MOTION ANALYSIS OF A SUBJECT WALKING ON A TREADMILL

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Abstract: The paper presents a study based on experimental measurements developed in order to establish a protocol for human gait analysis. In order to find this protocol, the gait cycles of a number of 10 healthy subjects were recorded. The kinematic analysis was performed using the Zebris measuring system and a HAMMER Walkrunner Treadmill. The Zebris measuring system performs a simple and fast analysis of all important parameters of the human gait. The treadmill has special features that help to streamline the speed and inclination as desired. The kinematic parameters are compared with those of the normal gait.

1. INTRODUCTION

The human gait represents a succession of stance and swing phases of the both limbs in a specific order. Due to the variety of the human beings, the gait presents typical features for each person. Up to now, several types of normal gait and hundreds of abnormalities were recorded.
Gait analysis represents a useful tool for identifying and evaluating abnormal movements, which are connected with different deficiencies in joints, muscles, and nerves. By gait analysis it is possible to contribute both to establish the best treatment for patients, and develop therapeutic strategies to compensate the existing deficiencies. Thus, based on a protocol for gait analysis, in correlation with other clinical investigations, the doctors are able to diagnose different disorders or monitor the patients during their rehabilitation.
The gait parameters are grouped to spatial-temporal (step length, step width, walking speed, cycle time, step speed, and cadence) and kinematic (joint rotation of the hip, knee and ankle, mean joint angles of the hip/knee/ankle, and thigh/trunk/foot angles) classes [6].
The human gait has traditionally been studied subjectively through visual observations. By combining advanced measurement technology and biomechanical modeling, human gait can now be objectively done. Today, physiotherapists, orthopedists and neurologists all use gait analysis to evaluate a patient's status, treatment and rehabilitation [5].
In order to investigate and analyze the human gait, a large number of equipments are available on the market. The kinematics of the gait means a description of angles, spatial positions, velocities and accelerations of the human lower limbs. There are several possibilities and methods to evaluate the human gait from the kinematical point of view [2], [3]:

- electrogoniometers;
- ultrasound and electromagnetic tracking systems;
- optical (video based) systems;
- inertial systems.

With 3-dimensional kinematical analysis, the gait is evaluated from three viewing positions. The side view, for example, allows for the measuring of the flexion and extension of hip, knee, and ankle joints. It is better to measure abduction and adduction of the hip joints and extremities, respectively, as well as the pelvic obliquity. The transversal view is the view from above or below and represents for example the rotations of the feet.
Gait analysis can be performed both in the over ground condition and on the treadmill [1], [4]. The analysis can be assessed by the use of the same measuring system consisting in two similarly recordings, or using an advanced treadmill system.

The Kistler Gaitway Instrumented Treadmill System™ is a piezoelectric ground reaction force measurement system housed in a commercially manufactured treadmill. The treadmill is able to measure vertical ground reaction force and centre of pressure for complete, consecutive, multiple foot strikes during walking and running [7].
The paper objective consisted in analysis the treadmill locomotion of 10 healthy subjects. The paper presents a study based on experimental measurements developed in order to establish a protocol for human gait analysis on treadmill.
Comparing with the measurements performed in over ground condition when can be recorded only 2-3 steps, walking on a treadmill offers a larger sequence of movements, depending on the investigation period.

