ANALYSIS OF A FIXED TRAJECTORY FOR THE ANKLE OF A LOW-COST GAIT REHABILITATION ROBOT

M. Volpini*, V. Bartenbach**, M. Pinotti*, R. Riener**

*Bioengineering Laboratory of Federal University of Minas Gerais – Labbio/UFMG, Universidade Federal de Minas Gerais, Belo Horizonte/Brazil
** Sensory-Motor Systems Lab – SMS Lab/ETH, Swiss Federal Institute of Technology, Zürich/Switzerland
email: marivolpini@yahoo.com.br

Abstract: Although treadmill training is widely used in rehabilitation, in many cases, its isolated use does not generate the expected therapeutic effect because the therapist alone is unable to prevent misalignments or biomechanical compensatory movements by the patient, and is unable to assist the patient long enough to promote motor learning. Therefore, robotic devices have been increasingly integrated into rehabilitation programs; however, such devices remain expensive and are therefore rarely used in developing countries. The purpose of this paper is to study the kinematics trajectory of the ankle at different speeds to examine the feasibility of employing a single pre-defined trajectory for a low-cost gait rehabilitation robot. Case study results of a healthy subject show that kinematic trajectories vary at different speeds. Therefore, during treatment, the therapist must choose an appropriate speed for the patient that is closer to the speed at which the trajectory was extracted.
Keywords: bioengineering, gait therapy, low-cost rehabilitation robot, rehabilitation robotics.

Introduction

Gait rehabilitation in individuals suffering from lesions in the central nervous system is an important treatment because it can influence the independence and autonomy of the patient [5]. Ideally, to re-learn how to walk, the patient should repetitively train all walking movements using a normal pattern [5]. Rehabilitation studies have shown that different approaches, from conventional therapy to robot-assisted gait training, may be useful in treating gait disturbances [6].

One of the biggest problems of conventional therapy for gait rehabilitation is that, in most cases, at least two physiotherapists are required, one for each lower limb, to assist the patient in walking. Such a procedure does not prevent compensatory movements by the patient, generating an enormous physical effort by the therapists and making it impossible to maintain the exercise for an appropriate amount of time. Robotic devices seem to offer a solution to this problem. However, sophisticated equipment for gait rehabilitation is usually costly, requires a specialized staff, and is not widely available for clinical treatment, especially in developing countries [5].

To make robotic gait rehabilitation more accessible in such countries, a robotic gait rehabilitation system with low complexity was designed to reduce costs [7]. One of the goals of this new low-cost robot for gait rehabilitation is to assist and facilitate movements that are similar to actual physiological movements.

The applied device is basically composed of an ankle guidance system with a fixed predefined trajectory. This trajectory represents the kinematic ankle path described in the scientific literature for healthy subjects when walking on a treadmill [12]. Its perimeter is 925 mm and it forces a step length of 429 mm, which has been reported to be the step size of children between the ages of 7 to 10 [12]. The proposed system consists of a chain and two sprockets, and is driven by a motor synchronized to a treadmill. An orthosis for the lower limbs is used to connect the patient's foot to the machine using a pin located on the pivot point of the ankle at the level of the lateral malleolus. The velocity can be set individually from 0 to 3.0 km/h, as suggested in the rehabilitation protocols for robotic devices associated with gait training [8], [9], [10], [11]; however, we do not know the influence that a change in speed may have on the pattern of a fixed ankle trajectory.

This paper aims to investigate the variations in the kinematic pattern of the ankle when changing the speed to verify whether a fixed path can be used in a low-cost robot for gait rehabilitation while still maintaining the ability to assist with the training in a physiological manner.

Materials and methods

Because the proposed equipment has the capability to regulate its speed according to the rehabilitation protocols, and is composed of an ankle guidance system with a predefined trajectory, it is important to check the behavior of the ankle kinematic trajectory in healthy subject at different speeds to make sure that an ankle fixed path can be used.

Equipment

The low-cost robot for gait rehabilitation was described in more detail in another article [7]. The device is composed primarily of four main components, as shown in figure 1: (1) a body weight support, (2) a Hip Knee Ankle Foot Orthosis (HKAFO), (3) two ankle guidance systems, one for each of the lower limbs, and (4) a treadmill.

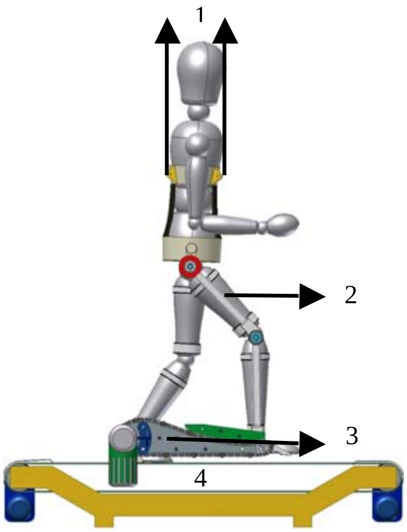

Figure 1: Low-cost gait rehabilitation robot with four main components: (1) a body weight support, (2) an orthosis, (3) ankle guidance systems, and (4) a treadmill.

When the robot is turned on, the patient's foot is “forced” to conduct a movement pre-defined by the corresponding guidance system [7].

Clinical measures

The kinematic pattern of the ankle was analyzed by recording the gait data from a reflective marker attached to the ankle (at the lateral malleolus) of the subject. The unilateral kinematic trajectories were captured at 200 Hz using a Qualisys Motion Analysis System with five digital Oqus 300 cameras.

