ARTÍCULO DE INVESTIGACIÓN ORIGINAL

Mimetic orthosis for lower limbs to be applied on rehabilitation for hemiplegic persons

P.S. Luna,*
E. Cardiel,
R. Muñoz,
R. Urrutia,**
D. Villanueva,***
P.R. Hernández

* Universidad Politécnica de Cataluña, Barcelona, España.
** Fisiología del Esfuerzo y Desempeño Humano, FES Iztacala, UNAM.
*** Centro de Diagnóstico Biomecánico.

Correspondencia:
P.S. Luna
CINVESTAV, Departamento de Ingeniería Eléctrica, Av. IPN Núm. 2508
Col. San Pedro Zacatenco,
Del. Gustavo A. Madero 07360
México, D.F. México,
E-mail: pablo.rogeli@cinvestav.mx.

ABSTRACT

A rehabilitation tool based on an innovative mimetic active orthosis for hemiplegics is presented. It follows concepts of neuronal learning from afferent information from movements, similar to those lost after brain damage. An artificial gait pattern is applied on knee and hip articulations of a functional modified limb by using an exoskeleton powered by pneumatic muscles.

Key Words: Active orthosis, mimetic orthosis, gait rehabilitation.

RESUMEN

Se presenta una herramienta para rehabilitación de personas con hemiplejía, basada en una ortesis mimética activa. La herramienta sigue los conceptos de entrenamiento neuronal por medio de la información aferente de los movimientos, similar a los que se perdieron después del daño cerebral. Se aplica un patrón artificial de marcha a las articulaciones de rodilla y cadera de un miembro modificado funcionalmente utilizando un exoesqueleto activado con músculos neumáticos.

Palabras clave: Ortesis activa, ortesis mimética, rehabilitación de la marcha.

INTRODUCTION

Hemiplegia is a condition that has affected the life style of many people, often over many years, or permanently in some cases. Commonly, hemiplegia is the result of a vascular brain accident that may alter posture and movement, may produce paralysis and insensitivity in the face, in an arm or a leg, or in both upper and lower limb to a greater or lesser extent[1]. Usually, the recovery time and movement recuperation depends on the extent of neuronal damage. Practical therapies are planned to induce pharmacological reduction of spasticity at first, allowing the generation of specific movements to avoid muscle atrophy. Additionally, some rehabilitation programs include movements similar to those

performed during normal gait. These actions are mainly directed to reduce spasticity and in many cases a significant recuperation has been obtained by a combination of different features like force exercising, emphasis of gait symmetry, utilization of equilibrium reflexes, stepping automation, endurance training, and cyclic movements[2,3].

Literature[3,4], has reported studies about functional recovery of the brain due to neuronal plasticity. This theory maintains that the cortical motor maps are not considered immutable and can change according to stimuli experiences. It has been demonstrated[5], that an ischemic lesion over a specific zone in the brain cortex has evoked the utilization of a nearby zone that may adopt the lost functions when movements are induced by

artificial gait patterns and then afferently transmitted to the brain cortex for training and re-learning purposes. Information to be stored in the re-assigned zone will be provided by conditions and movements of the structures that have been functionally modified. This is the starting point of our proposal supported by a mimetic active orthosis developed in the present work.

Therefore, the mimetic active orthosis has been developed to be used as a rehabilitation tool to generate similar gait movements on a function modified lower limb. We kept in mind that a comfortable active orthosis might be developed to avoid patient rejection before conceiving a rehabilitation tool. These movements are induced by an artificial pattern formed from the information provided by the instrumentation placed on the non-altered lower limb. The orthosis was designed and constructed for hip and lower limbs. Metallic bars, commonly prescribed in prosthetics and orthotics were used to build an exoskeleton that was attached to lower limbs and around pelvis and thorax. One part of the exoskeleton included sensors based on deformation properties for plantar pressure points and angle measurement devices to generate reference parameters for the artificial gait pattern (AGP). Pneumatic actuators for hip and knee articulations, commanded by the AGP, were placed on the contralateral side.

The measurement instrumentation, circuitry for pneumatic actuators, and computational programs for the artificial patterns were evaluated and characterized in our laboratory. A global evaluation was performed using a commercial optical system for movement analysis with the orthosis being worn by persons with an apparent normal gait.