2. METHODS AND EQUIPMENTS

The measurements were realized in Motion analysis Laboratory of Politehnica University of Timisoara using Zebris measuring system CMS-HS and HAMMER Walkrunner Pro Treadmill.
Ten young healthy students with an average age of 20.6, years old (range from 20 to 22 years) participated in the experiment. Subjects must be healthy without a history of leg or lumbar spine pain, neurological or vestibular impairment, injury or operation that could affect their locomotion. All the subjects gave their informed consent to the experimental procedure.
The Zebris measuring system for gait analysis enables simple and fast analysis of all important parameters of the human gait. The measuring system allows an objective kinematical analysis of the human gait by means of analyzing the tracks of body surface markers [8].
The measuring method is based on the determination of spatial coordinates of miniature ultrasound transmitters (markers) by measuring the delay between the emission of sonic pulses by the transmitters and their reception at the microphones of the measuring sensor. The exact spatial position of the markers is determined by triangulation method (figure 1).
Usually, the measurement starts with the attachment of the two markers on the body in two key points. The first marker triplet it's 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 dedicated software creates the geometrical model (figure 2). Signals from the left and the right side of the body are measured simultaneously. The marker spatial positions (determined by trilateration) and geometrical model of the investigated subject are calculated and displayed during the subject motion, using the WinGait Software.
HAMMER Walkrunner Pro Treadmill has special features that help to streamline the speed and inclination as desired. The treadmill has digital display for monitoring performance and heart rate. It has many programs, monitors calories, speed, pulse, time, distance and allows inclination multiple settings (figure 3).

Measuring and Basic Units

Cable adaptor

Pointer

Markers

Figure 1: Zebris CMS-HS measuring system

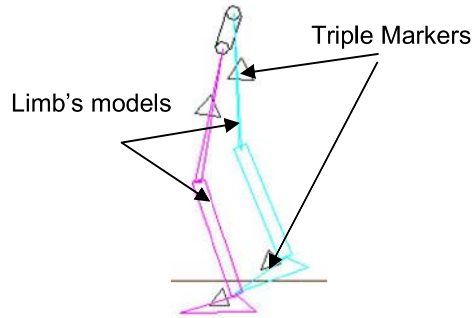


Figure 2: Geometrical model

Figure 3: HAMMER Walkrunner Pro Treadmill

Under the mentioned conditions, temporal-spatial parameters of gait, including self-selected velocity, cadence, stance time, swing time, double support time, and step length were assessed by the use of Zebris measuring system. Zebris measuring system enables a detailed analysis, documentation and comparison of movements. 2D views and graphs of motion parameters as well as biomechanical models facilitate understanding and analysis (figures 4, 5 and 6). The graphs show the angular variation for each individual joint in all the possible movements: flexion-extension, abduction-adduction and rotations.
The diagram (figure 6) shows the angular variation for each individual joint in all the possible movements: flexion-extension, abduction-adduction and rotations. The flexion-extension movements of the thigh, knee and ankle present the highest amplitudes, with the values included in the normal range for a gait cycle. The diagrams for the left limb joint variations are highlighted in the upper part of the figure 6, and at the bottom of the same figure, the same parameters for the right limb. The angular variations of the left and right limbs prove also, the similitude between the limbs. So, the angular parameters indicate a gait movement close to the normal one.

