The role of i-Walker in post-stroke training

Giuliani B. a, Cortés U. b, Martínez-Velasco A. b, Barrué C. b1 and Annicchiarico R. a

a Fondazione Santa Lucia, Rome, Italy
b Universitat Politècnica de Catalunya, Barcelona, Spain

Abstract. In nowadays aging society, many people require assistance for pedestrian mobility. In some cases, assistive devices require a certain degree of autonomy when the persons’ disabilities difficult manual control. Our aim is to develop an open and innovative reference architecture, based upon ontologies and agent services, that will allow plug and play and cost-effective interconnection of existing and new services in all domains required for the independent and autonomous living of the elderly and their enhanced Quality of Life. We show how the use of a robotic platform with some embedded intelligence the i-Walker, helps to improve and speed-up the performance of the post-stroke individuals’ rehabilitation.

Keywords. assistive technologies, shared autonomy, rehabilitation

1. Introduction

The stroke is a syndrome manifested by sudden onset of focal neurologic deficits, or spread, with symptoms present for a period exceeding 24 hours, with lethal outcome and vascular origin. The causal mechanism may be ischemia or hemorrhage, localized in the parenchyma or in the spaces between the pial lining of the brain and other meninges, arachnoid and dura mater.

The ischemic stroke or cerebral infarction is the type of stroke by far more frequent, represents approximately 85% of all strokes, and due to a reduction of blood flow, which can be caused by a narrowing of an artery that carries blood to the brain. The closure of an artery may occur suddenly, because of an embolus, or it can occur gradually, for the gradual narrowing of the vessel due to the thickening of the walls (atherosclerosis) and to thrombus formation of coagulated blood (thrombosis). If the obstacle to the cerebral circulation is not removed within a few minutes, the nerve cells are not getting more oxygen and glucose undergo death.

Hemorrhagic stroke or primary intracerebral hemorrhage represents approximately 15% of strokes and is caused by the rupture of a cerebral artery. It can affect the brain parenchyma (intraparenchymal hemorrhage) constituting 12% of strokes, or more rarely, the meninges (subarachnoid hemorrhage or ESA), representing 3% of strokes. Brain hemorrhage is the most severe form of stroke with a morbidity of 20–40%.

1 Author was partially supported by the project Sistema Inteligente i-Walker: rehabilitacion colaborativa (ASISTIR), TEC2011-29106-C02-02
The stroke is the second leading cause of death worldwide. It is the third leading cause of death in industrialized countries, after cardiovascular diseases and tumors. Estimates for 2005 were attributed to stroke 6M deaths worldwide and by the year 2020 it is estimated that the mortality rate for stroke is doubled due to the elderly and the persistence of smoking.

Stroke is also the leading cause of disability in the elderly, with a significant impact on individual, family and community health. 35% of stroke patients, as a group, have a severe residual disability and marked limitation in their activities of daily living. The health expenditure for stroke accounts for 2% -4% of total expenditure in developed countries and the acute phase of stroke accounts for 25% -45% of all spending in the first year after the event. Considering the lifetime cost, for example all costs that the patient meets after the event, it was shown that these costs would be reduced by 10% if there was less than 1% mortality, while acting on disability reduction would be 25%.

1.1. Plan of the work

The plan of this paper includes a short overview of new approaches to rehabilitation, see §2. In particular, we study those that use an intelligent system to support rehabilitation. Many of those also include a robotic platform as main rehabilitation tool. This tools is called i-Walker (see §2.1). The pilot study is described in §3 as well as the methodology and materials. In section §4 we discuss the obtained results after a period of experimentation with real users in a controlled environment, in this case a rehabilitation facility located in Rome.

2. New approaches to rehabilitation

From the scenario depicted in §1 one can well understand the need for continued scientific research and the continuing interest in physician-directed rehabilitation to stroke patients. Because the human and economic burden that stroke produces is therefore enormous and indirect costs, resulting from impaired physical functions and the commitment of care, were higher than direct medical costs, growing attention in rehabilitation research in new technologies that are able to favor the outcome motor and to reduce the functional disability in post-stroke patients, so as to indirectly limit the socio-assistential costs. Physical mobility, the capability of autonomous movement, is necessary for the health and well-being of all persons, but is especially important in older adults because a variety of factors impinge upon mobility with aging.

