Efficacy of Virtual Reality Vestibular Rehabilitation Training in Patients with Sudden Hearing Loss and Vertigo (Postprint)

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Abstract

Background: Virtual reality (VR) rehabilitation training has been widely used in rehabilitation therapy due to its unique advantages; however, its efficacy in patients with sudden deafness accompanied by vertigo has not been investigated.

Objective: To observe the therapeutic efficacy of conventional vestibular rehabilitation training and VR technology-assisted vestibular rehabilitation training in patients with sudden deafness accompanied by vertigo.

Methods: A total of 84 patients with sudden deafness accompanied by vertigo admitted to the Department of Otolaryngology-Head and Neck Surgery of the First Hospital of Shanxi Medical University from January 2022 to January 2023 were enrolled and randomly divided into two groups (n=42 each) using a random number table. The control group received pharmacotherapy combined with conventional vestibular rehabilitation training, while the observation group received VR technology-assisted vestibular rehabilitation training in addition to pharmacotherapy. Both groups were assessed using the Dizziness Handicap Inventory (DHI) and Hospital Anxiety and Depression Scale (HADS) pre-intervention and at 7 and 14 days post-intervention.

Results: Eighty-one patients completed the trial (observation group: n=41; control group: n=40). A significant interaction between group and time was found for DHI-Functional (F), DHI-Emotional (E), DHI-Physical (P) subscales and total DHI score ($P<0.05$); both group and time demonstrated significant main effects on all DHI subscales and total score ($P<0.05$). No significant between-group differences were observed in any DHI subscale or total score pre-intervention ($P>0.05$). After 7 and 14 days of intervention, all DHI subscale scores and total scores decreased significantly from baseline in both groups ($P<0.05$), with lower scores in the observation group compared to the control

group (P<0.05). A significant group-by-time interaction was also found for HADS-Anxiety (A), HADS-Depression (D) subscales and total HADS score (P<0.05); both group and time showed significant main effects on all HADS subscales and total score (P<0.05). No significant between-group differences were observed in any HADS subscale or total score pre-intervention (P>0.05). After 7 and 14 days of intervention, all HADS subscale scores and total scores decreased significantly from baseline in both groups (P<0.05), with no significant differences between groups (P>0.05).

Conclusion: Vestibular rehabilitation training is effective for patients with sudden deafness accompanied by vertigo, and VR technology-assisted vestibular rehabilitation training can more significantly improve balance function and quality of life.

Full Text

Efficacy of Virtual Reality Vestibular Rehabilitation Training in Patients with Sudden Deafness and Vertigo

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Abstract

Background: Virtual reality (VR) rehabilitation training has been widely applied in rehabilitation therapy due to its unique advantages, but its efficacy in patients with sudden deafness and vertigo remains understudied. **Objective:** To observe the therapeutic effects of conventional vestibular rehabilitation training versus VR-assisted vestibular rehabilitation training in patients with sudden deafness accompanied by vertigo. **Methods:** Eighty-four patients with sudden deafness and vertigo admitted to the Department of Otolaryngology Head and Neck Surgery at the First Hospital of Shanxi Medical University between January 2022 and January 2023 were enrolled. Using a random number table method, patients were divided into two groups of 42 each. The control group received drug therapy combined with conventional vestibular rehabilitation training, while the observation group received drug therapy plus VR-assisted vestibular rehabilitation training. Both groups were evaluated using the Dizziness Handicap Inventory (DHI) and Hospital Anxiety and Depression Scale (HADS) before intervention and at 7 and 14 days post-intervention. **Results:** Ultimately, 81 patients completed the trial (41 in the observation group and 40 in the control group). Group and time showed significant interaction