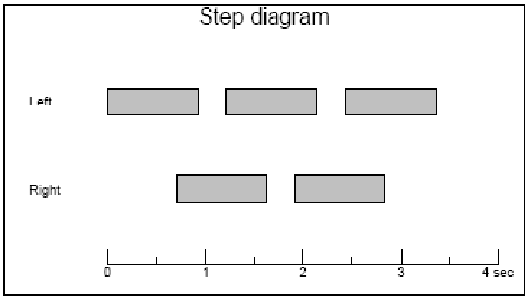


Figure 4: Step diagram during gait cycles

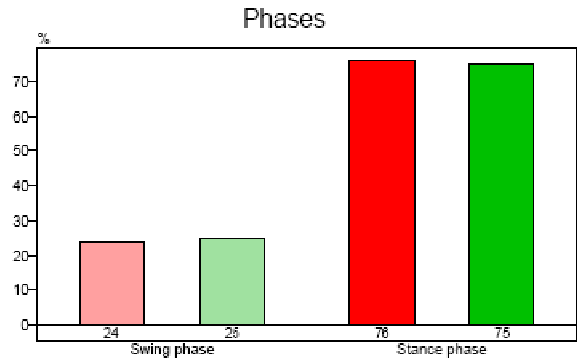


Figure 5: Swing –Stance phases

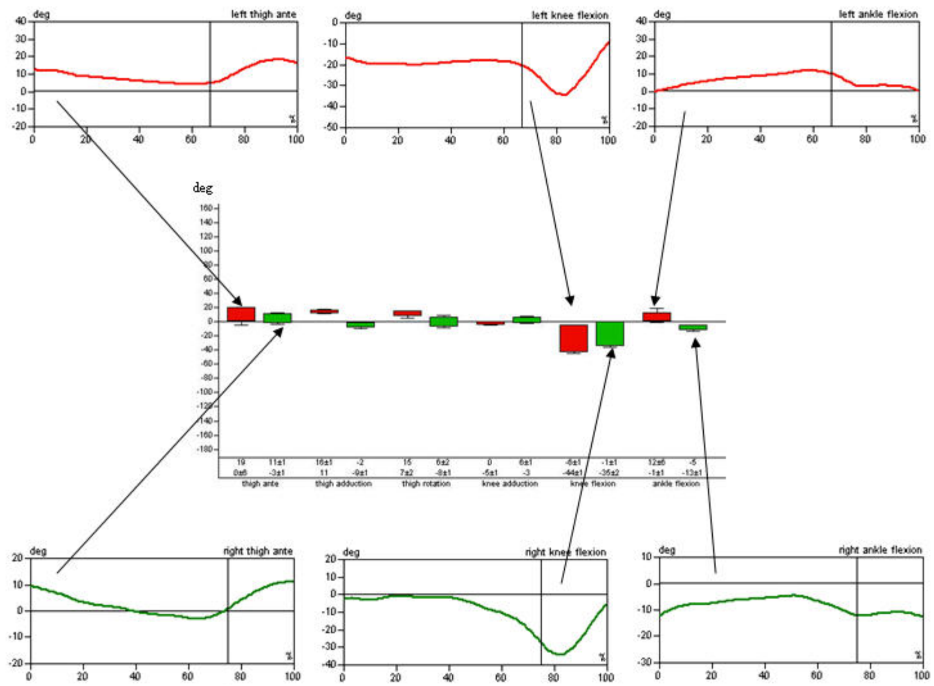


Figure 6: Angular variation in lower limb joints during a gait cycle

3. RESULTS AND DISSCUSIONS

The measurements begin with the marker attachment on the body on thighs and feet. Treadmill calibration is performed using the pointer, defining the treadmill level (height). The investigated subject climbs on the treadmill and stays in an orthostatic position. In the next step, the anatomic landmarks are marked with the pointer: thigh, outside of the knee, inner knee, outside of the ankle, inner ankle, Heel, and thumb. The treadmill parameters are set-up (1.5 km/h speed and 7% inclination). The patients walk on the treadmill in natural way and the measurements start (figure 7). Before the measuring, a 5-minute training session is useful. The measuring period was of 1 minute for each subject. Signals from the left and the right side of the body are measured simultaneously. The marker spatial positions and geometrical model of the investigated subject are calculated and displayed during the subject motion, using the WinGait Software.

Figure 7: Measurements of walking on the treadmill

To generate the analysis report, certain moments of walking must be marked, such as the time when the foot is on treadmill, since the moment when the heel reaches the treadmill until the next touch heel, i.e. swing phase (figures 8 and 9). Figure 8 shows the swing phase starting with the heel of his right leg and left foot position is the beginning stance. Figure 9 shows the swing phase starting with the heel of his left leg and right leg support is in early position.

There were recorded and analysed three sessions of walking on the treadmill for each subject. The accuracy and reliability of measurements in routine laboratory use were verified based on intra-subject comparisons.

In figure 10 are presented the gait parameters of the subject 5 (second session): geometrical model in sagittal plane; signals for left and right thigh anterior rotation, knee flexion, ankle flexion; step diagram during gait cycles; swing–stance phases; angular variation in lower limb joints during a gait cycle.

