Comparison of Cawthorne-Cooksey Exercises and Sinusoidal Support Surface Translations to Improve Balance in Patients With Unilateral Vestibular Deficit

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Objective: To compare the effectiveness of vestibular rehabilitation by using Cawthorne-Cooksey exercises with that of instrumental rehabilitation.

Design: The main study (n=32) used a pre-post rehabilitation (A-B) design; the ancillary studies used a subset of 11 patients 1 month before rehabilitation versus pre-post rehabilitation (A-A-B design) and 9 patients pre-post rehabilitation versus 1 month after (A-B-B design).

Setting: Division of physical therapy and rehabilitation at a scientific institute in Italy.

Participants: Patients (Cawthorne-Cooksey, n=17; instrumental rehabilitation, n=15) with a complete or incomplete unilateral vestibular lesion due to ischemic, inflammatory, cranial nerve VIII sectioning, or unknown cause.

Interventions: Cawthorne-Cooksey exercises or instrumental rehabilitation training consisting of standing with eyes open (EO) or closed (EC) on a platform moving, relative to the subjects, in the anteroposterior (AP) or mediolateral direction, at a sinusoidal translation frequency of 0.2 or 0.6Hz; training sessions for both interventions were twice daily, 30 minutes per session, for 5 days.

Main Outcome Measures: Body sway and subjective score of sway during quiet stance with EO or EC, with feet 10cm apart (FA) or together (FT); the standard deviation of the AP displacement of the malleolus, hip, and head during AP platform translations; the Dizziness Handicap Inventory (DHI); and performance-oriented evaluation of balance and gait (according to Tinetti).

Results: Both interventions improved patients' balance. Under each postural and visual condition, both groups showed reduction in body sway, and the post rehabilitation sway values approached those observed in normal subjects; improvement was significantly better for instrumental rehabilitation under FA EO, FA EC, and FT EC conditions. All patients reported a subjective feeling of increased steadiness. Sway recorded 1 month before treatment did not differ from that at the start of treatment. The follow-up evaluation showed persistence of effect. Parallel to the improved stability, a decrease in the SD of the displacement of hip and head in balancing on the movable platform was present in both groups; improvement was better in the instrumental rehabilitation group than the Cawthorne-Cooksey group under the EC condition. Balance and gait assessment improved to the same extent in both groups. Scores on the physical, functional, and emotional questions of the DHI improved significantly in both groups after treatment, but to a larger extent in the instrumental rehabilitation patients.

Conclusions: Both Cawthorne-Cooksey and instrumental rehabilitation are effective for treating balance disorders of vestibular origin. Improvement affects both control of body balance and performance of activities of daily living. The larger decrease in body sway and greater improvement of DHI after instrumental rehabilitation suggests that it is more effective than Cawthorne-Cooksey exercises in improving balance control.

Key Words: Balance; Dizziness; Posture; Rehabilitation; Vestibule.

PATIENTS WITH VESTIBULAR disorders frequently report imbalance and gait problems,[1] and are at risk of falls.[2] Imbalance, gait problems, and dizziness can be ameliorated by rehabilitation. Vestibular patients who underwent a rehabilitation program to avoid movements that can trigger vertigo had no improvement of their balance control,[3] but several studies[4-9] have shown improvement when appropriate rehabilitation schemes, implying gross head and trunk movements, were used. Rehabilitation training can be based on exercises customized for each patient[10-12] or composed of a full, fixed scheme such as Cawthorne-Cooksey exercises[13] or Vestibular Habituation Training.[5,14] All these exercises include head and trunk movements to stimulate the vestibular system and lead to improved balance and reduced vertigo and dizziness,[15,16] even when administered long after the acute event.[17] The clinical recovery aided through these exercises is thought to rely on the following mechanisms: adaptation, that is, modification of the gain of the relevant vestibulo-oculomotor and vestibulospinal circuits,[18] and habituation,[10,19] that is, a central process of learning that is independent of sensory adaptation and motor fatigue.[20] However, mechanisms such as central compensation,[9,21] that is, a counterbalancing of any defect of structure or function, and substitution with other sensory inputs[22,23] are also acknowledged.[15,24]

Although recent studies[10-12,14] have suggested that customized, supervised treatment for each patient may be better with

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respect to balance, dizziness, and gaze stability than the old, unsupervised Cawthorne-Cooksey exercises, Cawthorne-Cooksey exercises are widely used. However, because no systematic comparison of the effectiveness of Cawthorne-Cooksey exercises with respect to other treatments has been made, we decided to administer these exercises as a standardized set for balance rehabilitation in vestibular patients and to compare their effectiveness with that of instrumental rehabilitation.

It is possible to assess postural instability and deficits in body segment coordination in vestibular patients by having them stand and balance on a supporting platform continuously moving in an anteroposterior (AP) direction.[25] This kind of perturbation induces predictable postural displacements of legs, trunk, and head; these displacements have to be appropriately counteracted and anticipated.[26-28] During body displacement in response to an unexpected perturbation, sensory input provides information about the nature of the balance disturbance and is used to trigger the appropriate postural response in a feedback mode.[29] Conversely, when the balance perturbation is administered in a periodic fashion, as in a continuously moving platform, subjects can anticipate the appropriate postural adjustment.[26,27] A platform moving according to a sinusoidal program requires subjects to use sensory input both in a feed-back and feed-forward mode to produce an adequate motor output.[30-32]

Three considerations prompted us to use the moving platform model as a way to treat patients with vestibular disease. First, the continuous movement of the platform prevents subjects from relying on the support surface as a stable reference for balance, as occurs in a bottom-up mode of postural control. Rather, it forces them to use vestibular input in a top-down mode.[33] The anticipatory postural adjustments seem to depend on normal vestibular function, as suggested by the abnormalities in postural coordination observed in vestibular patients standing on the moving platform.[25,26] Second, in the recovery process of vestibular patients, slower exercises are likely to be more effective than faster exercises.[34] The head displacements induced by the continuous translatory displacement of the support surface of our moving platform are infrequent[26] and appear appropriate to train these patients. Third, encouraging results have been already obtained by using treadmill or other movable platforms to improve the balance of elderly subjects[35,36] and patients with neurologic diseases,[30,37] but such instrumental rehabilitation has not been tested in vestibular disease. We hypothesized that training vestibular patients by a repeated administration of continuous perturbation[25-27] would help improve their balance and dizziness at least as much as training with conventional vestibular exercises. To test our hypothesis, we compared the outcomes of 2 groups of patients with similar vestibular deficits. One was treated with a full set of Cawthorne-Cooksey exercises and the other with the movable platform training. Both treatments were performed on an inpatient basis because standing balance can be improved more with supervised treatment than without it.[16,38]

Most researchers studying the mechanisms of recovery from and rehabilitation for vestibular deficit focus on bilateral vestibular deficit.[15,39,40] The more frequent unilateral vestibular deficit is erroneously considered only a transitory balance deficit that spontaneously recovers without rehabilitation. Unilateral deficit also leads to a postural syndrome that involves, especially, head and trunk coordination.[41] Although recovery is fast (within days) in patients with unilateral deficits as far as static symptoms (ie, symptoms not due to motion) are concerned, patients' ability to respond to dynamic vestibular stimuli does not recover spontaneously.[41-43] Patients with unilateral chronic deficit or uncompensated loss are good candidates for vestibular rehabilitation,[16,21] even if they have had dizziness and imbalance for more than 5 years.[10] In the present study, we assessed the efficacy of 2 types of treatment in patients affected by either complete or incomplete unilateral vestibular deficit with variable duration of the disease.