effects on DHI-Function (F), DHI-Emotion (E), DHI-Physical (P) subscales and total DHI score (P<0.05), with significant main effects of both group and time (P<0.05). No significant differences existed between groups in DHI subscales or total score before intervention (P>0.05). At 7 and 14 days post-intervention, both groups showed significant reductions in all DHI scores compared to baseline (P<0.05), with observation group scores significantly lower than control group scores at both time points (P<0.05). Similarly, group and time demonstrated significant interaction effects on HADS-Anxiety (A), HADS-Depression (D) and total HADS scores (P<0.05), with significant main effects (P<0.05). No baseline differences existed between groups in HADS measures (P>0.05). Both groups exhibited significant reductions in HADS scores at 7 and 14 days (P<0.05), though between-group differences were not statistically significant (P>0.05). **Conclusion:** Vestibular rehabilitation training is effective for sudden deafness patients with vertigo, and VR-assisted vestibular rehabilitation training can more significantly improve patients' balance disorders and quality of life.

Keywords: sudden deafness; vertigo; hearing loss, sensorineural; vestibular rehabilitation training; virtual reality; treatment outcome

1. Materials and Methods

Sudden deafness with vertigo is defined as sudden sensorineural hearing loss occurring within 72 hours, with 28%-57% of patients experiencing concurrent vestibular symptoms including vertigo, nausea, and vomiting [1,2]. The incidence of sudden deafness has been rising in China in recent years, with epidemiological data showing prevalence rates of 5-27 per 100,000 in the United States, accounting for approximately 66,000 new cases annually [3]. While numerous studies have addressed hearing prognosis in these patients, vertigo symptoms also substantially impact work and daily life, with consensus indicating that sudden deafness patients with vertigo have poorer outcomes. Research demonstrates that the rate of effective hearing improvement is significantly higher in patients without vertigo compared to those with vertigo, establishing vertigo as a key factor affecting treatment efficacy and prognosis [4]. Furthermore, vertigo reduces quality of life and triggers psychological issues, particularly anxiety and depression, which create a vicious cycle [5-7] that further compromises outcomes. Vestibular rehabilitation training, a physical therapy approach designed to improve vertigo symptoms and balance function, works by training the vestibulo-ocular and vestibulospinal reflexes to promote neural plasticity mechanisms of adaptation, habituation, and compensation.

Rapid technological advances have positioned virtual reality (VR) as an emerging technology integrating modern computer graphics, simulation, and human-computer interaction to create three-dimensional environments that provide immersive experiences [8]. VR has been widely applied in rehabilitation therapy

due to its unique advantages [9]. Studies indicate that VR-assisted vestibular rehabilitation yields better long-term outcomes than conventional approaches, improving postural control, dizziness symptoms, and balance confidence [10,11]. This study compared the efficacy of conventional versus VR-assisted vestibular rehabilitation training in hospitalized patients with sudden deafness and vertigo.

1.1 General Information

Sample size was calculated using the formula for measurement data: $N = [2(Z\alpha+Z\beta)\sigma^2]/d^2$, where $\alpha = 0.05$, $\beta = 0.1$, $Z\alpha = 1.96$, and $Z\beta = 1.28$. Based on standard deviations and mean differences from relevant literature [12], the calculated sample size was $N_1 = N_2 = 29$. Accounting for a 20% attrition rate, the final required sample size was $N_1 = N_2 = 35$, yielding a minimum of 70 participants.

Eighty-four patients with sudden deafness and vertigo admitted to our department between January 2022 and January 2023 were selected and randomly divided into two groups of 42 using a random number table method. The study received ethical approval from the Ethics Committee of the First Hospital of Shanxi Medical University (2022K190), and all patients and their families provided informed consent.

Inclusion criteria: (1) Age 18-75 years; (2) Diagnosis of sudden sensorineural hearing loss according to the 2015 Guidelines for Diagnosis and Treatment of Sudden Deafness by the Chinese Society of Otolaryngology Head and Neck Surgery, with hearing loss $ $20 dB in at least two adjacent frequencies within 72 hours, accompanied by vertigo, nausea, and vomiting, plus evidence of ipsilateral vestibular dysfunction on caloric or head impulse testing; (3) No mental or intellectual disorders; (4) No communication barriers; (5) Understanding of the intervention process and voluntary participation with signed informed consent.