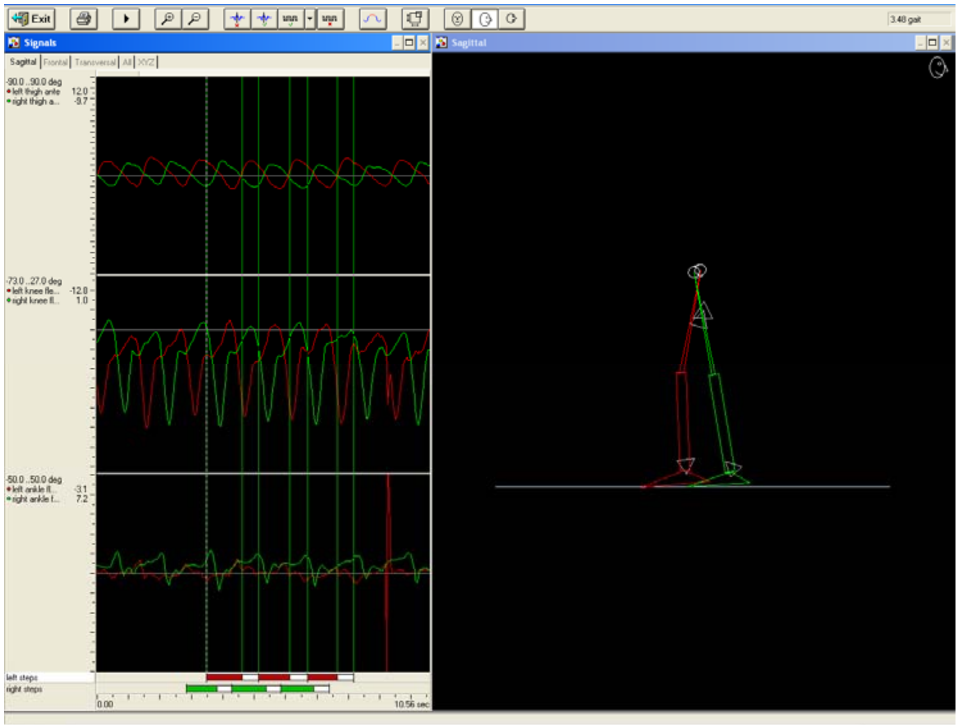


Figure 8: Marking of the left leg movement

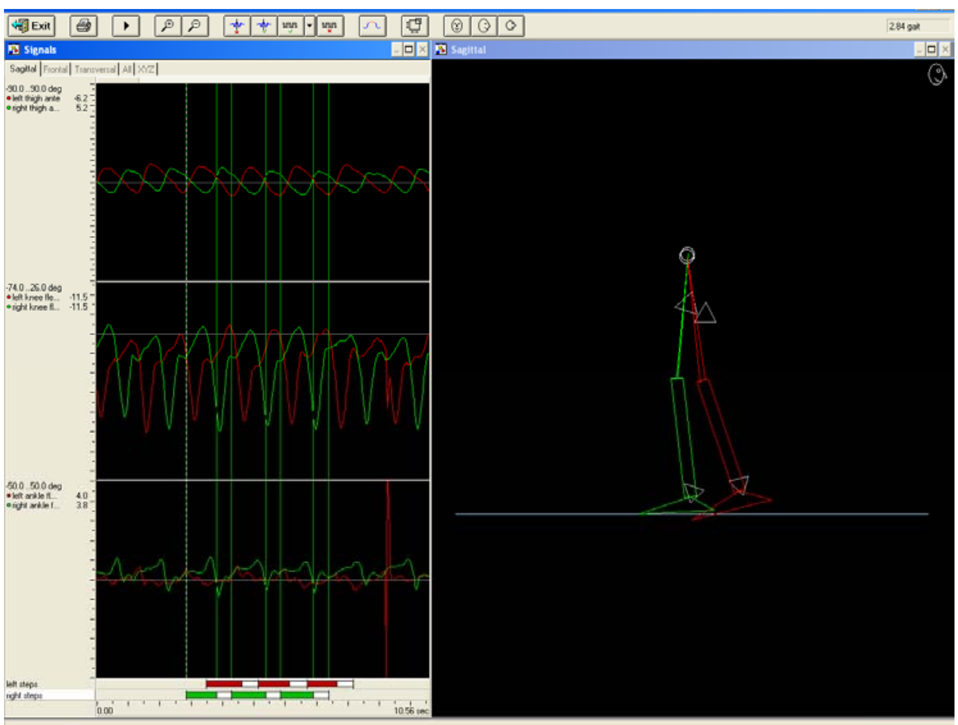