Because the low-cost equipment proposed is a 2D device, in other words, the gait facilitation is only along a single plane (the sagittal plane), the reflective marker was positioned on the lateral malleolus to record the gait data of the kinematic ankle trajectory along the sagittal plane. The lateral malleolus was also chosen because the connection between the patient and machine is also at this level.

The subject walked on the treadmill at a comfortable speed (3.5 km/h) as determined during a single pre-session during which the subject became familiar with the treadmill. After this period of familiarization, and once the subject could achieve a steady state without holding the handrail, the data were collected for a period of 50 s. The same procedure was conducted again after decreasing and increasing the speed by 0.5 km/h, to 3.0 km/h and 4.0 km/h, respectively. Because the gait rehabilitation protocols suggest using speeds between 0 and 3 km/h, we decided to conduct additional measurements at 2.0 km/h.

Results

Because the objective of this study was to analyze the behavior of the kinematic ankle trajectory at different speeds, we chose two parameters to analyze this variation: the length and maximum height. The length of the path is directly related to the step size (stride length), and the maximum height (stride height) is related to how high the foot rises to conduct the swing phase. The length and maximum height of the trajectory are shown in figure 2.

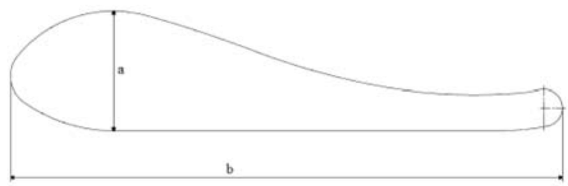

Figure 2: Stride (a) height and (b) length.

Table 1 summarizes the average ± standard deviation (SD) of the stride length and height obtained from one subject after 25 complete gait cycles for each speed.

Table1: Temporal and spatial gait variables

STATISTIC	2.0 km/h	3.0 km/h	3.5 km/h	4.0 km/h
Stride length (mm)	414 ± 10.5	507 ± 9.7	559 ± 6.6	599 ± 4.6
Stride height (mm)	109 ± 3.5	136 ± 2.0	142 ± 1.4	147 ± 1.0
Average cycle time (in s)	1.68	1.21	1.15	1.09

average ± SD

The first result that can be extracted from Table 1 is that the step stride length is directly related to the gait speed, and is therefore a velocity-dependent parameter. By analyzing the stride length, the calculations show that the SD is largest at speeds further from the comfortable speed of the subject, i.e., 2.0 km/h. This alone suggests that the stride length is probably more variable away from the comfortable speed. Table 1 shows that the stride height also varies with the speed. It is also interesting to note that both the stride length and stride height change in a similar proportion, suggesting that the ankle path remains basically the same, and is modified only in size, i.e., is bigger or smaller.

Discussion

Many studies have investigated the effects of walking speed on the gait parameters. Normal gait parameter values provide valuable information not only for choosing the best therapeutic approach in traditional therapy, but also as a database for robotic rehabilitation aiming to provide a normal gait pattern [1]. However, this investigation is very complex because many of these parameters such as the cadence, stride length, stance period, and swing phase period are interrelated. Previous studies have shown that many gait parameters are velocity-dependent [2], [3]. However, such studies have not analyzed the relationship between the velocity and kinematic trajectory of the lower limb joints.

Prior research on ten subjects has shown that the preferred walking speed for healthy adults varies from 3.5 to 4.5 km/h [13]. However, the gait in individuals with a neurological dysfunction can be characterized by a slow speed, asymmetry, short stride length, and/or small cadence [4].

During gait therapy, if the speed is increased without the patient being physically fit and having the appropriate motor conditions required to sustain the increase, the associated reactions, especially in the upper limbs, become more evident, worsening the biomechanical misalignments, the quality of movement, and the quality of the gait. Thus, gait training is conducted at low speed, typically much lower than the gait speed considered comfortable for healthy individuals, so as to not favor the emergence of these associated reactions. For this reason, the velocity used during gait training can be set individually from 0 to 3.0 km/h [8], [9], [10], [11].

The results show that the influence of speed on both the stride length and stride height is in similar proportions. In addition, because the results also showed a large SD, indicating a great deal of variability in the trajectory when walking at 2.0 km/h, it seems that it is also unpleasant for healthy people to walk at uncomfortable speeds The suggested kinematic ankle trajectory was extracted from a study in which healthy subjects walked at an average speed of 2.6 km/h. To minimize the effect of the speed on the kinematic trajectory, particularly on the step size, it seems reasonable to use the same or a similar speed. This will probably be the speed at which the most comfortable interaction between the machine and patient is seen because this is the velocity at which the trajectories show the most similar measurements; however, tests using the proposed equipment will be necessary to confirm this hypothesis.

The goal of the low-cost robot for gait rehabilitation is not to replicate the exact kinematic trajectory exhibited by healthy subjects, but rather to help people with neurological dysfunctions achieve a natural gait pattern during therapy.

We believe that, although the ankle guidance system for the low-cost gait rehabilitation robot best represents the kinematic ankle trajectory at a particular speed, i.e., 2.6 km/h, the system will help achieve a more natural gait pattern without the need to employ a large number of compensatory strategies within the speed range most suitable to therapeutic results (0 to 3.0 km/h). Instead, it seems more reasonable to use the equipment at a speed close to 2.6 km/h.

To validate the proposed device, clinical trials will be conducted as future work.

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