement analysis of lower limb during the gait on a plane surface, at confortable speed, and follow the trajectories of the main important points on the lower limb like (knee and maleolas) and also variation of angular amplitude for knee and ankle joints.

Participants walked at a self selected speed in the most natural manner possible on a 10 m walkway at least 3 times, interspersed with suitable rest times.

The values of flexion-extension angles are compared with reference values proposed by Perry in his protocol [27].

In our study the recorded values have been used for evaluation the symmetry of the kinematic parameters of lower limb.

The symmetry has been demonstrated by qualitative shape using cyclograms and for this we propose the following indexes:

Symmetry ratio (R) [28]:

$$R = \frac{Xs}{Xd} \qquad (1)$$

Symmetry index (SI) [29]. This index expressed 3 relation used in literature [21]:

$$SI1 = \frac{(Xs - Xd)}{Xs} 100\ [\%] \qquad (2)$$

$$SI2 = \frac{(Xs-Xd)}{Xd}100\ [\%] \qquad (3)$$

$$SI3 = \frac{2(Xs-Xd)}{Xs+Xd}100\ [\%] \qquad (4)$$

Gait asymmetry (GA) [30]:

$$GA = 100ln\frac{Xs}{Xd}\ [\%] \qquad (5),$$

Xd and Xs are the measurements parameters for right and left lower limb.

Based on the recording we make the cyclogram of angular amplitude for knee and ankle-foot complex, for a gait cycle, following the protocol of Kutilek [31].

The cyclogram has an area delimited by the curve generated from each diagram angle-angle and angular deviation of long ax of cyclogram from reference system reported to line of 45 degree.

Cyclogram orientation (degrees): this feature is identified by the absolute value of angle formed by the 45 line, which corresponds to perfect interlimb symmetry.

7. RESULTS

Below, we further present the results of the recorded parameters.

Graph 1 shows the variation of the knee flexion-extension angle for a walking cycle according to Perry protocol [27].

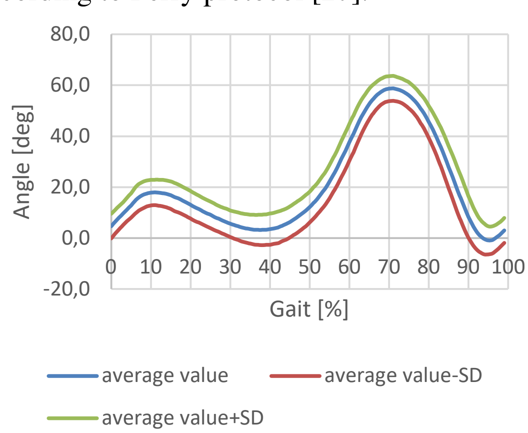

Fig. 2. The variation of the knee flexion-extension angle during/for a gait cycle according to Perry protocol [27].

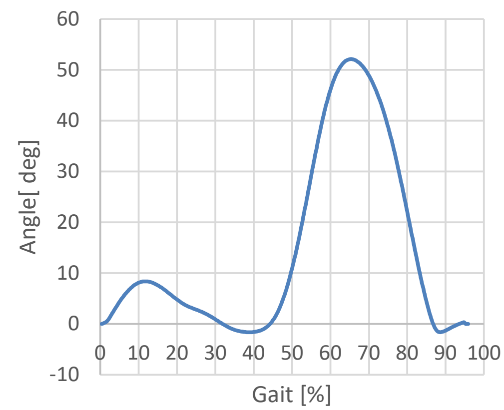

Fig.3. Variation of the knee flexion-extension mean angle for a gait cycle in healthy subjects

