ASBGo – Multimodal Smart Walker for rehabilitation assistance and clinical evaluation *

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***Abstract*— This article presents a brief summary of the team work in the development of the ASBGo Smart Walker with the intent of helping patients with high disorders of balance, such as cerebellar ataxic patients. It also describes the first steps towards the proposal of a new treatment with the ASBGo with real, ataxic patients. It describes the walker and associated sensory systems; the implementation of four operating modes (autonomous, manual, safety and remote control) in the ASBGo and application of the developed gait and posture assessment tool into the rehabilitation of patients with ataxia.**

I. Motivation and Scope

Locomotion is an important human faculty that affects an individual's life, bringing implications not only in social and personal development but also in the aspect of employment. Thus, it becomes necessary to find means and tools to improve or help to restore and increase the mobility of the affected people, so they can recover their independence. For that purpose walkers were designed to improve pathological gait, through the provision of a support base for the upper limbs that improves the balance of the individual and reduces the load on the lower limbs. However, a large number of walker owners experience problems related to use of a walker or to its design, and the number of accidents is increasing at a faster rate than the number of users. Therefore, smart walkers (SW) appeared to provide for a more stable gait and easy maneuverability, and became a clinical tool for gait evaluation, thus bringing more quality for the rehabilitation of its users and work of the physiotherapists.

II. Overview of the Research

This article describes a new smart walker, ASBGo (Assistance and monitoring System Aid) that improves the stability of assisted gait of people with physical disabilities. Thus, four sensory subsystems were developed: (i) four operation modes that can be selected according with the rehabilitation purpose; (ii) a system that captures the relatives evolutions between the lower limbs of the user and the walker as well as the trunk, given us information related to gait pattern and stability for further clinical evaluation.

A smart walker is intended to be a device that can act as a versatile rehabilitation functional compensation. It should be adaptive considering the necessities of its user and its use should be safe. Patients present different necessities according to their intrinsic characteristics, their diseases and therapies. In order to help them, a smart walker should provide for different functionalities that adapt to user the needs. This project includes the implementation of four different operating modes (autonomous, manual, safety and remote control modes) that allow the physiotherapist to choose the most appropriate one for the type of difficulty of the patient. In addition, the design of the presented walker was planned for specifically help prescribed walker patients for gait therapy.

Besides these functionalities, the developed smart walker, ASBGo, will be turned into a measurement tool for evaluating the walker's user gait. The smart walker is integrated with sensory systems (active depth camera and accelerometer) that enable to evaluate, in real-time, the progress of the patient in terms of spatiotemporal and postural stability parameters. This information is then analyzed to follow the evolution of the patient and helps on deciding when the patient should leave the smart walker, to go to next stage of treatment.

Since the potential of using walking aids is promising and studies focusing on its use were not found, this project also includes the proposal of a new treatment with ASBGo, developed with the intent of helping patients with high disorders of balance, such as cerebellar ataxic patients (full description in [1]).

Thus, this article will be divided into three main goals: description of the ASBGo and associated sensory systems; implementation of four operating modes (autonomous, manual, safety and remote control) in the ASBGo and application of the developed gait and posture assessment tool into the rehabilitation of patients with ataxia.

III. Methods

A. *ASBGo Smart Walker*

The ASBGo walker (Fig. 1) has a mechanical structure that allows the installation of motors, sensors and other electronic components. ASBGo has four wheels and a supporting structure that partially supports the patient's body weight Its front casters can freely rotate. Two motors drive its right and left rear wheels independently.

For rehabilitation purposes, the ASBGo provides adequate physical stability and safety that is required in early stages of treatments and is able to aid the progression of the patient, as the users become more independent to control the walker's handling. The configuration of the handles can provide adequate stability levels and may also be used in man-machine interactions, such as detection of the user's movement intentions [10]. Thus, the ASBGo walker design provides two types of grasping and support: forearm support

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with vertical handgrips, for users with extension problems on their arms; horizontal handgrips for users with shoulder problems.

The electronics and heavy components are installed in a lower level of the walker to improve the general stability of the ASBGo.

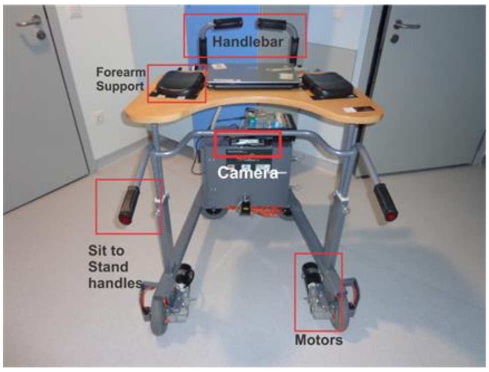

Figure 1. ASBGo walker.

