Research Article

Efficacy of Combining Conventional Vestibular Rehabilitation with Whole Body Vibration and Galvanic Vestibular Stimulation on Balance of Patients with Uncompensated Unilateral Vestibular Neuritis

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Highlights

- CVR, WBV, and GVS can improve the balance of people with UVN
- Combining these 3 rehabilitations led to more improvement in posturography and vHIT

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ABSTRACT

Background and Aim: Previous studies have demonstrated that uncompensated Unilateral Vestibular Neuritis (UVN) is the most prevalent cause of dizziness. Use of Conventional Vestibular Rehabilitation (CVR) has some limitations. The use of tool-based rehabilitation methods can be more pleasant to these patients and encourage them to complete the rehabilitation course. This study aimed to compare the effects of combining CVR with Whole Body Vibration (WBV) and Galvanic Vestibular Stimulation (GVS) on balance function in patients with UVN.

Methods: In this study, 51 patients with uncompensated UVN aged 30-50 years were randomly divided into three groups of 17, including CVR (group 1), CVR+WBV (group 2), and CVR+WBV+GVS (group 3). The interventions included four weeks of CVR, twenty 5-minute sessions of WBV, and eight 20-minute sessions of GVS. Outcome measures were postural control parameters, Vestibulo-Ocular Reflex (VOR) gain asymmetry, cervical Joint Position Sense Error (JPSE), and Dizziness Handicap Inventory (DHI) score that were assessed before and after interventions.

Results: Of 51 patients, 45 completed the study. There was a significant improvement in all measured variables in all groups, where the group 2 and group 3 showed significantly greater improvement than the group 1 in posturography results, cervical JPSE, and DHI score ($p<0.05$). There was no significant difference among the groups in the VOR gain asymmetry ($p>0.05$).

Conclusion: The CVR, CVR+WBV and CRV+WBV+GVS can improve the balance of UVN patients among which CVR+WBV and CRV+WBV+GVS are more effective. Combining CVR with WBV and GVS leads to additional therapeutic effects in UVN patients.

Keywords: Vestibular neuritis; vestibular rehabilitation; whole body vibration; galvanic vestibular stimulation

Introduction

Uncompensated Unilateral Vestibular Neuritis (UVN) leads to complex symptoms and disorders in both static and dynamic states, typically affecting eye movement and postural control [1-4]. UVN is the third most common cause of vertigo after benign paroxysmal positional vertigo and Meniere's disease. Patients with uncompensated UVN often experience imbalance, ataxia (especially in low-visibility conditions or on uneven surfaces), and oscillopsia during movement [5-7]. Currently, the most common treatment and rehabilitation approach for unilateral vestibular disorders includes structured physical exercises and movements in the form of Conventional Vestibular Rehabilitation (CVR) [3, 8, 9]. Although CVR offers several advantages, it also has limitations. CVR requires patients to have an adequate physical condition, actively participate in the exercises, and provide appropriate feedback. In today's society, due to increasingly sedentary lifestyles, many patients find it difficult to participate in CVR exercises. Additionally, CVR places less emphasis on proprioception, which is crucial for calibrating vestibular inputs at the perceptual level because it is the only signal that consistently provides reliable information about changes in head position relative to the trunk [3]. The goal of CVR is to improve and accelerate the recovery process in the vestibular system. In this approach, using the mechanism of central plasticity (adaptation, habituation, and substitution), static and dynamic balance are increased and vestibular-ocular interactions are improved in situations with conflicting sensory information [10]. Research has demonstrated that complete recovery is often not achieved by central compensation exercises alone. Alternative methods such as proprioceptive training, can yield more effective and efficient results. Relying on a single rehabilitation method may not achieve all rehabilitation goals; integrating proprioceptive and vestibular inputs into a program can enhance rehabilitation outcomes [11].

