Computerized system to improve voluntary control of balance in neurological patients

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ABSTRACT

The treatment of acquired impairments of balance is one of the most elusive problems rehabilitative medicine is facing. Computerized systems to measure how patients control their balance in static conditions have been introduced long ago into clinical practice and proved to be useful; we have designed and developed a computerized system called “BioGP” which combines features of a classic stabilometric platform with those of a retraining device based on visual feedback The aim of this study was to identify homogeneous groups of patients and to provide objective proof of effectiveness for the rehabilitation of patients with balance disorders. The findings confirm that the new equipment provides clinically valid and sensitive information concerning subjects’ ability to control voluntary shifts of COP while standing. The information is relevant to VR applications using basically the same approach (Alpini et al., 1998) and are encouraging for possible use of the system as a rehabilitation instrument.

1. INTRODUCTION

The assessment of motor control impose a multivariate analysis on different parameters. A specific assessment is necessary in order to set up an experiment or to plan a rehabilitation program suited to the patients’ needs.

(Tesio, 1999) clarify the differences between a classical experiment in biological sciences an experiment carried out in the rehabilitation field. The movements we ask our patients to perform must be assessed by simultaneously detecting different parameters because of the multidimensionality of the task required. Often the variables are not measurable with any degree of precision and the researcher has to use ordinal or nominal data for the statistical analyses (Tesio, 1999). Moreover, important data may not be directly measurable by the therapist (Winter , 1980). Several devices have been developed to describe aspects of motor control (such as posturography or basography) and to collect data not directly available to the rater. Data provided by these devices are not very interesting for the therapist because they do not describe the strategy used by the patient. Improved devices such as the ELITE system for the analysis of gait allow us to better understand how our patients perform a given movement.

Another category of devices have been developed for rehabilitation in different clinical settings; these systems have been called “biofeedback devices”. They give to the patient information not directly available to him using visual or auditory stimuli. The first experiences with biofeedback system date back to 1920, when Jacobson was able to produce a relaxation in muscles of anxious patients (Jacobson, 1929). From 1960 on, biofeedback devices have been utilized in different rehabilitation settings, although data on the efficacy of this therapy are often divergent because of different choice of parameters used to defined the problem, different starting hypotheses, or different technical solutions employed. The key point in biofeedback rehabilitation is to make the patient aware of the specific parameter of interest and to make him learn to control it. The control signal provided must be easy to understand, instantaneous and proportional to the variable to be trained.

The system we developed is based on studies on posturometric platform (Guidetti, 1980) and studies on balance in standing position (Alpini and Cesarani ,1999; Winter, 1995). The underlying theory on standing balance from a mechanical point of view consider the body as a rigid mass pivoting about the ankle joints (inverted pendulum theory); the fore-aft oscillation are usually within 8 degrees (Baron 1950). This means that the displacement of the baricentre in a man 1,7 metres high is about 70 millimetres. These oscillations are controlled by the postural system. One must consider that the maximum possible movement exceeds that figure. In fact, the area of stability is almost as wide as the surface defined by the position of the feet on the

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ground. The control of oscillations exceeding 8 degrees is obtained by a different neural system described by the "projective model " (Droulez et Al, 1986) and is not usually assessed during a normal posturometric examination.

The system called "BioGP" can be considered as a feedback device, as the patient can see his centre of pressure (COP) on the PC screen. The task is to shift the COP along defined paths displayed on the screen. The system can be utilized both for the assessment of postural control and for the retraining of individuals with disorders of balance.

The BioGP used as an assessment device attempts to estimate the "projective model" and to answer some typical therapist's questions: what happens if we ask our patient to move voluntarily his baricentre forward ? Which strategy does the patient use to achieve this goal? Is he able to keep the baricentre in the middle of the feet without swaying? Does he experience more problems when the baricentre is shifted near the toes or near the heels? In a previous paper (Cattaneo et al., 2000) we provided data on the validity and discriminant power of the system. Pilot studies have since been started to verify the effectiveness of the system as retraining device.

