

## VESTIBOLOGY

# Postural control and risk of falling in bipodalic and monopodalic stabilometric tests of healthy subjects before, after visuo-proprioceptive vestibulo-postural rehabilitation and at 3 months thereafter: role of the proprioceptive system

*Controllo posturale e rischio di caduta alle prove stabilometriche bipodalica e monopodalica in soggetti sani prima, dopo e a tre mesi da un trattamento riabilitativo vestibolo-posturale con stimolo visuo-proprioiettivo: il ruolo del sistema proprioiettivo*

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## SUMMARY

Nine healthy volunteers (6 males, 3 females), mean age 34.5 years (SD = 11.52), underwent a vestibulo-postural rehabilitation cycle with a visuo-proprioceptive-type stimulus. All subjects in the study group were evaluated by means of stabilometric bipodalic and monopodalic tests both before and immediately after treatment, and again 3 months thereafter. The Delos Postural Proprioceptive System<sup>®</sup>, DPPS (Delos, srl, Turin, Italy), was used in performing these stabilometric tests and in the rehabilitation exercises. The first aim of the study was to evaluate to what extent the functional level of the proprioceptive system was reliable, in healthy subjects, in the control of postural stability; the second was to demonstrate the possibility to increase this level by means of a novel visuo-proprioceptive feedback training; the last was to establish whether or not the increase achieved was permanent. The bipodalic test did not reveal any deficit in posture either before or after rehabilitation. The monopodalic test prior to treatment, with eyes closed, revealed, in 2/3 of the study group, evidence of the risk of falling, expressed as the precautious strategy ( $8.57 \pm 6.18\%$  SD). An increase in the proprioceptive activity, obtained in the subjects examined immediately after the visuo-proprioceptive vestibulo-postural rehabilitation, led, in the monopodalic test, with eyes closed, to a significant reduction in the risk of falling (with the precautious strategy equal to  $1.09 \pm 2.63\%$  SD,  $p = 0.004$ ). The monopodalic test, with eyes closed, 3 months after rehabilitation, demonstrated results not unlike those pre-treatment with values, therefore, not more significant than those emerging from the pre-treatment test. Thus, from the above-mentioned data, it can be observed that, also in healthy subjects, there may be different levels of postural proprioceptive control related to a high risk of falling. These levels can be maintained constant for a certain period of time, until a significant reduction in the risk of falling is achieved, only if continuously stimulated by appropriate sensorial information.

KEY WORDS: Vestibulo-postural rehabilitation • Visuo-proprioceptive feedback • Risk of falling • Double-leg stance • Single-leg stance

## RIASSUNTO

Sono stati sottoposti ad un ciclo di riabilitazione vestibolo-posturale con stimolo di tipo visuo-proprioiettivo 9 soggetti sani, volontari, di età media pari a 34,5 anni (DS = 11,52) e valutati mediante test stabilometrici bipodalico e monopodalico prima, dopo e a tre mesi dal trattamento. Il Delos Postural Proprioceptive System<sup>®</sup>, DPPS (Delos, srl, Torino, Italy) è stato usato per l'esecuzione e la registrazione dei test stabilometrici e degli esercizi riabilitativi. Scopo primario dello studio è stato definire, in soggetti sani, il ruolo del sistema proprioiettivo nel mantenimento della stabilità posturale. Scopo secondario è stato quello di dimostrare la possibilità di migliorare, attraverso un ciclo di riabilitazione vestibolo-posturale con feedback visuo-proprioiettivo, il controllo posturale e di ridurre l'eventuale rischio di caduta. Ulteriore scopo è stato, infine, verificare se gli obiettivi raggiunti fossero permanenti oppure transitori. Il test stabilometrico monopodalico è risultato, rispetto al test bipodalico, un test più sensibile nel definire sia il livello di integrità del sistema proprioiettivo sia la percentuale della strategia precauzionale necessaria per evitare il rischio di caduta. Il test ad occhi chiusi, prima del ciclo riabilitativo, ha evidenziato, nei 2/3 del gruppo di studio, la presenza del rischio di caduta (strategia precauzionale pari a  $8,57 \pm 6,18\%$  DS). Il test, dopo il trattamento, ha messo in evidenza un incremento dell'attività proprioiettiva e una riduzione significativa del rischio di caduta (strategia precauzionale pari al  $1,09 \pm 2,63\%$  DS con  $p = 0,004$ ). Dopo 3 mesi dalla riabilitazione, i valori della strategia precauzionale e del rischio di caduta sono tornati ad essere sovrapponibili a quelli ottenuti prima del trattamento. Da quanto esposto, risulta come anche nei soggetti sani possa esservi un deficit proprioiettivo "sub-clinico", associato ad un elevato rischio di caduta. Gli effetti di questo tipo di programma

