DOI: 10.53469/jcmp.2025.07(12).17

Correlation of Abnormal Cervical Proprioception with Visual-Vestibular Interaction Dysfunction in Cervicogenic Dizziness

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Abstract: ***Objective**: To investigate the correlation between abnormal cervical proprioceptive input (joint position sense, JPS) and visual-vestibular interaction dysfunction in patients with cervicogenic dizziness (CV), providing objective evidence for the "sensory integration dysfunction" pathomechanism. **Methods**: A retrospective case-control study was conducted. Thirty-seven CV patients and 37 healthy controls were included. Objective data including cervical JPS error, key parameters of computerized dynamic posturography (CDP) sensory organization test (SOT) (primarily vestibular ratio and sensory integration ratio), and subjective visual vertical (SVV) deviation were collected and analyzed. Pearson or Spearman correlation analysis was used to examine the relationship between mean cervical JPS error and visual-vestibular function metrics. **Results**: Compared with the healthy control group, the CV group showed significantly greater cervical JPS error, as well as significantly abnormal vestibular ratio, sensory integration ratio in CDP-SOT, and SVV deviation (all P<0.001). Within the CV group, the mean cervical JPS error was significantly negatively correlated with the vestibular ratio (r=-0.658) and sensory integration ratio (r=-0.624), and positively correlated with the SVV deviation angle (r=0.573, all P<0.001). Multiple linear regression indicated that cervical JPS error was an independent factor predicting dizziness handicap inventory (DHI) scores (β=0.338, P=0.008). **Conclusion**: Patients with cervicogenic dizziness exhibit distinct abnormalities in cervical proprioceptive input, which are significantly correlated with impaired visual-vestibular central integration and spatial perception. This provides objective quantitative support for the sensory integration dysfunction mechanism in CV and suggests that clinical assessment and rehabilitation should focus on the restoration of sensorimotor integration function.*

Keywords: Cervicogenic Dizziness, Proprioception, Joint Position Sense, Postural Balance, Sensory Integration, Correlation Study.

1. Introduction

Cervicogenic dizziness (CGD) is a clinical syndrome induced by functional disorders of the cervical spine and its related structures, characterized by episodic or persistent vertigo/dizziness and balance disturbances. It accounts for a significant proportion of visits in relevant specialty clinics and substantially impacts patients' quality of life [1, 2]. However, its clinical diagnosis has long faced a core challenge: the lack of a consensus-based, highly specific objective diagnostic biomarker [3]. Current diagnosis primarily relies on inference from medical history and systematic differential diagnosis. This "exclusion-based" model carries a strong subjective component, easily leading to diagnostic inconsistency [4].

Modern pathophysiological perspectives tend to explain CGD using the "sensory integration disorder theory" [5, 6]. This theory posits that precise spatial orientation and postural control depend on the seamless integration and central processing of information from the visual system, vestibular organs, and cervical proprioception [7]. The cervical spine, especially the upper cervical segments, is rich in mechanoreceptors that continuously encode information about the spatial position and movement state of the head and neck to the central nervous system [8]. When these proprioceptive signals become abnormal due to degeneration, injury, or functional disorders, they conflict with normal visual and vestibular information during central integration (e.g., in the brainstem, cerebellum), thereby triggering vertigo, unsteadiness, and spatial disorientation [9, 10].

Cervical joint position sense (JPS) testing is a direct method for quantifying proprioceptive accuracy [11]. Computerized dynamic posturography (CDP) sensory organization testing (SOT) and subjective visual vertical (SVV) assessment are the gold standards for objectively evaluating visuo-vestibular interaction and spatial perception functions [12, 13]. Although independent studies suggest that CGD patients may exhibit abnormalities in these functions [14, 15], there is still a lack of systematic validation based on clinical objective data regarding whether a quantitative, direct intrinsic correlation exists between abnormal cervical proprioceptive input and visuo-vestibular central integration dysfunction. Utilizing existing, standardized clinical assessment data for a retrospective analysis is an efficient approach to fill this knowledge gap.

Therefore, this study aims, through a retrospective case-control analysis, to systematically explore the correlation between cervical JPS error and key CDP parameters as well as SVV deviation in CGD patients. We hypothesize that in CGD patients, decreased accuracy of cervical proprioception is significantly correlated with the degree of impairment in visuo-vestibular interactive function. The findings of this study are to provide objective evidence from clinical practice supporting the "sensory integration disorder" theory and offer references for optimizing the assessment strategy for CGD.

2. Methods

This study was a retrospective case-control study. By systematically querying the hospital information system database, we collected and analyzed clinical data and examination records from CGD patients and healthy controls who had previously completed standardized assessments.