In recent years, technological advancements have introduced additional methods, including the Whole Body Vibration (WBV) and galvanic vestibular stimulation (GVS). The WBV is a mechanical vertical stimulation technique that delivers vibrations to proprioceptors. It has potential effects on sensorimotor performance in various populations, including athletes [12], older adults, healthy adults, and children with Cerebral Palsy (CP) [13]. So far, no study has used the WBV stimulation for the rehabilitation of patients with vestibular deficit. WBV is a safe, easy-to-use clinical intervention, particularly for individuals who cannot actively participate in traditional exercises. It is hypothesized that vibration provides proprioceptive input to the central nervous system, which subsequently adjusts the weight of proprioceptive signals in the vestibular system, ultimately improving balance performance. In the WBV exercises, vibration is applied to the body through a plate. The human body acts like a spring and stores mechanical energy. When the body moves upward under stimulation, energy is stored, and when it falls downward under the influence of gravity, the energy is released. During these movements, muscles, tendons, and joints work together to manage energy flow through the body [14]. Studies have shown that vibratory sensory stimuli are transmitted to muscle spindle fibers and Golgi tendon organs, activating alpha motor neurons [15]. Recently, GVS has been introduced as another method that can affect the vestibular system. Nam et al [16] investigated the ameliorating effects of sinusoidal GVS on vestibular compensation by using a mouse model of Unilateral Labyrinthectomy (UL). They showed that GVS intervention significantly accelerated the recovery of locomotion and improved Vestibulo-Ocular Reflex (VOR) gain compared to the non-GVS groups. GVS is a noninvasive technique that activates various parts of the peripheral vestibular system and vestibular nuclei through electrodes placed on the mastoid. In normal individuals, GVS improves dynamic gait and postural and motor stability [17,18].

Combining physical exercises with proprioceptive vibration stimulation and GVS may result in enhanced synergistic effects. Therefore, this study aimed to investigate the effectiveness of adding WBV and GVS to CVR in treating UVN. All ethical principles, such as the informed consent of the participants, their confidentiality, and their right to leave the study, were considered.

Methods

Participants

This is an interventional study. The population of this study consisted of all individuals aged 30-50 referred to the Tohid Balance Evaluation and Rehabilitation Clinic in Isfahan, Iran. Inclusion criteria were having one or more subjective complaints for several days, including disequilibrium, gait instability, vertigo/dizziness, oscillopsia, or spontaneous nystagmus; a clinical diagnosis of uncompensated, non-progressive UVN confirmed by thermal caloric irrigation, a canal paresis of more than 25%, and a normal oculomotor Videonystagmography. Exclusion criteria were the presence of a disability, nausea, or vomiting during the tests or rehabilitation sessions, prior history of vestibular rehabilitation, or any acute medical conditions that could limit assessments or treatment options [19]. A total of 51 people met the inclusion criteria, of whom six were excluded. Finally, 45 people (23 males and 22 females, mean age: 39.90±7.02 years) participated in the study. They were randomly allocated into three intervention groups: group 1 (received four weeks of CVR), group 2 (received four weeks of CVR plus 20 five-minute sessions of WBV), and group 3 (received four weeks of CVR plus 20 five-minute sessions of WBV and eight 20-minute sessions of dcGVS). A simple random sampling method was used to assign people into three groups. A 1:1 allocation ratio was applied using a randomization sequence generated by the Random Allocation Software. All participants were informed about the study objectives and declared their written consent.

Measures

Video head impulse test

We used small lightweight glasses (Otometrics, USA) with 250 frames per second resolution. The subject focused on a point in dim light located 91 cm away on the wall. The experimenter then delivered ten impulses at a speed of 150–200°/s at unpredictable times and directions, aligned with each pair of semicircular canals. To measure VOR in every semicircular canal direction, head impulses were given in the yaw axis to test the left and right horizontal canals. The patient's head was turned approximately 35-45 degrees to the right to examine the right posterior and left anterior canals. The head was then turned 35-45 degrees to the left to assess the left posterior and right anterior canals. Finally, the vHIT was performed. Quantitative values were obtained by calculating the gain of eye movement relative to head movement. If present, the covert and overt compensatory saccades were recorded during and after the head impulse, respectively [20].