*riabilitativo agirebbero sia sui riflessi propriocettivi che a livello cognitivo, con una riduzione significativa del rischio di caduta e un progressivo miglioramento dell'equilibrio. I risultati così ottenuti da un solo ciclo riabilitativo, andrebbero però, per essere mantenuti costanti nel tempo, alimentati da continue ed adeguate informazioni sensoriali.*

**PAROLE CHIAVE:** *Riabilitazione vestibolo-posturale • Stimolo visuo-proprioceettivo • Rischio di caduta • Posizione bipodalica • Posizione monopodalica*

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## Introduction

By means of an analysis of the postural behaviour of a subject, it is possible to define the state of his/her equilibrium. The afferent visual, vestibular and proprioceptive systems offer the patient vital information for postural control and determine, respectively, three behavioural strategies<sup>1,2</sup>. The functional weight related to one system with respect to another in the control of balance is not the same in all subjects, inasmuch as each one, over the years, based on personal experience and lifestyle, depends primarily on a certain postural strategy rather than another. There are, therefore, subjects who are primarily “vestibular”, others “visual” or “proprioceptive”<sup>3</sup>. These systems are all indispensable and their integration, at the level of the central nervous system (CNS), offers the subject the possibility to maintain a certain position or to move from one place to another. A deficit in any one of these leads to lack of stability and dizziness. These effects are more evident in subjects in whom the deficit involves the predominant strategy.

Using posturography or stabilometry, it is possible to distinguish and to define, on the one hand, the healthy subjects not presenting disorders in the systems involved, and on the other, those subjects presenting a pathological condition who may have a visual, vestibular and/or proprioceptive defect. Furthermore, it is possible to evaluate the functional levels of the strategy used by each subject. A posturographic system, by means of standardized methods, should be able to analyse, therefore, the postural oscillations and the strategy used to maintain control of an upright stance, offer the possibility to analyse several parameters and provide comparable data. The computerized stabilometric systems usually used, at present, are Platforms for vertical force with which transducers detect the centre of pressure (CoP). The CoP defines, at ground level, indeed, at two coordinates, namely, x and y, the values of the centre of mass (COM), defined as the body's centre of gravity, averaged for a standardized population as far as concerns height and weight.

Static postural control of upright stance is normally analysed in bipodalic conditions. The basic test is performed with the patient standing still in double-leg stance, with eyes open (EO), and arms beside the body. In this condi-

tion, the patient maintains his/her balance aided by visual, vestibular and proprioceptive information. The patient is then submitted to a second test in the same basal conditions, but with eyes closed (EC). In this case, having abolished the visual cues, the patient maintains his/her balance only by means of the vestibular and proprioceptive inputs. Other complimentary means may be associated with these in which it is possible to evaluate the variations coinciding with the basal oscillations<sup>4</sup>. An analysis and the relationship of the values of the postural oscillations, in the various tests, in particular in those with EO and EC, offer the possibility to detect and define the predominating strategies which are responsible for maintaining the correct balance. In the test with EC, the vestibular and proprioceptive systems should, compared to the test with EO, increase not only the number, but also the speed, of the inputs in order that the spinal reflexes maintain adequate postural control<sup>5,6</sup>. Abolishing the visual cues, in the maintenance of the bipodalic upright stance, does not induce significant changes in posture, in normal subjects, inasmuch as a compensation is reached resulting in an increase in the vestibular and proprioceptive activity; provoking, instead, postural instability in subjects presenting a vestibular and/or proprioceptive deficit.