METHODOLOGY

Orthosis

Considering that available passive orthoses have been evaluated for a long time and their materials make up have resulted in lightweight, resistant, and unbreakable easily fitted to the patient, we decided to adopt those materials to build a mimetic active orthosis. Articulated bars of T4 aluminum (Becker Orthopedic, Inc.), customized polypropylene ferules, and a pair of tennis shoes were integrated and fitted to experimental volunteer subjects (Figure 1). Rotational axes of the bars were coincident with those of knee and hip in experimental subjects, approximately located between tibia and femoral condyles for the former and one inch above the greater trochanter for the latter. A goniometer based on flexible sensor devices was two-point affixed to the bars in

Figure 1. Picture of the mimetic active orthosis being worn by a subject.

the limb for sensing flexion range around the knee joint. Two pressure sensors were placed in one shoe to monitor both initial and final contacts of the foot.

Sensors

Two parameters were defined to act as references for the generation of the mimetic and artificial gait pattern. The first one, considered necessary, was the knee angle because it has been found that evoking cyclic and coordinated knee movements constitutes a modifying condition towards relaxation and an improved coordination of movements of other altered parts of the body. An electronic goniometer based on flexible membrane sensors (Abrams Gentile Entertainment) was built. The goniometer is integrated by a 100 μA current-supply, a differential amplifier circuit and an offset voltage adjustment for position compensation.

It is known that the starting point of a normal swing phase of gait is related to the same side terminal foot contact whereas the initial contact is at the end of the swing phase. Therefore, the duration of the knee flexion (or the swing phase) can be determined if initial and terminal contacts to the floor of the normal lower limb are detected. Consequently, the time between these contact points was used as a reference to generate the artificial pattern of knee flexion.
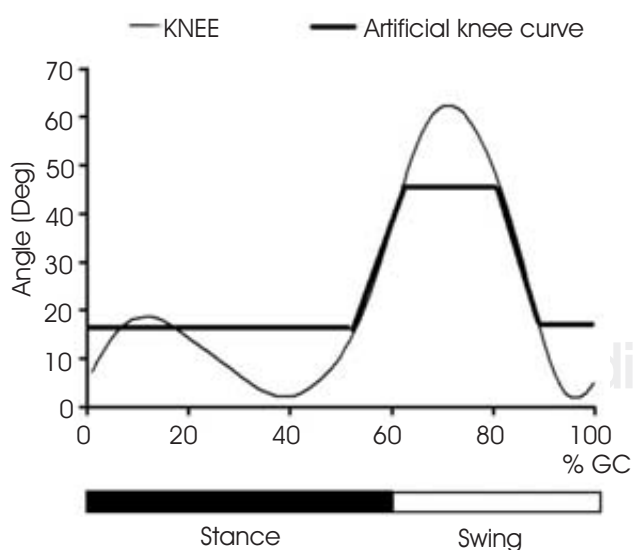
Foot wear pressure sensors were selected for the initial and terminal foot contacts and placed between two layers of cork glued together to form an insole. This set was glued to the ferrule to avoid sliding. The sensor is made of polyester film and silver (Flexi Force, Tekscan, USA), 0.127 mm thickness, 203 mm length, 14 mm width and 9.53 mm diameter of active sensing area.

Actuators

Pneumatic actuators, also called pneumatic muscles (Shadow Robot Company, UK), were utilized to activate half of the orthosis, 30 mm diameter for hip and 20 mm for knee. The pneumatic muscles act like the biological muscles, i.e. they pull both extremes to the center when activated. Besides, they have some advantages according to this application. They are lightweight, have an appropriate speed, present a power-weight ratio of 400:1 and may have a long lifetime of use.

The artificial gait pattern was approximated to the response curves of knee and hip displacements with linear segments (Figures 2A and 2B), which were obtained by using a proportional valve, as a first attempt (MPPE-3-1, FESTO, Mexico). The system was simplified because of the inertial response of the actuator and consequently the needed slopes could be generated when the actuator was supplied by rectangular pulses of 3.5 bar pressure air using on-off electrical valves.
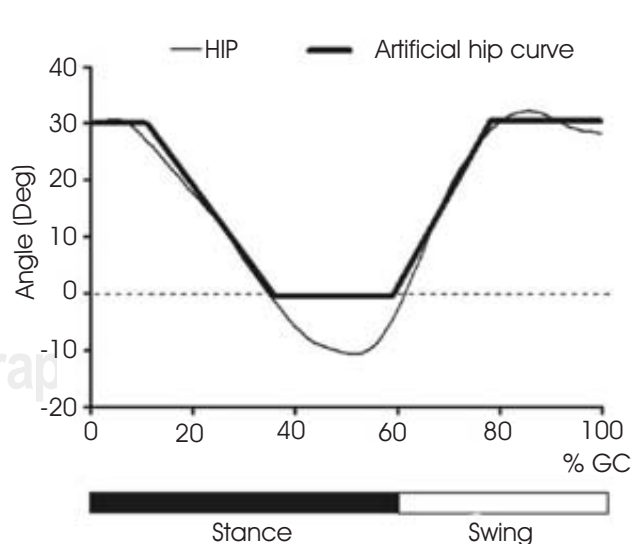