Most prospective studies have used force platform assessment (posturography) as the main outcome measure to show an improvement in postural stability.[16,39,44,45] However, this measure examines standing balance only. Further, when changes in posturography are compared with static balance tests and with functional performance tests in patients with vestibular disease undergoing exercise training, modest correlations are found.[46] This result is not surprising because there is no evidence to assume that a test in which the patient is asked to stand as quietly as possible should correlate with a functional assessment of gait. In the present study, posturography was only part of a larger number of outcome measures. We also assessed postural stabilization under dynamic condition and functional balance and gait evaluation, and we had the patients give a subjective assessment of their stability. Preliminary results have been previously published.[47-49]

METHODS

Participants

Thirty-two patients (16 men, 16 women) with a mean age ± standard deviation (SD) of 58.9±12.9 years, reporting imbalance due to a unilateral vestibular deficit, were included in the study (table 1). Mean height and weight were 164.8±11.0cm and 72.3±14.0kg, respectively.

Patients were hospitalized in the Division of Physical Therapy and Rehabilitation of the Institute of Veruno, Novara, Italy. They were transferred either from the ear, nose, and throat department of a nearby hospital or from the department of balance disorders of the Institute of Veruno. Subjects were still complaining of imbalance at study enrollment (see table 1). Admission criteria were that patients must not have had either rehabilitation treatment or chronic pharmacologic treatment for vertigo in at least the previous 3 months. Exclusion criteria were simultaneous occurrence of central or peripheral neurologic disease and postural imbalance due to benign positional vertigo.

The etiology of the vestibular impairment was multifactorial as a result of an acute deficit (ischemic, inflammatory, traumatic) or was due to neurinoma or section of cranial nerve VIII (see table 1). In 5 patients, the etiology was undetermined. Determination of the etiology was certain in the patient groups with neurinoma and traumatic brain injury, whereas in the case of ischemic or inflammatory cause,[50] clinical features such as patients' age, signs accompanying symptoms, and duration of the acute stage allowed for a presumptive diagnosis to be made according to published criteria.[51,52]

Confirmation of the diagnosis of complete or incomplete unilateral vestibular lesion was based on clinical and instrumental examinations, according to the following clinical findings: (1) positive Romberg and/or Fukuda tests; (2) abnormal voluntary eye movements while the patient gazed at a target in 9 fixed positions in the frontal plane and during saccadic or smooth pursuit eye movements in the horizontal plane; (3) nystagmus as determined with Frenzel's glasses while the patient was seated, gazing straight ahead or laterally, and in the supine position face up, on the left and on the right sides, and in the Rose position (supine, hyperextended head); (4) positional nystagmus, due to posterior and horizontal semicircular canal, as determined, respectively, by Dix-Hallpike and McClure tests; (5) asymmetry of vestibular response to head

Table 1: Patient Characteristics

Patient No.	Age (y)	Sex	Etiology	Duration	Fukuda	HSN	Caloric	Treatment
1	51	M	Neurinoma VIII	18y	Normal	Absent	cR	CC
2	68	F	Undetermined	5y	Normal	L	Normal	CC
3	72	F	Ischemia	3y	L	R	cL	CC
4	56	M	Undetermined	3y	R	L	pR	CC
5	60	M	Undetermined	3y	Normal	L	pR	CC
6	75	M	Ischemia	20mo	Normal	L	cL	CC
7	54	F	Ischemia	12mo	L	R	Imposs	CC
8	18	M	Head trauma	8mo	Normal	L	cR	CC
9	70	F	Neurinoma VIII	7mo	L	R	cL	CC
10	69	F	Undetermined	5mo	Normal	L	Normal	CC
11	64	F	Ischemia	4mo	Imposs	R	cR	CC
12	77	F	Ischemia	3mo	Normal	L	pR	CC
13	54	F	Inflammatory	37d	Imposs	R	pL	CC
14	72	M	Meniere's	30d	L	R	cL	CC
15	64	F	Inflammatory	28d	Imposs	R	pL	CC
16	52	M	Inflammatory	15d	L	R	cR	CC
17	34	M	Inflammatory	12d	L	Absent	cL	CC
18	59	F	Ischemia	15y	L	R	Normal	IR
19	62	M	Ischemia	15y	R	Absent	pR	IR
20	47	F	Meniere's	13y	R	R	cL	IR
21	35	M	Neurinoma VIII	9y	No data	No data	cR	IR
22	49	F	Undetermined	9y	Normal	R	pR	IR
23	62	F	Inflammatory	3y	Normal	L	Normal	IR
24	72	M	Ischemia	2y	R	L	Normal	IR
25	65	F	Ischemia	21mo	Normal	L	pR	IR
26	68	M	Head trauma	9mo	Imposs	R	Imposs	IR
27	53	F	Inflammatory	2mo	L	No data	pL	IR
28	53	M	Inflammatory	2mo	Normal	L	Normal	IR
29	68	F	Ischemia	2mo	Normal	L	pL	IR
30	66	M	Ischemia	38d	Imposs	Absent	cR	IR
31	62	M	Ischemia	28d	R	Absent	pL	IR
32	54	M	Ischemia	9d	Normal	R	cL	IR

Abbreviations: Caloric, result from caloric test; CC, Cawthorne-Cooksey; cL, complete left paresis; cR, complete right paresis; F, female; HSN, head-shaking nystagmus; Imposs, impossible to perform; IR, instrumental rehabilitation; L, left; M, male; pL, partial left paresis; pR, partial right paresis; R, right.

acceleration in the horizontal plane, as determined by the head-shaking nystagmus test; and (6) the caloric test, which was scored according to the following formula:

$$\text{(difference in the number of beats after right and left irrigation with warm water)} \div \text{(sum of number of beats after right and left irrigation with warm water).}^{53}$$

Patients were assigned to groups before the basal measurements were made: the group treated with the traditional exercise method (Cawthorne-Cooksey, $n=17$; mean age, 59.5 ± 15.4y)[13] or the group treated with the translating platform (instrumental rehabilitation, $n=15$; mean age, 58.3 ± 9.8y). The age difference between the 2 groups was not significant. Table 1 shows that the various etiologic conditions of the vestibular deficit were rather homogeneously distributed between the 2 groups. The Cawthorne-Cooksey and instrumental rehabilitation groups were composed, respectively, of 5 and 8 patients with previous ischemic acute deficit, 4 and 3 with an inflammatory acute deficit, 4 and 1 with deficit of undetermined origin, and 2 and 1 with vestibular deficit after surgery for acoustic neurinoma. Further, each group included 1 patient with vestibular deficit after head trauma and 1 with Meniere's disease (without acute attacks for >10y).

A group of age-matched (57.7 ± 11.6y) and sex-matched (116 men, 103 women) healthy subjects was taken from the laboratory database. Their mean height and weight were 156.2 ± 8cm and 70.3 ± 10.3kg, respectively. The number of the control subjects participating in the study differed for the various tests performed; the sample size of healthy subjects is reported in the relevant paragraphs dealing with the various comparisons.

Outcome Measurements

All patients included in this study were hospitalized and underwent a series of functional and self-evaluation scales and instrumental tests immediately before and at the end of treatment. The local ethics committee approved the experimental procedure.

Stabilometry. Body sway during quiet upright stance was recorded with a Kistler (type 9281B)[a] dynamometric platform. Each trial lasted 51 seconds; during this period, subjects were asked to stand upright and barefoot on the platform as still as possible with arms at their sides. Each subject was tested under 2 conditions: (1) visual, eyes open (EO) and eyes closed (EC), and (2) postural, feet parallel 10cm apart (FA) and feet close together (FT). Each subject performed 2 trials for each condition. For each condition, data from vestibular patients were compared with data obtained from age-matched normal subjects (FA, 219 controls; FT, 88 controls). Force signals were converted from analog to digital (sampling rate, 10Hz) and fed into a computer. The following variables were computed off-line: (1) the position of the instantaneous foot center of pressure (COP); (2) the projection of the foot COP on the sagittal (foot COPx) and frontal (foot COPy) planes ± the respective standard deviation (SDx, SDy); (3) the sway path, or distance covered during the trial by the moving foot COP; and (4) the sway area, or the surface swept by the line joining the mean foot COP to the instantaneously moving foot COP.[54] The mean data obtained by averaging the values of the 2 trials performed under each postural and visual condition were then calculated. Because SDx, SDy, sway path, and path velocity correlated positively with sway area, both in the control and patients groups, we analyzed sway area alone as a synthetic measure of body sway. Because sway area values were not distributed in a normal fashion, the $\log_{10}$ of the sway area value was considered for further analysis.