Study of upright stance, in the monopodalic condition, offers additional information regarding human postural control<sup>7</sup>. The latter, in fact, may be considered physiological behaviour, since it represents a fraction of the step. A step, in fact, is made up of four phases, two in the bipodalic phase and two in the monopodalic phase. The single-leg stance is the most destabilizing, able to affect the balancing area of a subject from one area to another and is aided by a subsequent bipodalic stabilizing phase. A study of the monopodalic stance, therefore, offers the possibility to evaluate, in a static form, a dynamic attitude of postural control. In this condition, the proprioceptive system is that most stimulated, inasmuch as it has to use less somatosensorial information (proprioceptive and plantar cutaneous) involving primarily only the foot on which the subject is standing. Therefore, as far as concerns the bipodalic condition, a larger number and a higher frequency of corrective actions are needed with this system. A healthy subject, in a monopodalic stance, with EO, is able to control the dynamic relationship not

only between the proprioceptive, but also the visual and vestibular types of information, thus maintaining a correct equilibrium and not triggering a significantly destabilizing effect in maintaining the position. With EC, on the other hand, without the visual input, despite normal vestibular input, these subjects are conditioned above all by the proprioceptive inputs. Inadequate levels of proprioceptive control may, even in healthy subjects, compromise postural stability with possible risk of falling. Evaluation of the monopodal stance thus offers the possibility to reveal, in healthy subjects, any eventual low levels of proprioceptive control, not otherwise revealed by the bipodal stance. This type of postural evaluation may, furthermore, in non-vestibular pathological subjects reveal a proprioceptive deficit<sup>8</sup> and, in the vestibular type, indicate the labyrinth affected and/or define the level of central compensation. Finally, an upright stance study may be useful also in the course of vestibular rehabilitation, to monitor recuperation of the postural defect.

### Aim of the study

The principal aim of the present study was to evaluate, in healthy subjects, the exact role played by the proprioceptive system in posture control, not only in an upright bipodal stance, but also in a monopodal condition.

Another aim was to demonstrate that an increase in the proprioceptive reflex activity results, by means of a cycle of visuo-proprioceptive vestibulo-postural rehabilitation, in a significant reduction in the risk of falling.

Finally, an attempt was made to ascertain whether or not the rehabilitative effects of the proprioceptive system on posture should be considered permanent.

### Material and methods

Between March - October 2008, a homogeneous group of 9 healthy volunteers, not presenting vestibular, visual or proprioceptive deficits, were enrolled in the study. The study group comprised 6 males and 3 females, age range 27-62 years, mean age 34.5 years (SD = 11.52). None of these subjects had a negative case history regarding neurological disorders and all underwent vestibular bedside examinations with video-oculographic monitoring, completed with caloric stimulation according to Fitzgerald-Hallpike's criteria<sup>9</sup>, in order to exclude any labyrinthine deficit. Thereafter, all subjects were submitted to a visuo-proprioceptive vestibulo-postural rehabilitation cycle and to 3 stabilometric evaluations: an initial evaluation prior to rehabilitation, a second immediately thereafter and the third after a three-month period, by means of the Delos Postural Proprioceptive System<sup>®</sup> DPPS (Delos, srl, Turin, Italy)<sup>10</sup>. Each postural evaluation, in accordance with the recommendations of Le Clair and Riach<sup>11</sup>, consisted in a stabilometric static double-leg stance (bipodal test) and a

stabilometric static single-leg stance (monopodal test).

The bipodal test consists in 2 attempts, the first of which with EO and the second with EC. Each test lasted 20 seconds, with the subjects standing barefoot on the ground with arms resting at their sides.

The monopodal test consists in 4 attempts, the first two with EO, one with weight on the left foot on the ground and the other foot relaxed but not touching the ground, the second with the weight on the right foot on the ground. The last two tests are carried out with EC, alternating leaning, as in the first two tests. Each test lasted 20 seconds, with the subjects standing barefoot on the ground, in an upright position, with arms at his/her side.