An additional support base for the upper limbs is implemented with forearm and trunk support (this can be removed if not necessary for the patient) and is illustrated on Fig. 1. This support was developed with the aim of providing enough support for patients with high balance disorders. Also, two handles on the back of the walker were added to help the patient in sit-to-stand transfers. These latter handles were also added for the physiotherapist in case he wants to walk on the back of the patient, protecting him or correcting his movements.

The handlebar acts as an interface and is based on low cost electronics composed by potentiometers [10]. These sensors will be the interface for the user to command the walkers' movement. To guide the ASBGo, a minimum strength is required from the upper limbs. For safety measures, force sensors were installed in the forearm supports, to stop the walker in time in case of a backward fall.

The walker also has 9 sonar sensors distributed in a three layer configuration to maximize the detection area (see configuration in Figure 2). A low ring of 6 sonars mounted forward-oriented detects the majority of ordinary obstacles, like people, walls or other low obstacles.

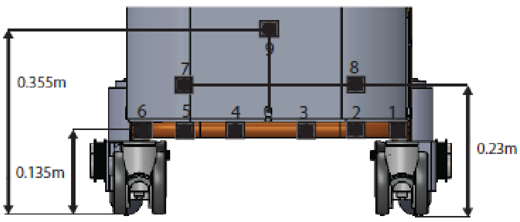

Figure 2. Frontal view of ASBGo. Conguration of the sonar sensors (Low ring, High ring and Stairs sonar).

High obstacles such as tables or shelves are more difficult to detect than ordinary obstacles since their support to ground can be undetected by the forward oriented sonars. They can lie in front of the walker and provoke a collision. Thus, a high ring of 2 sonars pointing upwards with an orientation of 30º is mounted to detect high obstacles. These 8 sonars are meant specifically for obstacle avoidance. An extra sonar pointing downwards with an orientation of 30º is mounted on the walker to detect stairs. This sonar does not contribute to the obstacle avoidance task, but stops the walker when changes in the ground, such as stairs or holes are detected. Sonars have a beam width of θ = 30º, a range of 1,5m and a dead zone of 0,15m. Low ring sonars are mounted such that any obstacle at a distance of 0,19m from the walker is detected.

B. Four Operating modes

In this project four operating modes were implemented: autonomous mode, manual mode, safety mode and remote control mode. These are explained in detail in [15].

The autonomous mode allows the user or the physiotherapist to set the desired position to which the smart walker should autonomously move while avoiding any obstacles in the environment. This was implemented using a technique of local navigation, called Nonlinear Dynamical Systems Approach [16].

The manual mode is characterized by the smart walker's movement under the guidance of commands defined on the handlebar. As the movement is defined by the patient, this mode is only recommended for patients with minimum visual capacities and/or cognitive, that have sufficient motor skills on the upper limbs.

The safety mode is characterized by a warning system that alerts the presence of obstacles in front of the walker as well as the monitoring of users fall risk. However, the smart walker's movement is controlled by commands set by the patient, as in manual mode.

Finally, remote control mode has been developed in order to allow the physiotherapist to control the orientation and velocity of the SW. Physiotherapist have here the opportunity to examine the behavior of the patients and possible gait reactions and corrections from the patient to different directions and velocities given by him.

C. Clinical, gait and postural stability assessment

Other important requirement of a SW is the possibility of doing clinical evaluation during walker-assisted gait. This is the first step to assess the evolution of a patient during rehabilitation and to identify his needs and difficulties. Advances in robotics made it possible to integrate a gait analysis tool on a walker to enrich the existing rehabilitation tests with new sets of objective gait parameters.

Postural disorders in cerebellar ataxia can be evaluated both qualitatively and quantitatively. Qualitative evaluations are based on a precise assessment of clinical symptoms. Also, certain generic evaluations of balance disorders and ordinal scales evaluating the various components of ataxia can be used to quantify the severity of postural disorders in cerebellar ataxia. The generic evaluations of balance include the Berg Balance Scale (BBS), time standing tests, like the Time Up and Go (TUG) and posturography [6]. Generic gait assessments are also useful and include basic spatiotemporal gait parameters (stride length, stance duration, etc) [6].

In this study, explained in detail in [1, 17], (a) balance was evaluated with BBS and TUG (b) spatiotemporal gait parameters (stance and swing duration, stride and step time and length, double support duration, step width and cadence) were measured with an active depth sensor technique [11] and (c) postural stability (trunk range motion, sway length, center of mass displacement and acceleration) was evaluated with accelerometers placed at the trunk.