Cervical joint position sense error test

In the cervical JPST, a laser pointer was attached to a headband worn by the patient. The patient sat on a chair 90 cm away from the wall and focused the laser light on a predetermined point. To prevent any trunk movement, the patient's torso was secured to the back of the chair with a strap. The patient was instructed to close their eyes, rotate their head to the extreme right or left (as far as possible without causing severe pain), and then return to the initial point. To avoid fatigue and increase the accuracy of the test, movements were performed at 15-second intervals. The average deviation from the midpoint after right and left rotations was measured in millimeters, and the Joint Position Sense (JPS) error was calculated in degrees. The cervical JPST was repeated six times for each side to ensure accuracy, and the average error was obtained from these six repetitions.

Dizziness handicap inventory

The Persian version of DHI was prepared and validated to assess the degree of disability caused by dizziness. The questionnaire has 25 items, each with three response options: yes (4 points), sometimes (2 points), and no (0 points). The patient completed the questionnaire with the help of the examiner, if needed. It took 10-15 minutes to complete, depending on the patient's ability. Higher scores indicate reduced handicap, while lower scores show no progress in response to the intervention.

Posturography

The posturography was conducted using a posturography device manufactured by Inventis, Italy. Before the test, the procedure was explained to the participant. The subject stood barefoot on a designated spot on the device's platform. The foot size was measured to ensure proper placement on the platform. The participant then stood upright without leaning or using any support. First, the pressure distribution across the sole was measured. Then, the range of stability for forward, backward, and lateral movements was assessed, and Limits of Stability (LOS) and Composite Score (CS) in the Sensory Organization Test (SOT) at two Anteroposterior (AP) and Mediolateral (ML) directions were obtained. The sensors embedded in the platform recorded and calculated the extent of movement fluctuations in various directions [21].

Interventions

Conventional vestibular rehabilitation

The CVR was performed over four weeks, at three sessions per week, each for one hour. The sessions took place in the clinic under the supervision of an operator. In this method, three physical exercises are used for rehabilitation including VOR exercises, saccadic eye movement exercises, and Cawthorne-Cooksey exercises [22, 23]. To do VOR exercises, the patient was asked to sit facing a sticker on a wall three feet away, keep their eyes fixed on the wall during exercise and turn rhythmically their head a little to the right and then to the left for at least 1 minute. During saccadic eye movement exercises, the patient was asked to keep their head still and move their eyes quickly looking at the right to the left target and then from the left to the right target. S/he repeats this back-and-forth eye motion for 1 minute. The Cawthorne-Cooksey exercises are a set of head, eye, and body movements in prone, sitting, standing, and walking positions that can improve balance through different compensatory mechanisms.

Whole body vibration

The WBV is a vertical mechanical stimulation method that provides mechanical vibration to proprioceptive receptors. Commercial WBV usually provides a frequency below 50 Hz, which is safe. For the WBV intervention, we used a commercial-grade vibration machine (LV-1000, X-Trend, Taiwan) with a presentation frequency of 20 Hz and constant sine wave vibrations (range: 0–4 mm). Participants underwent WBV for five minutes in each session while standing normally. The exercises were performed five times weekly for four consecutive weeks [24].

Galvanic vestibular stimulation

In the GVS method, bilateral-bipolar electrical stimulation was performed by using a direct current stimulator (Tanin Pardaz Pasargad Co., Iran). First, the electrode placement sites on the mastoid bones behind each ear were cleaned using a cleaning gel. Electrocardiography electrodes were then attached to the skin and the impedance was below 5 kΩ. The cathode electrode was placed on the mastoid of the lesion side and the anode electrode on the opposite mastoid. The stimulation was applied at an intensity level of 100 µA above the skin threshold, while the subject was sitting with closed eyes, at eight sessions for four weeks (two sessions per week, each for 20 minutes). It should be noted that the skin threshold was achieved in 50-µA steps, starting from an intensity level of 200 µA.

