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Effects of Saccular Function on Recovery of Subjective Dizziness After Vestibular Rehabilitation

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Objective: We attempted to investigate whether the integrity of saccular function influences the severity of subjective dizziness after vestibular rehabilitation in vestibular neuritis.
Study Design: Retrospective analysis.
Setting: Tertiary referral center.
Patients: Forty-six patients with acute unilateral vestibular neuritis were included.
Interventions: Diagnostic, therapeutic, and rehabilitative.
Main Outcome Measures: All the patients completed vestibular rehabilitation therapy until their computerized dynamic posturography and rotary chair test results were significantly improved. The rehabilitation patients were classified into the normal to mild subjective dizziness and moderate to severe subjective dizziness groups according to the dizziness handicap inventory score (cutoff of 40). Differences between the two groups were analyzed.
Results: After rehabilitation, 32.6% of the patients still complained of moderate to severe dizziness. Age, sex distribution, the presence of comorbidities, caloric weakness, pre- and postrehabilitation gain values in rotary chair test, postrehabilitation composite scores in posturography, and the duration of rehabilitation were not significantly different between the two groups. However, initial dizziness handicap inventory (DHI) score and composite score in dynamic posturography were worse and the proportion of patients with absent cervical vestibular-evoked myogenic potential in the moderate to severe group was much higher (93.3% vs. 35.5%, $p < 0.001$). After multiple regression analysis of those factors, initial DHI score and absent cervical vestibular-evoked myogenic potential response were identified as being associated with higher postrehabilitation DHI score.
Conclusion: Saccular dysfunction in acute vestibular neuritis can contribute to persistent subjective dizziness, even after the objective parameters of vestibular function tests have been improved by vestibular rehabilitation. **Key Words:** Saccule—Vestibular neuritis—Vestibular rehabilitation—Vestibular-evoked myogenic potential.

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Acute vestibular neuritis is a disorder characterized by sudden vertigo, nausea/vomiting, and imbalance persisting for few days to weeks with decreased vestibular function (1). The etiology of the disease is thought to be viral, microvascular, or autoimmune, but no specific etiology has been clearly identified (1–3). The recovery from vestibular neuritis depends upon the recovery of peripheral vestibular function and/or central compensation (1,4,5). Vestibular rehabilitation has been reported to be a useful treatment approach to develop central compensation in acute vestibular loss (6,7). This rehabilitation is composed of exercises for adaptation, substitution, and habituation and eventually enhances visual and postural stability. Recently, creating individually customized exercises has become popular in clinics because the degrees of vestibular loss and subjective symptoms differ among patients (6,8). The recovery of subjective symptoms after acute vestibular neuritis can be influenced by various factors, such as extent of vestibular loss, the patient's cooperation, visual dependency, and psychogenic comorbidities (6,9). According to studies using various vestibular function tests, the superior vestibular nerve is most commonly involved, followed by the total vestibular nerve and the inferior vestibular nerve (1). The saccule, which is an otolithic organ innervated by inferior vestibular nerve that mainly

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All the procedures performed in the studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The institutional review board of the authors' institution approved this study. For this type of study, formal consent is not required.

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senses vertical linear acceleration and gravity, should play an important role in maintaining posture and head position during various movements, and the integrity of its function after acute peripheral vestibulopathy which can be measured using cervical vestibular-evoked myogenic potential (cVEMP) should be important for improving balance and subjective dizziness. However, few studies have evaluated the relationship between the recovery of a patient's subjective dizziness and the extent of vestibular neuritis (10). We hypothesized that saccular function is important in the recovery of objective and subjective parameters in patients with acute vestibular loss. Accordingly, in this study, to identify whether saccular function integrity is an important factor for the recovery of subjective dizziness, we aimed to investigate the influence of various factors such as extent and amount of vestibular loss, subjective dizziness before vestibular rehabilitation, and recovery of dynamic imbalance after rehabilitation on differences in subjective dizziness after vestibular rehabilitation.