2. AIM

The aim of this study was twofold: a) clustering: identify homogeneous groups of patients and b) treatment: to provide objective proof of effectiveness of the rehabilitation of patients with balance disorders. The classification of patients into different clusters allowed us to define treatments based on the main characteristics of each group.

3. PATIENTS AND METHODS

Thirty five adults, 16 males and 19 females, suffering from multiple sclerosis were selected for this study. They were diagnosed as defined or probable multiple sclerosis. Patients showed mild-to-moderate impairments of balance and muscle strength as a result of their illness. We included only individuals meeting the following criteria: walk unaided or with minimal support, able to stand with eyes closed (Romberg position), unimpaired near distance vision and no spontaneous nystagmus.

Patients' balance and limb strength was assessed by rating their performance on the Ataxia Battery Test and on the Motricity index. The main characteristics of the patients' group are presented in Table 1.

Table 1. *Subjects (Evaluation protocol).*

Ataxia battery test: Mean and (Standard Deviation) of Ataxia Battery Test.
Motricity index: : Mean and (Standard Deviation) of Motricity index test; R: right side, L: left side

	N	Age	Male	Female	Ataxia battery test	Motricity index R	Motricity index L
Patients	35	35 (10.1)	16	19	434 (171.1)	94 (7.9)	88 (18.5)

Nine patients were chosen randomly and assigned to a treatment group (15 rehabilitation sessions). The characteristics of this subgroup of patients are reported in table 2.

Table 2. *Subjects (Treatment protocol).*
Ataxia battery test: Mean and (Standard Deviation) of Ataxia Battery Test.
Motricity index: : Mean and (Standard Deviation) of Motricity index test; R: right side, L: left side.

	N	age	Male	Female	Ataxia battery test	Motricity index R	Motricity index L
Patients	9	43.7 (15.1)	5	4	337.3 (252.5)	96.3 (11.3)	83.3 (23.2)

Ataxia battery test: is a widely used clinical test for the assessment of balance during standing and walking (Fregly, 1966). For the statistical analyses we used each subject's total score on the 5 items assessing the ability to maintain balance in static conditions; scores can range between 0 (severely impaired balance) to 900 (excellent balance). The 5 items took on average 25 minutes to complete.

Motricity index: a clinical test of motor loss developed for use after stroke, but useful in any patient suffering from upper motor neuron disease (Wade,1995). The patients were tested while seated on a chair and the procedure took about 10 minutes to complete. Scores ranged from 0 (paralysis) to 100 (normal strength)

The BioGP prototype: The system (Brescia and Mincarone, 1997) is composed by a force platform (Kystler 918 1B), a newly developed amplifier, an A/D converter, and a standard PC with an 17 inch. colour monitor. The actual version of the proprietary software runs under DOS 6.2. The incoming signals from the weight sensors in the platform are A/D converted and processed on-line in order to dynamically display in real time the momentary position of COP on the PC monitor along with its trajectory. Additional summary information such as total time, time spent outside the path, total trace length, relative length, and trace length outside the path is also displayed on the monitor at the end of each single trial (see appendix 1 for a glossary of terms). One horizontal and one vertical virtual paths can be selected for testing the subjects' ability to move the cursor by shifting their COP along X and Z axes (latero-lateral and antero-posterior) while standing on the platform. To personalize the test the software allows one to change the sensitivity (gain) of the feedback (i.e. sensitivity 2,4 means that movement of the cursor is 2,4 bigger than sensivity 1) and the size of the cursor. It is also possible to replay the last tracing off-line and to recalibrate the system if the subject moves his feet on the platform. A specific software has been developed in order to draw new virtual paths to be used for rehabilitation.

Output variables: the system's output consists of numerical variables and graphics. A complete list and description of the variables is reported in appendix 1. Variables can be classified as summary measures - such as RL (relative length) which is the ratio between the length of the trace falling outside the borders of the path and the total trace length and tells whether the subject has been able to travel its COP within the path or not. Other variables assess, for example, if a subject swayed most while descending or ascending a vertical path or if he/she made more exits on the right or the left side of a path.