The great interest in the treatment of disability has been reflected in the use of technological tools more or less sophisticated, the so-called Assistive Technologies (AT) [4],[3]. The AT can be defined as technical devices that can eliminate or improve or compensate for functional limitations. These tools are able to support people with disabilities, while making more effective and efficient interaction of the subjects themselves with their surroundings, physical and social.

Among the various technological tools, the walker is certainly a valid factor to increase the autonomy and to encourage integration of disabled people in social and family contexts, reducing the care burden of caregivers and improving motor performance. Many users are not prescribed a standard rollator because they lack the necessary cognitive skills or their impairment prevents them from steering it safely.
So far this tool has not been used in practice in rehabilitation of post-stroke patients, as they are difficult to manage by the patient. In the SHARE-it project we devised a walker modified to be accessible to post-stroke patients: the i-Walker [2]. The use of this technology in this population is a clear case of success of Artificial Intelligence techniques in this field.

2.1. i-Walker

The i-Walker is a robotic rollator that integrates sensors and actuators. It uses a standard walker frame modified for this purpose. Actuators are two hub motors integrated in the rear wheels and are used for braking or helping the user. Sensors are arranged in the frame to detect forces, tilt and movement. An integrated battery supplies power. Finally, a network of distributed micro controllers drives the system and records and provides information to the therapists.

The i-Walker does help passively detecting the force imposed by the user on the handles through its sensors, so it is possible to determine and adjust the amount of help that each motor should be giving to the side with a deficit. The support given by the i-Walker is passive because it is never pulling the user, only when pushing forces are detected on the handles the i-Walker applies helping strategies through its motors. This configurable amount of support given by each rear wheel allows to daily adapt the i-Walker, according to the increased capacity of the upper paretic and support the patient in applying the necessary forces during walking, see figure 1.

Four main services are provided by the i-Walker platform. Three are related to elder/impaired assistance. The fourth is used for data logging. A physiotherapist should plan all the assistance. Services provided are:

- Active motor assistance to compensate lack of muscle force on climbs.
- Active brake assistance to compensate lack muscle force on descents.
- Active differential assistance to compensate unbalanced muscle force.
- Recording of sensor measurements and actuators activities for later evaluation (left and right hand forces, normal forces, tilt and odometry)

The amount of helping percentage and braking force in each hand can both be determined by a doctor. Described strategies are not exclusive: we can have the user pushing the i-Walker going downhill and at the same time the walker relieving him from part of the necessary pulling/pushing force to move around. For safety reasons the i-Walker automatically stops when the user releases the handles, that is, when no forces are detected on them.

The i-Walker platform has an integrated multi-agent system [1] that allows the configuration and management of the different services described previously. The therapist can configure the different helping parameters using the agents’ interface and watch the logged data represented coming from the different sensor readings. The main objective of this agent system is to autonomously establish the helping parameters of the i-Walker depending on the user profile and his gait performance. In order to do that, the agents will use a specific disability ontology that allows to describe the user profile in terms of diseases, symptoms, assessments and assistive services prescribed. The continuous monitoring of the user’s performance with the i-Walker will let the agent system to modify the user profile and dynamically adapt the support services that the i-Walker provides.
In the shared control paradigm tasks are performed by both the user and the system in perfect harmony so the two control inputs, the operator and the control system act in a collaborative manner. This means that the user is the one who makes decision, except possibly in hazardous situations. A previous step to be performed for its deployment is to determine the support and rehabilitation potential of the i-Walker with real disabled in-patients.

The pilot study, that we undertook, aims to assess any differences in the recovery and management of motor skills, with an outcome of stroke in patients who were undergoing a training-ambulatory with the i-Walker, see §3. For this study, the agent system only offered configuration and data logging services to the professional therapists, having disabled the autonomous support calibration.

Figure 1. The i-Walker compared with the use of parallel bars for rehabilitation in psot-stroke individuals

Over the past decade, robotics has provided new material for rehabilitation of neurological patients. Theoretically and in practice, the robots are useful tools for studying the evolution of recovering, for the quantitative assessment of therapeutic effect [6] and, finally, for the execution of the same exercise rehabilitation. Compared with conventional rehabilitation techniques, where it is difficult to quantify the dose, intensity and execution of the proposed exercise, the robot therapy is proposed as a valuable tool to study the processes of motor recovery.