Subjective evaluation of stability during quiet stance. In accordance with a recently developed method in our laboratory,[55] at the end of each stabilometric trial, patients were asked to score their own balance performance. Scores ranged from 10 ("I felt really still as if holding onto a stable frame") to 0. By way of example, a medium score (5) would correspond to the sensation felt by a normal subject standing in upright position with 1 foot placed in front of the other on the same line; 0 could be scored by a subject standing on 1 leg with EC and eventually putting down the other foot. Two scores for each postural (FA, FT) and visual (EO, EC) condition were performed. The mean score obtained by averaging the subjective evaluation of the 2 trials performed under each condition was considered for further analysis.

Evaluation of balance during sinusoidal translation of the supporting surface. Under this condition, subjects stood upright for 30 seconds on a platform that moved continuously 60mm forward and backward on the horizontal plane at a frequency of sinusoidal translation of 0.2 or 0.6Hz.[26] Subjects were required to keep their balance with the EO then EC conditions. Two trials for each frequency and visual condition were performed. Body and head were aligned in the direction of platform displacement. The first 10 seconds of platform displacement were not recorded, to avoid unpredictable startling effects of displacement onset. Subjects were not secured by a harness during the session, to avoid altering the postural set[56] by any unnatural feeling of stability. However, a technician stood by the side to support the patient in case of possible loss of balance. Body movements were recorded through the detection of 3 infrared light-emitting diodes (LEDs) placed on the lateral malleolus, the greater trochanter (hip), and the temporomandibular joint (head). The LEDs were detected through an optoelectronic device (CoSTEL),[b] which recorded their position through 3 cameras. The LED signals were sampled at a frequency of 50Hz. A software program reproduced off-line the time course of the displacement of the LEDs along the AP axis. We also calculated the SD of the average displacement throughout the acquisition period. The SD of the LED signals was considered as a synthetic way of expressing an average range of displacement of head and hip, because the SD value was influenced both by the absolute periodic displacement and by other shifts in space not directly connected to the shift of the platform.[26] The mean SDs obtained by averaging the values of the 2 trials performed under each frequency and visual condition were then considered for further analysis. Data from vestibular patients were compared with data from a group of 35 healthy subjects.

Clinical evaluation of balance and gait. The balance and gait evaluation was performed according to the Performance-Oriented Assessment of Balance and Gait.[57,58] This assessment is divided into 2 sections: one tests balance (13 items), and the other tests gait (9 items). A trained physiotherapist scored the performance for each item. The maximal score of the balance section is 26, and that of the gait section is 11.

Self-evaluation of feeling of dizziness during daily living. The Dizziness Handicap Inventory[59] (DHI) was administered to all patients. The DHI consists of 25 questions concerning the presence of dizziness during performance of specific movements (physical questions) and during normal daily life activity (functional questions) and concerning the emotional impact caused by dizziness symptoms (emotional questions). Answers to each item were scored 4 if dizziness was present all the time, 2 if it was present sometimes, and 0 if it was never present.

Rehabilitation Procedures

To perform the supervised rehabilitation sessions twice a day, all patients were hospitalized. The conventional rehabilitation was performed in the gymnasium, and the instrumental rehabilitation was performed in the posture and movement laboratory. All study participants were able to complete the entire rehabilitation program. The 2 subject groups treated with either Cawthorne-Cooksey exercises or instrumental rehabilitation underwent 10 sessions, with 2 sessions daily (morning, afternoon), for 5 consecutive days. Each session lasted 30 minutes for both exercises. For the rest of the day, the patients were not engaged in any other rehabilitation program.

Cawthorne-Cooksey exercises are based on a series of exercises of increasing complexity involving first eye and head movements and then movements of the whole body while lying down, sitting, and in the upright position both with EO and EC.[13] The full set of these exercises was administered to the patients: each exercise was repeated 5 times, first in the EO condition and then in the EC condition.

For instrumental rehabilitation, subjects were required to stand upright on the same movable platform used for balance evaluation, either with the EO or EC condition, with the body oriented first in the same direction as the platform motion and then perpendicular to it. The platform sinusoidally moved forward and backward for a total excursion of 60mm, at a frequency of 0.2 or 0.6Hz.[26] During each session, 8 trials were performed (ie, 1 trial of approximately 3min for each body orientation and visual and frequency condition). Subjects were not secured by harnesses during the session. However, a physiotherapist stood by the side to support the patient in case of loss of balance. Less than 1 minute of rest elapsed between trials.

Experimental Design

The main study was an A-B design (pre- vs postrehabilitation evaluation), with subjects randomized into 2 intervention groups. Allocation to a particular treatment group was done sequentially and before clinical examination. Eleven patients were tested a month before admission to the hospital for the rehabilitation treatment, at study commencement, and at completion study in an A-A-B experimental design to control for spontaneous recovery. Nine patients were tested at the beginning and end of the rehabilitation and 1 month after hospital discharge, in an A-B-B design, to study retention or carryover effects. The researcher who performed in the analysis of the results had no knowledge of the type of rehabilitation procedure.