IV. Operating Modes

The main goal of SW is the rehabilitation and functional compensation of patients with mobility and balance problems. Since patients can present different types of difficulties and disorders associated with locomotion, the SW has to adapt to these limitations. Thus, through four operating modes is possible to adapt the operation of ASBGo depending on the difficulties of the patient and provide for a safer, comfortable and efficient rehabilitation.

A. Autonomous Mode

Autonomous mode allows the user or physiotherapist to define the desired position coordinates while guiding the SW in the environment. In the case of locomotion recovery in the hospital, the physiotherapist initially defines the possible different targets to be achieved and the walker starts the process. The locomotion recovery starts and continues without any intervention of the patient and without the need for outside help, such as physiotherapists or family. Simultaneously, the autonomous mode allows monitoring the patient's behaviour, so that the physiotherapist can assess his progress in recovery. To turn the ASBGo autonomous is necessary to integrate a module to ensure obstacle avoidance and movement to the target.

In [8], the authors presented an obstacle avoidance technique for SW based on Nonlinear Dynamical Systems [18] approach (DSA) and in [19] the stability of DSA for obstacle avoidance was addressed. In this presentation, real experiments on a lab and a hospital environment will be presented.

B. Manual Mode

The Manual mode is characterized by the movement of the ASBGo under the guidance of commands defined on the handlebar. In this way, the patient is responsible for supervising the ASBGo movement while not getting any feedback controller to avoid the obstacles in front of the SW. As the movement is defined by the patient, this mode is only recommended for patients with visual and cognitive capabilities, as well as motor coordination and strength to manipulate the handlebar. To implement this mode of operation it was necessary the development and installation of a handlebar [10]. The handlebar is shown in Figure 4. To acquire user's commands, the proposed handlebar has two potentiometers to detect the forward and turning directions. The control system will use these forces for forward and turning-speed control. With this system, the user can intuitively manipulate the smart walker at his own pace. If the user pushes or forces to a side the handgrips, the smart walker moves forward or turns accordingly. The smart walker interprets these two basic motions and controls the motors speed and direction, accordingly. It is not allowed to walk backwards.

The pre-processing of both potentiometers is presented in detail in [10]. A fuzzy control strategy classifies the signals sent by the potentiometers and transforms them into motor inputs, in such way that the SW drives the motors according to the user's commands [11].

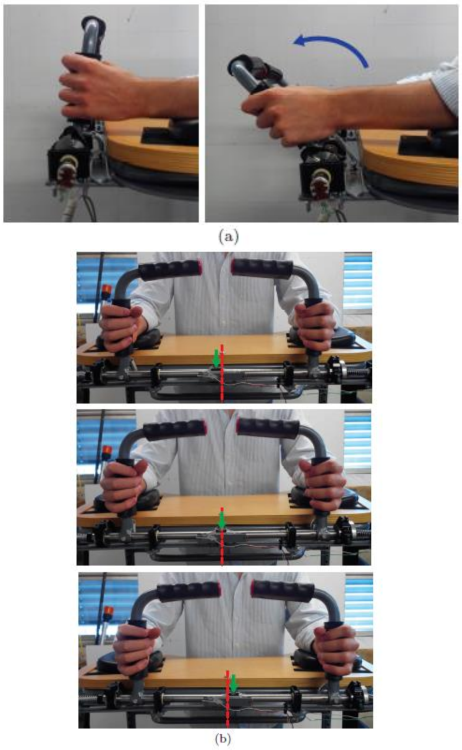

Figure 3. Schematic configuration of the two movements of the handlebar: linear and rotary potentiometer.

C. Safety Mode

A very important aspect of smart walker is to provide for security/safety such that the user feels safe while controlling the smart walker. Otherwise, the user will not use this device and resort to others devices such as the wheelchairs. On the ASBGo safety mode, the patient guides the smart walker and a warning system is activated if a dangerous situation is detected. Both the environment and the patient are monitored. The monitoring of the environment is characterized by a warning system that alerts the presence of obstacles in front of the smart walker. Additionally, an audible alarm system, with different sound frequencies associated to these different distances, may also be triggered if the patient is visually impaired.

In addition to warn the patient of possible obstacles, it is necessary to monitor the risk of fall of the smart walker user. Thus, the detection of user's falls while walking with the smart walker was one of the aims integrated in this device [21].

D. Remote Control Mode

The remote control mode was developed to allow the physiotherapist to monitor the user behavior and control the velocity and orientation of the smart walker accordingly.

V. Clinical Assessment

A. Berg Balance Scale (BBS) and Timed up and Go TUG)

BBS was developed to measure balance among older people with impairment in balance function by assessing the performance of functional tasks [13]. It is a valid instrument used for evaluation of the effectiveness of interventions and for quantitative descriptions of function in clinical practice and research. The BBS has been evaluated in several reliability studies [4]. The test takes 15–20 minutes and comprises a set of 14 simple balance related tasks, ranging from standing up from a sitting position, to standing on one foot. The degree of success in achieving each task is given a score of zero (unable) to four (independent), and the final measure is the sum of all of the scores (56) [13].