Figure 2A. Thin line shows the normal angular displacement in a sagittal plane of the knee joint whereas the heavy line shows the trajectory generated artificially.

Figure 2B. Thin line shows the normal angular displacement in the sagittal plane of the hip joint whereas the heavy line shows the trajectory generated artificially.

Artificial pattern

Knee and hip flexions were the selected movements taken as references for an artificial pattern generation. This statement emerges because knee flexions always include upper and lower muscles around this articulation, mainly related to hip and ankle articulations. Moreover, small knee movements produce significant changes on foot or body positions. In this state, the mobility and stability of the knee are fundamental factors for an adequate performance of the human gait[6,7]. Consequently, we considered appropriate that afferent information produced by those muscle actions, combined with plantar pressure point activation during gait, were the main elements to initiate the experimental task.

The knee and hip flexions are actions to avoid the floor contact when a lower limb swings and moves forward. According to this point, a minimum flexion angle around 15 degrees for knee and 0.4 degrees for hip, corresponding to the terminal contact, were observed.

On the other hand, duration of stance and swing phases depends on the cadence, but it has been found that under slow cadence, proportionality between them is preserved[8-10]. To prove this concept, twelve kinematical recordings of knee and hip movement, from persons with no apparent locomotor disorder, were performed. Results were compared to available databases[11] and good correlation was observed. Taking a typical curve as a reference, and normalizing time duration to 300 ms, a time base t is generated and a useful proportionality is obtained. Table 1 summarizes actions and duration values. Having determined the proportionality, cadence can be imposed on the patient without loosing synchronization between both lower limbs.

Artificial patterns were developed using a microcontroller (μC) device PIC16F84 (Microchip, Technologies).

The program was designed to start with the first step of the reference lower limb when both pressure sensors are loaded. This condition activates a timer in the μC to produce a 300 ms delay time. Once elapsed, a knee actuator is activated to produce a flexion during the time t_{Knee} (Figure 3) which was previously measured from the last swing phase of the reference lower limb when it crossed 15 degrees of the knee flexion response. The voltage output from the goniometer, related to the knee flexion angle, is electronically compared with voltage references that correspond to those angles graphically indicated in Figure 3. When the voltage pro-

duced by knee angle exceeds the first reference of 15 degrees, a timer runs until the voltage is now less than that reference. Therefore, if cadence is modified, duration of knee flexion also changes. This time will be measured only if both pressure sensors are unloaded.

The command for initiating knee flexion in the altered lower limb will be sent by μC only when both sensors are being loaded during the stance phase of reference limb, and when 300 ms delay time is over. This condition helped to give stability and security.

The hip flexion actuator was time-based commanded. It will be activated after 240 ms elapsed from the knee flexion initiation, corresponding to maximum flexion of the active lower limb. Hip extension begins at 1,730 ms and ends at 2,400 ms approximately in the gait cycle.

EVALUATION AND RESULTS

Separate characterization and evaluation were performed in our laboratory for almost all the parts of the mimetic orthosis. We developed electronic circuits and mechanisms, as well as simulation programs, to allow such purposes. A commercial optical system for movement analysis (Bioengineering Technology System, Italy) was utilized for dynamic evaluation and validation of the measurement instrumentation attached to the reference lower limb.

Three subjects, free of apparent locomotor disorders, were submitted for kinematic evaluation. Tests were accomplished by using a treadmill to produce a comfortable cadence defined by each user. Gait analyses without and with the mimetic orthosis were performed in order to determine alterations in gait patterns when the mimetic orthosis was used.