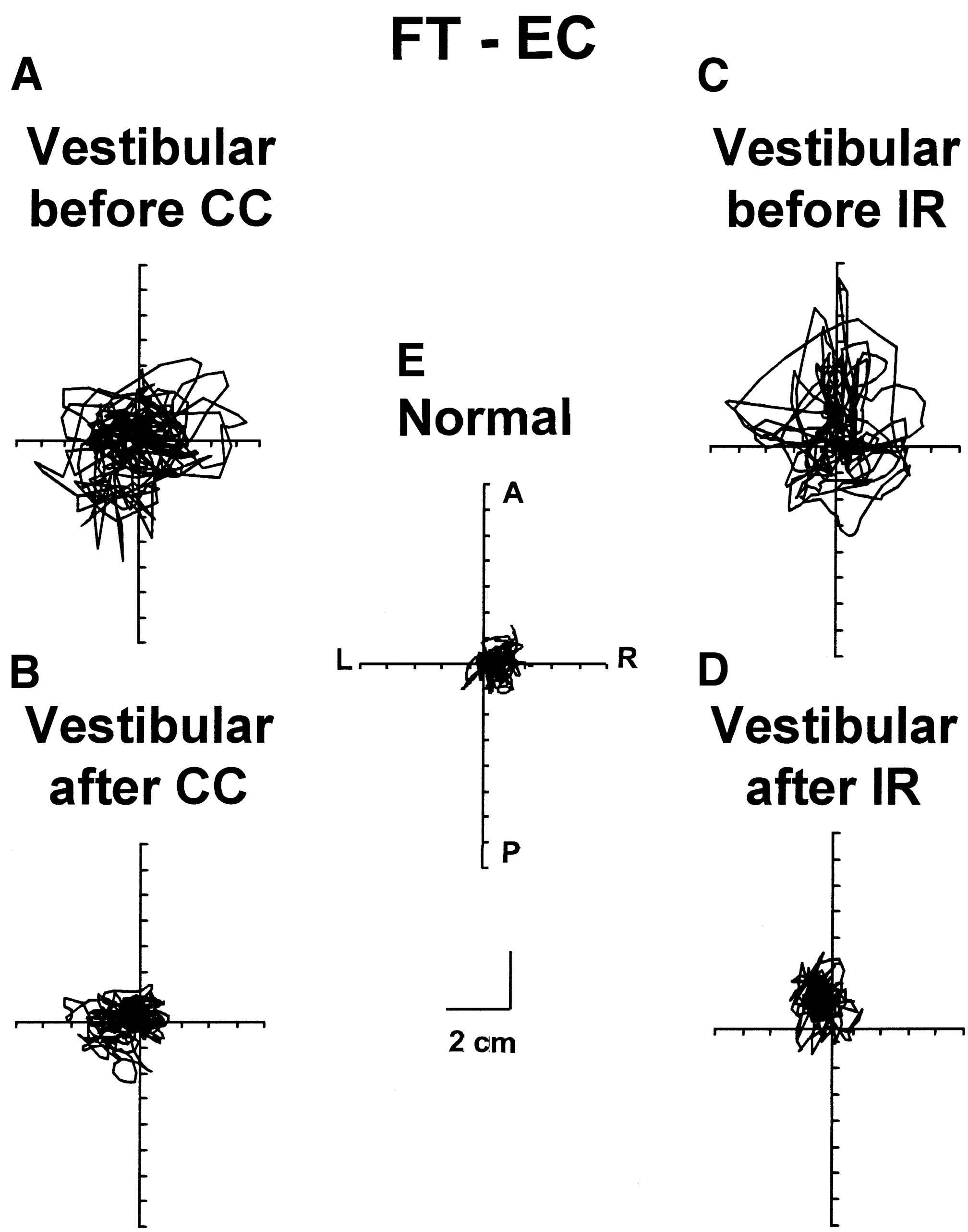

Fig 1. Example of stabilometric recordings performed with FT and EC in a vestibular patient (A) before and (B) after Cawthorne-Cooksey exercises (CC), in another patient (C) before and (D) after instrumental rehabilitation (IR) on the movable platform, and (E) in a representative healthy subject. Direction of sway is reported (anterior [A], posterior [P], left [L], right [R]).

Statistical Analysis

Body sway area values during quiet stance were logarithmically transformed to use parametric statistics. An analysis of variance (ANOVA) between the 2 treatment groups (Cawthorne-Cooksey, instrumental rehabilitation), using 2 postural conditions (FA, FT) by 2 visual conditions (EO, EC) as independent variables and before and after rehabilitation evaluations as 2 repeated measures, was performed. The head and hip movements (ie, the SDs of their AP displacement) during periodic postural perturbations were also analyzed by ANOVA between 2 treatment groups (Cawthorne-Cooksey, instrumental rehabilitation) by using 2 frequency conditions (0.2, 0.6Hz) by 2 visual conditions (EO, EC) as independent variables and before and after rehabilitation evaluations as 2 repeated measures. When ANOVA gave significant results, the Newman-Keuls post hoc test was performed. For sway area and SD of segment displacement, each patient entered the analysis with the mean value of the 2 trials performed under each condition, both before and after treatment. When scores were compared (subjective evaluation of stability during quiet stance, clinical evaluation of balance and gait according to Tinetti, self-evaluation of dizziness [DHI] during daily living), a nonparametric method was applied. In particular, the Wilcoxon matched-pairs test was used to compare data before and after treatment within the same patient groups. To compare the Cawthorne-Cooksey and instrumental rehabilitation groups before or after rehabilitation, we used the Kolmogorov-Smirnov test. The relation between subjective evaluation of stance and sway area was analyzed by simple regression analysis. Comparison of slope and parallelism between different regression lines fitted

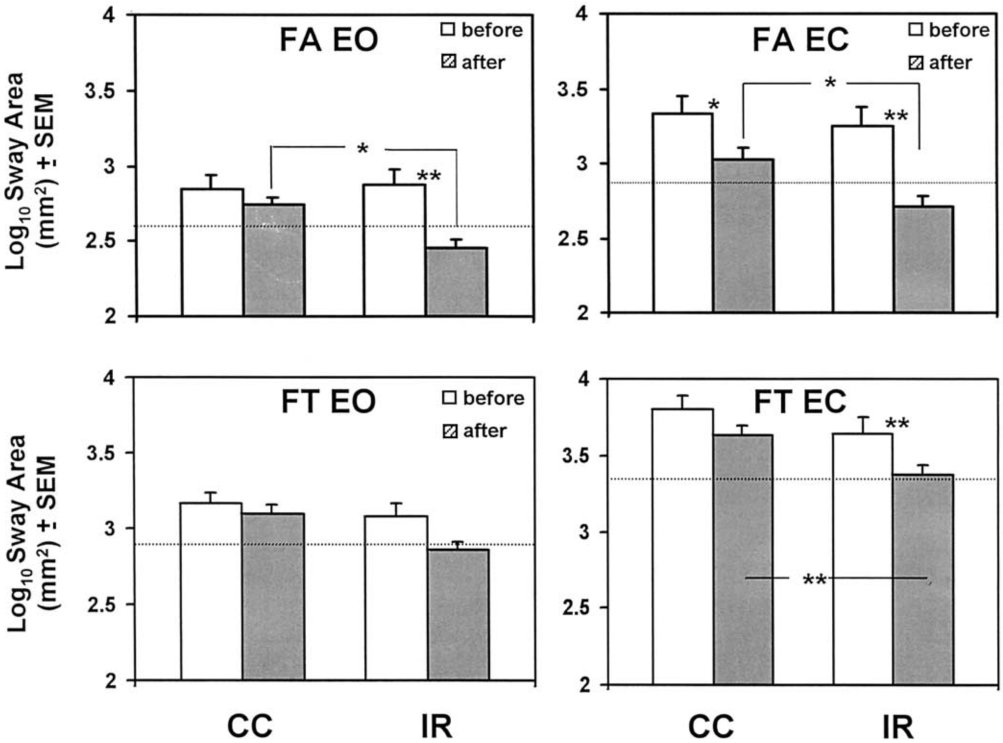

Fig 2. Results of static balance testing under all conditions. Normalized ($\log_{10}$) mean body sway area ± SEM was obtained from stabilometric recordings performed during quiet stance under the 4 experimental conditions: FA or FT with EO or EC. *$P<.05$; **$P<.01$ (Newman-Keuls post hoc test).

through the data points was performed, respectively, by ANOVA and analysis of covariance (ANCOVA).[60] For all statistics, results were considered significant at *P* less than .05. We used Statistica[c] software for statistical analysis.

RESULTS

Stabilometry

An example of a stabilometric recording performed under the FT and EC condition of 2 representative vestibular patients who underwent the Cawthorne-Cooksey rehabilitation method and the instrumental rehabilitation method is reported in figure 1. Note the decrease of body sway in both patients after rehabilitation with respect to before treatment evaluation, approaching the normal value (fig 1E).

Figure 2 shows the average value of sway area ± standard error of the mean (SEM) under all visual and postural conditions. All patients were able to perform the test under each condition before and after treatment. The values of sway area recorded before treatment are similar between the 2 groups of patients but larger than the 95th percentile of normal subjects (dotted line). Note the decrease in sway area under all conditions in both patients treated with Cawthorne-Cooksey or instrumental rehabilitation with respect to the values recorded before treatment. In both groups of patients, decrease of sway area approaches normal values. Under all conditions except FT EO, patients treated with instrumental rehabilitation show a larger decrease of sway than those treated with the Cawthorne-Cooksey method. These findings were confirmed by statistical analysis. ANOVA of the sway area mean value obtained before treatment produced a significant difference among the 3 groups (normal, Cawthorne-Cooksey, instrumental rehabilitation) of the subjects ($F_{2,660}=97.3$, $P<.00001$). Under all postural and visual conditions, the post hoc test showed sway area values significantly ($P<.01$) larger in the group of normal subjects. No significant difference was found between the 2 groups of patients under any testing condition.