SUBJECTS AND METHODS

Selection of Patients and Evaluation of Vestibular Function

A total of 52 consecutive patients diagnosed with acute unilateral vestibular neuritis with unilateral caloric weakness were included initially; however, six patients were excluded from this study due to poor compliance with treatment and follow-up loss. Thus, 46 patients were finally enrolled in this study. The mean age of the enrolled patients was 60.5 ± 9.9 years, and the male-to-female ratio was 18:28. The lesion sides were right in 27 patients and left in 19 patients. Basic laboratory examinations (complete blood cell count, liver function test, blood sugar level, ion balance, thyroid function tests, kidney function test) and complete neurologic/neurotological examinations were performed in all the patients. All the patients showed spontaneous nystagmus directed to one side and corrective saccade on the head impulse test in the opposite direction to the spontaneous nystagmus. Other abnormal signs suggesting central lesions were not identified in the neurologic/neurotological examinations. The patients had no histories or signs of visual or psychiatric disorders, and their vertigo persisted for a few days to weeks. No patient complained of hearing loss, tinnitus, or aural fullness. All the patients underwent pure-tone audiometry and vestibular function tests, including the random amplitude saccade, smooth pursuit, optokinetic and optokinetic after nystagmus, slow harmonic acceleration test (SHA) of rotatory chair test (RCT) (NOTC-S, Neuro Kinetics, Inc., Pittsburg, PA), cVEMP(ABaer, Natus Medical, Inc., CA, U.S.A.), bithermal caloric test (SLVNG, SLMED, Seoul, Korea), and computerized dynamic posturography (CDP) (SMART EquiTest, Natus Medical, Inc., Pleasanton, CA) at 7 to 10 days after the vertigo episode. The parameters measured to evaluate vestibular function in the tests were the canal paresis (CP) value using Jonkee's formula in the bithermal caloric test (11), gain/phase/asymmetry for the SHA test, the presence and absence of the P13 and N23 waves in cVEMP, and the composite score for sensory organization test of CDP. For the cVEMP test, active electrodes were placed on the upper half of the bilateral SCM muscles, while reference and ground electrodes were placed on the suprasternal notch and forehead, respectively. Electromyographic signals were amplified, bandpass-filtered between 30 and 3000 Hz, and monitored to maintain background muscle activity at 50 μV. Acoustic stimuli were 1000 Hz 95 dB nHL short-tone bursts with rarefaction polarity and were delivered through an inserted earphone. An average of 100 responses were recorded for each run, with the subject sitting with the head rotated sideways toward one shoulder to activate the SCM muscle. The cVEMP was measured by monaural acoustic stimulation with ipsilateral recording. Prestimulus rectification on selected waveform during 20 ms was averaged, and new rectified waveforms were obtained. The first positive and second negative polarities of biphasic waveform were termed waves p13 and n23, respectively. Consecutive trials were performed to confirm the reproducibility of peaks p13 and n23, following which cVEMP responses were considered present. Conversely, cVEMP responses were considered absent when the biphasic p13–n23 waveform was not reproducible. The results were defined as abnormal in the absence of cVEMP response. The SHA test and CDP were regularly followed up (1-mo interval) during the vestibular rehabilitation period to monitor the vestibular adaptation and compensation.

Questionnaires for Subjective Dizziness Evaluation

To evaluate patients' subjective dizziness, the Korean version of the Dizziness Handicap Inventory (DHI) was used. This is a widely used useful clinical tool that clarifies the patient's symptomatic complaints and perceptions of their functional abilities and has been shown to have high test–retest reliability (1,12). The questionnaire consists of 25 questions related to a patient's physical (7), functional (9), and emotional (9) problems. There are three closed-form answers where patients may check one of the following: yes, no, and sometimes. The score for each answer item is assigned as follows: No = 0, Sometimes=2, and Yes=4. The maximum score of 100 indicates the greatest disturbance to the patient, and the minimum score of 0 indicates no handicap. The questionnaires were administered during patients' initial visits and then regularly followed up during vestibular rehabilitation.

Vestibular Rehabilitation and Patient Follow-up

Vestibular rehabilitation was started within a week of the disease onset. A vestibular suppressant was stopped before rehabilitation in all the patients.

