Comparison of Treadmill-Based and Overground Gait Analysis

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Abstract— **This preliminary study was designed to assess the feasibility of gait analysis on a treadmill allowing multiple steps recording at a constant velocity, based on a comparative analysis between treadmill and overground gait. The measurements were realized using Zebris measuring system CMS-HS and a commercially available Hammer Walkrunner Pro Treadmill. One young volunteer (male, 24 years old) with mild instability of left ankle was involved in the study. To evaluate the spatio-temporal and kinematical parameters, the investigated subject performed gait with self-selected velocity both on the treadmill and overground. The main spatio-temporal parameters which have been analyzed are stance and swing phase, stride time, cadence, and velocity. The studied kinematical parameters were the flexion-extension angles of the hip and knee joint, and dorsi- plantar flexion angles of the ankle joint. The comparison of the kinematic parameters was focused on the left limb joints. The walking disorder of the patient has influenced both the kinematic parameters and gait symmetry.**

Keywords— **motion analysis, overground gait, treadmill-based gait, spatial-temporal parameters, joint angles.**

I. Introduction

Contemporary motion analysis is performed for the purpose of research (measuring system development), diagnosis, rehabilitation, improvement of sport performance and injuries prevention.

Quantitative gait analysis is one of the most used motion analysis due to the alteration of its characteristics when various problems (neurological, skeletal or neuromuscular) occur. Also, it's an objective analysis of the walking ability in healthy persons.

A complex gait analysis consists of three main investigations: kinematic analysis (provide detailed information regarding the spatio-temporal and kinematic parameters of gait), kinetic analysis (pressure distribution and trajectory of mass center and center of pressure are determined during dynamic movements), and EMG (provide data about neuromuscular activity). The gait parameters are grouped to spatio-temporal (swing and stance phases, step length, step width, walking velocity, stride time, and cadence) and kinematic (joint angles of the hip/knee/ankle, and thigh/trunk/foot angles) classes [1], [2].

The relevance of the results is always proportional to the number of valid trials and recorded strides. Usually, gait analysis refers to overground (OG) walking on a walkway located in a laboratory. The ability to obtain significant measurements in these conditions is constrained by the limited length of the walkway and the subjective control of the walking velocity [3].

The evaluation drawbacks of normal and pathological (OG) gait could be overcome by walking on a treadmill [4]. It is often more convenient to perform a treadmill (TM)-based gait analysis since it is possible to acquire more consecutive strides without overcoming the measurement range of the equipment. Another benefit of (TM) gait consists in controlling of walking velocity, which has a significant influence on gait's parameters. The velocity of the treadmill can be sequentially modified. For any given value of velocity, the equipment provides constant belt movement which lead to relatively uniform movements of the subject.

One limitation when using a treadmill consists in adapting of the individual gait to the natural walking which is more difficult in older population and individuals having some disabilities [5].

Some authors have reported no mechanical difference between the two modes (OG and TM gait) while others have documented statistically significant differences regarding the gait parameters [3].

The purpose of the presented study was to perform a comparative analysis of (TM) gait versus (OG) gait in order to understand the relationship between these two modes and to provide a valid foundation about the possibility of treadmill using in clinical gait investigation and rehabilitation. In connection to the clinical target of the investigation, the selected subject presents mild left ankle instability. Thus, the comparison of the kinematic parameters was focused on the left limb joints only.

II. Materials and methods

The measurements were realized in Motion analysis Laboratory of Politehnica University of Timisoara using Zebris measuring system CMS-HS and a commercially available HAMMER Walkrunner Pro Treadmill. The measuring method is based on the determination of spatial coordinates of the miniature ultrasound receptors (markers), by measuring the time delay between the emission of sonic pulses and their reception. The spatial position of the markers is determined by triangulation method.