Analysis of sway area changes observed before and after rehabilitation in the Cawthorne-Cooksey and instrumental rehabilitation groups showed a significant decrease of sway ($F_{1,113}=59.1$, $P<.00001$) after rehabilitation compared with before rehabilitation (all conditions collapsed), a significant effect of patient group ($F_{1,113}=11.8$, $P<.001$), and a significant effect of the postural ($F_{1,113}=68.6$, $P<.00001$) and visual ($F_{1,113}=80.0$, $P<.00001$) conditions. A significant interaction ($F_{1,113}=8.0$, $P<.005$) was found between the patient groups and time of testing (before and after rehabilitation): post hoc comparison of sway area between the 2 groups showed a significantly ($P<.05$) greater decrease of sway area in the instrumental rehabilitation group with respect to the Cawthorne-Cooksey group under FA EO, FA EC, and FT EC conditions.

To show that sway reduction after rehabilitation was not due to chance or to a time effect, we tested 11 patients (6 from the Cawthorne-Cooksey group, 5 from the instrumental rehabilitation group) a month before the treatment started (fig 3A). Apart from 2 patients in whom a small spontaneous reduction in sway area was evident, there was no time effect in sway area (fig 3A). Comparison of sway area values with those recorded immediately before the onset of rehabilitation showed no spontaneous reduction in sway area. In contrast, a striking decrease of body sway occurred at the end of treatment. Five patients, who showed no increase in sway area before training, did not show appreciable changes after treatment. Nine patients (3 from the Cawthorne-Cooksey group, 6 from the instrumental rehabilitation group) also underwent a follow-up recording session approximately a month after treatment (fig 3B). The sway area values recorded at the end of treatment and 1 month after treatment ended did not differ significantly; that is, the

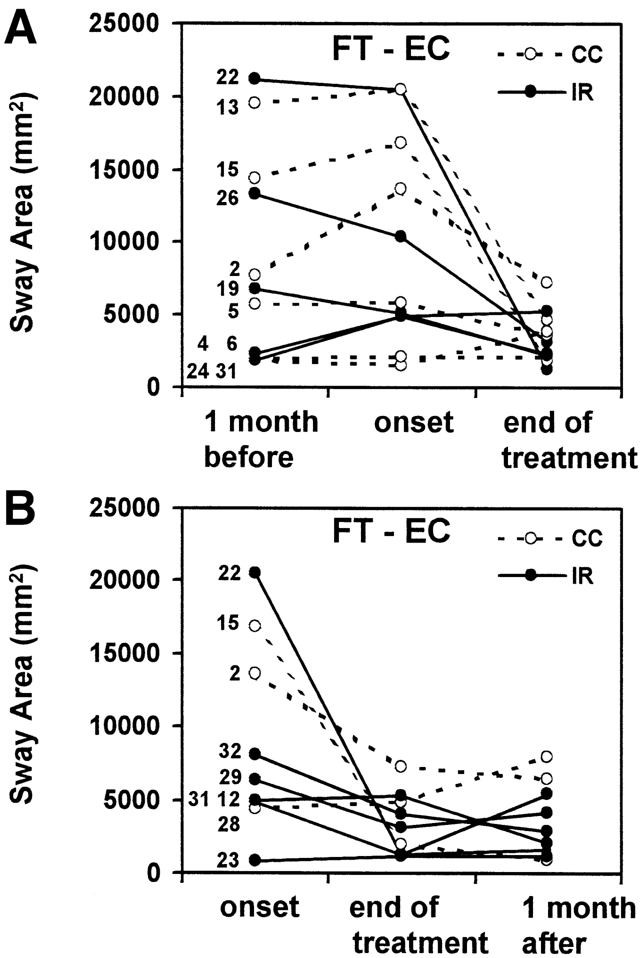

Fig 3. Stabilometric findings at different evaluation times: (A) posturography results a month before the initiation of the treatment (n=11, A-A-B design) and (B) after the end of treatment (n=9, A-B-B design). Each series of 3 symbols corresponds to the changes in sway area recorded in a patient treated with Cawthorne-Cooksey or instrumental rehabilitation under the FT and EC condition. The numbers on the left of each trace correspond to the patients listed in table 1.

improvement observed after treatment persisted for at least a month.

One-way ANOVA was performed on sway area values, pooled from all visual and postural conditions, across the following observation times: a month before the start of treatment, at the onset of treatment, at the end of treatment, and a month after treatment ended. Results showed a significant effect of the sequence of observation (F_3=13.7, $P<.0001$). The post hoc test was significant ($P<.005$) in the comparison of the sway area values between onset and end of treatment. Conversely, the comparison of the sway area values between 1 month before and at the time of treatment and the comparison of the sway area values between the end of treatment and 1 month afterward did not differ significantly.

A regression was made between the percentage of change in sway area after rehabilitation and type or duration of disease. No effect of type or duration of disease was observed (all postural and visual conditions collapsed) in either treatment group.

Stability During Quiet Stance

At the end of each stabilometric trial, both before and after rehabilitation treatment, all participants were asked to judge their performance by using the criteria described in the Methods section. Statistical analysis of the data showed no significant difference (Kolmogorov-Smirnov test) between the 2 groups before treatment (figs 4A, B). After rehabilitation both groups showed a highly significant (Wilcoxon matched-pairs test, $P<.00001$) increase in mean score, a sign of higher self-confidence in balance. This improvement was true under all tested conditions (EO, EC, FA, FT), and the improvement was similar in both patient groups. There was a good match in the decrease of sway area and in the improvements in the feeling of stability (compare figs 2 and 4). Both groups showed increased feelings of steadiness at the end of treatment as compared with before treatment. The increased feeling of steadiness was similar in both groups.

To check whether a correspondence existed between increased self-confidence and improved balance control, we studied the relationship between sway area values and scores before and after treatment (fig 5). Before treatment, subjective feeling of stability correlated linearly with sway area values (all visual and postural conditions collapsed). The slope of the regression lines fitted through the data points was significant ($P<.00001$) and similar for both patient groups (ANOVA, P=not significant [NS]). After rehabilitation, the linear relationship between sway area and score remained negative in both groups and similar to the before-treatment value (ANOVA, P=NS). However, the significant upward shift of the data points (ANCOVA, $P<.00001$) indicates an average better scoring for equal sway. The difference in the intercept of the regression lines was similar for the Cawthorne-Cooksey and instrumental rehabilitation groups (ANCOVA, P=NS) both before and after treatment.

Balancing During Sinusoidal Translation of the Supporting Surface

Figure 6 shows the behavior of 2 vestibular patients, one treated with Cawthorne-Cooksey exercises and the other with instrumental rehabilitation. The figure shows the displacement of malleolus, hip, and head that occurred when the patient stood, eyes closed, on a platform that continuously moved in

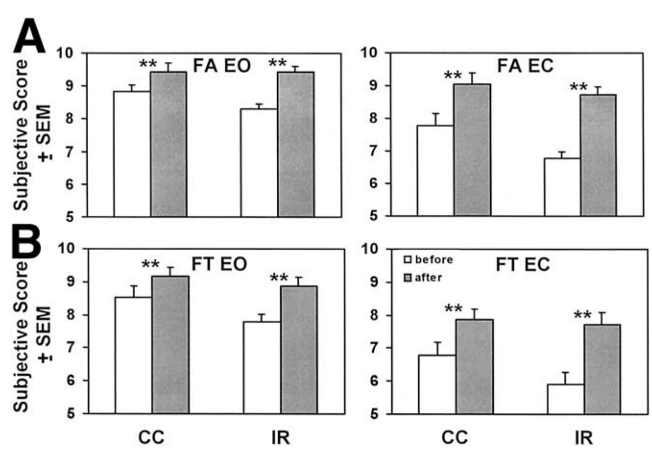

Fig 4. Subjective evaluation of stability during quiet stance with (A) FA and (B) FT, showing the grand average ± SEM of the subjective score for all postural and visual conditions before and after rehabilitation. **$P<.01$ (Newman-Keuls post hoc test).