The Timed Up and Go test (TUG) is a simple test used to assess a person's mobility and requires both static and dynamic balance [2]. It uses the time that a person takes to rise from a chair, walk three meters, turn around, walk back to the chair, and sit down. During the test, the person is expected to wear their regular footwear and use any mobility aids that they would normally require.

B. Spatiotemporal Gait Parameters

Clinical evaluation during walker-assisted gait is the first step to assess the evolution of a patient during rehabilitation and to identify his needs and difficulties. Advances in robotics made it possible to integrate a gait analysis tool on a walker to enrich the existing rehabilitation tests with new sets of objective gait parameters.

In [11], the team of this study developed a legs detection method to estimate legs position during assisted walking. Then, gait events were identified in order to calculate the corresponding spatiotemporal parameters. The following spatiotemporal parameters can be calculated with such method for each leg: step and stride length (STP and STR), stride width (WIDTH), gait cycle (GC), cadence (CAD), velocity (VEL), stance and swing phase duration (STAD and SWD), double support duration (DS) and step time (STPT). Through the video records and by knowing the distance walked by the subjects an average error of ±3cm in the measures of distance and ±0.1 s were obtained. This error is acceptable for gait evaluation.

With these spatiotemporal parameters, it is possible to calculate stride-to-stride variability. This is a strong indicator of risk of fall. Other important indicator is the symmetry of parameters. This can tell us if the coordination between legs is improving or not. Thus, these two indicators will be calculated.

C. Postural Stability

To assess postural stability, an accelerometer is located near to the center of mass (COM) as suggested in [12]. In this work, an accelerometer is placed at the level of the sacrum and COM displacement parameters were based in [14]. However, the evaluation performed in [14] was done for the standing position and not during walk. So, in [12] the team of this study validated the use of such evaluation in assisted ambulation, concluding that it was suitable to infer postural stability parameters in such situation (assisted ambulation). Therefore, the same system was used on this study and tests were performed in two situations: standing position (3 conditions: comfortable stance, right and left semi-tandem stance) as shown in Fig. 2, and while the patient was walking with ASBGo. These two situations will help to infer the evolution of the static and dynamic postural stability of the patient as well as his risk of falling.

The calculated postural stability parameters are the root mean square of anterior-posterior (AP), horizontal (HOR) and medio-lateral (ML) accelerations (RMSAP, RMSHOR and RMSML), range of motion of AP and ML directions (ROMAP and ROMML) and sway length (SLML, SLAP and SLHOR). In addition, the COM trajectory in AP and ML directions was also acquired. The variability of these parameters will be also calculated to infer risk of fall.

Figure 4. Test Conditions: Comfortable stance (CS) on the left and semi-tandem stance (SS) on the right [13].

D. Statistical Analysis

For each parameter the mean and standard deviation was calculated. Then, One-way ANOVA was performed for each parameter (spatiotemporal parameters and postural stability parameters) in order to verify if there were significant differences through the progression of the patient. Pearson correlation was also calculated between the set of spatiotemporal parameters as well as between the set of postural stability parameters for each condition in order to verify if the parameters show correlated behaviors between the weekly measures. To verify if the variability of parameters significantly decreased between Week 0 and Week 4, Levene’s test (right tail) will be performed. The level of significance was set to $p<0.05$.

VI. Results and Discussion

A. Operating Modes

1) Autonomous Mode

After implementing DSA in simulation [18], real experiments were performed in a lab environment. Before testing with patients it is fundamental to verify how the system behaves in a real environment. Thus, in order to be faithful to a Hospital environment, three different experiments were performed, with both static and dynamic obstacles. Finally, the ASBGo was brought to the hospital for the final tests with patients. In [22] it is possible to watch some seconds of the autonomous mode with a patient.

2) Manual Mode

The manual mode is characterized by controlling the movement of the ASBGo under guidance of commands defined on the handlebar by the user. In this mode, the patient is responsible for taking the decisions regarding the ASBGo movement (Fig. 5).

The combination of the positioning of the two potentiometers allows the patient to move the ASBGo in the environment. Through fuzzy control system [10] the ASBGo acquires a smooth and safe motion for the patient who controls it.

In [22] it is possible to watch some seconds of the manual mode with a patient.