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The measurement starts with the attachment of two marker triplets on the body in two key points. The first marker triplet is attached on the thigh and the second one on the upper part of the foot. In the next step, the anatomic landmarks are marked with the pointer, and the system software creates the geometrical model of the lower limbs. Signals from the left and right side of the body are measured simultaneously. The spatial positions of the markers and geometrical model are computed and displayed during the subject motion, using the WinGait Software.

Hammer Walkrunner Pro Treadmill has the possibility of adjusting the velocity and inclination of the belt. From the point of view of inclination, all measurements were performed with the treadmill belt in horizontal position.

To evaluate the gait kinematical parameters, one young volunteer (male, 24 years old) having mild instability of left ankle performed gait both on treadmill and overground, with self-selected velocity. In order to adapt his walking to the measurement conditions a trainning session of five minutes was firstly performed. Based on this training session the treadmill velocity was set.

There were performed ten overground valid trials, each consisting of only two strides due to the limitations of the measuring equipment. On the treadmill, the belt velocity was selected according to the self-selected velocity of the subject walking. Because the gait cycles could be endless on treadmill, the duration of trial recording was limited to 50 seconds, which represents around 31 strides.

The sampling rate of the recordings was selected in both cases at 25 Hz, according to the movement velocity. Collection and comparison of spatial-temporal and kinematical parameters of the gait were performed for both limbs executing successive strides, in both modes.

The numerical results of the joint angle measurements were exported for further processing and have been ordered in columns to compute the mean values and standard deviations. The series with large phase difference were eliminated for smoother results achievement. The phase difference series usually corresponds to the velocity changing during walking.

III. Results and discussion

The main spatio-temporal parameters which have been analyzed are: stride time, cadence, velocity, and swing and stance phases of both limbs. The phases of the gait cycle indicate the symmetry between the limbs movement. In case of a healthy person, the left and right limbs have to exhibit a symmetrical behavior with a stance phase of 60 % and 40 % for swing. In our case the average stance percentage in (OG) gait is 65% while average swing is 35%, almost similar for both limbs. In (TM) gait case, the gait phases differ with 1%, for the left limb only. The similar percentages of the gait phases in both walking modes allow a comparison of the results.

The stride time is usually 1.6 seconds in regular walking. The records reveal an average time interval per stride of 1.4 seconds in case of (OG) gait and 1.75 seconds for (TM) walking. In both modes, the gait cycle was computed as a mean of all the recorded strides during the exercise. The difference of 0.35 seconds between stride times in (OG) and (TM) walking is also underlined by the movement cadence, which is 0.7 steps/second in case of (OG) gait and 0.57 steps/second for (TM) gait respectively. Smaller cadence means longer gait cycle which is usually achieved by an extended period of stance phase. This result also indicates that the selected treadmill velocity (0.55 m/s) was smaller than the velocity of the (OG) walking (0.76 m/s).

Three dimensional motion data were obtained for hip, knee and ankle motions. In quantitative approaching of the results, the average variations of the joint angles were represented in time and time-normalized per stride. The average values were computed by manually extracting the data series which represents a stride. The landmark in every series was considered the angle value recorded in knee joint, at the heel contact phase.

Based on the joint angles in different anatomical planes, there were selected the representative movements for each joint: flexion-extension for hip and knee, and dorsi - plantar flexion for ankle. Mild instability in left ankle joint caused correlated effects in joints of both limbs, especially for the left limb. Thus, joint angle variations were determined for both lower limbs, but only for the left limb are presented, the study being focused on the pathology influence on the movements.

Figure 1 presents the averaged joint angle curves in time representation for hip during flexion-extension, in both cases. Both figures illustrate the movement variations and standard deviation of the series. The standard deviation is represented as vertical lines accompanying each data point. The joint motions occur almost entirely within the normal range of motion [1], [6].

