Research Square

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Efficacy of Integrated Vestibular-Spatial Working Memory Rehabilitation: A Comparative Study of Vestibular Neuritis and Recurrent Vestibulopathy

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Abstract

Background

Vestibular dysfunction often transcends simple postural instability, affecting higher-order cognitive processes such as spatial navigation and working memory.

Objective

This study aims to compare the effectiveness of vestibular-spatial working memory rehabilitation in patients with vestibular neuritis (VN) and recurrent vestibulopathy (RV).

Material and Methods

A total of 40 patients diagnosed with VN (n = 20) and RV (n = 20) were included. Participants underwent a vestibular-spatial working memory rehabilitation program consisting of 16 sessions (48 minutes each, once a week). Assessment was performed using Computerized Dynamic Posturography (CDP) Sensory Organization Test (SOT) and Limits of Stability (LOS) test.

Results

Statistically significant improvements were observed in pre-test and post-test comparisons of SOT and LOS in both groups ($p < 0.05$). Improvements in global, visual, and vestibular parameters support both the motor and cognitive efficacy of the rehabilitation.

Conclusion

Vestibular spatial working memory rehabilitation provided significant improvement in both balance and cognitive functions in patients with VN and RV. These findings demonstrate the clinical efficacy of combined rehabilitation approaches.

Introduction

The vestibular system is a complex neural network critical for maintaining balance and spatial orientation [1]. Current research indicates that this system is closely integrated with cognitive processes in addition to motor functions [2,3]. Its role in higher cortical functions, such as spatial working memory and environmental navigation, highlights the neurocognitive dimension of the vestibular system [4].

Vestibular dysfunction typically manifests with symptoms such as dizziness, postural instability, and visual stabilization issues [5]. Clinically, vestibular neuritis (VN) presents with acute unilateral vestibular

loss, while recurrent vestibulopathy (RV) is characterized by episodic vestibular symptoms [6]. Both conditions significantly limit patients' activities of daily living.

Vestibular rehabilitation is an evidence-based approach for treating these pathologies [7]. Recently, the integration of cognitive components into rehabilitation protocols has gained importance [8]. Adding spatial memory exercises to standard vestibular rehabilitation offers an innovative approach to support both motor and cognitive recovery [3]. However, there are limited studies comparing the efficacy of combined vestibular-cognitive rehabilitation in clinical conditions with different pathophysiological features like VN and RV. This gap leads to uncertainties regarding disease-specific modifications of rehabilitation strategies.

This study aims to comparatively evaluate the effectiveness of vestibular spatial working memory rehabilitation in VN and RV patients. Using objective measurements like the CDP-SOT and LOS, changes in both vestibular and cognitive parameters were systematically examined.

Materials and Methods

Participants This study was conducted at a tertiary Ear, Nose, and Throat (ENT) clinic in Istanbul, approved by the local ethics committee (Protocol No: 2021/536) in accordance with the Helsinki Declaration. The study included 20 patients with VN and 20 patients with RV diagnosed according to Barany Society criteria [9]. VN patients presented with acute unilateral vestibular hypofunction. RV patients were selected based on a history of at least three spontaneous rotational vertigo attacks, unilateral horizontal persistent nystagmus on videonystagmography (VNG), horizontal canal gain < 0.8 on video head impulse test, > 25% unilateral canal paresis on caloric testing, and positive Fukuda/Unterberger tests. Diagnostic definitions for RV were based on clinical descriptions by Pan et al. and van Esch et al. [10,11]. Meniere's disease, BPPV, and central pathologies were excluded. All participants had normal hearing thresholds.

Procedure Rehabilitation for the VN group began one month after diagnosis. For the RV group, the disappearance of spontaneous nystagmus in control VNG following the last attack was the criterion for initiation. Assessments were performed using the Synapsys Posturography System Version 3.0 (Marseille, France). SOT consisted of two 20-second trials for each condition. The individualized program consisted of 16 weekly sessions (48 minutes each). Exercises utilized CDP game modules focusing on stabilization, weight shifting, and postural control. Each module lasted 60 seconds and was repeated three times. Effectiveness was evaluated via pre-test, mid-test (after 8 sessions), and post-test (after 16 sessions).

Statistical Analysis Data were analyzed using IBM SPSS 22. Normality was assessed via Shapiro-Wilk test and histograms. Friedman test was used for multiple comparisons within groups, and Mann-Whitney U for comparisons between groups. Effect size was calculated using Kendall's W, classified from very weak (0.01–0.20) to very strong (0.81-1.00) [12].