The Delos Postural Proprioceptive System<sup>®</sup>, used in performing these stabilometric tests and in the rehabilitation exercises, instead of the other system with platforms for vertical forces, makes use of an angular speed detector – Delos Vertical Controller (DVC) – oval shaped, 7 X 4.5 X 2.5 cm in size, connected to a computer. The DVC, applied in correspondence to the sternum, by means of elastic bandaging, exactly defines, following instantaneous calibration of the software, the COM of the subject under examination. With this instrument it is possible to test both bipodal and monopodal stance and to record the variations in the position of the COM, with a sensitivity of 0.1 degrees. For each test performed, the software defines the closeness of the angle from the median x-y axis, the mean distance x-y from the COM, the mean x-y speed and the mean x-y inversion frequency.

Furthermore, the novel DPPS system consisting of an adaptable steel structure for hand support, the Delos Postural Assistant (DPA), equipped with an infra-red sensor, which is also connected to the computer. The DPA is placed in front of the patient in order that he/she, during the examination, can easily rest his/her hands, in the event he/she risks falling. This leaning bar, by avoiding this risk, is able to record the frequency and duration of the corrective events that the subject has to perform in order to maintain the position assumed.

As already pointed out, the equilibrium of a subject who is standing immobile, in a bipodal or monopodal position, is maintained with EO by the activity of the visual, vestibular and proprioceptive strategies. In the event there is a defect in one or more of these systems, the subject is forced to make use of the DPA in order to avoid the risk of falling. The greater the number of times and the longer the time the patient relies on the bar, the worse his/her balance becomes. Whether or not the DPA is used offers a series of indispensable parameters for evaluation of a subject's posture. One of these parameters is the precautional strategy which expresses in terms of percentage just how much the equilibrium of a subject is related to the duration and frequency of the leaning of their hands on the DPA. This pathological

postural strategy is directly proportional to the risk of falling. Absence of this strategy indicates that the subject is able to maintain a correct posture employing the normal physiological strategies – visual, vestibular and proprioceptive strategies. With the use of the DPA bar, in performing the monopodalic test, it is possible to obtain further useful information, such as the maximum time without leaning and the mean time of leaning.

The visuo-proprioceptive vestibulo-postural rehabilitation to which the 9 healthy subjects, in this study, were submitted, foresees 8 sessions twice weekly, each lasting 50 minutes. The DPPS system, employed for training purposes makes use of an electronic Freeman Board-like rocking platform, Delos Equilibrium Board (DEB), together with a visual feedback. The DEB, upon which this type of postural reprogramming is based, is connected to the software in order to monitor the level of instability of the lower limbs and trunk.

After having positioned the DVC at sternum level and having correctly positioned the DPA, the patient is placed in front of the monitor and asked, whilst in a standing position, both monopodalic and bipodalic conditions, to carry out a series of tests, not only static but also dynamic, carefully following, on the video, the moving targets only with their eyes or also with their trunk. The patient carries out some of these exercises on the DEB board, in double- and single-leg stance, in order to maintain, or improve his/her personal balancing conditions. The DEB movements and the variations in the position of the DVC are recorded and traced, either together or separately, in real time on the monitor. The visual target recording of these movements offers the patients under examination a visuo-proprioceptive feedback able to trigger, particu-

larly at sub-cortical level of the CNS, rapid reflexes of a corrective nature on posture control.

### Statistical analysis

Student's t test for paired data was used in the statistical analyses of the closeness of the angle from the median x-y axis, the precautonal strategy, the maximum time without leaning and the mean time of leaning on the DPA bar in the bipodalic and monopodalic tests compared before and after, as well as at 3 months after visuo-proprioceptive vestibulo-postural rehabilitation.

### Results

The results of the bipodalic test, performed before, after and at a distance of 3 months after rehabilitation, did not reveal any significant difference, either with EO or with EC, with respect to the closeness of the angle from the median x-y axis (CAXY). With EO, mean CAXY was 0.48 (SD = 0.15°) pre-treatment, 0.63 ± 0.27° post-treatment (p = 0.15) and 0.52 ± 0.19° at 3 months (p = 0.58). With EC, mean CAXY was 0.53 (SD = 0.12°) pre-treatment, 0.54 ± 0.15° post-treatment (p = 0.87) and 0.58 ± 0.16° after 3 months (p = 0.51) (Table I).