Statistical analysis

Descriptive statistics were reported using means and standard deviations. The Kolmogorov-Smirnov test was used to assess the normality of data distribution. One-way ANOVA was used to assess the difference in the baseline characteristics of normally distributed data, while Chi-Square test was used to assess the gender difference between the three groups. For within-group comparisons, paired t-test was employed for normally distributed data, and Cohen's d was used to measure the effect size, which is classified as small (d=0.2), medium (d=0.5), and large (d=0.8). For between-group comparisons, one-way ANOVA was used. The Bonferroni test was used for pairwise comparisons of the three study groups.

Results

Demographic characteristics of the participants are presented in Table 1. The age range for participants was 30 to 50 years. The mean age was 40±7.75 years in the group 1, 39.20±6.05 years in the group 2, and 39.93±5.57 years in the group 3. The gender distribution in the group1 was 41.2% females and 58.8% males. In the group 2, the distribution was 47.1% females and 52.9% males. In the group 3, the distribution was 52.9% females and 47.1% males. Differences in age and gender between groups were insignificant ($p>0.5$). At the beginning of the study There was no significant difference in unilateral weakness between the three groups ($p>0.5$).

Within-group comparisons

The results of within-group comparisons are shown in Table 2. In the group 1, significant improvements were

Table 1. Demographic characteristics of the participants

Characteristics	CVR (n=17)	CVR+WBV (n=17)	CVR+WBV+GVS (n=17)	p
Age	39.82(7.44)	39.94(6.05)	40.24(5.31)	0.960*
Sex (male/female)	10/7	9/8	8/9	0.790**
Unilateral weakness(percent)	44.14(9.71)	45.47(12.85)	43.23(9.40)	0.737*

CVR; conventional vestibular rehabilitation, WBV; whole body vibration, GVS; galvanic vestibular stimulation
* One-way ANOVA, ** Chi-Square

Table 2. Within-group comparisons for vestibular, postural and questionnaire outcome measures

		Mean(SD)			
Parameter	Group	Before intervention	After intervention	p*	d/Power
Horizontal VOR asymmetry	CVR	27.19(14.90)	18.19(5.32)	<0.001	1.56
	CVR+WBV	28.82(22.54)	14.83(10.75)	<0.001	1.35
	CVR+WBV+GVS	24.95(13.61)	7.80(5.32)	<0.001	1.81
Anterior VOR asymmetry	CVR	8.28(4.69)	6.48(4.51)	0.001	1.03
	CVR+WBV	9.25(5.41)	7.36(3.57)	0.062	0.52
	CVR+WBV+GVS	10.17(9.52)	9.54(6.52)	0.274	0.29
Posterior VOR asymmetry	CVR	10.48(10.61)	8.27(8.71)	0.004	0.88
	CVR+WBV	6.19(6.81)	5.47(6.81)	0.052	0.55
	CVR+WBV+GVS	8.26(5.54)	8.10(5.39)	0.968	0.01
JPS error	CVR	3.58(0.74)	2.89(0.58)	<0.001	2.48
	CVR+WBV	3.67(0.55)	2.18(0.32)	<0.001	3.36
	CVR+WBV+GVS	3.57(0.31)	1.97(0.10)	<0.001	5.81
ML displacement	CVR	55.06(3.17)	67.73(4.04)	<0.001	12.58
	CVR+WBV	54.76(3.88)	72.07(62.4)	<0.001	16.30
	CVR+WBV+GVS	55.35(3.02)	82.00(4.44)	<0.001	15.58
AP displacement	CVR	47.71(2.59)	56.60(3.31)	<0.001	10.91
	CVR+WBV	47.76(2.99)	62.07(5.14)	<0.001	4.84
	CVR+WBV+GVS	47.35(2.12)	67.60(3.48)	<0.001	14.03
LOS	CVR	67.88(7.41)	74.33(9.30)	<0.001	2.27
	CVR+WBV	67.18(7.56)	82.13(9.47)	<0.001	6.79
	CVR+WBV+GVS	66.82(5.97)	88.80(7.20)	<0.001	9.35
DHI score	CVR	43.53(14.65)	34.00(13.93)	<0.001	2.83
	CVR+WBV	43.54(15.93)	23.20(12.55)	<0.001	3.05
	CVR+WBV+GVS	42.00(15.41)	13.33(6.44)	<0.001	2.61