2.1 Data analysis

Assessment protocol: cluster analysis is performed to classify objects into a small number of groups especially when a priori hypotheses are lacking. An important question is how to organize the observations into meaningful structures. We used two different methods: joining (tree clustering) and K-means clustering. The first method joins object into successive larger clusters; the typical output is the hierarchical tree plot (see Figure. 2). The second method is used when the number of the clusters to end with is already known (usually defined after a joining analysis). After clustering an examination of the means of each cluster and how clusters differ from each other is in order.

2.2 Experimental procedures

2.2.1 Assessment protocol. Subjects were instructed to take off their shoes and to stand on the platform in front of the monitor. The best visual stability was achieved at a distance of 1 meter from the screen (Barnes, 1993). They were shown how the PC was able to display in real time the position of their COP which was represented by a cursor and how they could shift it at will by appropriate body sways. Subjects were then encouraged to practice for a few minutes with the equipment. Then the system was calibrated and subjects were given precise instructions on how to move the cursor along the path displayed on the monitor. In case of a vertical path (Figure. 1), for example, one must first move the cursor down by bending backward and then move the cursor back up by bending forward. All the trials started after the cursor had been placed in the rectangular zone (A). The subjects saw their trajectory as they moved the cursor across the screen. We selected one vertical and one horizontal paths having the same length, width and sensitivity and an additional vertical path with an increased sensivity. To complete the experimental session each subject had to go through the following sequence of tasks: 4 vertical paths with sensitivity 1, rest for 1min., 4 horizontal paths with sensitivity 1, rest for 1min., 4 vertical paths with sensitivity 2.4.

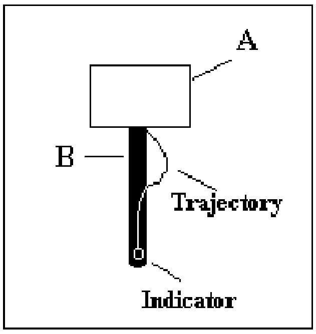
2.2.2. Rehabilitation protocol. Patients were first assessed as described above and then took 12-15 rehabilitation sessions, 2 sessions weekly for a total of 6-7 weeks; each session lasted about 45 minutes. During this period the patients did not receive any other treatment. On each session patients had to complete 7 paths, 3 times each. We assessed the patients' balance score at the beginning and at the end of the treatment with laboratory and clinical tests.

The paths to be used for treatment were selected on the basis of the results of the assessment. Two of the paths were used on every session; the other 5 paths were randomly chosen from the list of all paths selected after the assessment procedures.

4. RESULTS

3.1 Assessment protocol

We report the data obtained from the analysis of V2 path which correlated mostly with the clinical test battery. First we performed the tree-clustering analysis to group patients into progressively larger clusters. The typical result of this analysis is the hierarchical tree (Figure.1). Considering the hierarchical tree plot 3, distinct clusters were identified. The first cluster included only 3 patients, while 18 and 14 patients were grouped into the second and third clusters respectively.