Results

Demographics

The study was conducted with 40 participants, with an equal gender distribution of 50% female (n = 20) and 50% male (n = 20). All participants were aged 18 years or older. The mean age was 63.2 ± 20.1 years for the Vestibular Neuritis (VN) group and 73.9 ± 7.3 years for the Recurrent Vestibulopathy (RV) group.

Sensory Organization Test (SOT) - Antero-Posterior (AP) Plane

Computerized Dynamic Posturography (CDP) analysis revealed statistically significant increases in Global, Vestibular, and Visual scores for both groups throughout the rehabilitation process ($p < 0.05$). The most prominent improvement was observed in Global scores, with effect sizes calculated as Kendall's $W = 0.70$ for the VN group and $W = 0.73$ for the RV group. Vestibular scores showed a moderate increase in the VN group ($W = 0.43$) and a weak increase in the RV group ($W = 0.36$). Visual scores demonstrated weak but significant improvements in both cohorts. Somatosensory scores significantly increased only in the RV group at the post-test ($W = 0.26$), whereas no significant change was detected in the VN group. Inter-group comparisons for the AP plane revealed no statistically significant differences in any SOT parameters ($p > 0.05$) (Table 1).

Table 1
CDP-SOT Sensory Analysis Findings in the Anteroposterior (AP) Plane

Parameter	Time-point	VN - Median (Q1–Q3)	RV - Median (Q1–Q3)	Inter-group Analysis (z, p)
Global	Pre-test (1)	37.5 (29.5–47.0)	39.0 (25.5–52.5)	z = -0.09, p = 0.92
	Mid-test (2)	50.5 (43.0–68.0)	58.5 (44.5–61.5)	z = -0.08, p = 0.94
	Post-test (3)	58.5 (52.0–68.0)	64.0 (56.5–69.0)	z = -0.54, p = 0.59
	Intra-group	x^2= 27.90, **p = 0.01**, W = 0.70	x^2 = 29.34, **p = 0.01**, W = 0.73	
	Pairwise	1 < 2, 3	1 < 2, 3; 2 < 3	
Somatosensory	Pre-test (1)	94.0 (81.0–97.0)	88.5 (83.5–97.5)	z = -0.31, p = 0.75
	Mid-test (2)	95.0 (90.5–99.5)	96.0 (92.0–99.5)	z = -0.46, p = 0.64
	Post-test (3)	98.0 (94.5–100.0)	98.0 (97.0–100.0)	z = -0.69, p = 0.49
	Intra-group	x^2 = 5.15, p = 0.08, W = 0.13	x^2= 10.44, **p = 0.01**, W = 0.26	
	Pairwise	—	1 < 3	
Visual	Pre-test (1)	63.0 (42.5–73.5)	60.5 (16.0–76.5)	z = -0.53, p = 0.60
	Mid-test (2)	73.0 (56.5–85.5)	74.5 (68.5–84.0)	z = -0.65, p = 0.52
	Post-test (3)	81.0 (71.0–86.5)	79.5 (74.5–82.0)	z = -0.77, p = 0.44
	Intra-group	x^2 = 11.38, **p = 0.01**, W = 0.28	x^2 = 12.70, **p = 0.01**, W = 0.32	
	Pairwise	1 < 3	1 < 2, 3	
Vestibular	Pre-test (1)	0.0 (0.0–47.0)	0.0 (0.0–32.5)	z = -0.12, p = 0.90
	Mid-test (2)	44.5 (21.5–64.0)	46.5 (20.5–58.0)	z = -0.47, p = 0.64
	Post-test (3)	55.5 (45.0–68.5)	63.5 (54.0–66.5)	z = -0.78, p = 0.43
	Intra-group	x^2 = 17.39, **p = 0.01**, W = 0.43	x^2 = 14.58, **p = 0.01**, W = 0.36	
	Pairwise	1 < 2, 3	1 < 3	

Note: *VN: Vestibular Neuritis; RV: Recurrent Vestibulopathy; W: Kendall's W coefficient (Effect size); z: Mann-Whitney U test statistic; p: Statistical significance level*

Parameter	Time-point	VN - Median (Q1–Q3)	RV - Median (Q1–Q3)	Inter-group Analysis (z, p)
Preferential	Pre-test (1)	66.5 (47.0–85.5)	76.5 (41.5–91.5)	z = -0.35, p = 0.72
	Mid-test (2)	75.0 (63.5–86.5)	74.5 (67.5–83.5)	z = -0.32, p = 0.75
	Post-test (3)	71.5 (62.0–85.5)	74.0 (64.5–88.5)	z = -0.24, p = 0.81
	Intra-group	x^2 = 0.40, p = 0.82, W = 0.01	x^2 = 0.48, p = 0.79, W = 0.01	
	Pairwise	—	—	