VOR; vestibulo-ocular reflex, CVR; conventional vestibular rehabilitation, WBV; whole body vibration, GVS; galvanic vestibular stimulation, JPS; joint position sense, ML; mediolateral, AP: anterior-posterior, LOS; limit of stability, DHI; dizziness handicap inventory; Bold numbers: p<0.05
* Paired t-test; d/Power; effect size with Cohen's d (small=0.2, medium=0.5 and large=0.8) or power (for p<0.05, effect size was calculated and for p>0.05 power of the test was calculated with Cohen's d)

observed between pre- and post-treatment measurements for all three VOR gain asymmetry, cervical JPS error, posturography results (AP and ML displacement and LOS), and DHI score ($p<0.05$; power≥0.88). In the group 2 and 3, significant improvements were found in horizontal VOR gain asymmetry, cervical JPS error, posturography results (AP and ML displacement and LOS), and DHI score ($p<0.05$; power≥1.35) but there were no statistically significant differences within groups 2 and 3 regarding posterior and anterior VOR gain asymmetry results ($p>0.05$; power≤0.55).

Between-group comparisons

The results of pairwise comparisons using the Bonferroni test are shown in Table 3. Between-group comparisons revealed significant differences in cervical JPS error ($F_{(2,42)}=36.32$, $p<0.001$), posturography results

Table 3. Between-group comparisons of vestibular, postural and questionnaire improvements

Parameters	Comparison groups		Mean difference	p*
Horizontal VOR asymmetry	CVR+WBV	CVR	9.33	0.063
	CVR+WBV+GVS	CVR	10.74	0.063
	CVR+WBV+GVS	CVR +WBV	1.41	1.000
Anterior VOR asymmetry	CVR+WBV	CVR	0.73	1.000
	CVR+WBV+GVS	CVR	0.45	1.000
	CVR+WBV+GVS	CVR+WBV	0.28	1.000
Posterior VOR asymmetry	CVR+WBV	CVR	1.75	0.346
	CVR+WBV+GVS	CVR	2.79	0.065
	CVR+WBV+GVS	CVR+WBV	1.03	0.340
JPS error	CVR+WBV	CVR	0.93	<0.001
	CVR+WBV+GVS	CVR	0.94	<0.001
	CVR+WBV+GVS	CVR+WBV	0.01	1.000
ML displacement	CVR+WBV	CVR	5.46	<0.001
	CVR+WBV+GVS	CVR	14.53	<0.001
	CVR+WBV+GVS	CVR+WBV	9.06	<0.001
AP displacement	CVR+WBV	CVR	6.06	<0.001
	CVR+WBV+GVS	CVR	11.66	<0.001
	CVR+WBV+GVS	CVR+WBV	5.60	<0.001
LOS	CVR+WBV	CVR	9.93	<0.001
	CVR+WBV+GVS	CVR	15.93	<0.001
	CVR+WBV+GVS	CVR+WBV	6.00	<0.001
DHI score	CVR+WBV	CVR	14.26	<0.001
	CVR+WBV+GVS	CVR	21.33	<0.001
	CVR+WBV+GVS	CVR+WBV	7.06	0.059