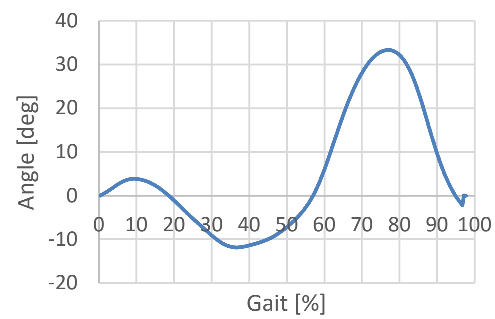

Fig.4. Variation of the knee flexion-extension mean angle for a gait cycle in MS subjects with an EDSS score 2

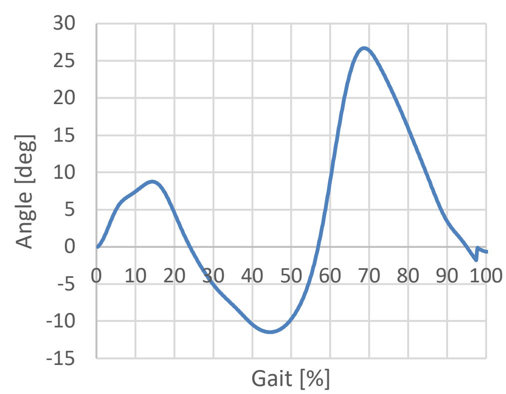

Fig.5. Variation of the knee flexion-extension mean angle for a gait cycle in MS subjects with an EDSS score 4

At the knee joint, the reference values according to Perry [27] are represented by the curves from the figure 2, in which it is observed that the total amplitude of movement is 70 degrees.

The amplitude of the knee extension flexion movement in MS subjects is much reduced: 38 degrees in MS subjects with an EDSS score 4 score (figure 5), respectively 44 degrees in MS subjects with an EDSS 2 score (figure 4).

In healthy subjects, the angular amplitude determinate was 60 degrees (figure 3), comparable to the reference value (figure 2).

A significant difference in range of motion can be observed between the three categories of subjects.

Figures 6, 7, 8 and 9 show the values of the amplitude of flexion-extension angle for the ankle joint.

At the ankle joint, the reference values according to Perry are represented by the curves in figure 6, in which it is observed that the total amplitude of movement is 37 degrees.

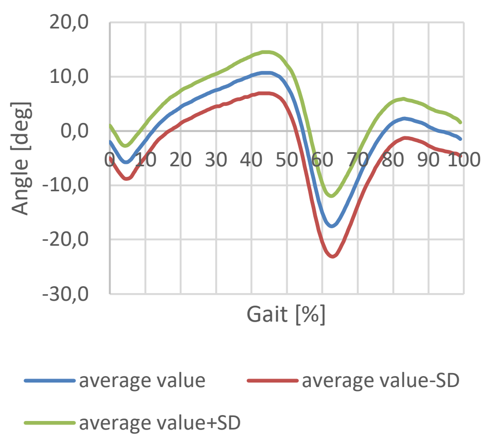

Fig.6. Variation of the flexion-extension angle of the ankle joint for a gait cycle according to Perry protocol [27].

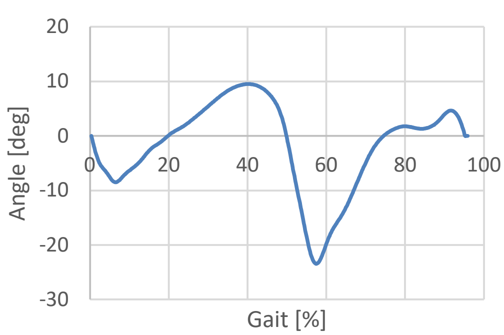

Fig.7. Variation of the flexion-extension average angle of the ankle for a gait cycle to the healthy subjects

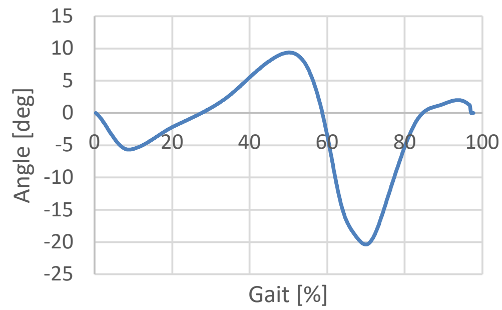

Fig.8. Variation of the flexion-extension average angle of the ankle for a gait cycle to the MS subjects with an EDSS 2 score