2.1 Study Subjects and Data Sources

All data were sourced from archived records in our hospital's electronic medical record system and the databases of the Rehabilitation Medicine Department/Vestibular Function Examination Room, covering the period from January 2020 to December 2023.

2.1.1 Case Group (Cervicogenic Dizziness Group, CV Group):

Identification and Screening: Potential cases were initially identified using primary diagnosis codes or keywords ("cervical vertigo", "cervicogenic dizziness").

Inclusion Criteria: (1) Age between 20-65 years; (2) A clear clinical diagnosis established by the attending physician based on a clear association between the patient's vertigo/dizziness symptoms and neck posture or movement, and after excluding other common vestibular diseases (e.g., benign paroxysmal positional vertigo, Ménière's disease, vestibular neuritis) and central nervous system lesions; (3) Complete retention of all core assessment data required for this study in the medical records (detailed in section 2.3).

Exclusion Criteria: (1) History of cervical spine surgery or severe head/neck trauma; (2) Comorbid severe neurological, psychiatric, or orthopedic/ophthalmic diseases affecting balance function; (3) Missing or incomplete key assessment data.

2.1.2 Control Group (Healthy Control Group, HC Group):

Inclusion Criteria: (1) Age matched to the case group (20-65 years); (2) No history of chronic dizziness, vertigo, neck pain, or neurological diseases; (3) Similarly complete retention of all core assessment data.

Exclusion Criteria: Same as items (2) and (3) in the case group exclusion criteria.

Sample Size Determination and Grouping: After screening according to the above criteria, a total of 74 subjects had complete data meeting the analysis requirements. To maintain inter-group balance, frequency matching by age and sex was employed, ultimately determining 37 cases each for the CV group and the HC group to be included in the final analysis.

2.2 Data Extraction and Assessment Indicators

Two uniformly trained researchers independently extracted the following data from medical records and examination systems, with cross-checking performed. Disagreements were arbitrated by a third senior researcher.

2.2.1 Demographic and Baseline Data

Age, sex, height, weight (for calculating body mass index). For the CV group, symptom duration (disease course) was additionally extracted.

2.2.2 Cervical Proprioception Data

Cervical Joint Position Sense (JPS) Test: records were extracted. This test uses standardized equipment (e.g., head-mounted laser pointer or inertial sensors) to measure the absolute error value (unit: degrees) when the subject actively returns their head to a preset target angle (left rotation 30°, right rotation 30°, extension 20°) under blindfolded conditions. The error value for each direction was extracted, and the average error value across the three directions was calculated as an indicator of proprioceptive accuracy.

2.2.3 Visuo-Vestibular Function Data

Computerized Dynamic Posturography (CDP) Parameters: The following key indicators were extracted from standard Sensory Organization Test (SOT) reports: Composite Balance Score, Vestibular Sensory Ratio, Sensory Integration Ratio, and the raw balance scores for Condition 5 (eyes closed, platform moving) and Condition 6 (eyes open, both platform and visual surround moving).

Subjective Visual Vertical (SVV) Data: The average absolute deviation angle (unit: degrees) recorded in the SVV test report was extracted.

2.3 Clinical Symptom and Function Scores: Dizziness Handicap Inventory (DHI) Total Score. Neck Disability Index (NDI) Score (expressed as a percentage).

2.3.1 Statistical Analysis

Data analysis was performed using SPSS statistical software (version 26.0). The normality of continuous data was assessed using the Shapiro-Wilk test. Normally distributed data are described as mean ± standard deviation, with inter-group comparisons made using independent samples t-tests. Non-normally distributed data are described as median (interquartile range), with inter-group comparisons made using the Mann-Whitney U test. Categorical data are expressed as number (percentage), with inter-group comparisons made using the chi-square test.

Primary Analysis: Within the case group (CV group), Pearson correlation analysis (for normal data) or Spearman rank correlation analysis (for non-normal data) was used to examine the strength of correlation between the average cervical JPS error and various visuo-vestibular function indicators (including Vestibular Sensory Ratio, Sensory Integration Ratio, Condition 5/6 scores, and SVV deviation angle).

Secondary Analysis: The correlation between the average cervical JPS error and subjective dizziness disability degree (DHI total score) was analyzed.

Exploratory Analysis: Using the DHI total score of the CV group as the dependent variable, and variables such as average JPS error, Vestibular Sensory Ratio, NDI score, disease course, and age as independent variables, multiple linear stepwise regression analysis was performed to explore factors independently influencing patients' subjective symptoms.

All hypothesis tests were two-sided, with a $P<0.05$ considered statistically significant.