As far as concerns the monopodalic test, for each patient, evaluations were made of the results obtained with right-leg stance, left-leg stance and also the mean values obtained from both right and left leg findings.

The monopodalic test with EO did not reveal any significant variation in CAXY, pre-rehabilitation, post-rehabilitation, and again 3 months thereafter. Mean CAXY ± SD left leg was 1.00 ± 0.29° pre-, 0.89 ± 0.31° post- (p = 0.44)

**Table I.** Results of closeness of angle from median x-y axis of double-legs with eyes open (EO) and eyes closed (EC) in bipodalic test pre-, post-rehabilitation and 3 months thereafter.

Bipodalic test	Closeness of angle from the median x-y axis					
	Pre		Post		Post-3 months	
	EO	EC	EO	EC	EO	EC
<b>Subjects</b>						
P.D.	0.30°	0.40°	0.40°	0.30°	0.30°	0.50°
A.D.	0.80°	0.60°	1.10°	0.50°	0.70°	0.70°
E.D.	0.40°	0.50°	0.60°	0.80°	0.60°	0.50°
G.D.	0.50°	0.50°	0.60°	0.60°	0.40°	0.50°
V.G.	0.40°	0.40°	0.40°	0.50°	0.30°	0.40°
M.P.	0.40°	0.70°	0.50°	0.70°	0.40°	0.70°
L.P.	0.40°	0.40°	0.50°	0.50°	0.50°	0.50°
I.S.	0.50°	0.70°	0.50°	0.60°	0.70°	0.90°
P.S.	0.60°	0.60°	1.10°	0.40°	0.80°	0.50°
<b>Mean</b>	0.48°	0.53°	0.63°	0.54°	0.52°	0.58°
<b>SD</b>	0.15°	0.12°	0.27°	0.15°	0.19°	0.16°
<b>Student's t</b>			0.15	0.87	0.58	0.51

**Table II.** Results of closeness of angle from median x-y axis of single-leg left, right and both mean in monopodal test pre-, post-rehabilitation and 3 months thereafter.

Monopodal test	Closeness of angle from the median x-y axis														
	Pre-rehabilitation				Post-rehabilitation				3 months after rehabilitation						
	Eyes open		Eyes closed		Eyes open		Eyes closed		Eyes open		Eyes closed				
Subject	Left	Right	Both	Left	Right	Both	Left	Right	Both	Left	Right	Both	Left	Right	Both
P.D.	0.80°	1.50°	1.15°	3.30°	2.20°	2.75°	0.50°	0.40°	0.45°	1.20°	1.50°	1.35°	0.50°	0.70°	0.60°
A.D.	0.70°	0.50°	0.60°	3.70°	1.60°	2.65°	0.60°	0.90°	0.75°	2.20°	3.00°	2.60°	0.60°	0.60°	0.60°
E.D.	1.10°	0.80°	0.95°	1.20°	3.10°	2.15°	0.60°	0.60°	0.60°	1.50°	1.30°	1.40°	0.60°	0.80°	0.70°
G.D.	0.70°	0.70°	0.70°	1.80°	4.30°	3.05°	0.70°	0.60°	0.65°	1.40°	1.60°	1.50°	0.60°	0.80°	0.70°
V.G.	1.10°	1.20°	1.15°	2.30°	2.80°	2.55°	1.30°	1.40°	1.35°	1.50°	2.80°	2.15°	1.80°	1.70°	1.75°
M.P.	1.50°	1.20°	1.35°	3.00°	5.00°	4.00°	1.10°	1.40°	1.25°	2.50°	2.40°	2.45°	1.20°	1.30°	1.25°
L.P.	0.70°	0.70°	0.70°	1.90°	2.80°	2.35°	0.80°	0.60°	0.70°	2.30°	1.30°	1.80°	0.80°	0.80°	0.80°
I.S.	1.20°	1.10°	1.15°	10.00°	3.00°	6.50°	1.10°	0.70°	0.90°	7.80°	5.50°	6.65°	1.00°	1.10°	1.05°
P.S.	1.20°	1.50°	1.35°	2.40°	4.40°	3.40°	1.30°	1.30°	1.30°	9.80°	10.70°	10.25°	3.40°	2.30°	2.85°
<b>Mean</b>	1.00°	1.02°	1.01°	3.29°	3.24°	3.27°	0.89°	0.88°	0.88°	3.36°	3.34°	3.35°	1.17°	1.12°	1.14°
<b>SD</b>	0.29°	0.36°	0.29°	2.64°	1.11°	1.34°	0.31°	0.39°	0.34°	3.16°	3.06°	3.06°	0.93°	0.56°	0.74°
<b>Student's t</b>							0.44	0.43	0.40	0.96	0.93	0.94	0.62	0.66	0.62
													0.69	0.79	0.67