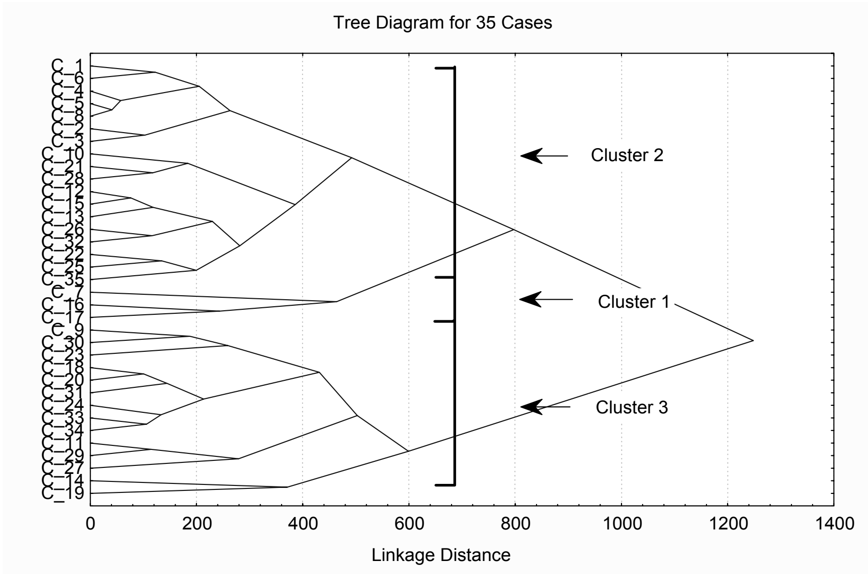


Figure 1. *Vertical Path.* **Figure 2.** *Tree diagram for the 35 cases and 3 clusters.*

As a result we hypothesized that our patients could be grouped into 3 clusters; we tried to cluster variables together in order to verify the differences among the clusters by "K-means cluster analysis". The qualitative differences among clusters are summarized in Figure 3.

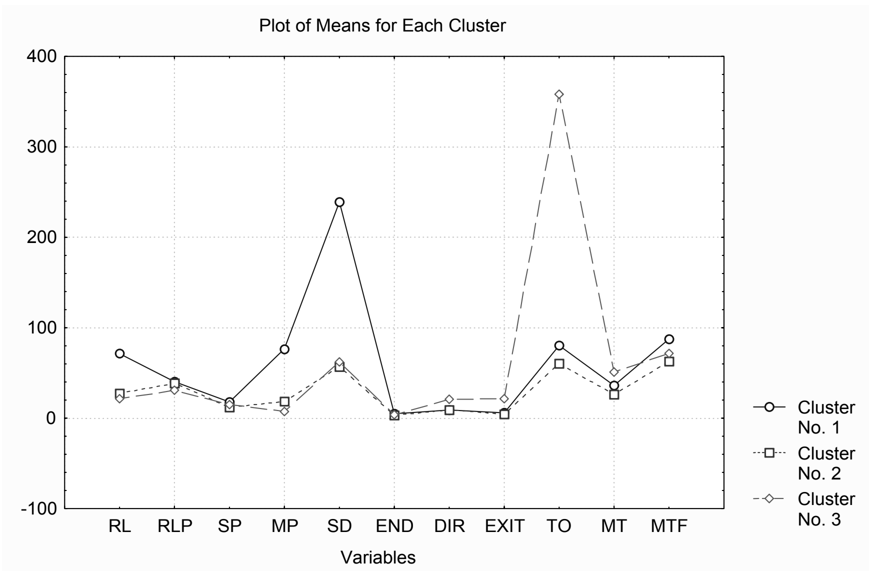


Figure 3. *Differences between the cluster.*

The groups extracted had almost the same cases of tree analysis; only three cases were placed in group 2 instead of group 3. The parameters that best discriminated the three clusters were: RL, SD, EXIT, TO whereas RLP and MTF were the least effective.

3.2 Treatment Protocol

Table 3 shows the experimental data obtained from pre and post treatment evaluations; Table 4 shows the results of the clinical test before and after treatment.

Table 3. *Laboratory data: mean and (standard deviation).*

Parameter	PRE		POST	
RL*	62.5	(16.9)	45.8	(21.2)
SPEED*	17.1	(10)	12.7	(8.1)
SWAY A*	176.9	(72.3)	113.4	(56.2)
SWAY R*	218.5	(162)	145.4	(97.1)

**P<0.01*

Table 4. *Score of Ataxia Battery Test: mean and (standard deviation) (P: 0.8)*

	PRE		POST	
Ataxia B	337.3	(252.5)	343.5	(234.5)

5. CONCLUSION

3.1 Assessment protocol

The cluster analysis identified groups which were quite different one from the other. Cluster 1 had the worst performances: general parameter like RLP showed low values. Patients of this group were not able to keep within the path; the oscillations were 2.4 times wider than the width of the path, and the mean position with respect to the center of the path was outside the boundary. Cluster 3 had the best general parameters: they were able to keep almost always within the path. The patients accomplished their task constantly controlling the position of the CoP, as demonstrated by high Exit and Dir Values (respectively 4 and 3 times more than the other clusters). The problem of this group of patients was the time spent outside the path: they were not able to quickly come back into the path after an exit. Cluster 2 had similar performances to cluster 1, but patients could better control the time spent outside the path.