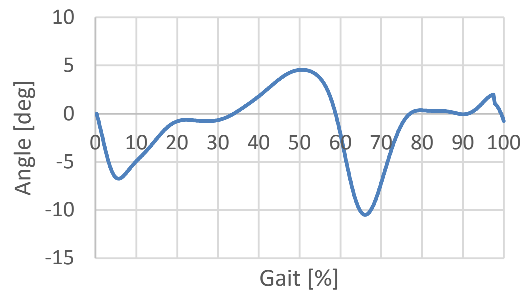

Fig.9. Variation of the flexion-extension average angle of the ankle for a gait cycle to the MS subjects with an EDSS 4 score

The amplitude of the ankle joint angle for the patients with MS is much reduced: 15.5 degrees in patients with MS who have the score of EDSS 4 (figure 9) and 30 degrees in patients with MS who have the score of EDSS 2 (figure 8).

In healthy subjects, the angular amplitude is 34 degrees (figure 6), comparable to the reference value (figure 6).

Cyclograms

Fig.10. The symmetry of the knee flexion-extension angle. Comparison between MS group EDSS score 4 and healthy people, for a gait cycle

Fig.11. The symmetry of the knee flexion extension angle. Comparison between MS group EDSS score 2 and healthy people, for a gait cycle

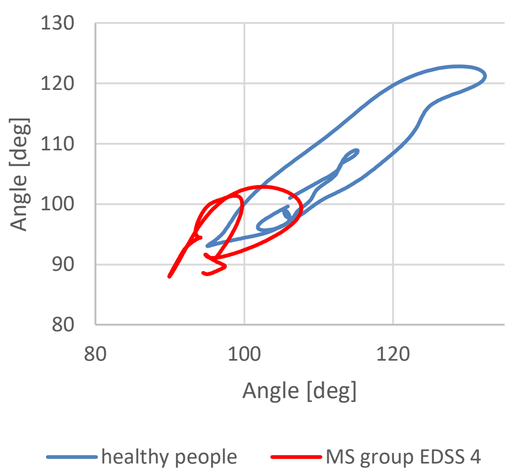

Fig.12. The symmetry of the flexion extension ankle angle. Comparison between MS group EDSS score 4 and healthy people, for a gait cycle

By analyzing figures 10-13, which refer to the symmetry of angles (cyclograms), we can see a significant difference in the gait symmetry of subjects with MS, compared to healthy subjects. Thus, in subjects with MS, it is found that the cyclograms have larger areas, resulting from small angular amplitudes, with a large dispersion of values compared to the 45-degree line.

On the one hand this means that the MS subjects present a decrease of the angular amplitude (aspect also revealed by figures 2-9), but also the appearance of a deficient motor control in MS subjects, more accentuated at the level of the ankle and of the foot.

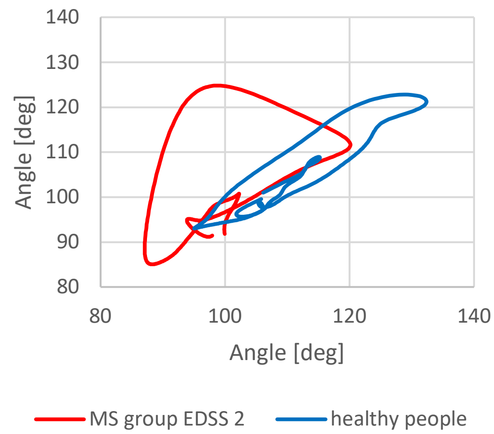

Fig.13. The symmetry of the flexion extension ankle angle. Comparison between MS group EDSS score 2 and healthy people, for a gait cycle

Variation of symmetry indexes (SI1, SI2, SI3, R, GA) for a gait cycle, have been analyzed for flexion extension knee and ankle angles, for MS patients and also for healthy people.

