ORIGINAL ARTICLE

Recovery of Dynamic Visual Acuity in Unilateral Vestibular Hypofunction

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Objective: To determine the effect of vestibular exercises on the recovery of visual acuity during head movement in patients with unilateral vestibular hypofunction.

Study Design: Prospective, randomized, double-blind study.

Setting: Ambulatory referral center.

Patients: Twenty-one patients with unilateral vestibular hypofunction, aged 20 to 86 years.

Intervention: One group (13 patients) performed vestibular exercises designed to enhance the vestibulo-ocular reflex, and the other group (8 patients) performed placebo exercises. The placebo group was switched to vestibular exercises after 4 weeks.

Outcome Measures: Measurements of dynamic visual acuity (DVA) during predictable (DVA-predictable) and unpredictable (DVA-unpredictable) head movements by means of a computerized test and measurement of intensity of oscillopsia by means of a visual analog scale.

Results: As a group, patients who performed vestibular exercises showed a significant improvement in DVA-predictable ($P<.001$) and DVA-unpredictable ($P<.001$), while those performing placebo exercises did not ($P=.07$). On the basis of stepwise regression analysis, the leading factor contributing to improvement was vestibular exercises. This reached significance for DVA-predictable ($P=.009$) but not DVA-unpredictable ($P=.11$). Other factors examined included age, time from onset, initial DVA, oscillopsia, and duration of treatment. Changes in oscillopsia did not correlate with DVA-predictable or DVA-unpredictable.

Conclusions: Use of vestibular exercises is the main factor involved in recovery of DVA-predictable and DVA-unpredictable in patients with unilateral vestibular hypofunction. Exercises may foster the use of centrally programmed eye movements that could substitute for the vestibulo-ocular reflex. The DVA-predictable would benefit more from this than would DVA-unpredictable.

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PATIENTS WITH vestibular hypofunction complain of imbalance, head movement–induced dizziness, and head movement–induced visual blurring (oscillopsia).[1-3] These problems are most severe in patients with bilateral loss, but are often significant in patients with unilateral vestibular loss as well. A number of randomized, prospective studies have documented that vestibular exercises improve postural stability and decrease subjective complaints of dizziness in patients with acute or chronic vestibular hypofunction.[4-6] No studies to our knowledge, however, have examined whether vestibular exercises improve visual acuity during head movements or decrease complaints of oscillopsia in these patients.

Oscillopsia, in people with unilateral vestibular hypofunction (UVH), occurs because of the decrease in gain of the vestibulo-ocular reflex (VOR) and suggests that compensation for the vestibular loss has not occurred. Decrements in visual acuity during head movement are potentially a serious problem and could contribute to decreased activity level, avoidance of driving with resultant diminished independence, and, ultimately, limited social interactions and increased isolation. The purpose of this study was to examine the effect of an exercise intervention on visual acuity during head movement in patients with UVH.

METHODS

PATIENTS

Patients included in the study had been referred to the laboratory for assessment from the clinical practice of 2 of us (S.J.H. and R.J.T.). Vestibular function was assessed in

these subjects by means of caloric and computerized rotary chair tests.[7,8] We used step-velocity rotary chair testing at 60°/s and 240°/s rotations with electro-oculography. Unilateral vestibular deficits were defined by a 25% or greater difference in slow-phase eye velocity between right and left sides on either the caloric or rotary chair test. We defined a complete loss of vestibular function as no response to cool, warm, and ice water irrigation unilaterally and a positive head thrust test, recognizing that this represents no function in the horizontal canal. Data on age, time from onset, degree of deficit (complete vs incomplete vestibular hypofunction), duration of exercises, and complaints of oscillopsia were collected on all subjects. Only patients with abnormal visual acuity during head movements (dynamic visual acuity [DVA]) were included. Abnormal DVA was defined as greater than the mean+2 SDs of the DVA of healthy subjects of the same age.[9] Informed consent was obtained in compliance with institutional review board protocol of the University of Miami, Miami, Fla, or Emory University, Atlanta, Ga.

