

Outcomes After Rehabilitation for Adults With Balance Dysfunction

Mary Beth Badke, PhD, PT, Terry A. Shea, BSc, PT, James A. Miedaner, MS, PT, Colin R. Grove, BSc, PT

ABSTRACT. Badke MB, Shea TA, Miedaner JA, Grove CR. Outcomes after rehabilitation for adults with balance dysfunction. *Arch Phys Med Rehabil* 2004;85:227-33.

Objectives: To assess balance, dynamic gait, and dynamic visual acuity outcomes after a vestibular and balance rehabilitation program and to determine which variables were significantly associated with improved balance and ambulation.

Design: Retrospective case series.

Setting: Outpatient setting at a tertiary care facility.

Participants: Twenty patients who were seen for vestibular and balance therapy between July 1999 and June 2000.

Interventions: A customized exercise program was developed for each patient according to the results of the assessment and included the following interventions, as indicated: gaze stabilization, balance and gait training, and habituation exercises.

Main Outcome Measures: The Dynamic Gait Index (DGI), Berg Balance Scale (BBS), Dynamic Visual Acuity Test (DVAT), and computerized posturography (Sensory Organization Test [SOT]).

Results: The mean change scores for the DGI showed significant improvement for both patients with peripheral vestibular dysfunction and patients with central balance disorders. For the central balance disorders group, the BBS score also showed significant improvement. No difference was noted for pretherapy and posttherapy SOT scores between groups. The total group appeared to show an average improvement of more than 2 lines on the visual acuity chart on the clinical DVAT. Patients who were 66 years or older were 1.5 times more likely to score less than 20 on the DGI, and those whose pretherapy vertical dynamic visual acuity was 20/80 or worse were 1.3 times more likely to score less than 20 on the DGI.

Conclusions: Patients showed functional improvements in balance, visual acuity, and gait stability after balance and vestibular physical therapy. Age and pretherapy vertical dynamic visual acuity score influenced dynamic gait outcome after a balance rehabilitation program.

Key Words: Balance; Gait; Posture; Rehabilitation; Treatment outcome; Vestibular diseases; Visual acuity.

© 2004 by the American Congress of Rehabilitation Medicine and the American Academy of Physical Medicine and Rehabilitation

PERSONS WITH VESTIBULAR DISORDERS often have difficulty with the dynamic of postural control.¹ Several studies^{2,3} have shown that patients with a variety of peripheral

and central vestibular disorders show abnormal sensory organization testing results during computerized dynamic posturography. Reports^{4,5} have also shown that people with vestibular dysfunction walk more slowly with a wider base of support, turn en bloc, and are fearful of sudden movements. The occurrence of abnormalities in gait has been shown to be higher in people with central and bilateral lesions than in those with unilateral vestibular loss.^{6,7}

Vestibular rehabilitation has become widely used in the management of patients with dizziness, disequilibrium, and gait instability. Many research reports, including case series with no controls^{3,8-12} and controlled studies,^{2,13,14} support the effectiveness of vestibular physical therapy (PT) for patients with peripheral vestibular disorders. Less is known about the response to specific rehabilitation programs in patients with central vestibular involvement.¹⁵⁻¹⁷ Some studies have excluded patients with central vestibular disorders; other studies have grouped a variety of peripheral and central disorders in reporting results. Overall, patients with peripheral vestibular disorders have better outcomes after therapy than do patients with central vestibular disorders. Shepard et al,¹⁰ however, found that site of lesion (eg, peripheral, central, mixed) did not influence final outcome as measured by global indexes of vestibular symptoms and disability.

Posturography has been used in a number of studies to measure changes in standing balance after vestibular rehabilitation.^{2,13,18} Patients with chronic peripheral vestibular dysfunction have shown a significant improvement in conditions 5 and 6 of the Sensory Organization Test (SOT) after a vestibular rehabilitation program.² Shepard¹⁰ showed a small but statistically significant improvement in the mean equilibrium composite SOT score after therapy in a sample of 152 patients, and 80% to 85% of the patients showed a reduction in symptoms and disability score after therapy. Even though the SOT may measure vestibular contributions to standing balance, no evidence suggests that these measures have any relationship to functional activities such as gait. O'Neill et al¹⁹ and Evans and Krebs²⁰ showed that the SOT subtests did not correlate well with clinical timed tests of static standing balance and that they correlated even more poorly with clinical and laboratory measures of dynamic stability during locomotion.