Maxim values, average and standard deviation of the indexes for knee joint are presented in Table 2 and for flexion extension ankle angles are presented in Table 3.

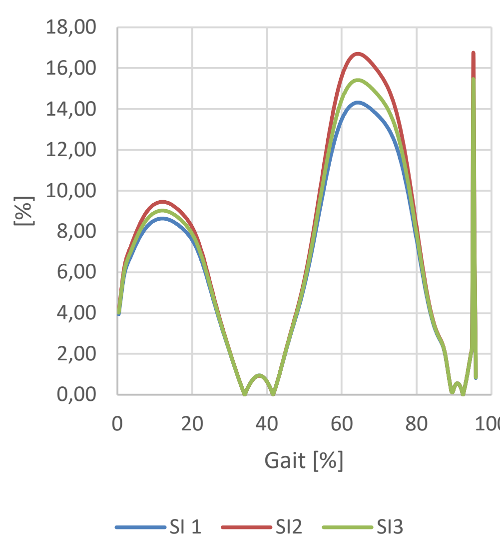

Fig.14. Variation of symmetry indexes SI1, SI2 and SI3, for a gait cycle, healthy people, knee flexion-extension

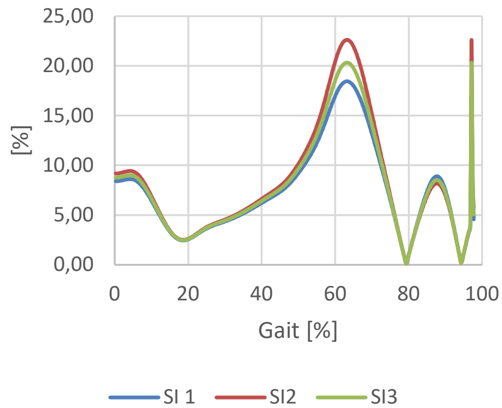

Fig.15. Variation of symmetry indexes SI1, SI2 and SI3, for a gait cycle, MS people EDSS score 2, knee flexion-extension

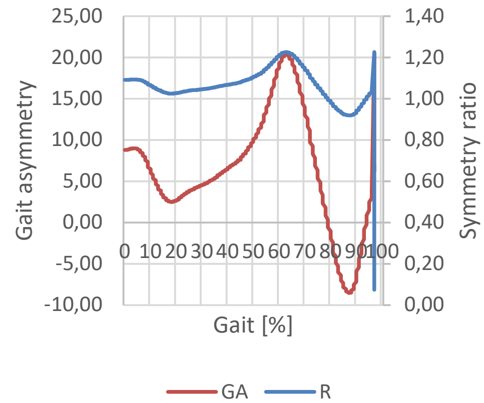

Fig.18. Variation of symmetry ratio (R) and Gait asymmetry (GA), for gait cycle, MS people EDSS score 2, knee flexion- extension

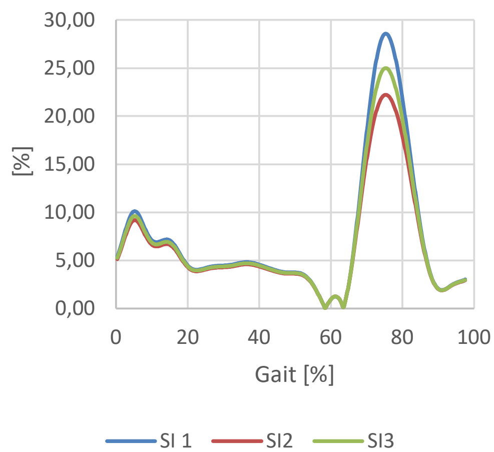

Fig.16. Variation of symmetry indexes SI1, SI2 and SI3, for a gait cycle, MS people EDSS score 4, knee flexion-extension

