Influence of Treadmill Velocity on Gait Characteristics – Case Study of a Patient with Ankle Instability

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Abstract— **The paper proposes a treadmill-based gait study in three particular cases of walking velocity. This study was designed to assess the feasibility of extended gait analysis on a treadmill in relation to the treadmill velocity. 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 spatiotemporal and kinematical parameters, the investigated subject performed treadmill-based gait with three velocities. The main spatiotemporal parameters which have been analyzed are stride time, cadence, double support time, and velocity. The gait symmetry was also analyzed based on the symmetry of the swing and stance phases between the lower limbs and pelvis obliquity. The studied kinematical parameters were the flexion-extension angles of the hip and knee joint, and dorsi- plantar flexion of the ankle joint. We concluded that higher velocity leads to a lower variability of the gait parameters, while accurate recordings and interpretations of the human gait are achieved when the subject is waking with lower velocity closer to his normal walking speed.**

Keywords— **motion analysis, treadmill-based gait, treadmill velocity, spatiotemporal parameters, joint angles.**

I. INTRODUCTION

Contemporary instrumented overground and treadmill-based gait analysis represents one of the most advanced and reliable method both in diagnosis and management of patient rehabilitation.

The use of a treadmill-based gait analysis is increasingly more used due to its major benefits. The main advantage of treadmill-based gait analysis consists in a smaller measurement space, thus being possible to acquire multiple consecutive strides (gait cycles). Another important benefit of treadmill-based gait consists in directly controlling of walking velocity, which has a significant influence on gait parameters. The treadmill provides a relatively uniform walking speed which can be continuously adjusted and monitored. Walking on a treadmill is more safety for elderly people and patients with certain disability because a harness and/or handrails can be used [1].

One limitation of the treadmill consists in adapting of the individual gait to the natural walking, which is more difficult in older population and individuals with disability [2]. Healthy subjects unfamiliar to walking on a treadmill may also alter their normal gait pattern, until they become accustomed to the treadmill inclination and speed.

Some authors have been theorized that there is no mechanical difference between the two modes while some studies have documented statistically significant differences regarding the gait parameters [3].

The influence of the speed on the treadmill-based gait was studied by several authors. There were performed studies on the spatiotemporal parameters, kinematical and kinetic parameters of gait, both for healthy subjects and patients with certain disability, including the benefit of treadmill gait for patient rehabilitation.

Some works were focused on spatiotemporal parameters of gait and certain joint of healthy subjects [4] while other studies reported the influence of systematic increases in treadmill walking speed on gait kinematics after stroke [5], [6].

Study of the effect of speed on kinematic, kinetic, electromyographic and energetic reference values during treadmill walking was performed both to assess the feasibility of extended gait analysis on a treadmill at a constant speed in young healthy subjects and to provide speed-specific kinematic, kinetic, electromyographic and energetic reference values [7].

Some studies reported no relationship between stride time variability and treadmill speed, while other authors reported either a linear or a non-linear relationship. Thus some results highlighted that speed lower than preferred self-selected speed of young healthy adults involves higher stride time variability [8].

Variability of ground reaction forces during treadmill walking has been also investigated and quantified in relation to different constant speeds. Variability of horizontal-anteroposterior force was minimized at the usual walking speed whereas those of the other two components (vertical and horizontal-mediolateral force) increased with increments in walking speed [9].

The purpose of the presented study was to assess information on gait spatiotemporal and kinematical parameters and perform a comparative analysis of treadmill-based gait in relationship with the treadmill velocity. This study is important to establish a valid foundation about the

S. Vlad and R.V. Ciupa (Eds.): MEDITECH 2011, IFMBE Proceedings 36, pp. 372–375, 2011.
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possibility of using a treadmill in clinical gait investigation and rehabilitation in our laboratory.

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. One marker triplet is attached on the thigh and second one on the upper part of the foot. The anatomical landmarks are marked with the pointer, and the system's software creates the geometrical model [10]. To evaluate the spatiotemporal and kinematical gait parameters and evidence the influence of the treadmil velocity, one young volunteer (male, 24 years old) with mild instability of left ankle performed gait on the treadmill at different velocities, having attached the ultrasound recording markers and without using the treadmill handrails.

He gave informed consent before taking part in the experiment. In order to adapt his walking to the measurement conditions a trainning session of three minutes for each selected velocity was firstly performed. After this adequate practice the treadmill velocity was sequentially set at 1, 3, and 5 km/h, corresponding to slow, average, and hurried walk. All the measurements were performed with the treadmill belt in horizontal position. There were performed three trials for each selected velocity, each trial having 60 seconds duration. The trial recording was started after five seconds familiarization period when the treadmill reached full velocity.