Note: *VN: Vestibular Neuritis; RV: Recurrent Vestibulopathy; W: Kendall's W coefficient (Effect size); z: Mann-Whitney U test statistic; p: Statistical significance level*

Sensory Organization Test (SOT) - Medio-Lateral (ML) Plane

In the ML plane, Global scores significantly increased over time in both groups ($p < 0.05$), with very strong effect sizes (VN: W = 0.91; RV: W = 0.90). In both groups, pre-test scores were significantly lower than mid-test and post-test scores. Similarly, strong to very strong improvements were observed in Vestibular scores (VN: W = 0.84; RV: W = 0.77). Visual scores showed significant differences, which were strong in the VN group (W = 0.60) and weak in the RV group (W = 0.38). No significant temporal changes were found in Somatosensory scores for either group ($p > 0.05$). Preferential scores showed a weak significant difference only in the VN group (W = 0.18). No statistically significant differences were found between the VN and RV groups across all ML plane SOT parameters ($p > 0.05$) (Table 2).

Table 2
CDP-SOT Sensory Analysis Findings in the Mediolateral (ML) Plane

Parameter	Time-point	VN - Median (Q1–Q3)	RV - Median (Q1–Q3)	Inter-group Analysis (z, p)
Global	Pre-test (1)	37.5 (31.5–45.5)	40.0 (29.5–46.5)	z = -0.07, p = 0.95
	Mid-test (2)	51.0 (45.0–67.0)	61.0 (45.0–65.0)	z = -0.11, p = 0.91
	Post-test (3)	58.0 (52.0–71.0)	65.0 (55.0–71.5)	z = -0.56, p = 0.58
	Intra-group	x^2 = 36.40, **p = 0.01**, W = 0.91	x^2 = 36.10, **p = 0.01**, W = 0.90	
	Pairwise	1 < 2, 3; 2 < 3	1 < 2, 3; 2 < 3	
Somatosensory	Pre-test (1)	97.0 (92.5–100.0)	97.0 (92.0–100.0)	z = -0.24, p = 0.81
	Mid-test (2)	98.0 (94.0–100.0)	99.0 (97.0–100.0)	z = -0.97, p = 0.33
	Post-test (3)	98.0 (97.0–100.0)	99.0 (96.5–100.0)	z = -0.08, p = 0.93
	Intra-group	x^2 = 1.53, p = 0.47, W = 0.04	x^2 = 0.37, p = 0.83, W = 0.01	
	Pairwise	—	—	
Visual	Pre-test (1)	42.0 (10.5–59.0)	17.0 (0.0–59.5)	z = -1.02, p = 0.31
	Mid-test (2)	62.5 (51.0–80.0)	70.0 (53.5–77.5)	z = -0.28, p = 0.78
	Post-test (3)	69.0 (56.0–80.5)	71.0 (67.0–77.5)	z = -0.56, p = 0.58
	Intra-group	x^2 = 23.86, **p = 0.01**, W = 0.60	x^2 = 15.18, **p = 0.01**, W = 0.38	
	Pairwise	1 < 2, 3	1 < 2, 3	
Vestibular	Pre-test (1)	0.0 (0.0–3.5)	0.0 (0.0–0.0)	z = -0.48, p = 0.63
	Mid-test (2)	38.0 (16.0–51.5)	42.0 (14.0–56.0)	z = -0.18, p = 0.86
	Post-test (3)	56.0 (46.5–70.0)	61.0 (39.5–66.0)	z = -0.14, p = 0.89
	Intra-group	x^2 = 33.75, **p = 0.01**, W = 0.84	x^2 = 30.77, **p = 0.01**, W = 0.77	
	Pairwise	1 < 2, 3; 2 < 3	1 < 2, 3; 2 < 3	

Note: *VN: Vestibular Neuritis; RV: Recurrent Vestibulopathy; W: Kendall's W coefficient (Effect size); z: Mann-Whitney U test statistic; p: Statistical significance level*