The patients were instructed to rotate and move their head up and down while trying to maintain their visual fixation on a target for 1 to 2 minutes two to three times per day. After being familiarized with the exercise, the patients were instructed to perform the same head movement while maintaining visual fixation on a horizontally and vertically moving target. They were also given instructions regarding exercises to improve posture and gait, which were started after those for visual adaptation. The patients were asked to maintain upright posture with a narrow foot base. If tolerable, they were instructed to continue remaining upright while closing their eyes and to repeat this exercise on a soft floor. After maintaining this posture, they were directed to attempt to march in place. If this exercise could be performed without an issue, the patient was instructed to walk and then to try a tandem gait. Horizontal and vertical head movements were then added during the gait exercise. Although the general rehabilitation protocol was as described above, it was modified according to the patient's individual symptoms. Immediately after providing the instruction, we ensured that the patient performed the exercise correctly and then sent the patients home with directions to repeat the exercise at least two to three times per day for 1 month. The patients visited an outpatient clinic a month later, and whether they performed the exercise correctly and consistently was

TABLE 1. *Changes in objective and subjective parameters before and after vestibular rehabilitation*

	Normal Value[a]	Before Rehabilitation	After Rehabilitation	*p* Value
Canal paresis value (%)	<25	72.2 ± 24.3	—	
cVEMP (N of no response/total)		25/46	—	
Composite score in CDP	76.0 ± 5.9	59.8 ± 16.0	75.0 ± 7.1	<0.001
Gain in rotary chair test				
0.04 Hz	0.45 ± 0.11	0.19 ± 0.05	0.27 ± 0.04	<0.001
0.12 Hz	0.46 ± 0.12	0.24 ± 0.04	0.48 ± 0.04	<0.001
0.25 Hz	0.47 ± 0.14	0.25 ± 0.04	0.53 ± 0.03	<0.001
0.50 Hz	0.57 ± 0.14	0.28 ± 0.04	0.67 ± 0.05	<0.001
1.00 Hz	0.65 ± 0.19	0.29 ± 0.05	0.69 ± 0.03	<0.001
DHI score				
Physical	0	13.3 ± 7.1	8.4 ± 6.2	<0.001
Emotional	0	14.7 ± 9.5	8.9 ± 7.6	<0.001
Functional	0	15.7 ± 9.8	8.9 ± 7.6	<0.001
Total	0	43.8 ± 24.4	26.2 ± 20.6	<0.001

[a]Normal values based upon the laboratory of senior author's institution.
CDP indicates computerized dynamic posturography; cVEMP, cervical vestibular-evoked myogenic potential; DHI, dizziness handicap inventory.

determined according to their exercise diaries and the evaluation of their exercise by requesting the patients to perform the educated exercise. The DHI questionnaire, SHA test, and CDP were performed to identify the recovery status of patients. Subsequently, the patients were reeducated about the exercise if their performance was insufficient or were given additional instructions if they had performed adequately. The patients were followed up 1-month intervals using the questionnaire, SHA test, and CDP until the SHA test and CDP parameters were normalized. The patients who showed poor compliance with vestibular rehabilitation therapy in their exercise diaries were excluded from this study.

Data Analysis

Changes in objective and subjective parameters after rehabilitation were evaluated first. Afterward, the patients were divided into two groups according to the final DHI score: the normal to mild handicap group (< 40) and the moderate to severe handicap group (≥ 40). The differences in patient demographics, CP values, SHA test results, CDP composite score, and cVEMP response between the two groups were analyzed. The data were analyzed with Fisher's exact test, Student's *t* test, and Wilcoxon signed-rank test. In addition, as these factors could influence the recovery of subjective dizziness in patients, we attempted to analyze the relationship between these factors and final subjective dizziness score (final DHI score) using multiple linear regression.

Values are presented as the mean ± standard deviation (SD). Differences were considered to be significant at $p < 0.05$.

RESULTS

Results of Vestibular Function Tests and Vestibular Rehabilitation

All the patients showed unilateral caloric weakness on a bithermal caloric test (mean CP value: 72.2 ± 24.3%). The SHA test showed decreased gain, phase lead, and asymmetry in all the patients. cVEMP response was absent in 25 patients. CDP showed decreased equilibrium scores on condition 5 or conditions 5 and 6 in all patients, and the mean composite score was 59.8 ± 16.0. The mean total DHI score at diagnosis was 43.8 ± 24.4. All the patients underwent vestibular rehabilitation until the objective results of the SHA test and CDP were normalized, except for one patient whose CDP composite score remained 46 (prerehabilitation: 46), even after vestibular rehabilitation for 6 months. The mean duration of the rehabilitation was 3.0 ± 1.4 months. The CDP composite score and total DHI score after rehabilitation were 75.0 ± 7.1 and 26.2 ± 20.6, respectively. The composite score ($p < 0.001$), gain on SHA test ($p < 0.001$), total DHI score ($p < 0.001$), and DHI score of each subcategory ($p < 0.001$) were significantly improved after vestibular rehabilitation. These data are summarized in Table 1.