Investigators have suggested using a variety of gait tasks to evaluate gait and functional performance. These tasks generally include tandem gait, gait with head turning, gait with eyes closed, and other clinical dynamic equilibrium tasks. The Dynamic Gait Index (DGI) is a tool that has been used to assess the associated gait instability that is often seen in persons with vestibular disorders. Whitney et al¹ showed that the DGI appears to be a good indicator of fall status in persons with vestibular disorders, regardless of age.

Only 1 study²¹ has assessed functional improvement associated with visual acuity. A few reports address the relationship between walking and dynamic visual acuity.²² One hypothesis is that the blurring of vision associated with head movements may provoke dizziness, which then causes gait instability.

The purposes of this chart review were (1) to assess dynamic gait and dynamic visual acuity outcomes in a retrospective case

From the Department of Orthopedics and Rehabilitation, University of Wisconsin Hospital and Clinics, Madison, WI.

No commercial party having a direct financial interest in the results of the research supporting this article has or will confer a benefit on the author(s) or on any organization with which the author(s) is/are associated.

Reprint requests to Mary Beth Badke, PhD, PT, Rehabilitation Services, 6630 University Ave, Middleton, WI 53562, e-mail: mb.badke@hosp.wisc.edu.

0003-9993/04/8502-8126\$30.00/0

doi:10.1016/j.apmr.2003.06.006

Table 1: Summary of the Vestibular Rehabilitation Protocols

	Supervised Sessions (weekly)	Home Program (between sessions)
Initial evaluation	<p>The following are reviewed: Otologic and medical history Lifestyle and ADLs/IADLs Physical assessment is made Orthostasis Occulomotor (if no ENG) Dynamic visual acuity Motion sensitivity (body position, vision) Musculoskeletal Coordination Lower-extremity sensation Balance including Equitest SOT Gait Endurance (6-min walk)</p> <p>A specific program is developed and targeted toward the subject's main complaints and functional deficits.</p> <p>Behavior modification techniques to decrease fear. Safety recommendations with movements and gait.</p>	<ol style="list-style-type: none"> 1. One or 2 simple exercises are given that target chief complaint and functional deficit. Exercises are performed 1 to 3 times a day. 2. General conditioning Walking program Length and frequency of the walks are to be increased (by minutes per day) as tolerated. Phone contact is made between subject and therapist as needed.
Second visit (1–2wk)	<p>The patient is observed performing the prescribed exercises, and progress is assessed. Exercises are modified as needed.</p> <p>Additional exercises are taught, again specific to the patient's individual symptoms and functional abnormalities.</p> <p>Dynamic balance and gait training. Visual feedback training is begun with the Balance Master. Motivational feedback is given.</p>	<ol style="list-style-type: none"> 1. Additional exercises are added to the first set. Frequency and duration of exercises may be increased, depending on progress. Main emphasis is on increasing complexity and increasingly challenging tasks. 2. Length and frequency of conditioning walks is slowly increased. Phone contact is made between subject and therapist as needed, and appointments may be made as required.
Subsequent visits (decreasing frequency to biweekly, monthly)	<p>Assessment continued and exercises added (and made more challenging). Visual feedback training with Balance Master continues. Dynamic balance and gait training. Equipment such as foam mats and trampoline may be used. Motivational feedback is continued.</p>	<ol style="list-style-type: none"> 1. Exercises progressively become more challenging and may be done more frequently and for longer periods. As symptoms improve, subjects are encouraged to leave the relative comfort of their dwelling and to venture out into the community. 2. Conditioning walks become longer, and other exercises or activities may be recommended. Phone contact is made between subject and therapist as needed, and appointments may be made as needed.
Final visit	<p>Physical assessment and symptom review are repeated (as for the initial visit). CDP is repeated. A discussion held regarding continuing exercises and conditioning to maintain improvement. A follow-up appointment is scheduled with the prescribing physician.</p>	<p>The subject is sent home with a clear idea of a maintenance program and instructed to continue that program. The subject may contact the therapist by phone or may return for follow-up appointments as needed.</p>