Evidence suggests that this is the principle to follow for best results and to set up a personalized rehabilitation program that gradually increases the patient’s active participation. The treatment should be challenging for the patient’s residual abilities. Increasing somatosensory inputs to the hemiparetic hemisoma, through intensive treatment based on the repetition of gestures, the robotic therapy uses machine learning techniques to adapt itself to the user and learn from interaction. It is in fact based on explicit instructions that lead the patient to a self awareness of the motor task being carried out. The treatment should involve different modes of exercise, inducing passive movement, active or active-assisted, to be applied at different stages of rehabilitation according to the the patient’s motor skills.
Without wishing to replace the physiotherapist, the robots can increase the opportunities available to the hemiplegic patients and the therapist, which can handle means of training can provide a treatment with high intensity and specific, adaptable to different settings, including the home [7].

3. Pilot

In common practice people with hemiparesis do not use a walker during rehabilitation. In the traditional version of rehabilitation, this aid is difficult to manage by patients who cannot exercise the same control on both sides of the upper and lower limbs, both in terms of recruitment of muscle tone. Our study aimed to investigate the possibility of using the *i-Walker* during the rehabilitation of post-stroke patients. Therefore, we are enforcing the cooperation of each user with the *i-Walker* by personalizing it to each of them. This personalization is in itself a winning characteristic. In particular, we had the objective to evaluate possible differences in the recovery and management of resources and mobility in these patients.

3.1. Methods and materials

In the study were included in-patients receiving treatment at the facilities of the Fondazione Santa Lucia IRCCS of Rome (FSL), in the period between January 2011 and November 2011, with an outcome of stroke [5]. Inclusion criteria for patients within the trial were as follows:

- Diagnosis of stroke-hemiparesis (acute event arose from no more than a year)
- Age ≥ 18
- Minimental state examination (MMSE) ≥ 20
- Canadian Neurological Scale-upper limb and lower limb > 0

Exclusion criteria were:

- Hemiplegia
- Severe cognitive impairment entities
- Global aphasia
- Severe neglect

The pilot study considered 20 subjects, 9 men (45%) and 11 women (55%), born between 1927 and 1984, with a mean age of 59.9 years. About the diagnosis of the hemiparesis: 5 subjects were suffering from left hemiparesis and 15 from right hemiparesis. The subjects were randomized into two groups: namely experimental and control groups.

- The experimental group received training on ambulatory with the *i-Walker*, five times a week, for 20 minutes, for four weeks, in addition to a day treatment of traditional therapy. The group was composed of 3 men and 7 women, born between 1927 and 1974, with a mean age of 56.5 years. One subject was suffering from left hemiparesis and nine with right hemiparesis. In figure 1 the left-most part shows how it is feasible to adjust the *i-Walker* and the central part a rehabilitation session.
The control group performed only the classical treatments, which consists of two treatments with a training diary for ambulation done through the use of parallel bars (see right-most part of figure 1), five times per week, for four weeks. The group consisted of 6 men and 4 women, born between 1928 and 1984, with a mean age of 63.3 years. Four subjects were suffering from left hemiparesis and six from right hemiparesis.

3.2. Protocol

The study was divided into four phases:

**Initial stage.** \( T_0 \): corresponds to the patient arriving to the FSL rehabilitation center to follow a traditional therapy within the unit. Then patient’s general data is collected: sex, age, date of birth, date of the event, reason for the event and event outcomes. In addition, each subject is clinically evaluated and undergoes specific assessments of several clinical, cognitive and psychological (Geriatric Depression Scale (GDS), MMSE) aspects. Other evaluations have been made to assess the tone in the various districts of the upper limb (shoulder, elbow and wrist) and lower limb (hip, knee and foot), using the modified Ashworth scale. It has also assessed the degree of autonomy in AVQ (Barthel Index) and the state of consciousness, orientation, language, motor function, and facial deficits (Canadian Neurological Scale).

**Intermediate stage.** \( T_1 \): corresponding to the time when the patient begins the school of ambulation using the parallel bars (control group) or with the *i-Walker* (experimental group). Each subject group undergone to the following assessments and related scales:

- assessment of the gait: Tinetti Scale, Six Minute Walk Test (6MWT), Ten Minute Walk Test (10MWT).
- assessment of the balance: Tinetti Scale [8].
- assessment of the tone in the various districts of the upper limb (shoulder, elbow and wrist) and lower limb (hip, knee and foot): modified Ashworth scale.
- assessment of the state of consciousness, orientation, language, motor function, and facial deficits: Canadian Neurological Scale
- assessment of autonomy in AVQ: Barthel Index

For the patients who carried out the treatment with the *i-Walker* were recorded as parameters the speed, the length and symmetry of the pitch, via a strap with the sensors placed on the patient’s shoes.