VOR; vestibulo-ocular reflex, CVR; conventional vestibular rehabilitation, WBV; whole body vibration, GVS; galvanic vestibular stimulation, JPS; joint position sense, ML; mediolateral, AP: anterior-posterior, LOS; limit of stability, DHI; dizziness handicap inventory. Bold numbers: p<0.05

* Bonferroni one-way ANOVA

(AP ($F_{(2,42)}$=126.96, p<0.001) and ML ($F_{(2,42)}$=467.16, p<0.001) displacement and LOS ($F_{(2,42)}$=172.96, p<0.001)), and DHI score improvement ($F_{(2,42)}$=27.80, p<0.001) but no significant differences were observed for all three VOR gain asymmetry improvement ($F_{(2,42}$< 3.2, p>0.05). The Bonferroni post hoc test showed a significant difference in cervical JPS error improvement between the group 1 and 2 (mean difference±SE:0.93±0.12; 95% confidence interval: 0.61 to 1.24; p<0.001) and between the group 1 and 3 (mean difference±SE:0.94±0.12; 95% confidence interval: 0.62 to 1.26; p<0.001), but no significant differences were observed between the group 2 and 3 (mean difference±SE:0.13±0.12; 95% confidence interval: 0.03 to 0.033; p=1.00), indicating greater improvement for cervical JPS error in the group 2 and 3 than group 1 but no significant difference was observed between groups 2 and 3. Also, significant differences were observed between the group 1 and 2 in posturography outcomes (LOS improvement (mean difference±SE:9.93±0.86; 95% confidence interval:7.77 to 12.09; p<0.001), AP displacement (mean difference±SE:6.06±0.73; 95% confidence interval: 4.24 to 7.89; p<0.001) and ML displacement (mean difference±SE:5.46±0.48; 95% confidence interval: 4.26 to 6.66; p<0.001)) and DHI score improvement (mean difference±SE:14.26±2.91; 95% confidence interval: 6.99 to 21.53; p<0.001). Also significant differences were observed for posturography outcomes (LOS improvement (mean difference±SE:15.93±0.86; 95% confidence interval: 13.77 to 18.09; p<0.001), AP displacement (mean difference±SE:11.66±0.73; 95% confidence interval: 9.84 to 13.49; p<0.001) and ML displacement (mean difference±SE:14.53±0.48; 95% confidence interval: 13.33 to 15.73; p<0.001)) and DHI score improvement (mean difference±SE: 21.33±2.91; 95% confidence interval: 14.06 to 28.60; p<0.001) between the group 1 and 3. Between the group 2 and 3, posturography outcomes (LOS improvement (mean difference±SE: 6.00±0.86; 95% confidence interval: 3.84 to 8.15; p<0.001), AP displacement (mean difference±SE: 5.60±0.73; 95% confidence interval: 3.77 to 7.42; p<0.001) and ML displacement (mean difference±SE:9.06±0.48; 95% confidence interval: 7.86 to 10.26; p<0.001)) and DHI score improvement (mean difference±SE:7.06±2.91; 95% confidence interval: 0.20 to 14.33; p=0.05) revealed significant differences. These results indicating greater improvement for posturography outcomes and DHI scores in group 2 and 3 than group 1 and greater improvement in group 3 than group 2. Also, no significant differences were observed between the groups for VOR gain asymmetry improvement in all semicircular canals (p>0.05).

Discussion

This study investigated the effects of combining CVR with GVS and WBV on the balance of patients with uncompensated UVN. The results demonstrated that all three rehabilitation methods significantly improved all study outcomes after rehabilitation, where the groups 2 and 3 showed greater improvements in all outcomes compared to the group 1, except for VOR gain asymmetry which was not significantly different. Additionally, the effect sizes for all outcomes were larger in the groups 2 and 3 than in the group 1.