NOTE. The vestibular rehabilitation training regimen was adapted, in part, from regimens published by Herdman^{38,39} and Gans.⁴⁰

Reprinted with permission from Black et al.⁴¹

Abbreviations: ADLs, activities of daily living; CDP, computerized dynamic posturography; ENG, electronystagmography; IADLs, instrumental activities of daily living.

series in 20 patients after a balance rehabilitation program and (2) to determine what variables were significantly associated with improved ambulation.

METHODS

Participants

Subjects were identified through a retrospective medical record review of patients seen for vestibular and balance reha-

bilitation between July 1999 and June 2000 at the Balance Rehabilitation Program of the University of Wisconsin Hospital and Clinics. Subjects were included if they had diagnoses of central or peripheral vestibular dysfunction and had a DGI screen at admission and discharge. Patients with central nervous system (CNS) pathology who had balance dysfunction were also included. Twenty subjects met the inclusion criteria. Subjects were excluded from the study if they had inadequate follow-up or any of the following problems: cognitive deficits,

Lighthouse Near Visual Acuity Test (SECOND EDITION)
 MODIFIED ETDRS WITH SLOAN LETTERS
 For Testing at 40 cm (16 inches)

Letter Size (metric)	Chart 1			
	Snellen Distance Equivalent		Diopters of Add For 1 M	
	at 40 cm	at 20 cm	at 40 cm	at 20 cm
8.0 M	20/400	20D	20/800	40D
6.3 M	20/320	15D	20/630	30D
5.0 M	20/250	12D	20/500	25D
4.0 M	20/200	10D	20/400	20D
3.2 M	20/160	8D	20/320	15D
2.5 M	20/125	6D	20/250	12D
2.0 M	20/100	5D	20/200	10D
1.6 M	20/80	4D	20/160	8D
1.25 M	20/63	3D	20/125	6D
1.0 M	20/50	2.5D	20/100	5D
.8 M	20/40		20/80	4D
.6 M	20/32		20/63	3D
.5 M	20/25		20/50	2.5D
.4 M	20/20		20/40	
.3 M	20/16		20/32	

Instructions: the 40cm test distance requires a maximum add of +2.50. If the patient cannot see the top line, move test distance to 20cm with a maximum add of +5.00. (Similarly if a 10cm test distance is required, the maximum add is +10.00)
 Record test distance and letter size from the left column. Examples: 40/4M, 20/4M
 The columns on the right provide: reference to Snellen distance equivalent for two test distances; diopters of add for 1M print size for two test distances.



LIGHTHOUSE
 36-20 NORTHERN BLVD.
 LONG ISLAND CITY, NY 11101

Cat. No. C170

Fig 1. Lighthouse modified ETDRS test chart. Actual size, 62x64cm. Reprinted with permission.⁴¹

joint replacements, cervical vertigo, or major neurologic disease.

Subjects were referred from the Departments of Otolaryngology, Neurology, and Geriatrics in the University of Wisconsin Hospital and Clinics. Examples of vestibular diagnoses included vestibular neuritis, Meniere's disease, labyrinthitis, and brainstem and cerebellar dysfunction. Other patients had central balance disorders as a result of vascular, traumatic, or degenerative brain injuries. All subjects were evaluated with a complete medical and neurologic history and with a physical examination including computerized dynamic moving platform posturography.

Subjects received vestibular and balance rehabilitation provided by 1 of 2 physical therapists with specialized training in the assessment and treatment of balance and vestibular disorders. A customized exercise program was developed for each subject according to the results of the assessment and included the following interventions as indicated: gaze stabilization, balance and gait training, and habituation exercises. Vestibular and balance rehabilitation therapy protocols are summarized in table 1.