Factors Related to Persistent Subjective Dizziness After Vestibular Rehabilitation

After rehabilitation, the DHI score was less than 40 (normal to mild group) in 31 patients and equal to or greater than 40 (moderate to severe group) in 15 patients. The mean prerehabilitation CDP composite score was significantly lower ($p = 0.032$), while total DHI scores and scores for each subcategory thereof were significantly higher ($p < 0.05$ in total and each subcategory of DHI) in the moderate to severe group than in the normal to mild group; however, the age, gender distribution, presence of systemic disease, postrehabilitation CDP composite score, CP value, and rehabilitation duration were not significantly different between the two groups ($p > 0.05$, Table 2). In both the groups, objective parameters (the CDP composite score and parameters in the SHA test) were significantly improved (Table 2). However, the subjective parameter (DHI score), which was improved after rehabilitation in the normal to mild group, was not significantly improved after rehabilitation in the moderate to severe group ($p > 0.05$). Interestingly, initial cVEMP responses differed between the two groups; the proportion of patients with absent cVEMP responses were significantly higher in the moderate to severe DHI score groups (93.3% [14/15] of moderate to severe group vs. 35.5% [11/31] of mild to moderate

TABLE 2. *Demographics and changes in objective/subjective parameters after vestibular rehabilitation in patients with normal to mild final DHI scores and those with moderate to severe final DHI scores*

	DHI < 40	*p* Value[a]	DHI ≥ 40	*p* Value[a]	*p* Value[b] (Before/After)
Age (yr)	62.0 ± 10.8		57.2 ± 6.9		0.073
Sex (M:F)	10:21		8:7		0.208
Systemic disease					
Hypertension (N)	8		2		0.460
Diabetes mellitus (N)	1		1		1.000
cVEMP (N of no response/total)	**11/31**		**14/15**		< 0.001
Canal paresis (%)	74.0 ± 25.0		68.6 ± 23.0		0.477
Rehabilitation duration (months)	3.0 ± 1.5		3.1 ± 1.4		0.895
Composite score in CDP (before/after)	63.5 ± 14.5/76.5 ± 5.8	< 0.001	52.1 ± 16.6/71.9 ± 8.6	0.001	0.032/0.071
Gain in rotary chair test					
0.04 Hz (before/after)	0.19 ± 0.05/0.26 ± 0.04	< 0.001	0.19 ± 0.05/0.28 ± 0.04	0.001	0.997/0.175
0.12 Hz (before/after)	0.24 ± 0.05/0.49 ± 0.04	< 0.001	0.23 ± 0.03/0.47 ± 0.05	0.001	0.323/0.314
0.25 Hz (before/after)	0.25 ± 0.04/0.53 ± 0.03	< 0.001	0.25 ± 0.03/0.53 ± 0.03	0.001	0.762/0.802
0.50 Hz (before/after)	0.28 ± 0.05/0.67 ± 0.05	< 0.001	0.27 ± 0.03/0.67 ± 0.05	0.001	0.262/0.753
1.00 Hz (before/after)	0.29 ± 0.05/0.69 ± 0.03	< 0.001	0.30 ± 0.04/0.69 ± 0.04	0.001	0.850/0.677
DHI score					
Physical (before/after)	11.3 ± 6.7/4.9 ± 3.6	< 0.001	17.3 ± 6.4/15.6 ± 3.8	0.180	0.006/<0.001
Emotional (before/after)	12.2 ± 9.2/4.8 ± 4.8	< 0.001	20.0 ± 8.0/17.3 ± 4.6	0.082	0.006/<0.001
Functional (before/after)	13.4 ± 9.8/4.6 ± 3.9	< 0.001	20.5 ± 8.1/17.7 ± 5.2	0.131	0.013/<0.001
Total (before/after)	36.7 ± 23.1/14.3 ± 10.7	< 0.001	58.5 ± 20.7/50.7 ± 13.0	0.075	0.003/<0.001

[a]*p* value between before and after vestibular rehabilitation.
[b]*p* value between DHI < 40 group and DHI ≥ 40 group.
CDP indicates computerized dynamic posturography; cVEMP indicates cervical vestibular-evoked myogenic potential; DHI, dizziness handicap inventory.

group, $p < 0.001$, Table 2). Consequently, the significant difference in the parameters used in this study between the two groups could be summarized as follows: prerehabilitation CDP composite scores were significantly lower, and DHI scores and the proportion of patients with absent cVEMP responses were significantly higher in the moderate to severe DHI score groups (Table 2).