DYNAMIC VISUAL ACUITY

An optotype (the letter *E*) was displayed on the monitor when the subject's head velocity was between 120°/s and 180°/s. Either the patient moved the head actively (DVA-predictable testing) or the head was moved by one of us (M.C.S.) to the right and left in random order (DVA-unpredictable testing). A computer-generated program altered the orientation of the *E* randomly. The computer was set so that the letter appeared during only the rightward or leftward portion of a horizontal head movement. There were 5 trials at each acuity level. The optotype size was changed decrementally so that changes in visual acuity from line to line were equivalent to 0.1 LogMAR.[10] When the subject indicated the direction of orientation of the *E,* the subject's response was recorded and the next trial was begun. The trial was scored as an error if the subject incorrectly identified the direction of the orientation of the *E* or if the subject did not know the orientation after viewing the optotype 5 times. When the subject incorrectly identified the orientation of the *E* for all optotypes presented at a particular acuity level, the test was stopped. Data are given as the number of errors in identifying the orientation of the optotype. Details of the test procedure have been reported previously.[9,11] Test-retest reliability of this computerized test is $r=0.92$ in patients with vestibular hypofunction (intraclass correlation coefficient, 1,1).

TEST PROTOCOL

The test was performed first with the subject's head stationary (static visual acuity). The series of optotypes was displayed and scored. The rate sensor was then placed on the subject's forehead and oriented to detect horizontal movement of the head. All subjects then performed a practice trial in which optotypes were presented during predictable head movements to the right, to familiarize the subjects with the test and to minimize a learning effect before data were collected. Data were then collected separately for display of the optotype during predictable rightward and leftward head movements (DVA-predictable). For DVA-unpredictable, subjects first performed a practice trial in which their heads were moved by one of us (M.C.S.) to the right and left in random order. The DVA was calculated by counting the total number of errors in identifying the orientation of the optotype and subtracting that value from the static visual acuity. Raw scores were then converted to a LogMAR score. The DVA-predictable and DVA-unpredictable were measured before entry into the study and at 2-week intervals after initiation of either control or vestibular exercises.

MEASUREMENT OF OSCILLOPSIA

We used a 10-cm visual analog scale to assess the degree of perceived visual blurring in the patients. One end of the scale was anchored with "No difficulty seeing clearly at all (normal)" and the other end was anchored with "The worst it could be." Patients were asked to rate their visual blurring first while they were sitting and then while they were walking. We used the difference between these scores as the oscillopsia score so that it would parallel the DVA score (difference between visual acuity with the head stationary and with the head moving). The test-retest reliability for this measurement, $r=0.65$ (intraclass correlation coefficient, 1,1) was based on 25 patients with unilateral or bilateral vestibular hypofunction.

EXERCISES

Patients were randomly assigned to either the vestibular exercise or placebo exercise group. The vestibular exercise group practiced exercises that consisted of adaptation exercises and eye-head exercises to targets (**Table 1**), which were designed to improve gaze stability.[12] They also performed gait and balance exercises. The placebo exercise group performed exercises designed to be "vestibular neutral." These placebo exercises consisted of saccadic eye movements with the head stationary while viewing a Ganzfeld (a large featureless surface). The placebo exercise group also performed gait and balance exercises, but exercises that specifically incorporated head movements were avoided. Each group had the same contact time with the investigators. All patients were seen in clinic on a weekly basis to review and update their exercise program, and they were taught an exercise program that they were to follow at home. All patients were asked to perform the exercises 4 to 5 times daily for a total of 20 to 30 minutes per day plus 20 minutes of balance and gait exercises. The progression of exercises was developed on the basis of clinical experience with patients who were in the acute and subacute stages after onset of vestibular dysfunction and therefore had considerable symptomatic complaints associated with head movement. Thus, the change in exercises from week to week represented a conservative progression, and patients followed the program unless they reported difficulties related to increase in their complaints of dizziness. If the exercises exacerbated the dizziness, the patient was instructed to work through the dizziness if possible. If this were not possible, the first step was to modify the exercises by decreasing the head velocity to a more tolerable level. If that did not relieve symptoms, the frequency of performing the exercises was decreased from 5 times daily to 3 times daily for 3 days, then increased to 4 times daily for the next 3 days. Patients were given a calendar to record exercise compliance and were instructed to bring the calendar with them each week. An individual was considered compliant if he or she performed more than 50% of the exercises. At the end of 4 weeks, subjects in the placebo exercise group started an individualized program of vestibular exercises.