Outcome Measures

The DGI, along with other clinical tests, was administered during the initial PT evaluation and again at discharge. The DGI was developed by Shumway-Cook and Woolacott²³ to evaluate the ability to adapt gait to changes in task demands. The DGI rates performance from 0 (poor) to 3 (excellent) on 8 gait tasks, including gait on even surfaces, gait when changing speeds, gait while performing head turns, stepping over or around obstacles, and pivoting during walking and stair climbing.²³ Scores on the DGI range from 0 to 24. Scores of 16 or less indicate a high risk of falls; scores above 19 indicate a decreased risk for falls. The DGI has been shown to have good interrater (.96) and test-retest reliability (.98) and is a valid predictor of fall status among the elderly.²⁴

A subset of patients was assessed using the Berg Balance Scale (BBS) before beginning the exercise program and after therapy was completed. The scale consists of 14 tasks common in everyday life. These include sitting, standing, reaching, leaning over, turning and looking over each shoulder, turning in a complete circle, and stepping.²⁵ Each item is scored on a

Table 2: Patient Characteristics

Characteristic	
Age (y)	
Mean ± SD	65.5±17.3
Range	30–89
Sex	
Men	4
Women	16
Vestibular dysfunction	
Peripheral	5
Central	9
Mixed	6
No. of comorbidities	
0–1	4
2–3	8
≥4	8
No. of medications	
0–2	6
3–5	8
≥6	6
Treatment duration (wk)	
Mean ± SD	21.2±10.9
Range	8–54
No. of visits	
0–5	3
6–10	5
11–20	12

Abbreviation: SD, standard deviation.

scale from 0 to 4, for a maximum of 56 points. A score of 0 to 20 indicates a high risk, 21 to 40 indicates a medium risk, and 41 to 56 indicates a low risk of falling. Berg et al²⁵⁻²⁷ found high reliability of the BBS (.71–.99), moderate correlations with other functional measures (.62–.94), and low to moderate correlations with laboratory measures of postural sway (–.38 to –.55).

Visual acuity during head movements was measured clinically as a way to assess an individual’s ability to maintain stable gaze and as a rough measure of visually enhanced vestibulo-ocular reflex function. This clinical technique has design problems, such as inability to control for periods when the head slows or stops.²⁸ Despite these limitations, test reliability is sufficient to use the test as a guide for treatment and treatment efficacy. The patient was seated in a chair 4m from a modified Early Treatment Diabetic Retinopathy Study (ETDRS) visual acuity chart with Sloan letters. The chart, which is designed to provide Snellen equivalent acuity ratios or the logarithm of the minimum angle of resolution (log MAR) values, is shown in figure 1. The therapist noted the lowest line that the patient could read and/or the number of optotypes the patient incorrectly identified with the head still. The examiner grasped the patient’s head firmly from behind and tilted it

Table 4: Logistic Regression Analysis for Predicting Dynamic Gait Outcome

Predictor	<20 on DGI	
	OR	95% CI
Age >65y	1.5	.23–9.6
Pretherapy vertical dynamic visual acuity 20/80 or worse	1.3	.19–8.7

Abbreviation: CI, confidence interval.

forward 30° so that the horizontal semicircular canals were level in the horizontal plane. The head was moved side to side at a frequency of 2Hz while the patient read the lowest line possible. The lowest line with no errors and/or the number of optotypes the patient incorrectly identified were noted. The range of motion of the head movements was kept between 30° and 40° to keep central visual acuity within eyeglass frames and to minimize any neck discomfort. A similar procedure was done in the vertical plane with the head passing through a range of 20° to 40°, again staying within distance viewing of glasses. The decrement in horizontal or vertical dynamic visual acuity is measured by loss of legible lines. For persons 65 years of age or younger, loss of 2 lines (<50% optotypes missed) or less is normal.