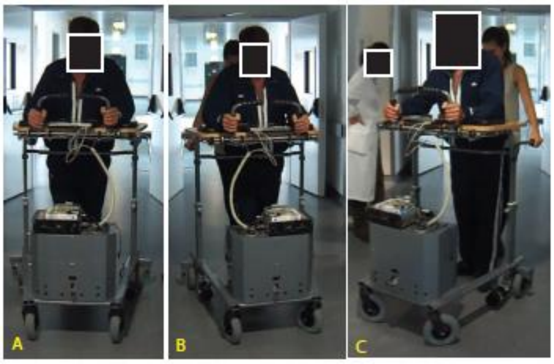

Figure 5. Patient with ataxic gait controlling the movement of the ASBGo through the handlebar. A: Walking forward; B: turning left; C: turning right.

3) Safety Mode

The safety mode implemented in ASBGo is characterized by a warning system that alerts in case obstacles in front of the ASBGo or a fall of the user are detected.

In this operation mode, the patient controls the ASBGo motion, like in the manual mode, but a warning system is triggered when a dangerous situation is detected like an obstacle or the risk of fall.

4) Remote Control Mode

The remote control mode was implemented in order to allow the physiotherapist to monitor and control the ASBGo speed and orientation. In this mode, the physiotherapist has the possibility to analyse the behaviour, compensations and reactions of the patient against sudden changes in speed and orientations given by the physiotherapist. Moreover, it is possible for the patient to concentrate in the correction of his gait pattern. This mode is controlled through a graphic interface.

B. Clinical Assessment

1) Participants

Three ataxic patients were selected to validate the manual and remote control mode of the ASBGo inserted in their rehabilitation program. Herein are detailed results for one patient. In the presentation the three case studies will be discussed.

Male patient, 64 years-old. Right ataxic hemiparesis with brachial prevalence, in acute phase, aetiology is still under investigation. The diagnostic possibility of a neurobrucelose was placed and appropriate antibiotic therapy was started, adequate to this nosological entity. Inform consent was signed by the patient. The study was approved by Braga Hospital Ethical Committee.

2) Examination/Evaluation

Before beginning the gait training with the SW, all baseline data was collected. Patient was evaluated weekly by application of BBS and static and dynamic tests where information was gathered by several sensors integrated in the device, which allowed characterizing the assisted gait and stability.

The static and dynamic tests consisted on 3 conditions: (1) static stance, (2) static semi-tandem stance and (3) walk with the smart walker. In each condition several parameters were acquired. Conditions (1) and (2) consisted on 3 trials with 1 minute of duration each and in condition (3) the patient had to walk 20 meters. In this presentation will be presented 3 case studies.

3) Intervention

For three weeks, the patient trained, 5 days a week, during 30 min, his gait with the smart walker. Since he had enough cognitive capacity to guide the walker, such task was handled by him. Velocity was set by the physiotherapist. Such velocity was increased when the patient felt comfortable to do so. In addition to the smart walker therapy, he performed tonus training.

A. BBS Results

In fig. 6 it is shown some of the BBS tasks performed by the patient. On table I, one can see that the patient presented on its initial stage a score of 6 points, which means that he had a high risk of falling and was only capable of using a wheelchair to move [13]. At this stage, he needed two subjects alongside him in order to help him to stand, to sit and to walk. In one week of training with ASBGo, its score increased to 23 points, passing him to the category of medium risk to fall [13]. At the end of the 3rd week he reached 38 points being capable of walking with crutches independently and walk without walking aids with supervision. At this stage, the clinician decided that the patient was capable of leaving the smart walker and continue its treatment with two crutches. At the end of his treatment, he presented a BBS score of 42 points, walking with one crutch or none.

Figure 6. Some tasks of Berg Balance Scale performed by the ataxic patient.

TABLE I. BBS RESULTS

Week	0 º	1º	2º	3º	5º
BBS	6	23	35	38	42

TABLE II. PARAMETERS CALCULATED IN EACH EVALUATION. 'R' AND 'L' ON EACH CONDITION STANDS FOR RIGH AND LEFT LEG, RESPECTIVELY.