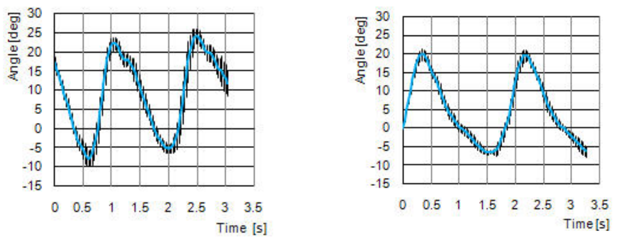
Several elements are differencing the two motions. The shape of the curve in (TM) gait is smoother and misses the horizontal complex which characterizes the weight shift from one leg to the other. The standard deviation is smaller for (TM) gait (average of 1.5 compared with 2.6 for overground gait) due to the repetitive motion imposed by the constant movement of the belt. This behavior is manifesting in each joint movement.

Figure 2 depicts the graphs of flexion-extension angles of the hip represented as average, time-normalized stride. As before, the standard deviations of the overground gait recordings are greater than the treadmill recordings. By overlapping the averaged motion curve (figure 3) the differences between the two modes can be analyzed.

Another important parameter in gait analysis is the angular variation of the knee joint, presented in figure 4. The larger standard deviations are occurring in overground gait (average of 6.7 compared with 2.3 for treadmill gait), especially when the curve is changing the slope sign. The inflexions are very sensitive points, thus the measurement could be improved by increasing the sampling rate of the data acquisition.

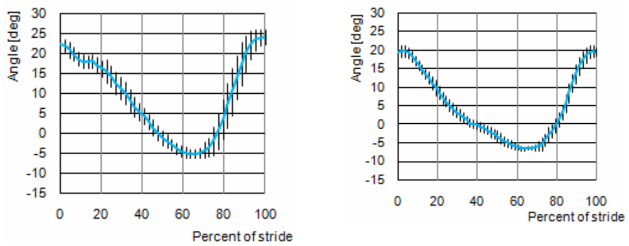
Figures 5 and 6 depict the graphs of flexion-extension angles of the knee joint as average, time-normalized stride, evidenceing a typical knee behavior in the case of overground gait. Also, the amplitudes of the movements are well shaped for the overground gait.

The last parameter is the angular variation of the ankle joint in dorsi and plantar flexion movement (figures 7, 8 and 9). The plantar flexion is represented by the highest amplitude, while the dorsiflexion is represented by lower peak. The average standard deviation for (OG) gait is 2.2, while for the (TM) gait is 0.57. A notable difference can be observed when overlap the variations of ankle angles for both gait cases. In treadmill gait, the ankle movement has lower amplitudes and lack of smoothness. This can be an effect of the belt movement beneath the feet.



a) Overground gait b) Treadmill gait

Fig. 1 Graphs of flexion-extension angles of the hip joint



a) Overground gait b) Treadmill gait

Fig. 2 Graphs of flexion-extension angles of the hip joint for one stride

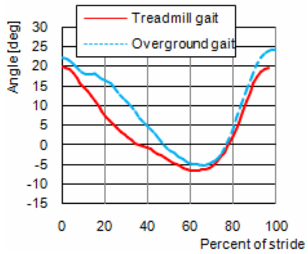
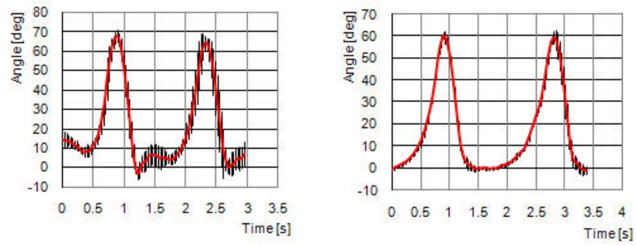
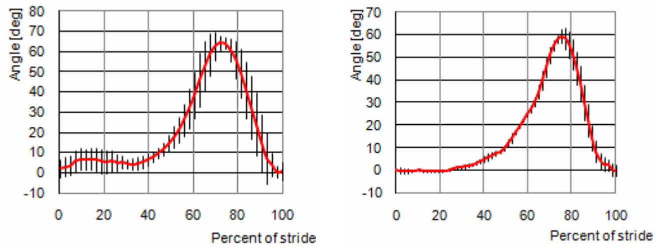