HYPOTHESES

We hypothesized that patients performing exercises designed to foster vestibular adaptation would have improved visual acuity during head movement compared with patients performing exercises that would not induce adaptation.

STATISTICAL ANALYSES

Differences between groups for age, time from onset, initial DVA score, initial complaint of visual blurring while walking, and duration of exercises were examined by unpaired, 2-tailed *t* test for unequal variances. Comparison of DVA-predictable and DVA-

Table 1. Progression of Vestibular Exercises

Exercise Weekly Progression	Duration	Frequency
Adaptation: X1 with target held in hand and also with target at distance, horizontal and vertical head movements	1 min each exercise	5 times daily; total time, 20 min
Adaptation: X1 with target held in hand and also with target at distance, horizontal and vertical head movements	1-2 min each exercise	5 times daily; total time, 30-40 min
Substitution: eye-head movements between 2 targets with emphasis on seeing clearly, horizontal and vertical eye-head movements		
Adaptation: X1 with target held in hand and also with target at distance, horizontal and vertical head movements; X1 with checkerboard with target placed in center held in hand, horizontal head movements	1 min each exercise	5 times daily; total time, 28 min
Substitution: eye-head movements between 2 targets; imaginary target paradigm		
Adaptation: X1 with checkerboard with target placed in center held in hand; X2 with target held in hand; both horizontal and vertical head movements	1 min each exercise	4 times daily; total time, 28 min
Substitution: eye-head movements between 2 targets; imaginary target paradigm		
Adaptation: X1 with target held in hand; horizontal and vertical head movements; X1 with checkerboard with target placed in center held in hand, horizontal and vertical head movements; X2 with target held in hand, horizontal and vertical head movements	1 min each exercise	4 times daily; total time, 36 min
Substitution: eye-head movements between 2 targets; imaginary target paradigm		

unpredictable before and after intervention for each group was examined with paired *t* tests. Individual improvement in DVA was defined as a change in DVA greater than the mean+2 SDs of the test-retest variability determined from a separate, representative group of subjects with vestibular hypofunction. We used a separate group of subjects to determine test-retest variability to avoid sampling bias. In addition, we compared final DVA with normal values of DVA by age for each subject. The contributions of age, time from onset, initial DVA score, complaints of oscillopsia, duration of exercises, and type of exercise on change in DVA were determined by means of stepwise multiple regression analysis.[13] Stepwise multiple regression analysis was also used to assess the contribution of age, time from onset, initial DVA, type of exercise, and duration of exercises to change in perceived oscillopsia. The correlation between change in DVA and change in the patient's oscillopsia while walking was examined with Pearson product moment correlation.

RESULTS

Twenty-three patients with unilateral vestibular hypofunction initially consented to the study and were randomly assigned to either the experimental group or the control group. Two control patients were dropped from the study; one came for only 2 visits and the other did the exercises incorrectly. The remaining subjects were in the experimental (n=13) or control (n=8) group (**Table 2**).

SUBJECT CHARACTERISTICS

There was no difference between groups in age, time from onset, initial DVA scores, initial complaint of oscillopsia, and duration of exercises ($P>.05$; **Table 3**). There was no difference in exercise compliance between the 2 groups (range, 50%-100%) based on weekly calendars. None of the patients in either group were taking vestibular suppressant medications during the study.