3. Results

3.1 Baseline Characteristics of the Study Population

This study retrospectively screened a total of 74 subjects who met all inclusion and exclusion criteria. For balanced comparison, 1:1 frequency matching by age and sex was performed, ultimately determining 37 cases each for the CGD group and the healthy control group to be included in the analysis. As shown in Table 1, there were no statistically significant differences between the two groups in baseline demographic characteristics such as age, sex composition, height, weight, and body mass index (all $P > 0.05$), indicating comparability. The average symptom duration in the CV group was (16.2 ± 11.5) months.

3.2 Inter-group Comparison of Cervical Proprioception and Balance Function

Comparison of objective assessment indicators between the two groups is shown in Table 2. The absolute error values of cervical JPS in all three test directions (left rotation, right rotation, extension) were significantly greater in the CV group than in the HC group (all $P < 0.001$). In the CDP test, the Composite Balance Score, Vestibular Sensory Ratio, Sensory Integration Ratio, and the raw balance scores for Condition 5 and Condition 6 were all significantly lower in the CV group than in the HC group (all $P < 0.001$). Furthermore, the absolute deviation angle of SVV was significantly greater in the CV group than in the HC group ($P < 0.001$), indicating a clear abnormality in their spatial vertical perception.

Table 1: Comparison of Baseline Characteristics Between the Cervicogenic Dizziness Group and the Healthy Control Group

Characteristic	Cervicogenic Dizziness Group (n=37)	Healthy Control Group (n=37)	Statistic	*P* - value
Age (years)	49.5±9.8	47.9±8.6	t=0.75	0.455
Sex (Male/Female)	16/21	18/19	χ^2=0.24	0.624
Height (cm)	164.8±7.9	166.2±8.3	t=-0.74	0.463
Weight (kg)	66.3±10.5	64.5±10.1	t=0.75	0.457
Body Mass Index (kg/m²)	24.4±3.2	23.3±2.8	t=1.59	0.116

Table 2: Comparison of Cervical Proprioception, Postural Control, and Spatial Perception Indicators Between the Two Groups

Assessment Indicator	Cervicogenic Dizziness Group (n=37)	Healthy Control Group (n=37)	Statistic	P-value
Cervical Joint Position Sense Error (°)				
Left Rotation 30°	5.2 ± 1.7	2.2 ± 0.8	t = 9.67	<0.001
Right Rotation 30°	5.4 ± 1.9	2.4 ± 0.9	t = 8.86	<0.001
Extension 20°	4.1 ± 1.5	1.9 ± 0.6	t = 8.29	<0.001
Average Error	4.9 ± 1.4	2.2 ± 0.7	t = 10.43	<0.001
Dynamic Posturography Parameters				
Composite Balance Score	66.3 ± 10.5	81.9 ± 5.0	t = -8.17	<0.001
Vestibular Sensory Ratio	49.1 ± 19.8	77.4 ± 14.2	t = -7.12	<0.001
Sensory Integration Ratio	53.4 ± 17.9	79.6 ± 11.8	t = -7.51	<0.001
Condition 5 Balance Score	43.5 ± 21.4	74.2 ± 16.8	t = -6.97	<0.001
Condition 6 Balance Score	47.8 ± 20.6	76.5 ± 14.5	t = -7.10	<0.001
Spatial Perception				
SVV Absolute Deviation Angle (°)	3.1 ± 1.7	1.2 ± 0.5	t = 6.53	<0.001

3.3 Correlation Analysis Between Cervical Proprioception and Visuo-Vestibular Function

The correlation analysis conducted within the CV group (Table 3.) showed that the average cervical joint position sense error was significantly associated with multiple indicators reflecting visuo-vestibular integration function:

Table 3: Correlation Analysis Between Average Cervical Joint Position Sense Error and Key Functional Indicators

Associated Indicator	Correlation	Correlation Coefficient (r)	P-value
Vestibular Sensory Ratio	Significant Negative	-0.643	< 0.001
Sensory Integration Ratio	Significant Negative	-0.605	< 0.001
Condition 5 Balance Score	Significant Negative	-0.677	< 0.001
Condition 6 Balance Score	Significant Negative	-0.618	< 0.001
SVV Absolute Deviation Angle	Significant Positive	0.554	< 0.001
Severity of Subjective Symptoms (DHI Total Score)	Moderate Positive	0.463	0.004
All indicators in the Healthy Control Group	No Significant Statistical Correlation	-	> 0.05

Abbreviations: DHI, Dizziness Handicap Inventory; SVV, Subjective Visual Vertical.

Furthermore, the average cervical JPS error showed a moderate positive correlation with the severity of patients' subjective symptoms (DHI total score) ($r = 0.463$, $P = 0.004$). In the healthy control group, none of the aforementioned indicators showed statistically significant correlations with each other (all $P > 0.05$).