The current study showed a significant decrease in VOR gain asymmetry, particularly in the horizontal canals, among the three groups after rehabilitation. This finding suggests improved gait stability during head movement in patients with UVN. Notably, the increase in the VOR gain of the three groups for the horizontal semicircular canal in the affected side was significantly higher than for the vertical canals after rehabilitation. This was accompanied by a notable reduction in the VOR gain of the horizontal canal compared to other two canals in three groups. The goal of CVR is to accelerate the recovery of the vestibular system by leveraging the central neuroplasticity mechanisms of adaptation, habituation, and substitution. These processes induce active neural changes in the brainstem and cerebellum in response to sensory conflicts caused by vestibular pathways. Ultimately, this leads to improved static and dynamic balance and enhanced VOR gain and yaw stability during head movements [25].

Our results did not show a significant difference in VOR gain asymmetry reduction between the three groups. However, the VOR gain of horizontal canal results was close to being significant. These results are expected because in some patients with uncompensated UVN, the posterior and anterior canals were involved. The improvement of the VOR gain following CVR has also been reported in other studies [26, 27], but no study has been conducted on the effect of WBV on the improvement of VOR gain so far. Although CVR exercises effectively improved VOR gain in the group 1, but groups 2 and 3 did not directly affect VOR outcomes.

In this study, the cervical JPST was performed before and after rehabilitation. The significant reduction in cervical JPS error, observed on both sides, was more pronounced in the groups 2 and 3 than in the group 1, but no significant difference was observed between groups 2 and 3. This means that GVS has no effect on the cervical JPST results. The use of GVS improves the processing of sensory information in the vestibular system. Vestibular signal detection thresholds are reduced, resulting in the processing of weak and subthreshold vestibular inputs, which ultimately improves information processing in the neurons of the central vestibular system and the formation of vestibular-spinal reflexes [28]. Vestibular information is not required to correctly detect head movements relative to the body; cervical proprioceptive information is sufficient for this function. During vibration, the central nervous system receives proprioceptive input, which alters the weight of proprioceptive signals in the vestibular system, ultimately enhancing balance performance. Sensory substitution is an essential component in vestibular rehabilitation to maintain the postural control of uncompensated UVN patients. It relies on increasing residual inputs by manipulating visual and somatosensory cues. Sinusoidal vibration can stimulate proprioceptive receptors, such as muscle spindles and joint mechanoreceptors [29]. Since WBV improves muscle strength and balance, and muscle stiffness and joint stability can be modified through mechanoreceptor activity via gamma efferent stimulation, this type of vibration has the potential to train and alter proprioception throughout the body. The improvement in proprioception likely occurs through type I afferents and alpha motor neurons, and due to an increase in the number of type II muscle fibers. It is well established that proprioceptive input from type I afferent pathways is crucial in generating isometric contractions [30]. The increase in isometric strength following WBV is probably due to a positive proprioceptive feedback loop. The underlying mechanisms of WBV are not limited to muscle mechanics and proprioception; it also involves hormonal and non-hormonal pathways. Changes in testosterone, growth hormone, growth factors, epinephrine, and norepinephrine levels have been observed following WBV [31].

The results of this study are consistent with the results of Khavarghazalani et al., who found that using GVS along with vestibular rehabilitation led to improvements in the balance of UVN patients [32]. It seems that GVS mainly changes vestibular afferents with irregular discharge that transmit phasic or high-frequency information. This is significantly important for the restoration of dynamic balance after UVN. Based on the results of previous studies, the use of GVS modulates the activity of calcium and sodium-dependent channels and the activity of N-methyl-D-aspartate receptors and creates a mechanism similar to long-term potentiation. It is possible that the simultaneous use of two interventions (CVR and GVS) caused the stimulation of more parts, resulting in higher effects on the balance performance of UVN patients.