Table 2. Patient Characteristics

Patient No./ Sex/Age, y	Cause	Time From Onset, mo	oVAS Initial
	Experimental Group		
1/F/31	Neuronitis	0.75	1.7
2/M/40	Previous VNS	0.5	6.2
3/F/49	Neuronitis	11	NA
4/F/59	Previous AN	4.25	0
5/M/62	Previous AN	0.5	6.7
6/F/66	Previous petrous	5.75	9
7/F/71	Neuronitis	2	1.6
8/M/72	Neuronitis	3	NA
9/F/76	Neuronitis	0.5	NA
10/F/77	Previous cochlear	3	0
11/F/78	Neuronitis	2	0
12/M/80	Neuronitis	12	5.4
13/F/86	Ramsay Hunt	1	1.4
	Control Group		
14/F/35	Previous AN	1.5	2.2
15/M/52	Neuronitis	5.5	4.3
16/F/58	Previous AN	0.75	0.1
17/M/65	Neuronitis	4	5.1
18/F/68	Neuronitis	36	0
19/F/79	Neuronitis	12	0
20/F/81	Neuronitis	11.75	3.8
21/M/81	Neuronitis	2	1.7

Abbreviations: AN, acoustic neuroma; cochlear, cochlear implant; NA, not obtained from patient; oVAS, oscillopsia visual analog scale; petrous, petrous bone surgery; VNS, vestibular nerve section.

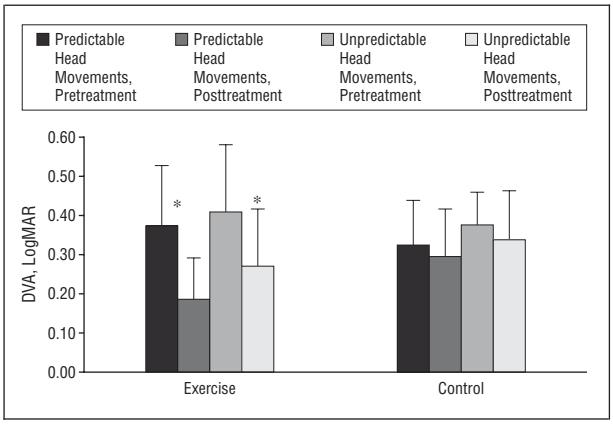
DVA CHANGE—EXPERIMENTAL GROUP

As a group, there was a significant improvement in DVA-predictable in the experimental group ($P<.001$; **Figure**). Twelve of 13 subjects in the experimental group had an

Table 3. Subject Characteristics*

Characteristic	Experimental Group (n = 13)	Control Group (n = 8)	*P* Value Between Groups
Age, y	65.2 ± 16.5	64.9 ± 16.2	.97
Time from onset, mo	3.6 ± 3.9	9.2 ± 11.7	.22
Initial DVA-predictable, LogMAR	0.372 ± 0.155	0.323 ± 0.117	.42
Initial DVA-unpredictable, LogMAR	0.408 ± 0.173	0.374 ± 0.085	.62
Initial complaint of visual blurring while walking (oVAS score)	3.2 ± 3.2	2.2 ± 2.1	.43
Duration of exercises, wk	4.1 ± 1.6	4.9 ± 1.0	.85
Underlying abnormality, No. (%)	Neuronitis 8 (62%); postsurgery 5 (38%)†	Neuronitis 6 (75%); postsurgery 2 (25%)‡	NA

Abbreviations: DVA, dynamic visual acuity; NA, not applicable; oVAS, oscillopsia visual analog scale.
*Data are given as mean ± SD, unless otherwise indicated.
†Resection of acoustic neuroma, 2; vestibular nerve section, 1; petrous bone surgery, 1; cochlear implant, 1.
‡Resection of acoustic neuroma, 2.