Exclusion criteria: (1) External auditory canal lesions (e.g., otitis media, tympanic membrane perforation) preventing examination cooperation; (2) Ear trauma; (3) Diagnosed psychiatric disorders; (4) Other conditions causing vertigo; (5) Benign paroxysmal positional vertigo; (6) Cerebellopontine angle space-occupying lesions such as acoustic neuroma; (7) Severe cardiovascular disease with training intolerance; (8) Post-orthopedic surgery or mobility impairment; (9) Central vestibular disorders; (10) Visual impairment.

1.2 Interventions

All patients underwent vestibular function and hearing assessments, including caloric testing, head impulse testing, otolith function tests, pure-tone audiometry, and acoustic immittance testing. Comprehensive health education was provided upon admission, explaining rehabilitation exercises and precautions using successful case examples to demonstrate efficacy and improve compliance. Given that participants had hearing loss, communication involved text messaging via mobile devices when necessary, and training displays included text

prompts for all movements.

Both groups received medication according to the latest guidelines: batroxobin (administered every 1-2 days after fibrinogen testing), Ginkgo biloba extract (Ginaton), methylprednisolone sodium succinate intravenously, and dexamethasone sodium phosphate intratympanic injection, with 14 days constituting one treatment course.

Control group intervention: Conventional vestibular rehabilitation training included: (1) Eye movement exercises (looking up/down, left/right, and diagonally, 20 repetitions each direction); (2) Basic balance exercises (feet shoulder-width apart, arms extended sideways for 15 seconds, repeated twice; arms crossed over chest for 15 seconds, repeated twice); (3) Walking exercises (walking along a straight line in bright light, with eyes closed, and in dark environments, 2 minutes each). Training began 48 hours after onset, administered twice daily for 15 minutes each session. Initial assessments evaluated patients' mobility and acceptable training intensity, with follow-up assessments conducted at 7 and 14 days post-training.

Observation group intervention: Patients used head-mounted displays and handheld controllers to complete designated tasks in virtual scenarios [Figure 1: see original paper]. The computer system replaced the external sensory world with an artificial environment that updated according to the patient' s orientation and body movements. Patients were immersed in a 360° virtual environment, performing actions in response to voice prompts for task-specific training within set time limits, earning training scores upon completion. Virtual training scenarios could be switched according to participants' needs and preferences, creating a gamified experience that increased engagement and reduced monotony. Training modes included seated [Figure 2: see original paper], standing [Figure 3: see original paper], and gaze stabilization exercises, administered twice daily for 15 minutes each session, beginning 48 hours after onset. Initial setup involved instruction on device wearing, controller operation, and adjustment for patients wearing glasses. Training progressed gradually from seated to more challenging exercises, with assessments at 7 and 14 days.

1.3 Outcome Measures

Both groups were evaluated using DHI and HADS at baseline and at 7 and 14 days post-intervention.

1.3.1 DHI Scale: This instrument assesses subjective dizziness and balance dysfunction severity across three domains: physical (P), emotional (E), and functional (F). The 25-item questionnaire uses a scoring system of "yes" (4 points), "sometimes" (2 points), and "no" (0 points), with total scores ranging 0-100. Scores of 0-30 indicate mild dizziness, 31-60 moderate dizziness, and >60 severe dizziness, with higher scores representing greater handicap.

1.3.2 HADS Scale: This comprises two 7-item subscales: HADS-Anxiety

(A) and HADS-Depression (D). Each item uses a 4-point Likert scale (0-3), yielding subscale scores of 0-21, where higher scores indicate more severe anxiety/depression. Scores of 0-7 are normal, 8-11 indicate mild mood disturbance, and >11 suggest moderate to severe disturbance.

1.4 Statistical Analysis

SPSS 25.0 software was used for statistical analysis. Normally distributed measurement data were expressed as mean ± standard deviation ($\bar{x}\pm s$), with between-group comparisons using independent samples t-tests, within-group comparisons using paired t-tests, and temporal comparisons using two-way repeated measures ANOVA. Categorical data were expressed as frequencies or percentages and compared using ^{2} tests. Statistical significance was set at $P<0.05$.