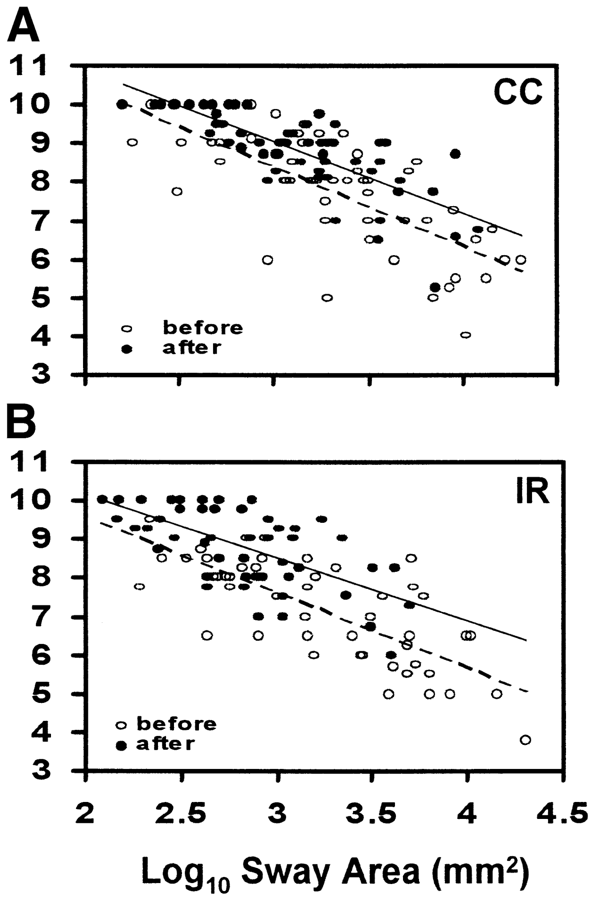

Fig 5. Relation between subjective evaluation of stability and body sway area during quiet stance for (A) Cawthorne-Cooksey exercises and (B) instrumental rehabilitation. A significant negative linear regression existed between score of stability and log$_{10}$ of sway area (all 4 conditions pooled together). Before rehabilitation, both groups of patients had proportionally smaller scores (dashed line; CC: $y=-2.08x+14.67$, $P<.00001$, $R^2=.51$; IR: $y=-2.03x+13.74$, $P<.00001$, $R^2=.56$). After rehabilitation, the reduction of sway area produced an increase of subjective scores for the same range of sway area, without significant changes in the slope of the regression line (continuous line; CC: $y=-1.84x+14.57$, $P<.00001$, $R^2=.59$; IR: $y=-1.64x+13.45$, $P<.00001$, $R^2=.40$).

the AP direction at a 0.2-Hz frequency. The stick figures beside each graphset are synthetic representation of the displacement of those body segments. For comparison, the normal upper confidence limits (arrows) of the SD of malleolus, hip, and head displacement are shown. As reported in previous studies[25,26] in normal subjects the head was less stable in space than the hip when vision was occluded. The stick figures show that, in both patients before treatment, the SDs of the hip and head were larger than the upper confidence limit of the corresponding body landmark.

Before treatment, several patients were unable to balance with their eyes closed on a platform whose perturbation frequency was 0.6Hz. We found that 53% and 69% (χ^2=NS) of patients in the Cawthorne-Cooksey and instrumental rehabilitation treatments, respectively, either lost their balance or stepped off the support base. Only the findings obtained in those patients who could withstand the trials both before and after rehabilitation entered the analysis, the results of which are summarized in figure 7. In those patients able to perform the test before treatment, the SD of head and hip displacement was larger than that in the healthy subjects, though the overall pattern of oscillation was similar to normal: ANOVA of SD of head and hip displacement produced a significant group effect (head, $F_{2,167}=23.8$, $P<.00001$; hip, $F_{2,168}=19.2$, $P<.00001$). Results of the post hoc test differed significantly ($P<.05$) between patients and healthy controls for displacement SD of head and hip only under a 0.6-Hz perturbation frequency, both with EO and EC. No significant difference in displacement SD of head and hip was found between the 2 groups of patients.

Figure 6 shows that after rehabilitation, the 2 representative patients treated with Cawthorne-Cooksey or instrumental rehabilitation reduced their displacement SD of head and hip to within the normal upper limit. After treatment, all patients could withstand the trials, both those treated with Cawthorne-Cooksey (except 1 for the 0.6-Hz EC condition) and those treated with instrumental rehabilitation. Furthermore, a general reduction of head and hip displacement was found under all conditions after rehabilitation in both groups (head, $F_{1,92}=23.6$, $P<.000005$; hip, $F_{1,92}=13.0$, $P<.0005$). Only under the 0.6-Hz perturbation frequency with the EC condition was the decrease of SD of head and hip significantly (post hoc test, $P<.05$) larger in the instrumental rehabilitation group than in the Cawthorne-Cooksey group. Figure 7 shows the average patients' behavior with EC: the horizontal dotted lines indicate the upper confidence limit of head and hip displacement in the healthy subjects. Both head and hip reduced their displacement after treatment, to a larger extent after instrumental rehabilitation than Cawthorne-Cooksey exercises.

Balance, Gait, and Dizziness During Daily Living Activities

Before rehabilitation, the scores of the Performance-Oriented Assessment of Balance and Gait according to Tinetti was similar (Kolmogorov-Smirnov test) between patient groups (figs 8A, B). After treatment, each patient showed an improvement: both the mean balance and mean gait scores showed a significant (Wilcoxon matched-pairs test, $P<.000005$) improvement. The improvement was similar (Kolmogorov-Smirnov test) for both groups.

Before rehabilitation, DHI total score was similar between patients undergoing Cawthorne-Cooksey exercises or instrumental rehabilitation (Kolmogorov-Smirnov test) (fig 8C). After rehabilitation, the DHI score showed a significant reduction in symptoms (Wilcoxon matched-pairs test, $P<.002$). Both groups demonstrated a significant improvement in the subjective feeling of dizziness. The comparison of data obtained after rehabilitation showed no difference between the 2 patient groups (Kolmogorov-Smirnov test). However, patients treated with Cawthorne-Cooksey exercises or instrumental rehabilitation decreased their DHI scores by approximately 14 or 27 points, respectively. According to Newman and Jacobson,[61] only a reduction larger than 18 points in DHI score is considered significant; therefore, we concluded that, on average, the instrumental rehabilitation intervention produced a significant change in patients' self-perceived balance handicap.

DISCUSSION

The general results substantiate the value of rehabilitation in patients complaining of imbalance or dizziness of vestibular origin[12,45]: patients in both groups improved their postural control. The improvement was measurable both subjectively (increased self-confidence during maintenance of quiet upright stance under both the EO and EC conditions; decreased feeling of dizziness) and objectively (decreased body sway area, better