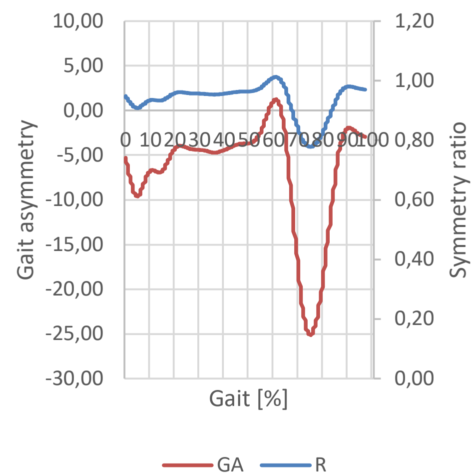

Fig.19. Variation of symmetry ratio (R) and Gait asymmetry (GA), for gait cycle, MS people EDSS score 4, knee flexion- extension

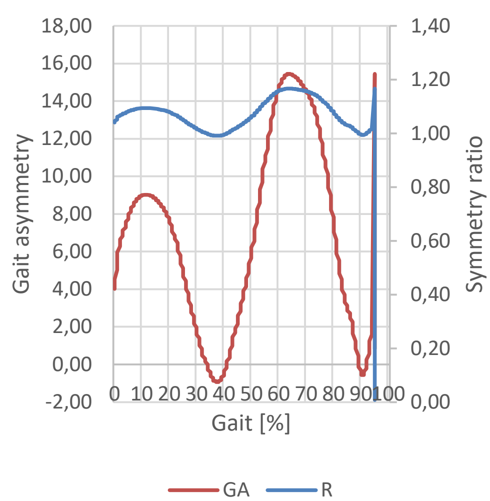

Fig.17. Variation of symmetry ratio (R) and Gait asymmetry (GA), for gait cycle, healthy people, knee flexion- extension

Analysis of symmetry indexes (figures 14 and 17) give us information about healthy people, for knee flexion-extension angle and the results are that it is a maximal asymmetry at pre-swing phase of gait.

Figures 15 and 18 show us that MS people EDSS score 2, present the same asymmetry also in the pre-swing phase, but is more then healthy people (Table 2).

Figures 16 and 19 present the results for MS people EDSS score 4, and the results show that the maximal asymmetry of knee flexion-extension is in the middle of pre-swing phase, and it is more very high (Table 2).

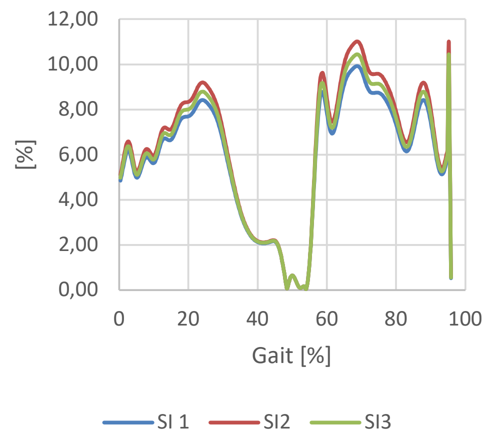

Fig.20. Variation of symmetry index SI1, SI2 and SI3, for gait cycle, healthy people, ankle flexion-extension angle

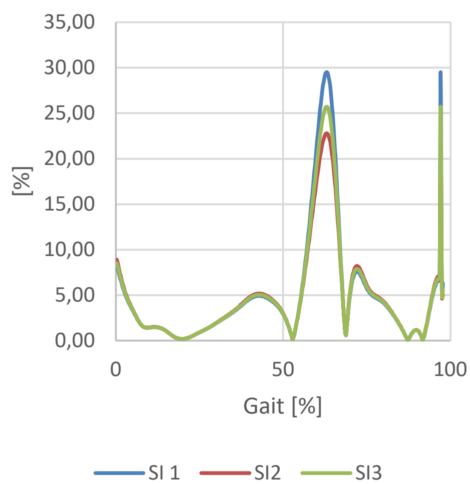

Fig.21. Variation of symmetry index SI1, SI2 and SI3, for gait cycle, MS people EDSS score 2, ankle flexion-extension angle