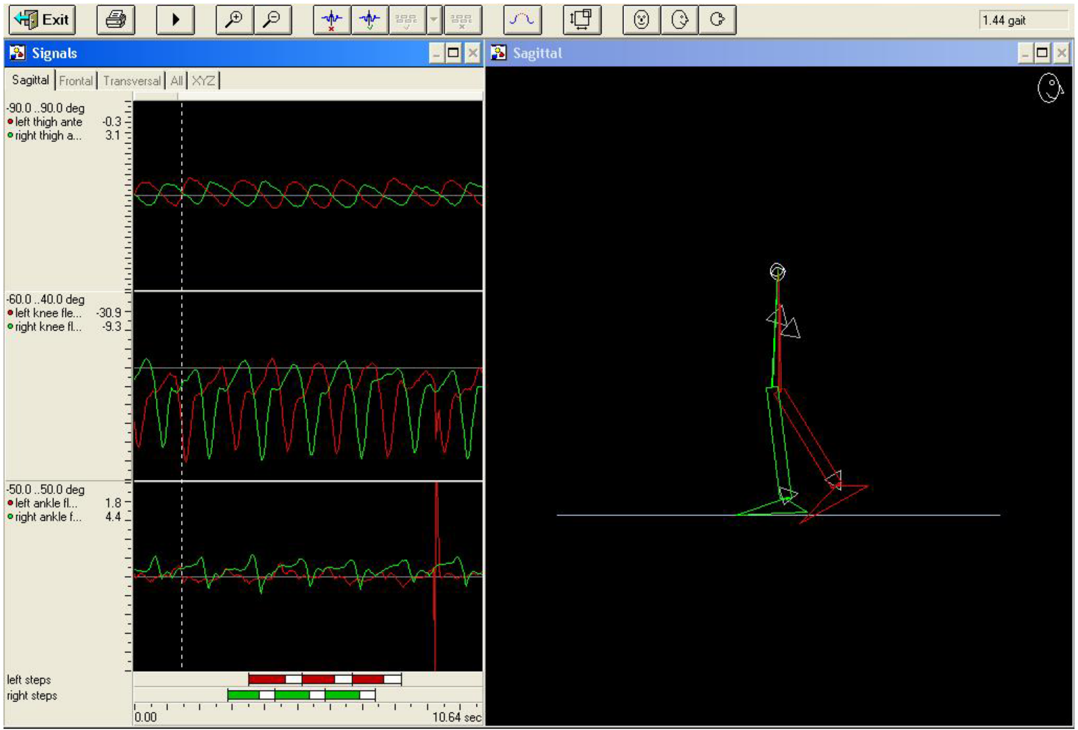
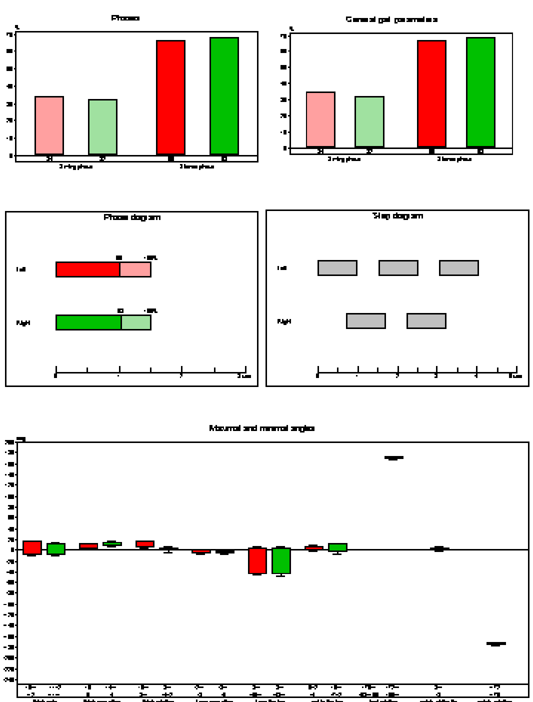
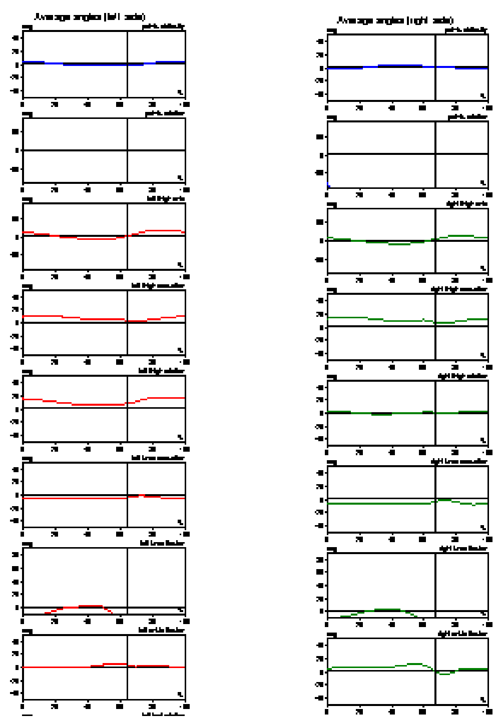