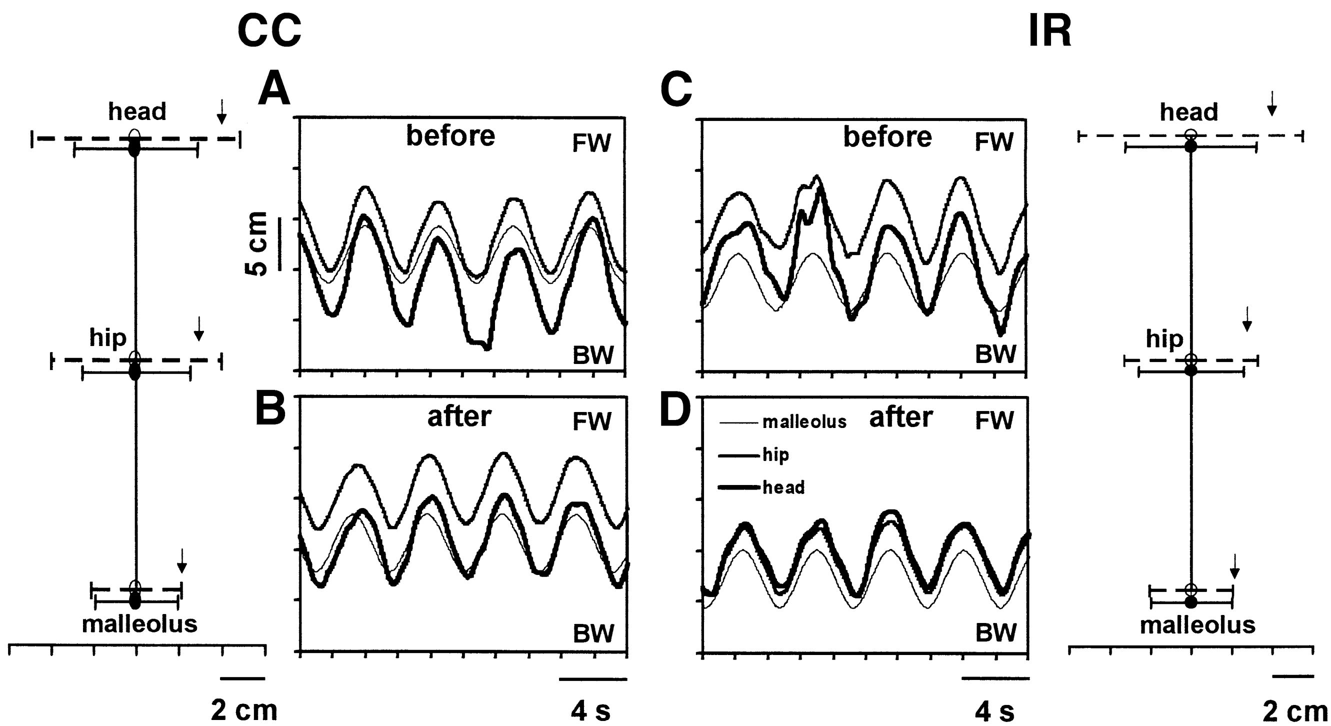

Fig 6. Dynamic balance test in 2 vestibular patients under the EC condition, at 0.2Hz showing the malleolus, hip, and head horizontal displacement in 1 patient (A) before and (B) after Cawthorne-Cooksey exercise and in another patient (C) before and (D) after instrumental rehabilitation. The offset of the traces is due to the different AP position of the body along the platform. Direction of displacement: BW, backward; FW, forward. The insets show the SD values of the malleolus, hip, and head before (dashed lines) and after (continuous lines) treatment in the corresponding patients compared with the 95th percentile of the relevant SDs from healthy subjects (arrows).

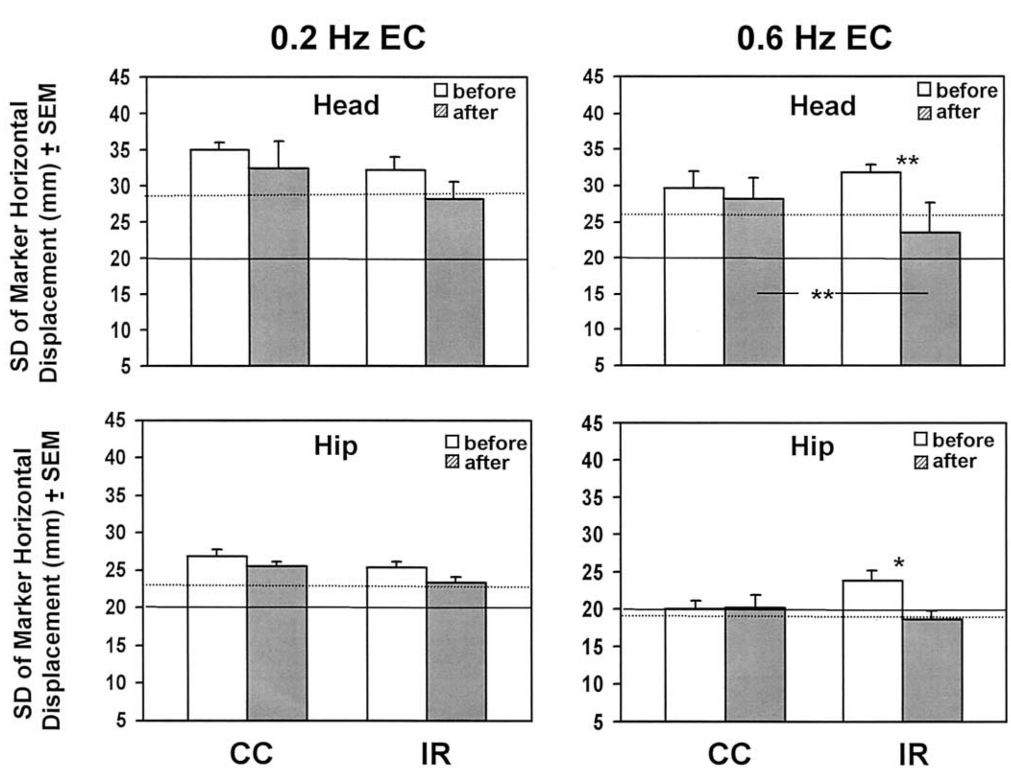

Fig 7. Dynamic balance test performed, EC, under 0.2- and 0.6-Hz perturbation conditions, showing the mean SD ± SEM of horizontal displacement of head (top) and hip (bottom). The displacement of head and hip recorded before treatment was similar between the 2 groups of patients but was larger than the 95th percentile of healthy subjects (dotted line). Displacement was decreased under all conditions in both groups of patients, with respect to the values recorded before treatment, approaching the values in normal subjects. Hip and head displacement were reduced significantly only in the instrumental rehabilitation group. *$P<.05$; **$P<.01$ (Newman-Keuls post hoc test). The continuous line in each graph shows the SD of displacement of malleolus, which is fixed with respect to platform movements.

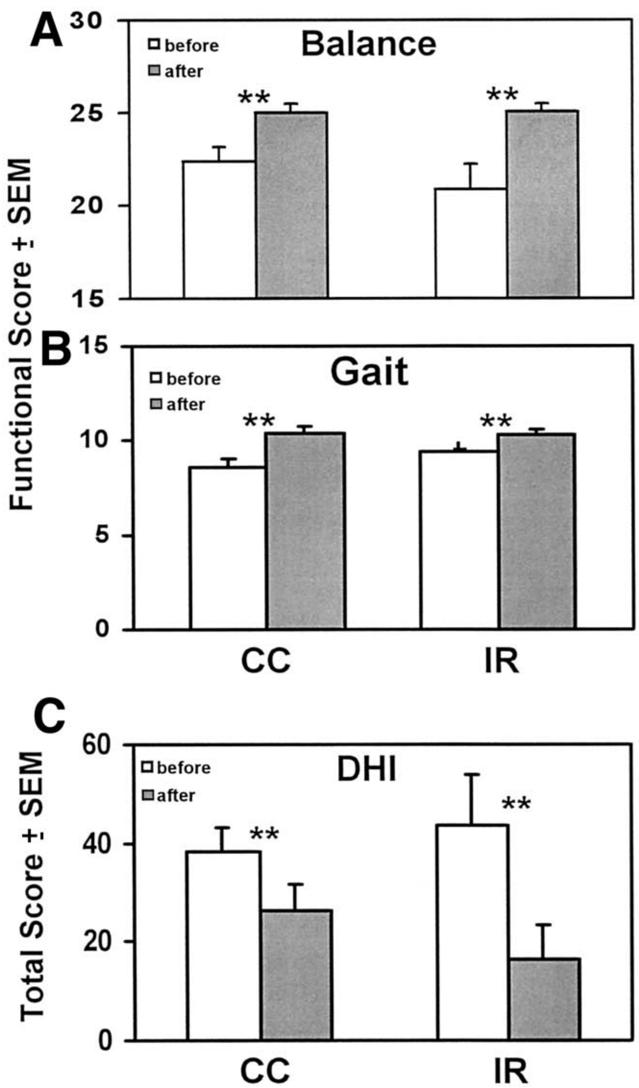

Fig 8. Mean scores ± SEM of the Tinetti balance and gait assessment and of the DHI: the performance-oriented assessment of (A) balance and (B) gait and (C) the total score obtained from the sum of physical, functional, and emotional questions. **$P<.01$ (Wilcoxon matched-pairs test).

stabilization of body segments during platform perturbation, higher scoring of functional balance and gait evaluations). Moreover, both types of balance rehabilitation proved to be effective in recovering balance and gait performances during activities of daily living (ADLs) and in decreasing the feeling of dizziness.