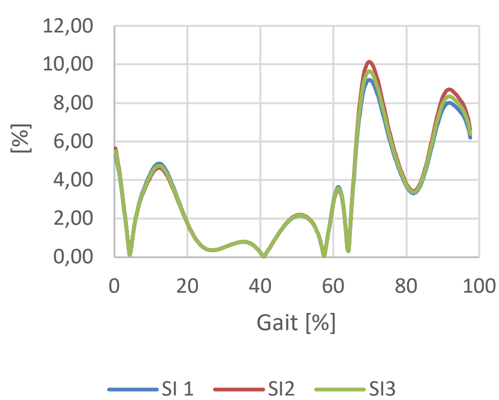

Fig.22. Variation of symmetry index SI1, SI2 and SI3, for gait cycle, MS people EDSS score 4, ankle flexion-extension angle

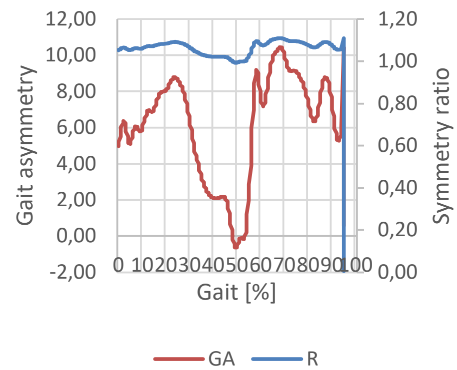

Fig.23. Variation of symmetry ratio (R) and Gait asymmetry (GA), for gait cycle, healthy people, ankle flexion-extension angle

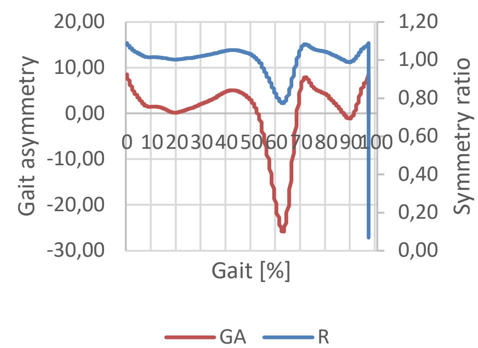

Fig.24. Variation of symmetry ratio (R) and Gait asymmetry (GA), for gait cycle, MS people EDSS score 2, ankle flexion-extension angle

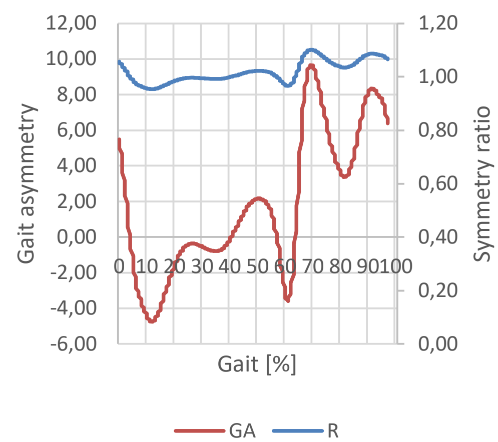

Fig.25. Variation of symmetry ratio (R) and Gait asymmetry (GA), for gait cycle, MS people EDSS score 4, ankle flexion-extension angle

In figures 20 and 23 we can see that ankle flexion-extension angle has a maxim asymmetry at the beginning of swing phase, extreme value at 68% from gait cycle, for healthy people.

Figures 21, 22 and 24, 25 for MS people, demonstrate that ankle flexion-extension angle has an asymmetry during swing phase , and during the single support ankle symmetry is well.

Extreme values and average values of these indexes, are presented in Table 2 for knee flexion-extension angle, and for ankle flexion-extension angle, are presented in Table 3.