Fig. 3 Comparison of means of flexion-extension graphs of the hip joint for one stride



a) Overground gait b) Treadmill gait

Fig. 4 Graphs of flexion-extension angles of the knee joint



a) Overground gait b) Treadmill gait

Fig. 5 Graphs of flexion-extension angles of the knee joint for one stride

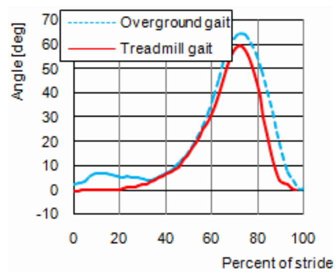
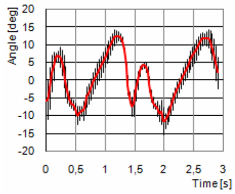
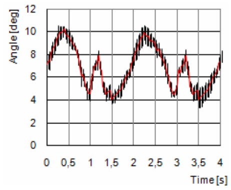


Fig. 6 Comparison of means of flexion-extension graphs of the knee joint for one stride

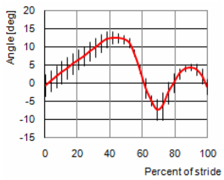


a) Overground gait

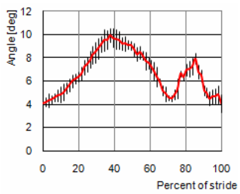


b) Treadmill gait

Fig. 7 Graphs of dorsi-plantar flexion angles of the ankle joint



a) Overground gait



b) Treadmill gait

Fig. 8 Graphs of dorsi-plantar flexion angles of the ankle for one stride

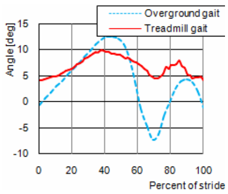


Fig. 9 Comparison of means of dorsi-plantar flexion graphs of the ankle joint for one stride

The means values for discrete angles in (OG) and (TM) gait determined during the performed trials were compared between the two modes by use of an unpaired t-test. Values of $p < 0.05$ were considered statistically significant, while values of $p > 0.05$ indicate no difference between the groups. The flexion-extension angles of the hip ($p = 0.0167$) and dorsi-plantar flexion of the ankle ($p = 0.0086$) were significantly different, while the flexion-extension angles of the knee were not significantly different ($p = 0.112$).

IV. Conclusions

This preliminary study presents a comparative analysis between (TM) and (OG) gait of a patient with a certain walking disorder. The study objective was to underline the gait modifications occurred when moving on the treadmill, and to provide preliminary data about the possibility of using the treadmill in clinical gait investigation and rehabilitation. The walking disorder of the patient has influenced both the kinematic parameters and gait symmetry.

The recorded spatio-temporal parameters present a good similarity. The kinematical parameters reveal that statistical significant differences occur regarding the flexion-extension angles of the hip joint and dorsi-plantar flexion of the ankle joint of the left lower limb. The angular amplitudes in ankle joint are lower when walking on the treadmill than in overground mode and the instability is more obvious. The lack of smoothness of the flexion complex in left ankle in TM-mode is induced by the treadmill movement.

Better results meaning smaller standard deviations are recorded in (TM) case when a certain velocity is imposed. This fact leads to repetitive results, valid for statistical interpretations. On the other hand, accurate recordings and interpretations of the human gait are achieved when the subject is freely waking on the floor. The presence of the moving belt modifies some complexes of the gait cycles, and could lead to inexact interpretations.

The treadmill could be a useful device in routine gait analysis since it allows recording of a large number of successive strides in a short time interval and over a wide range of gait velocities. Still, more practice on (TM) gait analysis should be involved in future studies.

Further research will be performed with a representative lot of subjects, both healthy and having certain disorder to verify the present results and create a data base in order to validate the method for various pathologies.

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