**The final stage.** \( T_2 \): corresponding to the period of four weeks after walking using the parallel bars (control group) or with the *i-Walker* training (experimental group). Patients were administered the same steps of the stage \( T_1 \): Barthel Index, Canadian Neurological Scale, Tinetti Scale, Ashworth Scale, 6MWT, 10MWT. Only the experimental group was also given the questionnaire PIADS. For patients who have therapy with the *i-Walker* were recorded as the speed parameters, the length and symmetry of the step, via a strap with the sensors placed on the shoes of the patient.

**Stage discharge** \( T_3 \): corresponds to the patient’s discharge from the patient hospital. Both groups were reassessed with regards to the autonomy in AVQ (Barthel Scale) and cognitive status (GDS).
4. Results

The pilot study, as already explicated in the §3, was conducted on a sample of 20 outcomes of stroke patients hospitalized within the FSL, between January 2011 and November 2011. Specifically, the sample consisted of 9 men (45%) and 11 women (55%), born between 1927 and 1984, with a mean age of 59.9 years. Regarding the diagnosis of the hemiparesis: 5 subjects were suffering from left hemiparesis and 15 from right hemiparesis.

The subjects, after being admitted within the FSL, were randomized into two groups numerically equivalent: experimental and control. At various stages in which the study was divided (T₀, T₁, T₂, T₃) were collected the data and the scales are extensively described in [5].

We analyze in detail some of the data collected in relation to the two samples taken into consideration:

**Experimental group**

- The average age of the experimental group is 56.5 years.
- The average values of the Tinetti T₁ is 9.6 (3.8), while in T₂ is 18 (3.9).
- The t test for paired data on Tinetti, shows a P = 0.001 or a value significant.

The average values of the 6MWT in T₁ is 44.8 (15.2), while in T₂ is 108.3 (47.2). The t test for paired data on 6MWT P = 0.001 and then returns a meaningful value. The average values in the 10MWT T₁ is 75.3 (40.4), while in T₂ is 30.6 (15.4). The t test for paired data on reported 10MWT P = 0.001 and then a value significant.

Consequently the values resulting from the analysis of the Tinetti Scale in the individuals of the experimental group, show a significant improvement of this between the initial phase of training with the *i-Walker* (T₁) and final (T₂), after 4 weeks of training with the *i-Walker*. Also, the average values of the 6MWT and 10MWT show an increase between the initial phase of training with the *i-Walker* and the final one. The average results of PIADS, administered only to patients in the experimental group are given in table 1.

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<table>
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<tr>
<th>Ability</th>
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<td>Adaptability</td>
<td>1.779</td>
</tr>
<tr>
<td>Self-stime</td>
<td>1.06</td>
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</tbody>
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Table 1. PIADS Results for Experimental Group

Based on these values we can say that there has been a good percentage of satisfaction from the patients using the *i-Walker*. In particular, regarding to the adaptability and the ability achieved due to its use.

**Control group**

The average age of the control group is 63.3 years. The average of the values in the Tinetti in T₁ is 11 (4.9), while T₂ is 16.3 (5.7). The t test for paired data on the Tinetti shows a P = 0.001 or a value significant. The average values of the 6MWT in T₁ is 67.4 (48) while T₂ is 137.6 (119.6). The t test for paired data on 6MWT P = 0.015 and then returns a meaningful value.
The average values in the 10 MWT in T\textsubscript{1} is 60.1 (39.1), while in T\textsubscript{2} is 44.6 (36.4). The t test for paired data on reported 10MWR P = 0.001 and then a value significant. Also with regard to the control group, there is a significant improvement from the analysis of the data resulting from the Tinetti scale, from 6MWT and 10MWT, between the initial phase of the training ambulatory using the parallel bars (T\textsubscript{1}) and the final stage (T\textsubscript{2}) after 4 weeks.

We compare the results of the two groups. Let us report the findings from the analysis of variance (ANOVA) between the two samples examined. Although in both groups there is an improvement in the scale Tinetti, however, the ANOVA performed on this scale, shows that the average increase in the Tinetti test group 8.4 (3.3) and another of 5.3 (2.6) P = 0.032, so the first increase was significantly better than the second.