A special attention when using treadmill has to be focused on reflection avoidance of the ultrasounds, by the various elements and handrails of the equipment. In order to achieve this goal, the subject was asked to walk along the longitudinal axis of the belt surface, without changing the spatial position of the body during recording period. By changing the spatial position on the belt, the variations of the joint angles could lose the reference.

The sampling rate of the ultrasound system was selected to 30 Hz and maintained for all gait velocities. Using this frequency for the maximum waking velocity, the gait phases are fully described by the recorded values. This is proved by the presence of all gait complexes at maximum velocity, in comparison to other velocities. At much higher speeds, higher sampling rate should be used.

The data acquired by the measuring equipment are the spatial positions of the markers for both limbs during the trial duration. Using these values, the WinGait software computes the characteristic parameters of the gait: swing and stance phases, walking velocity, stride time, cadence, time of double support, and joint angles in all planes.

The numerical results of the joint angle measurements were exported for further processing from the system software and have been computed the mean values, standard deviations, and *P values*. The series with large differences were eliminated for smoother results achievement. The valid results were graphically represented in various combinations and compared in order to express relevant behavior of each spatiotemporal and kinematical parameter of the gait.

III. RESULTS AND DISCUSSION

The main spatiotemporal parameters which have been analyzed are: symmetry of the swing and stance phases between the lower limbs, stride time, cadence, and double support time. Because the investigated subject presents a mild instability at the left ankle's level, the results are presented in close relation to this issue. Thus, data regarding the symmetry between lower limbs and also the variations of the joint angles of the left limb, at different walking velocity are graphically presented.

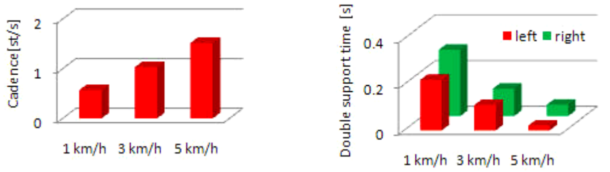
The phases of the gait cycles (table 1) indicate a slight difference between the two limbs, which increases with the enhancement of the moving velocity. The average value of stride time was 1.77 seconds (1 km/h), 0.98 seconds (3 km/h), and 0.62 seconds (5 km/h), respectively.

Table 1 Swing and stance percentages for different speeds

Limb/ Phase	1 km/h		3 km/h		5 km/h	
	Swing [%]	Stance [%]	Swing [%]	Stance [%]	Swing [%]	Stance [%]
Left	36	64	37	63	40	60
Right	35	65	40	60	49	51

The average values of cadence and double support time are presented in relation to the walking velocities (figure 1). From this charts an expected tendency can be outlined. When the walking velocity is increased whether by the subject or imposed by mean of the equipment, the cadence of the movement grows, while the double support time significantly decreases. For much higher velocities, the double support time tends to zero.

Three dimensional motion data was obtained for hip, knee and ankle motions. In order to analyze the joint angles tendencies at different velocities, the average gait cycles were computed for each lower limb. There were considered the following joint angles: flexion-extension of the hip and knee joint, dorsi-plantar flexion of the ankle joint, and obliquity of the pelvis. Of these four parameters, the pelvis obliquity is determined by the pelvic girdle while the other three are joint characteristics, so they are represented for each limb joint in relation to the walking velocity.



a) Cadence b) Double support time

Fig. 1 Cadence and double support time at different walking velocities

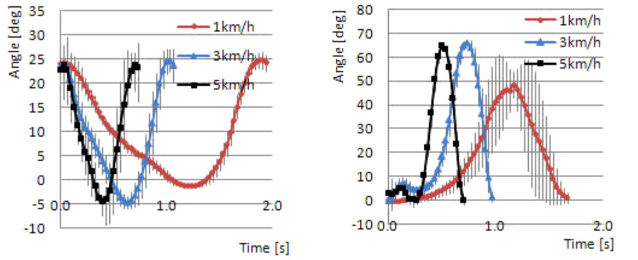
In the paper, the ankle is the only joint presented as a comparison between left and right lower limbs, because the other joint angles indicate no significant statistical difference between limbs. Differences between joint angles in each considered motion during the performed trials were compared between the two lower limbs by use of an unpaired t-test. These values are presented in table 2. Thus, the hip and knee joint angles under different treadmill velocity are presented for the left lower limb only (figure 2).

To evidence the average variability, the standard deviations are represented as vertical lines accompanying each data point. The presence of high values of the standard deviation is usually caused by the phase difference of the movement. The maximum value of the mean standard deviation was 8.7, recorded for angles of the knee joint at lowest movement velocity. The mean standard deviation computed for the gait cycles presents lower values for higher velocities of movement (4 and 3.3 for the knee joint angles at 3 and 5 km/h velocities). Large standard deviations occur when the walking velocity is changed during one exercise. These movements also called non-harmonically, have a higher incidence of occurring at lower movement velocities. The differences of the wave lengths in the graphs are generated by the imposed walking velocities, lower wave lengths being recorded for higher velocities.