Instrumental rehabilitation appeared to be as effective as Cawthorne-Cooksey exercises in improving functional performance in balance and gait tasks, as assessed through the Tinetti evaluation. The similar level of improvement suggests that both types of rehabilitation programs ameliorate both the feedback and feed-forward neural circuits underlying postural coordination[32] in balance control during common motor tasks of daily living. Indeed, Cawthorne-Cooksey exercises feature gross head and trunk movements. Such movements produce anticipatory postural adjustments and also trigger reflex postural adjustments (see Massion[62]). Similarly, during training on the continuously moving platform, patients must rely on both feed-back and feed-forward control of posture.[30,31] In this way, they produce an adequate motor output to coordinate the various degrees of freedom of body joints aimed to maintain the projection of the center of gravity within the base of support.[32]

The larger decrease in sway area of quiet stance after instrumental rehabilitation suggests that it is more effective than Cawthorne-Cooksey exercises in improving the mechanisms important for balance control during quiet stance and not directly assessed by the Tinetti evaluation. Instrumental rehabilitation, which implies active control of body movements while standing on a continuously moving platform, likely has the capacity of leading to smaller and smaller upper-body movements, thereby inducing a decrease of body sway also during quiet stance. In contrast, Cawthorne-Cooksey exercises emphasize active movements, which would increase movement of the center of mass (COM) over the base of support, thereby actively reconfiguring the control of the COM over the base of support. This may lead to Cawthorne-Cooksey exercises having a minor effect on body sway during quiet stance, compared with instrumental rehabilitation. In this context, instrumental rehabilitation may be superior to Cawthorne-Cooksey exercises for treating the vestibular problems that are most disturbing while standing upright.

Both Cawthorne-Cooksey and instrumental rehabilitation significantly ameliorated the balance coordination and body AP oscillations, as tested during the dynamic task of standing on the moving platform. In turn, the improvement (less oscillation) was significantly larger in the instrumental rehabilitation case. Of course, part of the effect on head and hip stabilization while on the platform after the instrumental rehabilitation treatment may simply be attributable to practice on the specific balance task. This would be the expression of learning to cope with the platform movements.[63] Actually, during instrumental rehabilitation, subjects were given the opportunity to learn to cope with a similar perturbation (albeit not quite identical) both for oscillation direction and duration of trials in a maneuver that was used to test their stabilization capacity at the end of the instrumental rehabilitation treatment. We feel, however, that the postural perturbations induced by the instrumental rehabilitation treatment not only had a specific effect, but were also rich enough to allow subjects to generalize their improved stabilization capacity to other balance tasks, such as stability during quiet stance, control of equilibrium during execution of postural tasks, and gait—all tasks not practiced during the treatment. However, the head stabilization, as tested during sinusoidal translation, was better with EC than EO in the instrumental rehabilitation group as compared with the Cawthorne-Cooksey group. This finding argues against training having a specific effect on balance performance. In fact, if such had been the case, one would have expected similar improvement of head stability under both visual conditions.

For ethical reasons, no control group (untreated) of vestibular patients was studied. One could interpret the observed effects, therefore, as connected with a placebo effect, because of unspecific effects of any treatment performed during the hospitalization. However, the 2 types of treatments showed different effects: in particular, the instrumental rehabilitation group had a greater improvement of body sway and head stabilization in space and a greater increase of feeling of stability and reduction of self-perceived balance handicap than did patients in the Cawthorne-Cooksey group. These differences in outcome contradict the hypothesis that the observed changes are merely due to a placebo effect. An improvement of balance attributable to the natural history of the disease appears unlikely, considering the results obtained from the subgroup of patients tested in the A-A-B design. The results of the stabilometric evaluation performed approximately a month before the treatment were similar to those obtained immediately before the rehabilitation treatment.

Understanding the mechanisms of recovery brought about by the 2 rehabilitation methods is not easy. In principle, the 2 methods might well produce a similar result (improvement in the motor program for upright stance) by different mechanisms. Because Cawthorne-Cooksey exercises are entirely voluntary, the improved stability might depend on a more effective, deliberate control of the postural muscle chain. In, Cawthorne-Cooksey exercises, patients are encouraged to move into positions that provoke symptoms. It is believed that reduction of symptoms is then obtained through habituation of the vestibular system.[10] Cawthorne-Cooksey exercises combine head movements while fixating a target to produce retinal slip. The central nervous system then attempts to reduce this error signal by modifying the gain of the vestibular system, that is, through adaptation of the vestibular system.[64] Instrumental rehabilitation, by contrast, compels the subjects to actively and continuously counteract the destabilizing movement and likely forces them to exploit the incoming information from the displaced body segments and learn to appropriately use feedback mechanisms.[26,27] Because the perturbation effects soon become known to the subjects, because of the repetitive sinusoidal forward and backward motion of platform and body, the anticipatory adjustments may be improved and restructured.[32] Finally, it should be considered that the maximum frequency of platform translation was rather low (0.6Hz). Faster frequencies of surface translation were not used because even the perturbation frequency of 0.6Hz proved hard to sustain for several patients, particularly in the EC condition. The frequencies used here appear to be a reasonable trade-off between contrasting needs, in particular within the first few days of the rehabilitation program, when patients may still be very unstable. In conclusion, improvements after instrumental rehabilitation might be partially explained by the substitution phenomenon,[22] that is, the ability to use other sources of sensory input to provide information for balance control.

As far as the neuronal basis of recovery is concerned, one should take into consideration the rapid (within 1wk) onset of positive effects after both rehabilitation procedures when they are provided intensely (twice daily for 5 consecutive days). This phenomenon suggests that for both types of training, motor learning of new postural strategies or alteration of the relative weight of inputs to the posture control system could play a major role in improvement, rather than any substantial recovery of vestibular function through central compensation, habituation, or adaptation.[65] Such early improvements might support substitution phenomena as an explanation for the improvement. Obviously, because the patients did not show complete bilateral loss of vestibular function but had only different degrees of unilateral deficit, one cannot exclude that the remaining vestibular input also allowed some degree of adaptation phenomenon. The persistence after 1 month (devoid of any treatment) of the improved stability of quiet stance would, however, suggest the occurrence of a true sensorimotor reorganization.[16]

The instrumental rehabilitation used in the present study shows several advantages over Cawthorne-Cooksey exercises: (1) it may allow for more controlled treatment of patients; (2) it produces better results; and (3) it is suitable for elderly patients who have difficulty performing the Cawthorne-Cooksey exercises because of their advanced age,[28] neck or back pain, or movement restriction due to joint degenerative disorders or obesity.

CONCLUSION

Both Cawthorne-Cooksey and instrumental rehabilitation procedures, when provided intensely, led to measurable improvement in balance and gait, in body segment coordination during postural challenges, and in the subjective feeling of dizziness in patients affected by balance disorders of vestibular origin, independently of their cause and severity. Both types of training led to improved stability during quiet stance and ADLs. Instrumental rehabilitation may be more effective than Cawthorne-Cooksey exercises for improving stability (ie, body oscillations) during quiet stance and in a surface-perturbation task.

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