We performed multiple linear regression to confirm if the above three factors actually influenced subjective dizziness after rehabilitation. Age, total DHI score before rehabilitation, CDP composite score before rehabilitation, CP value, and cVEMP response were considered in this analysis. Therein, total DHI score before rehabilitation ($p = 0.001$) and cVEMP response ($p = 0.048$) were significantly related to total DHI score after rehabilitation, whereas age, CP value, and CDP composite score before rehabilitation showed no correlation with total DHI score after rehabilitation. When there was no cVEMP response, total DHI score after rehabilitation increased (Table 3; Fig. 1).

DISCUSSION

Vestibular rehabilitation is reported to be a safe and effective method for the treatment of acute peripheral vestibular loss (1,6,8). The treatment outcome of this rehabilitation can be measured by objective and subjective methods (9). The objective methods include CDP and RCT, and the subjective methods include various validated questionnaires, such as DHI, the Activities-specific Balance Confidence Scale, and the Vestibular Disorders Activities

TABLE 3. *Factors influencing total DHI score after rehabilitation on multiple linear regression (R square 0.441, adjusted R square 0.371)*

Factor	B	Standard Error	β	t	*p* Value	VIF
Constant	49.912	22.432		2.225	0.032[a]	
Age	−0.459	0.250	−0.220	−1.835	0.074	1.025
Total DHI score before rehabilitation	0.411	0.118	0.486	3.491	0.001[a]	1.388
CDP composite score before rehabilitation	−0.079	0.171	−0.061	−0.459	0.649	1.260
CP value	−0.064	0.104	−0.075	−0.613	0.543	1.076
cVEMP response	−10.288	5.054	−0.251	−2.036	0.048[a]	1.089

R square and adjusted R square were 0.329 and 0.313, respectively, when only total DHI score before rehabilitation was a factor. Also, R square and adjusted R square were 0.126 and 0.107, respectively, when only cVEMP response was a factor.
[a]*p* value < 0.05.
β indicates standardized coefficients; B, unstandardized coefficients; CDP, computerized dynamic posturography; CP, canal paresis; cVEMP, cervical vestibular-evoked myogenic potential; DHI, dizziness handicap inventory; t, t value; VIF, variation inflation factor.

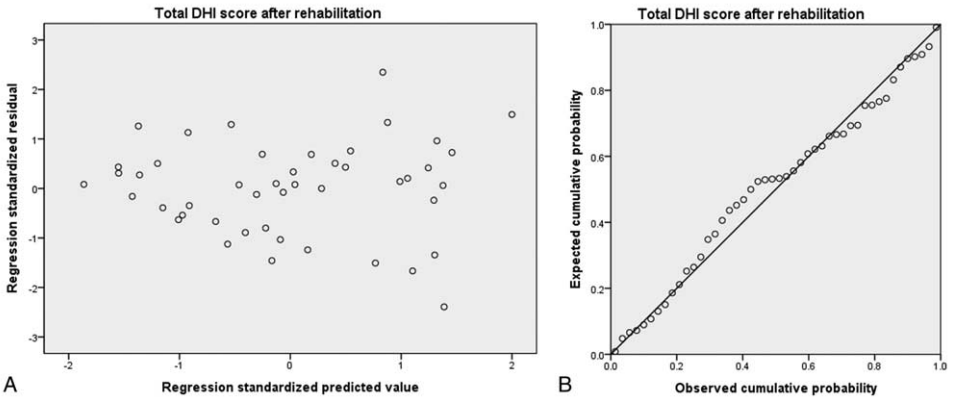

FIG. 1. Factors influencing total DHI score after rehabilitation in multiple linear regression. *A*, Scatterplot of regression standardized residual and regression standardized predicted values. *B,* Normal P-P plot of regression standardized residual. Two images demonstrate that this multiple linear regression satisfies equal variance and normal distribution so the analysis is appropriate. DHI indicates dizziness handicap inventory.