Based on the results, the augmentation of WBV and GVS with CVR can be a valid and effective strategy to enhance neural plasticity and alter proprioception. Changes in proprioception of patients with UVN may serve as a compensatory strategy for reduced vestibular function. Sensory substitution is a critical component of vestibular rehabilitation, helping to maintain postural control in patients with unilateral vestibular deficits during standing and walking. CVR focuses on enhancing residual inputs by manipulating visual cues (e.g., eyes open, eyes closed, optokinetic stimulation) and balance (e.g., standing on a fixed surface, foam, or a moving surface), often combining both protocols [33].

In this study, a significant increased LOS in the SOT was observed in all groups after rehabilitations, indicating improved patient stability. Based on the DHI score, a significant improvement in DHI after one month of rehabilitation suggests better patient performance in daily activities. As previously mentioned, postural control relies on sensory information transmitted from the visual, vestibular, and somatosensory systems. The sensory system provides information about the support surface and joint angles. The visual system offers environmental cues, and the vestibular system delivers data regarding the head's angular velocity, linear acceleration, and orientation concerning gravity [34]. One of the postural control strategies is the ankle strategy. When a person is on a firm and smooth surface, movements occur within the range of the ankle joint. In this position, the upper and lower body move together, causing the body to resemble an inverted pendulum in the sagittal plane, maintaining stability. Vestibular input is unnecessary to initiate or execute a normal ankle strategy, and proprioceptive information alone is sufficient to control it. The difference in the LOS between the group 1 and 2 after rehabilitation may be due to vibration-based stimulation in the CVR+WBV group's rehabilitation program.

In a study by Tseng et al. [35] WBV and heat therapy were used for individuals over 45 years of age who did not have a regular exercise regimen. WBV was administered for three consecutive months (three sessions per week, each for 5 minutes), and heat therapy for 20 minutes at a temperature of 40°C. After the intervention, LOS and muscle strength were assessed using a balance system and a dynamometer, while flexibility was evaluated using the sit-and-reach test. A significant improvement in muscle flexibility was observed in both WBV and WBV+heat therapy groups, which is consistent with the findings of our study.

In our study, the CS of the SOT at both AP and ML directions increased significantly after rehabilitation in the three groups. This increase was more pronounced in the combined groups 2 and 3 than in the group 3. In contrast to our findings, Eder et al. [36], found that adding GVS to the CVR in patients with bilateral vestibular hypofunction did not result in more effective outcomes compared to the CVR alone in postural tests and questionnaires. This discrepancy may be attributed to differences in the type and duration of the CVR program, patient groups, evaluation methods, or the use of GVS at varying intensities. Combining WBV with CVR can enhance balance by improving muscle strength and altering proprioception. The DHI scores significantly improved after rehabilitation in all groups. The DHI score reflects the patient's perceived severity of dizziness and the degree of instability caused by vestibular defects in daily life. A significant difference in the DHI score was observed between the three groups. Due to time constraints, we could not examine the long-term effects of WBV. We suggest an investigation of the long-term effects of WBV in future studies.

Conclusion

Combining Conventional Vestibular Rehabilitation (CVR) with GVS and whole body vibration can lead to more significant improvements in the balance of patients with uncompensated Unilateral Vestibular Neuritis (UVN) compared to the CVR alone. It highlights the enhanced effectiveness of using three rehabilitation methods together. Clinically, this new combined rehabilitation can speed up the recovery of patients with uncompensated UVN.

Ethical Considerations

Compliance with ethical guidelines

All procedures performed in 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 study was conducted with the approval of the Ethics Committee of Shahid Beheshti University of Medical Sciences (Code: IR.SBMU.RETECH.REC.1403.034).

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Authors' contributions

AJ: Acquisition of data, interpretation of the results and drafting the manuscript; MA: Study design, interpretation of the results and drafting the manuscript; FH: Statistical analysis and drafting the manuscript.

Conflict of interest

The authors declare that they have no conflict of interest.

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