Postural Stability Parameters		ROMAP (mm)	ROMML (mm)	SLAP (mm)	SLML (mm)	SLHOR (mm)	RMSAP (g)	RMSML (g)	RMSHOR (g)
Week 0	CS	2.19±1.44	6.71±0.42	12.71±2.30	4.93±0.94	13.63±5.65	0.26±0.33	0.19±0.10	0.33±0.12
	SSL	3.93±0.37	6.57±0.46	17.70±3.45	7.72±0.34	19.32±4.35	0.45±0.38	0.24±0.12	0.51±0.09
	SSR	2.10±1.12	7.29±0.70	13.69±3.46	6.70±0.25	15.24±3.54	0.30±0.12	0.24±0.19	0.39±0.17
	ASBGo	14.11±1.95	19.20±0.92	56.86±4.52	43.59±2.32	71.65±7.34	0.48±0.11	0.33±0.17	0.58±0.14
Week 1	CS	1.34±1.01	4.24±0.41	6.98±1.21	1.46±0.88	7.13±4.23	0.12±0.05	0.02±0.00	0.12±0.09
	SSL	1.09±0.27	5.70±0.36	7.44±1.03	1.83±0.32	7.67±4.12	0.14±0.13	0.08±0.01	0.16±0.05
	SSR	1.80±0.97	2.60±0.69	4.20±1.33	2.88±0.24	5.09±4.23	0.06±0.07	0.07±0.02	0.10±0.02
	ASBGo	3.63±1.45	12.84±0.83	12.76±1.04	16.28±1.32	28.23±5.23	0.45±0.07	0.28±0.01	0.53±0.11
Week 2	CS	0.76±0.04	2.16±0.31	4.50±1.11	1.67±0.78	4.80±3.21	0.13±0.10	0.05±0.00	0.14±0.07
	SSL	0.91±0.05	5.43±0.23	6.63±1.01	3.66±0.31	7.58±4.10	0.30±0.09	0.09±0.02	0.31±0.05
	SSR	0.86±0.09	2.83±0.56	2.83±0.56	2.30±0.21	4.65±3.87	0.09±0.07	0.09±0.01	0.13±0.01
	ASBGo	3.10±1.01	5.78±0.78	26.39±0.95	10.62±1.01	14.45±2.48	0.81±0.05	0.33±0.10	0.88±0.10
Week 3	CS	0.29±0.02	2.20±0.28	3.95±0.96	0.39±0.71	3.97±1.85	0.08±0.09	0.01±0.00	0.08±0.03
	SSL	1.32±0.05	3.52±0.12	5.62±0.89	2.77±0.21	5.68±1.73	0.07±0.05	0.04±0.00	0.09±0.01
	SSR	0.73±0.04	1.18±0.10	2.84±0.35	1.14±0.10	4.98±0.23	0.12±0.04	0.07±0.02	0.14±0.01
	ASBGo	1.91±1.00	3.62±0.51	10.24±0.87	10.04±0.62	10.96±1.35	0.20±0.05	0.11±0.05	0.33±0.05
Week 5	CS	1.08±0.02	0.83±0.13	6.23±0.58	4.58±0.34	7.74±0.98	0.21±0.23	0.02±0.05	0.21±0.07
	SSL	1.20±0.04	2.64±0.15	8.42±0.80	5.24±0.25	9.92±1.54	0.17±0.12	0.10±0.02	0.20±0.05
	SSR	0.59±0.01	0.95±0.13	4.17±0.32	5.96±0.20	7.28±0.32	0.23±0.09	0.09±0.02	0.25±0.04

TABLE III. GAIT PARAMETERS CALCULATED IN EACH EVALUATION. 'R' AND 'L' ON EACH PARAMETER STANDS FOR RIGH AND LEFT LEG, RESPECTIVELY. VALUES ARE PRESENTED AS MEAN±STANDARD DEVIATION (SD). SYMMETRY (SI) IS ALSO PRESENTED.

Gait Parameters	Week 0		Week 1		Week 2		Week 3		Week 5*		P-value
	Mean±SD	SI	Mean±SD	SI	Mean±SD	SI	Mean±SD	SI	Mean±SD	SI	
STPR (cm)	25.57±4.65	0.214	24.02±3.52	-0,227	24.05±1.96	-0.196	26.06±1.66	-0.033	90.00±2.33	-0.021	0.050
STPL (cm)	31.94±6.45		31.06±3.20		29.95±4.13		26.95±3.13		92.00±2.35		0.003
STRR (cm)	57.63±8.38	0.001	54.96±5.49	-0.002	54.03±4.41	0.001	56.03±3.31	-0.005	46.43±3.43	-0,012	0.210
STRL (cm)	57.52±8.46		55.09±5.94		54.00±4.61		56.32±3.61		47.00±3.00		0.230
GCR (s)	3.10±0.67	0.139	1.85±0.20	-0.016	1.82±0.20	0.000	1.23±0.21	0.016	1.23±0.19	0.000	0.000
GCL (s)	2.72±1.40		1.88±0.16		1.82±0.11		1.21±0.18		1.23±0.17		0.000
STPTR (s)	1.49±0.43	-0.039	0.98±0.13	0.101	0.91±0.16	-0.022	0.88±0.16	-0.022	0.65±0.06	0,182	0.000
STPTL (s)	1.55±0.56		0.89±0.18		0.93±0.15		0.90±0.06		0.55±0.03		0.000
WIDTH (cm)	12.94±1.62	-	15.66±1.66	-	15.35±1.65	-	15.10±0.32	-	14.00±0.23	-	0.000
STADR (%)	65.38±9.18	-0.045	63.53±6.29	0.033	60.57±3.80	-0.037	60.43±4.00	0.004	54.43±2.75	-0.005	0.000
STADL (%)	68.47±9.66		61.45±6.10		62.93±3.72		60.18±2.72		54.74±1.63		0.000
SWDR (%)	34.61±9.18	0.098	36.46±6.29	-0.054	39.42±3.80	0.064	39.56±4.00	-0.006	45.56±2.75	0.006	0.000
SWDL (%)	31.52±9.66		38.54±6.10		37.06±3.72		39.81±2.72		45.25±1.63		0.000
DSR (%)	27.30±13.66	-0.146	19.64±4.74	-0.129	16.38±4.68	-0.041	20.93±3.12	0.096	23.96±5.01	0.110	0.000
DSL(%)	31.98±18.60		22.56±5.88		17.70±4.12		19.09±2.86		21.59±2.63		0.000
CAD (step/min)	38.00	-	60.00	-	68.00	-	70.00	-	91.00	-	-
VEL (m/s)	0.10	-	0.30	-	0.40	-	0.50	-	1.00	-	-