Always taking into account the ANOVA performed between the two groups, in 6MWT there is an improvement similar in both groups between before and after treatment, the experimental group was 63.5 (39.1), 70.2 in the control (74.1). It is therefore a P = ns, so in this case does not appreciate the differences between the two groups. The ANOVA between the two groups relative to the 10MWT reported values in the experimental group of 44.7 (31.3) while in the control group 15.5 (9.6). It is therefore significant p, with a value pariah to P = 0.011. Relatively to the Barthel Index, the ANOVA between the two groups, shows an increase in the experimental group equal to 29.6 (8.3), in the control group 19.9 (9.8) with a P = 0.029 which is therefore significant.

Then, from the results by the ANOVA, there was a significant increase of the results, between the T\textsubscript{1} phase and the phase T\textsubscript{2}, of Tinetti scale, the 10MWT and Barthel Index of the experimental group, compared to those of the control group.

In summary, on the basis of this analysis, we can say that there has been a generic improvement in relation to the measured scales and the tests taken into consideration, both in the control group and in the experimental group. These results are of course determined by the fact that both groups were subjected to rehabilitation therapy during the phases of the study. We showed that, in the experimental group who received the training with the \textit{i-Walker}, this leads to an increase of Tinetti scale, which takes into account the balance and walking, and 10MWT, also linked to walk. Equally significant is the increase in the Barthel Index in the group that carried out the training with the \textit{i-Walker}, compared with the results obtained for those individuals who have not benefited; this scale shows a general improvement in the patients’ functional autonomy. The complete set of data and detailed information about the pilot can be obtained in [5].

5. Discussion and conclusions

There is a need to improve more the cost-to-benefit ratio of robot-assisted therapy strategies and their effectiveness for stroke therapy. Still, our experimentation with real post-stroke individuals shows the feasibility and appropriateness of our approach. As stated in §3 we had the objective to evaluate possible differences in the recovery and management of resources and mobility in these patients.

The pilot study that we conducted, wanted to demonstrate how to effectively use Artificial Intelligence, in special Assistive Technologies, in therapeutics. In this case, using the \textit{i-Walker} to complete the rehabilitative intervention providing aid to a conventional system adding features that enable to achieve results not otherwise achievable. And above
all it can be used in a population that normally is excluded: people with hemiparesis. The traditional walker, in fact, cannot be provided to a patient with hemiparesis due to the excessive gap between the forces of the two sides, which would imply a trajectory unbalanced and dangerous. The help that the system delivers is customized with the i-Walker, see the left part of figure 1. It also allows the hemiparetic patient to guide the i-Walker through the user’s active participation supported by the shared control system, that provides only the amount of help needed in different situations, thus ensuring the user’s autonomous movement in complete safety.

In particular, our study aimed to assess the possibility of using the i-Walker during the rehabilitation of the stroke patient, integrating it within the traditional therapy, then going to assess any differences in the recovery and management of resources and motor skills of patients who did use it.

From the study, it has emerged a significant increase of the scales that take into account the walking (10MWT and Tinetti) and balance (Tinetti), in the experimental group who received therapy with the i-Walker for four weeks, compared with the control group that has not benefited with it.

As explained in §3.2 each subject is clinically evaluated and undergoes specific assessments of several clinical, cognitive and psychological aspects:

- Assessment of Mood: GDS
- Assessment of cognitive aspects: MMSE
- Assessment of spasticity Upper and lower limbs: Ashworth scale
- Assessment of global functions: Canadian scale
- Assessment of ADL: Barthel Index

The data obtained show how the use of the i-Walker allows to improve the gait and in general the user’s motor performance, see §4. From this it follows that the intelligent walker can be a valuable aid in gait training for hemiparetic patients, resulting in a tool that they can effectively complement to traditional therapy. Moreover, this aid, having regard to its structural characteristics, is presented as a device able to increase the intensity and duration of rehabilitative treatment even in complete autonomy and safety of the patients.

Equally important is the data emerged from the analysis of the scale Barthel Index, where also here it is noted a significant increase from the experimental group than in the control group. This result shows how the aid given by the i-Walker, increases the patient’s autonomy and improves the functional outcome of the general subject post-stroke, helping, in an indirect manner to reduce the degree of residual disability and the need for assistance. Moreover, we foresee an important application that could result important is its use at home, with a remote control from the therapist. The i-Walker can be used as a personalized tutor and trainer for the elders at home and support the elder’s communication with the care professionals.

Also, i-Walker can be used to help to prevent elders to fall, and therefore substantially prolonging the time that elderly people can live independently at home by providing ICT-based safety and fall prevention/detection services. One has to remember that falls are the most prominent among the external causes of unintentional injury, since they account for approximately 40% of all injury deaths.
References