of Daily Living Scale. It has been reported that the improvement of some patients' subjective parameters was correlated with that of the objective parameters, although this was not consistently observed in all patients (13–15); indeed, some patients still complain subjective dizziness and imbalance, even after the improvement of their objective parameters. The persistence of subjective symptoms after rehabilitation may be explained by several possibilities, such as incomplete rehabilitation, psychiatric comorbidities, and underlying diseases affecting sensory function and proprioception (6,9). Among these factors, physicians or physical therapists may overlook the possibility of incomplete rehabilitation if they evaluate the treatment result based only on objective parameters. In this study, approximately 33% (15/46) of the patients still complained of moderate to severe subjective dizziness after the recovery of the results of CDP and SHA test after rehabilitation. There was no difference in the presence of systemic disease or neurological disorder affecting the patients' balance or proprioception, history of psychiatric disorder, or their compliance with rehabilitation between patients with normal to mild DHI scores and those with moderate to severe DHI scores after rehabilitation. However, the proportion of patients with absent cVEMP response were significantly higher among those with moderate to severe DHI scores. Furthermore, absence of cVEMP response was revealed to be significantly related to the recovery of subjective dizziness by multiple linear regression analysis. In fact, the objective test method used to evaluate the rehabilitation results in this study was likely unable to detect the recovery or compensation of saccular function. The RCT mainly reflects the function of the lateral semicircular canal and changes in the adaptation of the vestibule-ocular reflex and cannot evaluate changes in the saccular or inferior vestibular nerve function. CDP can be a useful method to evaluate and monitor the recovery of postural instability in which saccule is partially involved in controlling the vestibulospinal reflex; however, CDP measures changes in the center of pressure based on changes of the feet pressure under various stimulations, and it has been reported that this method cannot reflect minute and complicated trunk sway motion (sway of center of mass) (16). For this, motion sensors able to detect the velocity or acceleration of body motion must be attached above the hip joint area, close to the real center of mass (17). A human is not a simple inverted pendulum model; indeed, the human body is more similar to a multisegment model using the ankle, hip joint, neck, and extremities to maintain its posture under various conditions. Therefore, measuring only the center of pressure when evaluating postural stability does not completely reflect the improvement of postural control after acute vestibulopathy. In addition, the results of CDP do not reflect the maintenance of balance during gait and locomotion, which is more complicated and difficult work than posture control during standing. Consequently, the improvement of posture control in CDP might not reflect the incomplete recovery of minute and complex trunk sway during standing and locomotion, resulting in discrepancies between the improvement of the composite score in CDP and the subjective dizziness score. Therefore, incomplete rehabilitation may occur, even when some objective parameters are significantly improved, and thus, subjective parameters should also be evaluated to monitor the effect of the rehabilitation. In addition, we should consider adopting more specific objective methods that measure trunk sway or locomotion to evaluate the improvement of balance; these methods may include center of gravity measurement during certain perturbation conditions as described above, stepping tests, timed up and go, and so forth.

In this study, cVEMP was the major factor found to influence subjective dizziness after rehabilitation in multiple regression analysis. Previously, saccular dysfunction was not shown to significantly influence response to rehabilitation in individuals with peripheral vestibular disorders (10). In the cited study, the authors categorized patients into two groups: one with abnormal caloric test results but no evidence of otolith dysfunction in SVV or cVEMP response (canal involvement only group) and another with abnormal caloric test results with abnormal results in SVV and cVEMP response (canal involvement