Effect of exercise on recovery of dynamic visual acuity (DVA) during head movement. Note the significant improvement in DVA with predictable and unpredictable head movements in the vestibular exercise group but not in the control group. Data are given as mean±1 SD. Asterisk indicates $P<.001$.

improvement in DVA-predictable. Twelve of the 13 subjects also returned to normal DVA-predictable for age. As a group, there was also a significant improvement in DVA-unpredictable ($P<.001$; Figure). The magnitude of change of DVA-unpredictable was half that of DVA-predictable. The improvement in DVA-predictable and in DVA-unpredictable occurred within an average of 4.1 ± 1.6 weeks.

DVA CHANGE—CONTROL GROUP

As a group, there was no change in DVA-predictable in the control group during the 4.9 ± 1.0 weeks of placebo exercises ($P=.07$; Figure). Only 1 of the 8 subjects had an improved DVA-predictable score. No subject's DVA returned to within the normal range for age. As a group, there was no change in DVA-unpredictable in the control group ($P=.68$; Figure).

FACTORS CONTRIBUTING TO IMPROVEMENT IN DVA

Table 4 shows the results of the stepwise multiple regression analysis and the statistical significance of each of the factors as it was entered into the model. Note that only type of exercise contributed significantly to change in DVA-predictable ($F=10.37$, $P=.009$) and accounted for 50.5% of change in DVA-predictable. No other factor measured (duration of exercises, age, time from onset, complaints of oscillopsia, or initial DVA-predictable) contributed significantly to change in DVA-predictable. For DVA-unpredictable, stepwise multiple regression analysis showed that none of the factors analyzed (type of exercise, duration of exercises, age, time from onset, complaints of oscillopsia, and initial DVA-unpredictable score) contributed significantly to the change in DVA-unpredictable (overall model, $F=1.17$, $P=.42$) (Table 4).

COMPLAINTS OF OSCILLOPSIA

There was no difference in the degree of oscillopsia reported by the placebo and the experimental UVH groups before initiation of exercises (Table 2). Both the experimental group and the placebo group showed a significant decrease in the intensity of perceived visual blurring (oscillopsia) during the course of the project (experimental group, $P=.03$, 2-tailed; control group, $P=.02$, 2-tailed). There was no correlation between improvement in oscillopsia while walking and improvement in DVA-predictable (Pearson $r=-0.07$) or DVA-unpredictable (Pearson $r=-0.267$). In addition, age, time from onset, initial DVA, exercise, and duration of exercises did not contribute to change in perceived oscillopsia (overall model $F=2.15$, $P=.14$).

COMMENT

The results of this study suggest that the use of vestibular exercises facilitates the recovery of gaze stability during predictable head movements and, to a certain extent, unpredictable head movements, as measured by the DVA test. The mechanism for recovery may be adaptation of the VOR from vestibular exercises. Although the total time the vestibular exercises were performed each day was relatively brief, no more than 40 minutes daily, there is evidence that relatively short periods of exercise can induce VOR adaptation in normal subjects.[14-16] In these studies, a 60-minute period of head or visual surround

Table 4. Results of ANOVA for Statistical Significance of Each Factor as It Was Entered Into the Model for DVA During Predictable and Unpredictable Head Movements

Source	Sum of Squares	*df*	Mean Square	F Ratio	*P* Value
		DVA-Predictable*			
Type of exercise	0.0767134	1	0.0767134	10.37	.009
Age	0.000728985	1	0.000728985	0.10	.76
Time from onset	0.0024609	1	0.0024609	0.33	.58
Oscillopsia	0.00102264	1	0.00102264	0.14	.72
Weeks of exercises	0.00197516	1	0.00197516	0.27	.66
Initial DVA-predictable	0.00232645	1	0.00232645	0.31	.59
Residual	0.0739563	10	0.00739563		
Total (Corrected)	0.238932	**16**			
		DVA-Unpredictable			
Type of exercise	0.0482597	1	0.0482597	3.34	.11
Age	0.00950336	1	0.00950336	0.66	.44
Time from onset	0.00146556	1	0.00146556	0.10	.76
Oscillopsia	0.00510475	1	0.00510475	0.35	.57
Weeks of exercises	0.0216103	1	0.0216103	1.50	.26
Initial DVA-unpredictable	0.00141503	1	0.00141503	0.10	.76
Residual	0.101113	7	0.0144447		
Total (Corrected)	0.202187	**13**			