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2. Results

2.1 Participant Characteristics

Eighty-one patients completed the trial (41 in observation group, 40 in control group). During the intervention, observation group patients initially experienced unfamiliarity with device operation (e.g., screen calibration), postural instability, and visual discomfort from various scenarios (typically resolving after 2 training sessions); one patient refused questionnaire completion. Control group patients experienced initial postural instability; two patients refused rehabilitation training due to boredom. No significant differences existed between groups in gender or age ($P>0.05$), ensuring comparability .

Table 1 Comparison of General Data Between Groups

Group	n	Gender (Male/Female)	Age (years)
Control	40	22 (55.0%) / 18 (45.0%)	47.7$±14.90\|\|*Observation*\|41\|22(53.7±13.92\|\|\chi\^{2}$
			(t) value
P value		0.889	0.685

2.2 Comparison of DHI Scores

Significant interaction effects between group and time were observed for DHI-F, DHI-E, DHI-P subscales and total DHI score ($P<0.05$), with significant main effects of both factors ($P<0.05$). No baseline differences existed between groups ($P>0.05$). At 7 and 14 days post-intervention, both groups showed significant score reductions from baseline ($P<0.05$), with observation group scores significantly lower than control group scores at both time points ($P<0.05$) .

Table 2 Comparison of DHI Subscores and Total Score ($\bar{x}\pm s$, points)

Measure	Group	Baseline	7 days	14 days
DHI-Function	Control	21.05$±6.01	16.15±4.95^{a}	9.95±3.99^{a}
	Observation	19.95±4.16	12.49±4.79^{ab}	6.0
DHI-Emotion	Control	13.35±3.63	9.95±4.09^{a}	6.00±2.90^{a}
	Observation	13.71±4.97	6.20±3.	
DHI-Physical	Control	16.85±3.89	11.00±3.65^{a}	6.00±2.90^{a}
	Observation	15.85±5.11	6.20±3	
TotalDHI	Control	51.00±9.94	37.10±10.73^{a}	21.95±5.60^{a}
	Observation	49.51±10.28	24.	

Note: indicates P<0.05 vs. baseline; indicates P<0.05 vs. control group at same time point.

2.3 Comparison of HADS Scores

Significant interaction effects between group and time were observed for HADS-A, HADS-D and total HADS scores (P<0.05), with significant main effects (P<0.05). No baseline differences existed between groups (P>0.05). Both groups demonstrated significant score reductions at 7 and 14 days compared to baseline (P<0.05), though between-group differences were not statistically significant (P>0.05) .

Table 3 Comparison of HADS Subscores and Total Score ($\bar{x}$±s, points)

Measure	Group	Baseline	7 days	14 days
HADS-Anxiety	Control	6.30$±2.38	4.23±1.66^{a}	2.70±1.44^{a}
	Observation	6.51±2.10	3.63±1.97^{a}	2.68±1.
HADS-Depression	Control	5.40±2.48	4.00±2.04^{a}	3.20±1.79^{a}
	Observation	5.12±2.28	3.54±1.86	
TotalHADS	Control	11.68±4.26	8.23±3.03^{a}	5.83±2.55^{a}
	Observation	11.63±3.50	7.17±3.	

Note: indicates P<0.05 vs. baseline.

3. Discussion

Vestibular rehabilitation training is a physical therapy approach that enhances balance through repetitive exercises involving the whole body and specific regions (head, neck, eyes) [13]. It has been widely applied in various vestibular disorders with demonstrated efficacy. Previous studies have employed different assessment time points, such as 2, 4, and 8 weeks post-training [12], 1 and 4

weeks [14], or 1 month [11,15]. The current study' s 1- and 2-week time points were selected because patients are more cooperative during the acute treatment phase, the standard hospitalization period is 2 weeks (ensuring good compliance), and the VR equipment was only available during hospitalization—a limitation of this study. Our control group demonstrated significant reductions in total DHI and its three subscale scores at 7 and 14 days ($P<0.05$), confirming that conventional vestibular rehabilitation effectively improves subjective vertigo symptoms in sudden deafness patients, consistent with findings from Lin et al. [12] and Wei et al. [15]. However, conventional training is often monotonous, leading to poor adherence; indeed, two control group patients withdrew due to boredom.