and  $1.17 \pm 0.93^\circ$  at 3 months ( $p = 0.62$ ). Mean CAXY  $\pm$  SD right leg was  $1.02 \pm 0.36^\circ$  pre-,  $0.88 \pm 0.39^\circ$  post- ( $p = 0.43$ ) and  $1.12 \pm 0.56^\circ$  at 3 months ( $p = 0.66$ ). Mean CAXY  $\pm$  SD of the mean values for both legs for each subject was  $1.01 \pm 0.29^\circ$  before,  $0.88 \pm 0.34^\circ$  after ( $p = 0.40$ ) and  $1.14 \pm 0.74^\circ$  at 3 months ( $p = 0.62$ ).

Also the analysis of CAXY, at the monopodalic test with EC, did not reveal any significant difference. Mean CAXY  $\pm$  SD of the left leg was  $3.29 \pm 2.64^\circ$  pre-,  $3.36 \pm 3.16^\circ$  post- ( $p = 0.96$ ) and  $2.86 \pm 1.79^\circ$  at 3 months ( $p = 0.69$ ). Mean CAXY  $\pm$  SD of the right leg was  $3.24 \pm 1.11^\circ$  pre-,  $3.34 \pm 3.06^\circ$  post- ( $p = 0.93$ ) and  $3.07 \pm 1.63^\circ$  at 3 months ( $p = 0.79$ ). Mean CAXY  $\pm$  SD of the mean between the two legs of each subject was  $3.27 \pm 1.34^\circ$  pre-,  $3.35 \pm 3.06^\circ$  post- ( $p = 0.94$ ) and  $2.96 \pm 1.60^\circ$  at 3 months ( $p = 0.67$ ) (Table II).

All subjects underwent the monopodalic test with EO pre-, post-rehabilitation and at 3 months thereafter, without any risk of falling; they maintained the single-leg stance without the use of the DPA and none had to make use of the so-called precautious strategy.

The monopodalic test with EC tripled the values of CAXY in all the subjects examined compared to the same test with EO and revealed, in 2/3 of the subjects examined before rehabilitation, the need of the precautious strategy (PrS), an expression of the risk of falling; the maximum time without leaning (MTWL), in these subjects, was found to be less than the maximum duration of each exercise.

The monopodalic test with EC, post-rehabilitation, revealed a significant reduction in PrS ( $p = 0.004$ ) and a significant increase in MTWL ( $p = 0.010$ ). Also the mean time of leaning (MTL) was significantly reduced between the two attempts ( $p = 0.008$ ). Mean PrS  $\pm$  SD showed a decrease from  $8.62 \pm 7.12\%$  left leg,  $8.51 \pm 8.19\%$  right leg,  $8.57 \pm 6.18\%$  mean of the legs pre-treatment, to  $0.42 \pm 1.27\%$  left leg ( $p = 0.004$ ),  $1.76 \pm 5.27\%$  right leg ( $p = 0.054$ ),  $1.09 \pm 2.63\%$  mean of the legs ( $p = 0.004$ ) post-treatment. Mean MTWL  $\pm$  SD showed an increase from  $16.68 \pm 3.2''$  left leg,  $15.73 \pm 4.41''$  right leg,  $16.21 \pm 3.09''$  mean of the legs pre-rehabilitation, to  $19.93 \pm 0.20''$  left leg ( $p = 0.024$ ),  $19.06 \pm 2.83''$  right leg ( $p = 0.076$ ),  $19.49 \pm 1.41''$  mean of the legs ( $p = 0.010$ ) post-rehabilitation. Mean MTL  $\pm$  SD showed a decrease from  $0.91 \pm 0.93''$  left leg,  $0.51 \pm 0.55''$  right leg,  $0.71 \pm 0.63''$  mean of the legs pre-treatment, to  $0.07 \pm 0.20''$  left leg ( $p = 0.017$ ),  $0.06 \pm 0.17''$  right leg ( $p = 0.029$ ),  $0.06 \pm 0.12''$  mean of the legs ( $p = 0.008$ ) post-treatment (Table III).