Patients also underwent posturography at their initial evaluation and again during their discharge visit. Postural stability was assessed using the NeuroCom Smart Balance Master System^a with the Equitest Sensory Organization^a software package. Briefly, patients stood on a force platform while body sway was calculated from the maximum peak-to-peak antero-posterior sway occurring during 3 separate 20-second trials. Six sensory conditions were tested. The first 3 used eyes open, eyes closed, and stance in a sway-referenced visual surround on a fixed platform. The remaining 3 conditions used a sway-referenced platform with eyes open and eyes closed and a sway-referenced visual enclosure. The purpose of sway referencing is to distort visual and/or somatosensory information so that inputs from the remaining sensory system (ie, vestibular) would be needed to maintain stance.²⁹ Trial results were considered abnormal if the patient needed to take a step, if the patient fell, or if the sway was greater than the established normal range of sway provided by NeuroCom.³⁰

Data Analysis

Paired *t* tests were calculated to determine whether the SOT and dynamic visual acuity scores changed before and after therapy. Scores before and after vestibular rehabilitation on the DGI and the BBS were compared using the Wilcoxon matched-pair signed-rank test, because the measures were ordinal. Spearman correlation coefficients were used to compare the outcome measures. Logistic regression was used to show, in practical terms, the potential impact of age and dynamic visual acuity on dynamic gait performance. The logistic procedure

Table 3: Mean Assessment Measure Values

	DGI	Horizontal Dynamic Visual Acuity	Vertical Dynamic Visual Acuity	Composite Equilibrium
Initial therapy visit	14.3	.47	.58	42.6
Discharge visit	18.7	.27	.30	51.1
Mean change	4.4	–.20	–.28	8.5
<i>P</i> value	≤.01	≤.05	≤.05	.08

Table 5: Peripheral Vestibular Dysfunction Group Mean Assessment Measure Values

	DGI	Horizontal Dynamic Visual Acuity	Vertical Dynamic Visual Acuity
Initial therapy visit	13	.46	.58
Discharge visit	20	.22	.30
Mean change	7	-.24	-.28
P value	<.05	<.10	<.05

provides modeling capabilities for dichotomous outcome variables using maximum likelihood techniques. The odds ratio (OR) was used as a central measure of association that was estimated from the combined group. This approach made it possible to calculate the probability of decreased gait performance.

RESULTS

Descriptive subject information concerning age, sex, diagnosis, and number and duration of treatments is described in table 2. The mean age ± standard deviation (SD) of the subjects was 65.5±17.3 years. Seventy-five percent had central balance disorders, and 40% reported 4 or more comorbid conditions. The number of visits ranged from 3 to 20 over a mean duration of 21±10.9 weeks (range, 8–54wk).

Total group mean assessment measure values at initial evaluation and discharge and the mean amount of change are identified in table 3. The DGI score improved in 95% of the patients. Scores increased from 1 to 9 points. One patient showed no improvement. The average change in DGI score from before therapy to after therapy was 4.4±3.3.

Horizontal dynamic visual acuity scores improved in 58% of the patients. Average improvement was more than 2 lines on the visual acuity chart (log MAR, -.20±.10). Vertical dynamic visual acuity improved in 75% of the patients. After therapy, dynamic visual acuities were between 0.0 and 0.7 log MAR, and the average change was -.28±.08.

The average change in SOT composite equilibrium score from before to after therapy was 8.41±4.5. The correlation between the composite score and the DGI score, using the Spearman correlation coefficient, was *r* equal to .55 and between the composite score and the BBS score was *r* equal to .69.

Table 4 shows the results of the logistic regression models with DGI score as the outcome variable. Persons 65 years or older were 1.5 times more likely to have a DGI score of less than 20. Looking at visual acuity, people with a pretherapy vertical dynamic visual acuity of 20/80 or worse were 1.3 times more likely to score less than 20 on the DGI.

The entire group was separated for additional analysis by diagnosis of either peripheral vestibular dysfunction or mixed

Table 7: Mean Change for SOT Scores

	Mixed/Central		Peripheral	
	Mean ± SD	P	Mean ± SD	P
Somatosensory	-3.83±3.9	NS	29.2±17.2	NS
Visual	9.86±7.9	NS	10.8±11.9	NS
Vestibular	10.28±8.8	NS	10.6±10.6	NS
Preference	-1.57±5.1	NS	9.0±6.9	NS
Composite equilibrium	6.42±3.8	NS	11.2±9.9	NS

and central vestibular dysfunction. Patients with CNS pathology who had balance dysfunction were also grouped with the patients with central vestibular involvement in reporting results. Mean assessment measure values at initial evaluation and discharge and the mean amount of change from pretherapy to posttherapy values for patients with peripheral vestibular dysfunction are identified in table 5. In patients with a diagnosis of peripheral dysfunction, significant differences were shown before and after treatment in DGI (*P*<.05) and vertical dynamic visual acuity (*P*<.05).