Parameter	Time-point	VN - Median (Q1–Q3)	RV - Median (Q1–Q3)	Inter-group Analysis (z, p)
Preferential	Pre-test (1)	78.0 (64.5–92.0)	88.0 (63.0–95.0)	z = -0.52, p = 0.61
	Mid-test (2)	78.0 (65.0–86.0)	76.0 (71.5–89.0)	z = -0.33, p = 0.75
	Post-test (3)	70.0 (62.0–79.5)	76.0 (71.0–81.0)	z = -1.76, p = 0.08
	Intra-group	x^2= 7.35, **p = 0.03**, W = 0.18	x^2= 1.24, p = 0.54, W = 0.03	
	Pairwise	1 < 3	—	

Note: *VN: Vestibular Neuritis; RV: Recurrent Vestibulopathy; W: Kendall's W coefficient (Effect size); z: Mann-Whitney U test statistic; p: Statistical significance level*

Limits of Stability (LOS/DST) Results

Total Surface scores significantly increased in both groups ($p < 0.05$), with a moderate effect size in the VN group ($W = 0.56$) and a strong effect size in the RV group ($W = 0.77$). Directional analysis showed significant improvements in the "Front" (VN: $W = 0.62$; RV: $W = 0.68$) and "Back" directions (VN: $W = 0.33$; RV: $W = 0.43$). Furthermore, "Right" scores exhibited strong significant improvements (VN: $W = 0.65$; RV: $W = 0.73$), while "Left" scores showed moderate improvements in both groups (VN: $W = 0.55$; RV: $W = 0.59$). No statistically significant differences were observed between the VN and RV groups in any directional DST measurement ($p > 0.05$) (Table 3).

Table 3
CDP-Limits of Stability (LOS) Values Across Rehabilitation Phases

Direction	Time-point	VN - Median (Q1–Q3)	RV - Median (Q1–Q3)	Inter-group Analysis (z, p)
Total Surface	Pre-test (1)	101.0 (74.5–147.5)	89.0 (69.5–123.0)	z = -0.58, p = 0.56
	Mid-test (2)	232.0 (187.0–283.0)	238.5 (184.5–302.5)	z = -0.41, p = 0.68
	Post-test (3)	268.5 (196.5–370.0)	272.0 (197.0–319.5)	z = -0.26, p = 0.80
	Intra-group	x^2 = 22.30, **p = 0.01**, W = 0.56	x^2 = 30.90, **p = 0.01**, W = 0.77	
	Pairwise	1 < 2, 3	1 < 2, 3	
Front	Pre-test (1)	23.5 (12.5–37.0)	18.5 (15.0–24.0)	z = -0.56, p = 0.58
	Mid-test (2)	63.5 (48.0–89.5)	74.0 (43.5–87.0)	z = -0.42, p = 0.67
	Post-test (3)	72.5 (56.5–103.0)	73.5 (51.5–97.5)	z = -0.53, p = 0.60
	Intra-group	x^2 = 24.84, **p = 0.01**, W = 0.62	x^2 = 27.30, **p = 0.01**, W = 0.68	
	Pairwise	1 < 2, 3	1 < 2, 3	
Back	Pre-test (1)	18.0 (15.0–42.0)	20.5 (11.5–32.0)	z = -0.76, p = 0.45
	Mid-test (2)	46.0 (36.0–59.5)	34.5 (23.0–59.0)	z = -1.14, p = 0.26
	Post-test (3)	51.0 (33.5–74.5)	54.0 (30.0–63.0)	z = -0.35, p = 0.73
	Intra-group	x^2 = 13.24, **p = 0.01**, W = 0.33	x^2 = 17.39, **p = 0.01**, W = 0.43	
	Pairwise	1 < 2, 3	1 < 2, 3	
Right	Pre-test (1)	21.5 (14.0–31.0)	21.0 (13.5–31.5)	z = -0.14, p = 0.89
	Mid-test (2)	60.0 (39.5–70.5)	56.5 (40.5–69.0)	z = -0.12, p = 0.90
	Post-test (3)	65.5 (49.5–89.5)	61.5 (51.0–83.0)	z = -0.74, p = 0.46
	Intra-group	x^2 = 25.90, **p = 0.01**, W = 0.65	x^2 = 29.10, **p = 0.01**, W = 0.73	
	Pairwise	1 < 2, 3	1 < 2, 3	

Note: *VN: Vestibular Neuritis; RV: Recurrent Vestibulopathy; W: Kendall's W coefficient (Effect size); z: Mann-Whitney U test statistic; p: Statistical significance level*