Figure 9: Marking of the right leg movement



Geometrical model in sagittal plane.
Signals for left and right thigh anterior rotation, knee flexion, ankle flexion





Step diagram during gait cycles. Swing –Stance phases

Angular variation in lower limb joints during a gait cycle

Figure 10: Gait parameters of the subject 5

The protocol was established according to the standardized techniques suggested by the measuring system manufacturer, treadmill features, and the objectives of the study. The measurements can be performed at different treadmill parameters (speed and inclination).

The analysis protocol of the kinematical parameters is synthetically presented in table 1.

Table 1: Protocol for gait analysis

System/Method	***General*** evaluation parameters	***Specific*** evaluation parameters	Evaluation of the parameters
Zebris CMS-HS / Kinematical analysis	- Number of steps - Double support time [sec] - Cadence [st/sec] - Velocity [cm/sec] - Step length [m] - Stride length [m] - Swing time [%] - Stance time [%]	- Joints angles [deg]	- Identifying of kinematic parameters of each investigated limb - Comparison with reference values - Identification of the possible problems - Comparison with values of the same patient in different stages

4. CONCLUSIONS

The human walking on a treadmill can be successfully evaluated using the presented method. The investigations using Zebris CMS-HS measuring system leads to a kinematical approach by analyzing the angular variation of each joint. The Zebris measuring system is a reliable, repeatable, and non-invasive tool for evaluation of human locomotion in case of walking on a treadmill. The proposed protocol can be used in clinical practice, both in investigation and rehabilitation.

Future works will consist in analysis the differences between over-ground and treadmill locomotion (at identical gait velocity) of a lot of healthy subjects and patients having a certain deficiency. Also, the investigation can be developed to evaluate the gait from the electrical activity point of view, using a dynamic electromyographic system.

Combining the three methods in a subject investigation, a diagnostic and the rate of rehabilitation could be more easily established. The different approaches allow identifying of all the gait abnormalities, helping to correct the problems in initial phase.

5. REFERENCES

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