It is worthwhile pointing out that the values of CAXY, at the monopodalic test with EC post-treatment, did not show significant variations and the subjects continued to present degrees of oscillation comparable to the pre-treatment test. This was due to the fact that they had performed the test with a significant increase in MTWL and with a significant reduction in MTL, in PrS and in the risk of falling<sup>12</sup>.

The significant improvement in posture control with EC,

in a monopodalic condition, obtained immediately after the visuo-proprioceptive vestibulo-postural rehabilitation, expressed by the almost complete disappearance of PrS, the significant increase in MTWL and the marked reduction in MTL, with time, become less efficacious. As far as concerns the results obtained with the monopodalic test performed 3 months after rehabilitation, the subjects examined tend, in the parameters under analysis, to present once again values comparable to the initial pre-treatment levels. PrS, mean  $\pm$  SD, returned to  $4.00 \pm 8.30\%$  left leg ( $p = 0.22$ ),  $6.81 \pm 12.26\%$  right leg ( $p = 0.73$ ),  $5.41 \pm 10.11\%$  mean of both legs ( $p = 0.44$ ); MTWL, mean  $\pm$  SD, returned to  $16.69 \pm 6.15''$  left leg ( $p = 1.00$ ),  $17.71 \pm 5.48''$  right leg ( $p = 0.41$ ),  $17.20 \pm 5.33''$  mean legs ( $p = 0.63$ ); MTL, mean  $\pm$  SD, displayed values of  $0.42 \pm 0.95''$  left leg ( $p = 0.29$ ),  $0.31 \pm 0.51''$  right leg ( $p = 0.43$ ),  $0.37 \pm 0.54''$  mean of both legs ( $p = 0.23$ ). These values are not unlike the initial values, losing the statistical significance reached following visuo-proprioceptive vestibulo-postural rehabilitation.

## Discussion and conclusions

The bipodalic test was correctly performed by all the subjects enrolled in the study both with EO and with EC, before, after and at 3 months after the end of the rehabilitation programme. The vestibular, visual and proprioceptive systems are, therefore, clearly able to compete, in the maintenance of bipodalic stance.

The monopodalic test requires, on the other hand, even in healthy subjects, greater activity on the part of the proprioceptive system. In the EC condition, in the absence of visual information, the proprioceptive inputs of the leg on which the subject is standing, are integrated with the vestibular inputs, activating control spinal reflex mechanisms on the only leg on the ground. It is in this critical postural condition that a deficit and/or reduced proprioceptive activity are triggered. This makes the monopodalic test not only more sensitive but also more specific in revealing the true functional level of the proprioceptive system compared to that of the bipodalic test.

Two thirds of the study group, at the pre-treatment monopodalic test, with EC, were unable to maintain the correct single-leg stance, but were forced to make use of the DPA in order to avoid the risk of falling. These results are an expression of the inadequate proprioceptive function level compared to the demands of postural control.

After rehabilitation, the subjects have reduced the use of the DPA and the risk of falling, while keeping unchanged the values of CAXY. This positive therapeutic effect could be due to increased proprioceptive reflex responses, but also to a cortical component in CAXY the changes of which are no longer perceived as dangerous and thus the subject no longer feels the need to lean on while swinging in the same way. Three months after the end of the reha-

**Table III.** Results of percentage of precautional strategy (risk of falling), maximum time (in seconds) without leaning and mean time (in seconds) of leaning on single-leg left, right and both mean in Monopodalic test - eyes closed - pre-, post-rehabilitation and 3 months thereafter.