A similar behavior regarding the wave length-speed relation was recorded for dorsi-plantar flexion of the ankle joint and pelvis obliquity (figure 3). Larger standard deviations are recorded, due to the evasively movements and lower amplitudes. The dorsi-plantar flexion angles of the ankle joint are presented by comparison between left and right lower limbs. The graphs are represented as average, time-normalized stride for each considered velocity (figure 4).

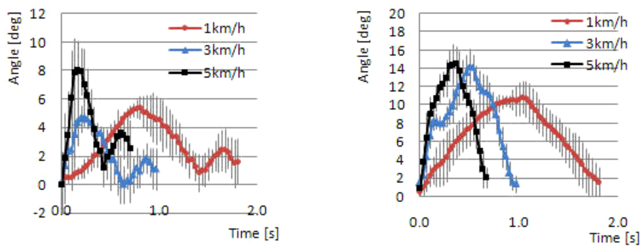
Table 2 *P values* computed for hip and knee angle series

P value	1 km/h	3 km/h	5 km/h
Hip joints	0.225	0.254	0.424
Knee joints	0.422	0.165	0.457



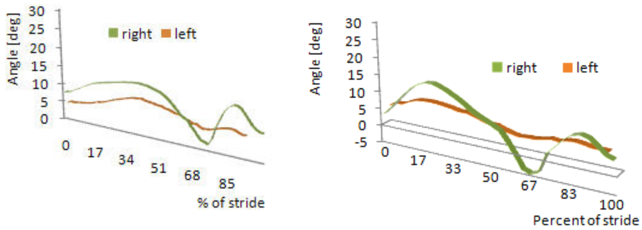
a) Hip joint angles b) Knee joint angles

Fig. 2 Graphs of flexion-extension angles in hip and knee joints, for one stride of the left lower limb

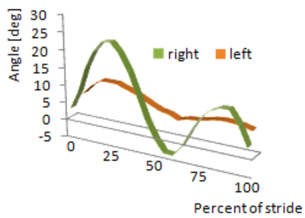


a) Ankle joint angles b) Pelvis obliquity angles

Fig. 3 Graphs of dorsi-plantar flexion of the ankle joint and pelvis obliquity, for one stride of the left lower limb



a) 1 km/h velocity b) 3 km/h velocity



c) 5 km/h velocity

Fig. 4 Graphs of dorsi-plantar flexion in left and right ankle movement at different velocities, for one stride

The graphs clearly express the differences between the movement capabilities in the two ankle joints. The healthy ankle exhibits normal amplitudes corresponding to the movement velocity, while the unstable ankle tends to maintain almost a constant angle. This maladjustment of the left ankle mobility can be associated with pain or physical restrictions of the range of motion. Again, higher walking velocities lead to lower wave lengths.

IV. Conclusions

This study offers some particular information regarding the gait characteristics of a selected subject for three current walking velocities imposed by treadmill equipment. The particularities of the results are generated by the subject's mild instability in left ankle.

The influence of the treadmill velocity on the gait spatial-temporal parameters should be always considered when perform treadmill-based gait analysis. The normal (3km/h) and higher waking velocities prove to lead in this case to a lower variability of the gait parameters allowing identifying all the gait complexes. Much higher velocity could modify some complexes of the gait cycles leading to inexact interpretations.

No significant differences were recorded between the hip and knee angles of the left and right lower limbs. But, due to the local instability of the left ankle, significant differences were recorded at this level between the left and right joint angles.

The mild instability of the left ankle produces a reduced effect in knee and hip joints, as we can conclude from the *P* values (table2). In ankle joint, where we expected larger instability of the left lower limb when the velocity is rising, we observed no major changing. On the other hand, at 5km/h waking velocity the gait complexes of the right limb are better evidenced, exhibiting lower standard deviations.

The mean standard deviation computed for the gait cycles presents lower values for higher velocities of movement. This finding indicates repetitive movements during the successive gait cycles at each velocity. Therefore, recordings having lower standard deviations are better representing the characteristics of the gait. The mild instability of the left ankle induces less repetitive results at 1km/h walking velocity, which are evidenced by larger standard deviations.

In the future work, higher velocities will be involved in the study, in order to identify which one offers a better compromise between having low standard deviations and keeping away from the running movement domain.

The treadmill could be a useful device in routine gait analysis since it allows recording of a large number of successive strides in a limited space and over a wide range of steady-state gait velocities. Still, more practice and experience on treadmill gait analysis should be involved in future studies. It will be the task of further studies to determine the optimum treadmill velocity according to the study objective and the subject particularities (healthy or with certain pathology, young or elderly people, freely motion or based on harness/handrails aids).

Further research will be performed with a representative lot of subjects, both healthy and having certain disorder to confirm the present results, collect reference data and validate the method across pathologies.

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