Abbreviations: ANOVA, analysis of variance; DVA, dynamic visual acuity.
*r^2 (Adjusted for $df = 50.5\%$).

oscillations was sufficient to increase VOR gain by as much as 15%. In addition, Szturm et al[17] described a reduction in VOR gain asymmetry in patients with chronic peripheral vestibulopathy who performed a series of exercises for approximately 30 minutes daily. As with our study, many of the exercises in the Szturm et al study required eye and head movement while fixating on a visual target. A second mechanism for recovery may be facilitation of central preprogramming of other types of eye movements to improve gaze stability from vestibular exercises.[18-20] We know from a previous study that subjects with UVH have better visual acuity when they actively perform the head movement than during unpredictable head movements.[11] This finding suggests that central programming of eye movements may contribute to gaze stability during predictable head movements toward the affected side. Centrally programmed eye movements that have been described in patients with peripheral vestibular hypofunction include compensatory saccades that occur during the head movement and high-velocity slow-phase eye movements (velocities of 80-120°/s).[18] Preprogrammed eye movements occur during both predictable and unpredictable head movements, although they are less common during unpredictable head movements.[18] The greater frequency of centrally programmed eye movements during predictable than during unpredictable head movements may explain why vestibular exercises were a significant factor for the improvement in DVA during predicted head movements, but only a high factor for unpredicted head movements in the current study.

Of interest to us were the factors that did not contribute to recovery of DVA, especially age and time from onset. There are conflicting reports on the effect of age on recovery after unilateral vestibular deficits. One study suggested that older individuals were less likely to show recovery with rehabilitation, while another indicated that age was not a factor.[21,22] Our study suggests that vestibular exercises are effective in improving DVA-predictable regardless of the subject's age. Clinically, it is also valuable to know whether time from onset is a factor in recovery of DVA-predictable. Inspection of the data shows that time from onset was longer in the control group than in the experimental group; however, this difference was not significant. In addition, the stepwise regression analysis showed that time from onset was not a factor in recovery. Our results provide evidence that specific exercises facilitate recovery even when initiated up to 12 months after onset.

The relationships between dynamic visual acuity and complaints of oscillopsia are not clear.[23-25] We found no relationship between improvement in DVA and improvement in the patient's perception of oscillopsia while walking. In addition, none of the factors we measured (type of exercise, age, time from onset, initial DVA, exercise, and duration of exercises) contributed to change in oscillopsia. This is similar to the findings of Schubert et al,[25] who found no relationship between DVA during vertical head movements and subjective complaints of oscillopsia in subjects with UVH. Grunfeld et al[24] examined patients with bilateral vestibular loss and suggested that oscillopsia was related to the patients' tolerance for retinal slip and to the patients' perception of the amount of control they have over the vestibular disorder. This may also apply to our patients with unilateral vestibular hypofunction.

CONCLUSIONS

The results of this study suggest that the use of specific vestibular rehabilitation exercises facilitates the recovery of gaze stability during head movement. The recovery of DVA is relatively rapid, occurring in less than 5 weeks of exercises. Neither age nor time from onset was

a significant factor in this recovery, suggesting that older patients and patients with chronic unilateral vestibular hypofunction may benefit from the use of vestibular rehabilitation. Interestingly, there was no relationship between improvement in DVA and improvement in complaints of oscillopsia. Further studies are needed to examine this finding. Vestibular exercises may enhance the development of programmed eye movements, which is very useful for gaze stability during active head movements (DVA-predicable).

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