Mean assessment measure values and the mean amount of change from pretherapy to posttherapy values for patients with central balance disorders are identified in table 6. This patient group showed significant differences in pretreatment and post-treatment scores for the BBS and DGI. The difference in horizontal and vertical dynamic visual acuity was not significant.

The mean changes in scores for the SOT are shown in table 7. No statistical difference was noted between pretreatment and posttreatment scores for either group. The average change in composite score from pretherapy to posttherapy was 6.42±3.82 for the peripheral group and 11.2±9.9 for the central disorders group.

DISCUSSION

After vestibular and balance rehabilitation, the DGI scores of both patient groups improved; however, this effect was not as strong in the case of the central balance disorders group. One possibility is that central lesions may interfere with recovery mediated by adaptation in the vestibular ocular and vestibular spinal system.³¹ The DGI scores for the total group improved from a mean of 14 to a mean of 19, which indicates a decrease in the risk of falling.²⁴ Although most subjects had improved DGI scores, they still had a moderate to high fall risk. For the central balance disorders group, the BBS, which included standing balance, also showed significant improvement. These findings are similar to those obtained by El-Kashlan et al,⁹ who found that, with therapy, patients with vestibular dysfunction showed improvements in 8 clinical dynamic equilibrium tasks. However, the equilibrium score remained below the normal level, and the investigators did not indicate whether the improvement in score was statistically significant.

Measurement of visual acuity during head movements provides the physical therapist with a way of assessing the functional impact of vestibular disorders. The results of the clinical Dynamic Visual Acuity Test (DVAT) were extremely limited because of the numerous design problems discussed elsewhere.³²⁻³⁴ Despite these problems, the total group showed an average improvement of more than 2 lines on the visual acuity chart. When separated into diagnostic groups, however, the central balance disorders group did not improve as much as the peripheral group on the DVAT. This finding may again be due to involvement of those structures in the cerebellum and inter-connecting pathways proposed to have a role in vestibular

Table 6: Central Balance Disorders Group Mean Assessment Measure Values

	BBS	DGI	Horizontal Dynamic Visual Acuity	Vertical Dynamic Visual Acuity
Initial therapy visit	43	14	.48	.51
Discharge visit	48	18	.41	.44
Mean change	6	4	-.07	-.07
P value	≤.05	≤.01	NS	NS

Abbreviation: NS, not significant.

plasticity. Patients with central balance disorders also tended to be older ($71.4 \pm 14.4y$) than those patients with peripheral vestibular dysfunction ($47.8 \pm 13y$), which may also have accounted for the differences between the groups. Given the observed changes in the clinical test, perhaps the dynamic visual acuity can be used as a valuable outcome measure for persons with impaired visual acuity during head movements. Only 1 other study has assessed the effects of exercise on recovery of dynamic visual acuity in patients with vestibular loss. With the use of a computerized system, Herdman et al²¹ found a significant difference in dynamic visual acuity with intervention for active head movements and for unpredictable head movements in patients with unilateral vestibular loss.

The SOT is designed to assess a person's ability to use visual, proprioceptive, and vestibular cues to maintain postural stability in stance. The changes in SOT vestibular score and SOT visual scores were fairly similar for the diagnostic groups. This may be because the difference between central and peripheral vestibular disorders on posturography was greater for the motor coordination part of the test than for the sensory component.³⁵ The change from initial evaluation to discharge for the composite equilibrium score was larger for the group with peripheral vestibular dysfunction, although the change scores were not statistically significant. Despite the questions about reliability, the SOT has been used in 4 studies^{2,3,13,18} to document changes in standing balance after vestibular dysfunction. These studies have shown an improvement in balance for patients across diagnostic groups after a vestibular rehabilitation program.