VR-assisted rehabilitation provides direct auditory and visual feedback, multitasking opportunities, varied environments, and a sense of presence and immersion, enabling patients to complete exercises more relaxedly [15-16]. VR-assisted training has been applied in vestibular disorders (Ménière' s disease [17], benign paroxysmal positional vertigo [18]) and central nervous system conditions (stroke [19], Alzheimer' s disease [20], mild cognitive impairment [21]), improving quality of life. Our findings showed that the VR-assisted observation group had significantly lower DHI scores than the control group at both 7 and 14 days ($P<0.05$), indicating more pronounced improvement in subjective vertigo symptoms, consistent with Jiao et al. [22]. This validates that VR-generated visual-vestibular-proprioceptive conflict, combined with microcirculation-improving medication, effectively alleviates dizziness. The observation group' s training included real-world activities (playing badminton, supermarket shopping, bus riding) that maintained high patient interest and adherence, with some patients requesting additional practice.

Mood fluctuations are common triggers for sudden deafness, and hearing loss further exacerbates negative emotions due to tinnitus, aural fullness, communication difficulties, and prognosis concerns [23]. Vestibular rehabilitation can reduce vertigo, improve hearing, and decrease negative emotions [15]. Our control group showed significant HADS score reductions at 7 and 14 days ($P<0.05$), confirming that conventional training improves anxiety and depression. The observation group also demonstrated significant HADS reductions ($P<0.05$), but between-group differences were not significant, suggesting comparable efficacy between methods for psychological symptoms. However, the observation group' s HADS scores decreased more substantially (baseline: $11.63\$\pm3.50; 7days : 7.17\pm3.41; 14days : 5.27\pm2.86) than the control group's (11.68\pm4.26; 8.23\pm3.03; 5.83\pm\$2.55)$, though without statistical significance. Possible explanations include: short observation period (some studies [12] show significant anxiety improvement only at 4-8 weeks), spontaneous resolution of acute emotional reactions over time regardless of intervention, and influence of family factors (economics, environment, support). The observation group' s DHI-Emotion scores decreased significantly more than controls, while HADS scores did not differ, likely because DHI-Emotion specifically reflects vertigo-related emotional impact

that improves with rehabilitation, whereas HADS assesses overall emotional status influenced by multiple factors beyond vertigo and hearing loss (tinnitus, recovery status, family issues) [24].

Many patients initially refuse rehabilitation due to severe vertigo, but earlier initiation post-vertigo onset yields faster recovery [25], emphasizing the importance of pre-emptive health education. Patient motivation and exercise standardization directly affect outcomes [26-27]. VR-assisted training immerses patients in 360° virtual environments with personalized, progressive exercises, enhancing enjoyment, motivation, and compliance [28], potentially accelerating recovery.

This study has limitations, including short observation duration, equipment availability restricted to hospitalized patients (preventing long-term intervention and follow-up), and single-center enrollment. Future large-sample, multicenter, long-term randomized controlled trials are needed to investigate differential effects at various time points and further validate VR-assisted vestibular rehabilitation efficacy.

In conclusion, VR-assisted vestibular rehabilitation training more significantly improves subjective vertigo symptoms and quality of life compared to conventional training in sudden deafness patients with vertigo, though both approaches show comparable efficacy for anxiety and depression symptoms.

Author Contributions: ZHAO Yanan was responsible for database quality control, data analysis, and manuscript writing/revision. HAN Shifan reviewed and guided intervention implementation. LI Ying and ZHOU Liyuan conducted on-site quality control. YANG Jie and WU Jiaxin participated in database quality control. CHEN Ganggang developed the overall intervention protocol, organized patient recruitment and staff training, and participated in manuscript revision.

Conflict of Interest: The authors declare no conflicts of interest.

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