Monopodalic test	Precautional strategy % - risk of falling - eyes closed								
	Pre			Post			Post-3 months		
Subjects	Left	Right	Both	Left	Right	Both	Left	Right	Both
P.D.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A.D.	13.80	0.00	6.90	0.00	0.00	0.00	3.00	7.90	5.45
E.D.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
G.D.	9.40	13.70	11.55	0.00	0.00	0.00	0.00	0.00	0.00
V.G.	9.40	14.20	11.80	0.00	15.80	7.90	24.90	38.30	31.60
M.P.	19.30	18.30	18.80	0.00	0.00	0.00	0.00	0.00	0.00
L.P.	11.40	16.20	13.80	0.00	0.00	0.00	0.00	8.10	4.05
I.S.	14.30	0.00	7.15	3.80	0.00	1.90	8.10	3.50	5.80
P.S.	0.00	14.20	7.10	0.00	0.00	0.00	0.00	3.50	1.75
<b>Mean</b>	8.62	8.51	8.57	0.42	1.76	1.09	4.00	6.81	5.41
<b>SD</b>	7.12	8.19	6.18	1.27	5.27	2.63	8.30	12.26	10.11
<b>Student's t</b>				0.004	0.054	0.004	0.22	0.73	0.44

  

Monopodalic test	Maximum time (in seconds) without leaning - eyes closed								
	Pre			Post			Post-3 months		
Subjects	Left	Right	Both	Left	Right	Both	Left	Right	Both
P.D.	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
A.D.	10.90	20.00	15.45	20.00	20.00	20.00	5.20	18.30	11.75
E.D.	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
G.D.	18.10	10.70	14.40	20.00	20.00	20.00	20.00	20.00	20.00
V.G.	18.10	10.90	14.50	20.00	11.50	15.75	6.60	3.20	4.90
M.P.	9.60	10.60	10.10	20.00	20.00	20.00	20.00	20.00	20.00
L.P.	17.70	16.40	17.05	20.00	20.00	20.00	20.00	18.40	19.20
I.S.	15.70	20.00	17.85	19.40	20.00	19.70	18.40	19.70	19.05
P.S.	20.00	13.00	16.50	20.00	20.00	20.00	20.00	19.80	19.90
<b>Mean</b>	16.68	15.73	16.21	19.93	19.06	19.49	16.69	17.71	17.20
<b>SD</b>	3.92	4.41	3.09	0.20	2.83	1.41	6.15	5.48	5.33
<b>Student's t</b>				0.024	0.076	0.010	1.00	0.41	0.63

  

Monopodalic test	Mean time (in seconds) of leaning - eyes closed								
	Pre			Post			Post-3 months		
Subjects	Left	Right	Both	Left	Right	Both	Left	Right	Both
P.D.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A.D.	0.30	0.00	0.15	0.00	0.00	0.00	2.90	0.30	1.60
E.D.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
G.D.	1.90	0.60	1.25	0.00	0.00	0.00	0.00	0.00	0.00
V.G.	1.90	1.30	1.60	0.00	0.50	0.25	0.40	0.40	0.40
M.P.	1.20	0.80	1.00	0.00	0.00	0.00	0.00	0.00	0.00
L.P.	2.30	0.60	1.45	0.00	0.00	0.00	0.00	1.60	0.80
I.S.	0.60	0.00	0.30	0.60	0.00	0.30	0.50	0.30	0.40
P.S.	0.00	1.30	0.65	0.00	0.00	0.00	0.00	0.20	0.10
<b>Mean</b>	0.91	0.51	0.71	0.07	0.06	0.06	0.42	0.31	0.37
<b>SD</b>	0.93	0.55	0.63	0.20	0.17	0.12	0.95	0.51	0.54
<b>Student's t</b>				0.017	0.029	0.008	0.29	0.43	0.23

bilitation programme, subjects returned to baseline pre-treatment. The results show that the postural control, even in normal subjects, has a margin of continuous improvement, particularly through repeated cycles of vestibular

rehabilitation, effects on proprioceptive reflexes and experience of cortical processing. These hypotheses regarding the postural behaviour of healthy subjects deserve further study in pathological patients.

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