Firstly, gait analysis of the subjects without the mimetic orthosis, walking naturally and under a self cadence, was performed. Subjects then wore the non-activated mimetic orthosis and walked on the treadmill at a self cadence too. The artificial pat-

Table 1.

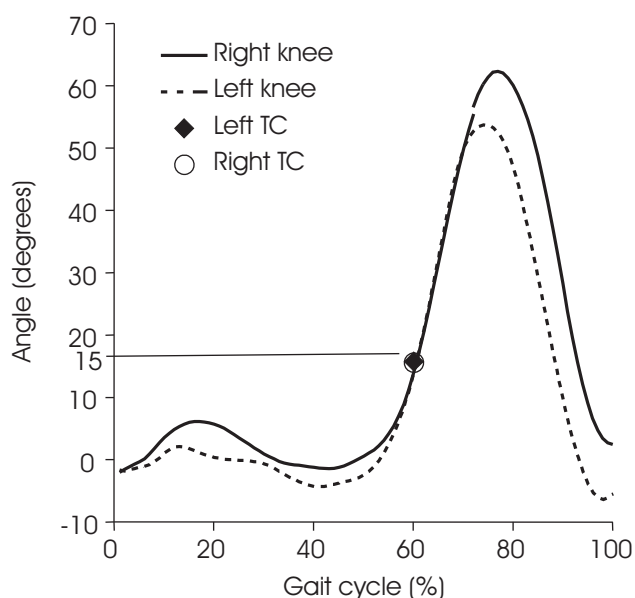| Time (ms)	Knee action	Hip action
0	Start flexion	NA
300 (= t)	Maximum flexion	Start flexion
600 (= 2t)	Hold flexion	Maximum flexion
900 (= 3t)	Start extension	Hold flexion
1200 (= 4t)	NA	Hold flexion
1500 (= 5t)	NA	Start extension

Figure 3. Relationship between angle and time of both displacement curves for knee articulations. Normal (solid line) and artificial (dashed line) patterns are shown. TC = Terminal Contact.
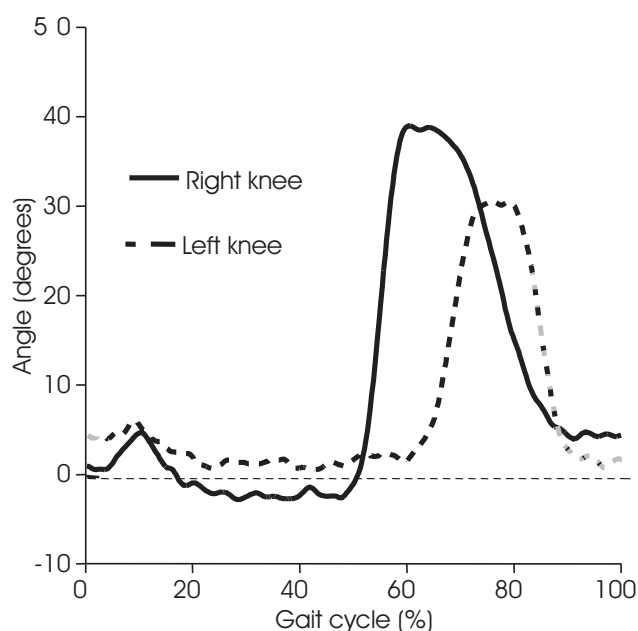

Figure 4. Behaviour curves of the mimetic active orthosis. Left knee (dashed line) was used as the reference and right knee (solid line) under the artificial gait pattern.

tern resulted nearly approximated and symmetrical when compared to the normal reference pattern (Figure 4). The relation of the pattern to the gait cycle was maintained in normal range. Moreover, the application can be performed in real time and the rate between swing and stance phases was preserved even cadence changes. Additionally, a comfortable and reliable gait was observed.

CONCLUSIONS

A mimetic active orthosis has been reported in this work. It has been conceived as a rehabilitation tool if we keep in mind that the main objective is the recuperation of motor control zones through learning patterns afferently sent to the brain cortex and produced by induced movements, very similar to those that were lost.

This proposal will permit the generation of movements in an altered lower limb with similar patterns of the contralateral lower limb. Both the mimetic orthosis and the technique based on body support have resulted interesting, promising, and practical for users and specialists on rehabilitation.

The resultant device is intended to be used as a research and rehabilitation tool. Lightweight and simplicity favor its use importantly, reducing or avoiding common rejection.

ACKNOWLEDGMENT

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