The logistic regression model shows, in practical terms, the potential effects of aging and pretherapy dynamic visual acuity on functional gait outcome or risk of falls. Of particular relevance, older persons and persons who have a pretherapy vertical dynamic visual acuity of 20/80 or less have increased odds for persistent gait instability, as measured by the DGI. Our finding concerning age is consistent with other reports that showed decreased gait stability and increased falls with increasing age.^{22,36,37} Because of the potentially confounding factors associated with the clinical DVAT, further studies are needed to determine the contribution of dynamic visual acuity and other factors to the DGI score.

CONCLUSIONS

To better characterize functional outcomes after vestibular rehabilitation, the aims of this study were to assess balance, dynamic gait, and dynamic visual acuity after PT and to determine which variables were significantly associated with decreased gait instability. To summarize, the results of our pilot study indicate that patients showed functional improvements in balance, visual acuity, and gait stability after vestibular PT and that dynamic gait outcome after a vestibular rehabilitation program is influenced by age and pretherapy vertical dynamic visual acuity score.

References

- Whitney SL, Hudak MT, Marchetti GF. The dynamic gait index relates to self-reported fall history in individuals with vestibular dysfunction. *J Vestib Res* 2000;10:99-105.
- Horak FB, Jones-Rycewicz C, Black FO, Shumway-Cook A. Effects of vestibular rehabilitation on dizziness and imbalance. *Otolaryngol Head Neck Surg* 1992;106:175-80.
- Cass SP, Borello-France D, Furman JM. Functional outcome of vestibular rehabilitation in patients with abnormal sensory-organization testing. *Am J Otol* 1996;17:581-94.
- Kerber KA, Enrietto JA, Jacobson SM, Baloh RW. Disequilibrium in older people: a prospective study. *Neurology* 1988;51:574-80.
- Herdman SJ. Vestibular rehabilitation. Philadelphia: FA Davis; 1999.
- Ishikawa K, Edo M, Terada N, Okamoto Y, Togawa K. Gait analysis in patients with vertigo. *Eur Arch Otorhinolaryngol* 1993;250:229-32.
- Sasaki O, Asawa S, Katsuno S, Usami S, Taguchi K. Gait initiation in bilateral vestibular loss. *Auris Nasus Larynx* 2001;28:295-9.
- Cowand JL, Wrisley DM, Walker M, Strasnick B, Jacobson JT. Efficacy of vestibular rehabilitation. *Otolaryngol Head Neck Surg* 1998;118:49-54.
- El-Kashlan HK, Shepard NT, Asher AM, Smith-Wheelock M, Telian SA. Evaluation of clinical measures of equilibrium. *Laryngoscope* 1998;108:311-9.
- Shepard NT, Telian SA, Smith-Wheelock M, Raj A. Vestibular and balance rehabilitation therapy. *Ann Otol Rhinol Laryngol* 1993;102:198-205.
- Asai M, Watanabe Y, Shimizu K. Effects of vestibular rehabilitation on postural control. *Acta Otolaryngol* 1997;528(Suppl):116-20.
- Szturm T, Ireland DJ, Lessing-Turner M. Comparison of different exercise programs in the rehabilitation of patients with chronic peripheral vestibular dysfunction. *J Vestib Res* 1994;4:461-79.
- Herdman SJ, Clendaniel RA, Mattox DE, Holliday MJ, Niparko JK. Vestibular adaptation exercises and recovery: acute stage after acoustic neuroma resection. *Otolaryngol Head Neck Surg* 1995;113:77-87.
- Krebs DE, Gill-Body KM, Riley PO, Parker SW. Double-blind, placebo-controlled trial of rehabilitation for bilateral vestibular hypofunction: preliminary report. *Otolaryngol Head Neck Surg* 1993;109:735-41.
- Cohen H. Vestibular rehabilitation reduces functional disability. *Otolaryngol Head Neck Surg* 1992;107:638-43.
- Gizzi M. The efficacy of vestibular rehabilitation for patients with head trauma. *J Head Trauma Rehabil* 1995;10(6):60-77.
- Shepard NT, Telian SA. Programmatic vestibular rehabilitation. *Otolaryngol Head Neck Surg* 1995;112:173-82.
- Fetter M, Diener HC, Dichgans J. Recovery of postural control after an acute unilateral vestibular lesion in humans. *J Vestib Res* 1990;1:373-83.
- O'Neill DE, Gill-Body KM, Krebs DE. Posturography changes do not predict functional performance changes. *Am J Otol* 1998;10:797-803.
- Evans MK, Krebs DE. Posturography does not test vestibulospinal function. *Otolaryngol Head Neck Surg* 1999;120:164-73.
- Herdman SJ, Schubert MC, Tusa RJ. Effect of exercise on recovery of dynamic visual acuity in patients with vestibular loss [abstract]. *Neuro Rep* 2001;25(4):133.
- Hillmann EJ, Bloomberg JJ, McDonald PV, Cohen HS. Dynamic visual acuity while walking in normals and labyrinthine-deficient patients. *J Vestib Res* 1999;9:49-57.
- Shumway-Cook A, Woollacott MH. Motor control theory and practical applications. Baltimore: Williams & Wilkins; 1995.
- Shumway-Cook A, Baldwin M, Polissar NL, Gruber W. Predicting the probability for falls in community dwelling older adults. *Phys Ther* 1997;77:812-9.
- Berg K, Wood-Dauphinee S, Williams JI, Maki B. Measuring balance in the elderly: validation of an instrument. *Can J Public Health* 1992;83(Suppl 2):S7-11.
- Berg K, Wood-Dauphinee S, Williams J, Gayton D. Measuring balance in the elderly: preliminary development of an instrument. *Physiother Can* 1989;41:304-11.
- Berg KO, Maki BE, Williams JI, Holliday PJ, Wood-Dauphinee SL. Clinical and laboratory measures of postural balance in an elderly population. *Arch Phys Med Rehabil* 1992;73:1073-80.
- Herdman SJ, Tusa RJ, Blatt P, Suzuki A, Venuto PJ, Roberts D. Computerized dynamic visual acuity test in the assessment of vestibular deficits. *Am J Otol* 1998;19:790-6.
- Black FO, Wall C III, Nashner LM. Effect of visual and support surface references upon postural control in vestibular deficit subjects. *Acta Otolaryngol* 1983;95:199-210.