Direction	Time-point	VN - Median (Q1–Q3)	RV - Median (Q1–Q3)	Inter-group Analysis (z, p)
Left	Pre-test (1)	37.5 (19.0–46.5)	24.5 (21.0–44.5)	z = -0.31, p = 0.76
	Mid-test (2)	66.0 (49.5–78.5)	70.5 (58.0–83.5)	z = -0.72, p = 0.47
	Post-test (3)	73.0 (42.5–93.0)	81.5 (53.0–94.5)	z = -0.55, p = 0.58
	Intra-group	x^2 = 22.05, **p = 0.01**, W = 0.55	x^2 = 23.77, **p = 0.01**, W = 0.59	
	Pairwise	1 < 2, 3	1 < 2, 3	

Note: *VN: Vestibular Neuritis; RV: Recurrent Vestibulopathy; W: Kendall's W coefficient (Effect size); z: Mann-Whitney U test statistic; p: Statistical significance level*

Discussion

This study provides a comprehensive evaluation of the efficacy of vestibular-spatial working memory rehabilitation in patients with VN and RV. The findings revealed statistically significant improvements in both Sensory Organization Test (SOT) and Limits of Stability (LOS/DST) measurements across both patient groups. These results suggest that vestibular rehabilitation is effective not only on motor functions but also on cognitive processes [3,13].

One of the most remarkable findings of our study is the lack of a significant difference between the VN and RV groups regarding treatment response. This situation sheds light on the pathophysiological mechanisms of RV. In a study examining 500 patients with RV over a 31-month follow-up period, Leeuwen and Bruintjes observed spontaneous recovery in 62% of the cases [14]. Similarly, Rutka and Barber reported a complete resolution of symptoms in 63% of patients with RV during an 8.5-year follow-up study [15]. These literature findings are consistent with the improvement rates observed in the RV group in our study.

Regarding the relationship between spatial working memory and vestibular functions, Guidetti et al. demonstrated impairment in visual-spatial working memory using the eCorsi Block-Tapping Test in patients with chronic vestibular hypofunction [3]. In our study, this relationship was revealed through an innovative approach using the LOS/DST. These findings support the complex interaction between the vestibular system and cognitive functions [1,2].

When analyzing the dynamics of rehabilitation effects over time, significant improvements were particularly observed between weeks 0 and 8. This finding is consistent with the hypothesis that vestibular compensation is more active in the early stages [16]. In a study by Kim et al., it was emphasized that performance in SOT conditions 5 and 6 is crucial for evaluating vestibular functions [17]. The improvements observed in these conditions in our study confirm the positive effects of rehabilitation on the vestibular system.

One of the most significant contributions of our study to the literature is demonstrating the efficacy of integrating Computerized Dynamic Posturography (CDP)-based spatial working memory exercises into standard vestibular rehabilitation. This approach supports the vestibular-cognitive integration model proposed by Micarelli et al. [13]. However, unlike the subjective scales used by Shim et al. [18], the use of objective measurement methods in our study increases the reliability of the findings.

The study has certain limitations. The relatively small sample size and the difference in age distribution between groups restrict the generalizability of the results. Furthermore, as emphasized by Ferber-Viart et al. and Domínguez et al., the lack of additional tests for a more detailed evaluation of vestibular functions is another limitation [19,20].

Limitations

The small sample size, age differences between groups, and lack of additional vestibular tests (e.g., VEMPs) are limitations.

Conclusion

Vestibular spatial working memory rehabilitation is effective for both VN and RV patients, showing no significant difference in therapeutic response between groups. This indicates that vestibular plasticity remains active despite the recurrent nature of RV. Integrating cognitive components into standard protocols enhances functional recovery, particularly when initiated early. Future research should focus on international standardization of protocols, randomized controlled trials comparing traditional vs. combined approaches, and the use of neuroimaging (fMRI/EEG) to elucidate neuroplasticity mechanisms.

Declarations

Author Contribution

Author(s) contribution(s): Idea/Concept: Bahriye Özlem Konukseven, Rumeysa Nur Akbaş Design: Bahriye Özlem Konukseven, Rumeysa Nur Akbaş Control/Supervision: Bahriye Özlem Konukseven Materials: Rumeysa Nur Akbaş Data collection/Processing: Rumeysa Nur Akbaş Analysis/Interpretation: Bahriye Özlem Konukseven, Rumeysa Nur Akbaş Literature Review: Rumeysa Nur Akbaş Writing the Article: Rumeysa Nur Akbaş Critical Review: Bahriye Özlem Konukseven, Rumeysa Nur Akbaş References: Bahriye Özlem Konukseven, Rumeysa Nur Akbaş

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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