3.2 Therapeutic protocol

Data obtained from this small group cannot be considered sufficient for final interpretation; also the experimental setting did not completely satisfy the rules of experimental procedure. Data collected showed an improvement of experimental parameters in every patient; the clinical test of 2 patients showed a great improvement while 2 patients had a moderate improvement . The lack of improvement obtained in the other patients can be explained in different ways: Errors in the evaluation of the parameters, number of sessions, paths, poor of sensitivity of clinical tests etc. Another possible explanation is inherent in biofeedback treatments. Patients often improve their skills just in the therapeutical situation and are not able to transfer their knowledge in different contexts. Patients fact should learn to adapt their acquired strategies to the tasks required and also in situations in which the control signal is not directly available but must be extrapolated from other inputs. We define this situation as context dependent learning. Biofeedback rehabilitation and laboratory evaluation have both problems of context . In spite of the accuracy of the data collected, there are some problems regarding the situations in which the patient is placed for assessment. These tests do not usually take into account different contexts in which the movement is usually performed.

Rehabilitation science needs to develop systems that can assess motor tasks in order to obtain reliable information without forcing the patient into situations far from the normal. Rehabilitation devices are needed in order to allow patients to use new strategies in situations normally occurring in everyday life.
Virtual reality could provide a reliable data collection and training protocol in situation that simulate normal environments.

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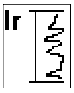
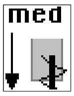
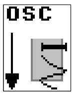
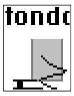
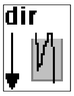
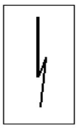
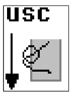
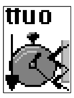
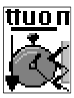
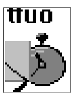
Appendix 1. *Definition of the parameters*

NAME	DEFINITION	CLINICAL MEANING
RL	Ratio between the trace outside the path and the total trace length.	The ability to shift the COP along the path. It is correlated with the ability to control the speed and the direction of movement. It is also correlated with the proper use of ankle strategy.
	**RLP**: the ratio between the total trace length and the path length.	Represents the quality of the performance in terms of energy lost.
	**SP**: speed; average speed (cm/sec)	The speed affects the control of the centre of gravity and the chances to correct a mistake.
	**MP**: mean position; it is the mean position with respect to the axis of the path.	It shows how much weight is shifted on the right or on the left leg. High values of this parameter bring the centre of gravity near one edge of the path.
	**SD: s**way; it is the standard deviation computed as percentage of the path	It tells how much a subject sways. It depends on the subject's ability to detect directional errors very quickly.
	**END**: represents the distance between COP position and the end of the path.	It is small when the subject stops quickly at the end of the path. It requires a good inversion of the muscular strength.
 	**DIR**: the number of times a subject produces a given pattern (combination) of movements (e.g. forward and backward);	It occurs when subjects become aware they are about to make a mistake and correct excessively (overshoot). It happens mostly on the horizontal path.
	**EXIT:** Exits; number of times the subject goes out of the path.	A high number of exits is correlated with a high number of "Dir";
	**TO**: It is the time spent outside the path.	It tells us how many seconds the patient stays outside the right or the left side of the path.
	**MT:** Average time outside; It is the ratio between the time spent outside the path and the variable called Exit	It is an index of reactivity. It tells us if the patient corrects his mistake quickly.
	**MTF:** Time spent outside the end	It tells us the time spent outside the end of the path.