with otolithic dysfunction including saccular and utricular dysfunction). They included utricular and saccular dysfunction as an otolithic dysfunction, which was different from the categorization in our study, in which saccular dysfunction was considered a parameter. Also, the study used SVV for the evaluation of utricular dysfunction; however, a lesion that can induce roll plane disorder, including utricular dysfunction, vertical canal dysfunction, and central disorders, can result in abnormal SVV. Although SVV can reflect utricular function to some extent, it is not always specific for utricular dysfunction. In addition, they used an abnormal amplitude ratio of cVEMP as a parameter for saccular dysfunction, and they did not specify the method for conducting cVEMP. For the evaluation of the amplitude abnormal ratio, rectification of cVEMP and/or the maintenance of both sides sternocleidomastoid muscle tension should be kept constant and equal during measurement, which was not described in detail in the aforementioned study. Furthermore, although several studies have described intact utricular function in patients with loss of a superior and lateral semicircular canal (10,18), utricular function is thought to be typically affected simultaneously, because the utricle is innervated with the superior vestibular nerve, which innervates superior and lateral semicircular canals. Therefore, we hypothesized that the outcomes of vestibular rehabilitation in patients with superior and inferior vestibular nerve dysfunction, which could be detected with caloric test and cVEMP test, would be different from those in patients with superior vestibular dysfunction only. As a result, the proportion of patients with an absent cVEMP response with moderate to severe DHI scores were significantly greater than those with normal to mild DHI scores (93.3% vs. 35.5%), which was further validated by multiple regression. In addition, DHI scores among patients with an absent cVEMP response in the moderate to severe DHI score group were not significantly improved, even after rehabilitation. Therefore, while the duration of the rehabilitation was likely to be sufficient for some patients with absent cVEMP response, it was insufficient for others and it is tempting to speculate that saccular function reflected by cVEMP response could contribute to persistent subjective dizziness reflected by DHI scores.

The mean CDP composite score and DHI score before rehabilitation in the moderate to severe group were worse than those in the mild to moderate group. Especially, DHI score before rehabilitation was found to be associated with sustained subjective symptoms after rehabilitation in multiple regression analysis. Although the initial DHI scores were not always higher in the patients with absent cVEMP response, patients who showed moderate to severe DHI after rehabilitation mostly had higher initial DHI and absent cVEMP response. This means that a certain proportion of patients with absent cVEMP response, which represents both superior and inferior vestibular nerve involvement, could show severe initial subjective and objective symptoms and that the patients could have sustained subjective dizziness even after normalization of objective parameters by rehabilitation. Therefore, one should be careful in monitoring the treatment results of vestibular rehabilitation in those patients.

Several limitations of this study should be considered. First, the recovery of vestibular function influences the improvement of patients' subjective dizziness. For example, caloric weakness has been reported to improve after acute vestibular neuritis in ~30% of patients (1). Thus, more patients may exhibit recovered caloric weakness and absent cVEMP response among those with normal to mild DHI scores after rehabilitation than among those with moderate to severe DHI scores. Reevaluating the caloric test and cVEMP after the rehabilitation would be desirable. However, repeating the caloric test typically bothers patients, eliciting severe vertigo, and repeating tests incurs additional costs; as a result, at our institute, this test is not routinely repeated. Second, the presence of comorbidities, such as a psychiatric disorder or peripheral neuropathy, which could influence the result of the rehabilitation, should be completely evaluated. It has been reported that psychiatric comorbidities, especially anxiety and depression, can delay the recovery of imbalance and subjective dizziness after rehabilitation (6). We do not routinely refer patients to a psychiatrist or neurologist unless they have histories of such disorders or show abnormalities during communication or physical examination or on the laboratory tests. No patients had any history of comorbid diseases or abnormal findings in neurological examinations and laboratory tests in this study. However, we cannot completely rule out the effects of comorbidities that may not have been detected. To definitely rule out the effects of other factors on vestibular rehabilitation, a well-designed prospective study involving various factors, including objective/subjective parameters, psychiatric features, and other related factors, should be performed in the future. Third, more delicate and localizing vestibular function tests have been introduced recently, including ocular VEMP and video head impulse test. These tools can be used to examine valuable information in localizing the extent of vestibular loss. If these tests are performed in combination with the tests used in this study, more precise information about the relationship between incomplete recovery of subjective dizziness and the extent of vestibular lesion could be deduced. However, these tests were only introduced at the authors' institute recently, and the number of patients enrolled in this study who underwent these tests was too small for statistical analysis. A study to identify the relationship between the recovery of subjective and objective imbalance and the extent of vestibular dysfunction should be performed for supporting and detailing the results of this study.

CONCLUSION

Saccular dysfunction in acute vestibular neuritis can contribute to persistent subjective dizziness, even after the improvement of the objective parameters of vestibular function tests after vestibular rehabilitation. The integrity

of saccular function and parameters of subjective dizziness should be considered when planning and monitoring the progress of vestibular rehabilitation therapy.

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