30. Data interpretation manual for the Smart Balance Master System. Clackamas (OR): NeuroCom Int; 1994.
31. Cooke DL. Central vestibular disorders. *Neurol Rep* 1996;20(3):22-9.
32. Burgio DL, Blackey BW, Myers SF. The high frequency oscillopsia test. *J Vestib Res* 1992;2:221-6.
33. Longridge NS, Mallinson AI. The dynamic illegible E-test. *Acta Otolaryngol (Stockh)* 1987;103:273-9.
34. Longridge NS, Mallinson AI. The dynamic illegible E (DIE) test: a simple technique for assessing the ability of the vestibulo-ocular reflex to overcome vestibular pathology. *J Otolaryngol* 1987;16:97-103.
35. Voorhees RL. The role of dynamic posturography in neurologic diagnosis. *Laryngoscope* 1989;99:995-1001.
36. Kerrigan DC, Lee LW, Nieto TJ, Markman JD, Collins JJ, Riley PO. Kinetic alterations independent of walking speed in elderly fallers. *Arch Phys Med Rehabil* 2000;81:730-5.
37. Woollacott MH, Tang P. Balance control during walking in the older adult: research and its implications. *Phys Ther* 1997;77:646-60.
38. Herdman SJ. Vestibular rehabilitation. In: Baloh RW, Halmagyi GM, editors. *Disorders of the vestibular system*. New York: Oxford Univ Pr; 1996. p 583-97.
39. Herdman SJ. Treatment of benign paroxysmal positional vertigo. *Phys Ther* 1990;70:381-8.
40. Gans RE. *Vestibular rehabilitation: protocols and programs*. San Diego: Singular Publishing Group; 1996.
41. Black FO, Angel CR, Pesznecker SC, Gianna C. Outcome analysis of individualized vestibular rehabilitation protocols. *Am J Otol* 2000;21:543-51.

Supplier

- a. NeuroCom International Inc, 9570 SE Lawnfield Rd, Clackamas, OR 97015.