Table 2

Extreme values of symmetry indexes for knee flexion-extension angle

		SI 1	SI 2	SI 3	R	GA
Healthy people	Maximal value	14.32	16.71	15.42	1.17	15.45
	Average value	6.59	7.31	6.93	1.07	6.81
	Standard deviation	0.82	0.87	0.84	0.01	0.84
MS people EDSS score 2	Maximal value	18.45	22.63	20.33	1.23	20.40
	Average value	7.50	8.27	7.85	1.07	6.24
	Standard deviation	4.57	5.64	5.05	0.07	6.97
MS people EDSS score 4	Maximal value	28.57	22.22	25.00	1.01	28.57
	Average value	7.44	6.56	6.96	0.94	7.44
	Standard deviation	7.13	5.57	6.26	0.06	7.13

Analysis of the data in Table 2 show us that the maximal values and also average values are more for MS people then healthy people, and values if symmetry indexes are around average value for healthy people and have a high dispersion for MS people.

Table 3

Extreme and average values of symmetry indexes for ankle flexion-extension angle

		SI 1	SI 2	SI 3	R	GA
Healthy people	Maximal value	9.92	11.01	10.44	1.11	10.4
	Average value	5.95	6.41	6.17	1.06	6.1
	Standard deviation	0.52	0.58	0.55	0.01	0.5
MS people EDSS score 2	Maximal value	29.52	22.79	25.73	1.09	8.5
	Average value	4.96	4.64	4.77	1.00	0.2
	Standard deviation	6.30	5.05	5.59	0.07	7.3
MS people EDSS score 4	Maximal value	9.20	10.13	9.64	1.10	9.6
	Average value	3.33	3.47	3.40	1.02	1.7
	Standard deviation	2.64	2.87	2.75	0.04	4.0

In Table 3 we can observe that values of symmetry indexes are around average value for healthy people and have a high dispersion for MS people, even if the extreme and average values have not a convergent sense.

Further research

Future research activity will involve biomechanic analysis of lower limb behavior during gait for improve the main components of analysis means initial input features, dimensionality reduction using feature selection and feature extraction, and learning algorithms via classification and clustering.

Identify the symmetry for each gait phases in mandatory for develop the mechanical assistive devices and design the rehabilitation protocols. In the same time a challenge of our research is to have an early detect of gait disorders and also gait dysfunction or progression based on wearable and nonwearable systems, which can overcome these problems.

However, future studies (possible longitudinal) are necessary to clarify the evolution of asymmetry during the disease progression, to identify specific peculiarities associated with MS type.

8. CONCLUSIONS

The study represents a first step in gait analysis for MS people and relieves the importance of analysis each lower limb segment for understand the deviation in each gait phases and also the lower limb behavior.

A significant decrease of knee joint angular amplitude was observed and also a high deviation before single support phase, at MS people then healthy people.

Regarding the ankle joint the MS people present a high variability of angle amplitude and reduce capacity to control the ankle which is observed also before single support phase. Limits of angular amplitude and high variability of this, at MS people could be explain by lack of motor control.

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Analiza simetriei ciclului de mers in scleroza multipla

Rezumat: Analiza mersului reprezinta o provocare. Scopul lucrarii este acela de a analiza gradul de asimetrie a parametrilor cinematici ai mersului, prin intermediul ciclogramelor si prin indicii de simetrie specifici (SI, R, GA), pentru pacientii scelroza multipla (SM) cu diferite grade, conform scalei EDSS. Scopul analizei a fost acela de a realiza o predictie a potentialului evolutiv de alterare sau agravare a mersului. Rezultatele indica diferente semnificative ale amplitudinilor unghiulare ale genunchiului si gleznei cu diminuari de aproximativ 50% la subiectii cu SM. Indicii de simetrie prezinta valori care arata larga asimetrie la subiectii cu SM. Toate aceste aspecte sunt mai evidente in faza de atac a solului, in faza de balans si sprijin unipodal, semnificand lipsa unui control motor adecvat.

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