* walking without assistance.

B. Spatiotemporal parameters Results

Table II presents the gait parameter' results of the four evaluations with the ASBGo using LRF. Week 5 results were acquired before the patient is discharged from the Hospital.

It is possible to verify that all parameters follow a good evolution for the improvement of the patient's gait pattern. Stride (STR) length of both legs increase from week to week. However this increase is not significant (p>0.05) because ASBGo influences this parameter. Since velocity (VEL) is pre-defined by the physiotherapist and the device has dimension limits, this may force the patient to decrease its stride length and maintain it constant. Step length (STP) increases significantly (p<0.05) through time. However, this parameter can be also influenced by ASBGo dimensions. Gait cycle (GC) and Step Time (STPT) significantly (p<0.05) decrease since the velocity of gait increased. Looking at the values of step width (WIDTH), it can be seen that this parameter increases significantly (p<0.05) its base of support, learning how to walk with a more stable pattern. This patient presented at the beginning a very narrow step width, which was instructed to be extended. Thus, the increased in WIDTH that is verified on Table II is a very satisfying result. Observing the gait phases, stance duration (STAD), swing duration (SWD) and double support duration (DS) one can see that the patient improves its pattern by presenting values closed to healthy normal subjects [15], i.e. STAD and SWD approximately 60% and 40%, respectively, and DS approximately 20%. The progression of these values is also significant (p<0.05).

Stride-to-stride variability is an indicator of fall risk and stability of gait [13]. By performing Levene's Test, it can be verified that from week to week the variability of all parameters decrease significantly (p<0.05), meaning that the patient presents an increase stability and decreased risk of falling. Other indicator that the patient is improving its pattern it is Symmetry (SI). The absolute symmetry was calculated and the negative/positive values indicate that the left/right leg is responsible for the asymmetry of the parameter. Since most parameters present negative asymmetry (Table II), the left leg is the one responsible for the asymmetric gait. Looking for the evolution of SI, one can see that SI of all parameters tend to zero week to week.

Testing for correlations between parameters, it was only found a strong correlation (>0.7) between step and stride length parameters. Thus, only these parameters show a dependent behavior on the weekly measures. All the other parameters present an independent behavior between each other.

4) Spatiotemporal parameters Results

Table II presents the gait parameter' results of the four evaluations with the ASBGo using LRF. Week 5 results were acquired before the patient is discharged from the Hospital.

It is possible to verify that all parameters follow a good evolution for the improvement of the patient's gait pattern. Stride (STR) length of both legs increase from week to week. However this increase is not significant (p>0.05) because ASBGo influences this parameter. Since velocity (VEL) is pre-defined by the physiotherapist and the device has dimension limits, this may force the patient to decrease its stride length and maintain it constant. Step length (STP) increases significantly (p<0.05) through time. However, this parameter can be also influenced by ASBGo dimensions. Gait cycle (GC) and Step Time (STPT) significantly (p<0.05) decrease since the velocity of gait increased. Looking at the values of step width (WIDTH), it can be seen that this parameter increases significantly (p<0.05) its base of support, learning how to walk with a more stable pattern. This patient presented at the beginning a very narrow step width, which was instructed to be extended. Thus, the increased in WIDTH that is verified on Table II is a very satisfying result. Observing the gait phases, stance duration (STAD), swing duration (SWD) and double support duration (DS) one can see that the patient improves its pattern by presenting values closed to healthy normal subjects [14], i.e. STAD and SWD approximately 60% and 40%, respectively, and DS approximately 20%. The progression of these values is also significant (p<0.05).

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5) Postural Stability Results

In fig. 7 the studied static and dynamic conditions are illustrated with the patient in study.

In Table III, all mean values of parameters present a significant decrease (p<0.05) through all conditions. Also, the variability decreased significantly (p<0.05) for all conditions through the weeks. This result is very satisfying since it means that the patient progressed week to week, gaining more and more stability to walk, decreasing his risk of falling.

COM displacement was acquired for all conditions (CS, SSL, SSR and ASBGo) and for better visualization the outside margins of the COM trajectory were fit into an ellipse, as illustrated on fig. 8. It is noteworthy that in all cases the ellipses decreased their radius. This result comes to reaffirm the gain of stability presented by the patient through its rehabilitation.

Figure 7. Postural stability evaluation tests with the patient in study:A- Comfortable stance (CS); B- Right semi-tandem stance (SSR); C- Left semi-tandem stance (SSL); D – Walk with ASBGo.

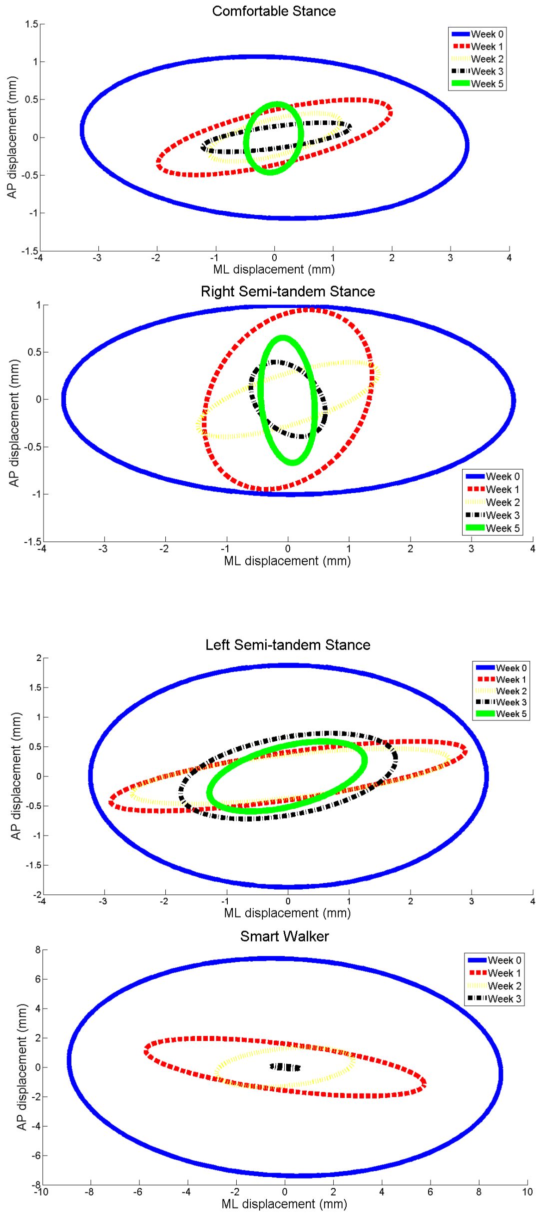

Figure 8. ML and AP COM displacement in comfortable stance, right and left semi-tandem stance and walking with smart walker ASBGo.

Results from these case studies suggest that the SW gait training is a promising intervention for improving gait in patients with cerebellar ataxia pathology.

1) *General Discussion*

The patient initially presented with an enlarged base of orthostatic position, unstable, unbalanced to right and a BERG scale of 6. On the first week, he did tone training and gait training with the walker for 10 minutes at a speed of 0.1 m/s. Three weeks later he exhibited good balance in orthostatic position and a BBS of 38. He was doing gait training with the walker for 30 minutes at a speed of 0.5 m/s. This velocity of the walker was predefined by the physiotherapist and it was very important for his gait training. This type of patient tends to have a very inconsistent velocity, presenting many accelerations and decelerations. The constant velocity obliges them to maintain the consistency of their gait. Despite not being the maximum velocity that he was capable of walking, the physiotherapist wanted to force him to control his velocity. Before discharging him, he could walk and climb stairs with vigilance at 0.9 m/s. There is no reported information about the recovery timeline of such type of patients.

In the presentation other patients will be discussed.

VII. Conclusion

The work herein described synthesizes the team latest work and will enable a technological breakthrough in the field of human pathological gait assistance, by providing more functional compensations with higher safety. The motivation is that this will contribute towards better rehabilitation purposes by promoting ambulatory daily exercises and thus extend users' independent living.

In the long run, it will serve not only as a measure of a treatment outcome, but also as a useful tool in planning ongoing care for various gait disorders.

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