3.4 Multiple Linear Regression Analysis of Factors Influencing Subjective Dizziness Disability

Using the DHI total score of the CV group as the dependent variable, variables found to be significantly correlated with it in univariate analysis (average JPS error, Vestibular Sensory Ratio, NDI score, disease course) were entered into a multiple linear stepwise regression model. The results (Table 4) showed that the variables finally retained in the model were the Neck Disability Index (NDI) score and the average cervical joint position sense error. This regression model was statistically significant ($F=21.84$, $P<0.001$), with an adjusted R^2 of 0.531, indicating that these two variables together explained approximately 53.1% of the variance in DHI scores.

Among them, the average cervical JPS error was a significant factor independent of neck pain and dysfunction in predicting the degree of subjective dizziness disability (β = 0.338, P = 0.008).

Table 4: Multiple Linear Stepwise Regression Analysis of Factors Influencing DHI Scores in Patients with Cervicogenic Dizziness

Model	Entered Variable	Unstandardized Coefficient B	Standard Error	Standardized Coefficient β	t-value	P-value
1	(Constant)	10.524	5.301		1.986	0.055
	NDI Score	1.155	0.175	0.624	6.594	<0.001
2	(Constant)	2.013	5.587		0.360	0.721
	NDI Score	0.986	0.171	0.532	5.762	<0.001
	Average JPS Error	3.594	1.286	0.338	2.795	0.008

Note: Dependent variable: DHI total score; Excluded variables: Vestibular Sensory Ratio, disease course.

4. Discussion

Through retrospective analysis of clinical historical data, this study found that patients with CGD exhibit significant objective impairments in cervical proprioception (joint position sense), visuo-vestibular interactive function (dynamic posturography), and spatial perception (SVV). More importantly, this study is the first to systematically demonstrate within this patient population that there is a significant quantitative negative correlation between decreased accuracy of cervical proprioception and the degree of impairment in visuo-vestibular central integration function. Furthermore, cervical proprioceptive error is an important factor, independent of neck pain and dysfunction, in predicting the degree of patients' subjective dizziness disability. These findings provide key clinical empirical support for the core pathological hypothesis of "sensory integration disorder" in CGD.

4.1 Interpretation of the Mechanisms Underlying the Core Findings

The strong correlations observed in this study (JPS error vs. Condition 5/6 scores, r values ranging from -0.605 to -0.677) have clear neurophysiological significance. Condition 5 primarily relies on vestibular and proprioceptive input, while Condition 6 introduces visual conflict; both challenge the central nervous system's ability to integrate inconsistent sensory information [16]. Abnormal cervical proprioceptive input acts like introducing systematic error into the "internal model" of spatial orientation [17]. When this erroneous signal is integrated within the brainstem (e.g., vestibular nuclei, nucleus prepositus hypoglossi), cerebellum, and thalamocortical networks, it competes with precise inertial signals from the vestibular organs and (in Condition 6) potentially conflicting visual signals. This competition leads to the CNS's inability to form a unified, accurate spatial judgment, thereby triggering the perception of vertigo and compensatory, inefficient postural control strategies (such as over-reliance on vision or adoption of rigid joint strategies) [18]. The positive correlation between SVV deviation and JPS error (r=0.554) further links peripheral sensory deficits to higher-level spatial cognitive dysfunction, as SVV directly reflects the brain's internal estimate of gravitational vertical [19].

4.2 Clinical and Theoretical Implications of the Findings

The findings of this study deepen the understanding of the pathological mechanisms of CGD. They not only confirm the coexistence of abnormal peripheral sensory input and central integration Dysfunction, but, more importantly, directly link these two aspects through quantitative data, forming a complete evidence chain of "peripheral input abnormality → central integration dysfunction → clinical symptoms." This provides a theoretical basis for moving beyond the traditional, symptom-description-based diagnostic model towards a diagnostic framework based on objective functional assessment.

The results suggest that the focus of rehabilitation for CGD should shift from the traditional model primarily aimed at pain relief and improving joint range of motion to targeted intervention centered on "sensorimotor re-education." The rehabilitation protocol should simultaneously include: (1) Cervical proprioception-specific retraining (e.g., head repositioning with eyes closed, neck control on unstable surfaces); and (2) Visuo-vestibular integration adaptive training (e.g., balance training under dynamic visual interference or complex sensory environments), aiming to directly repair the impaired sensory integration pathway and improve symptoms at their root [20].

The strength of this study lies in being the first to systematically validate the quantitative association between cervical proprioception and visuo-vestibular integration function using standardized clinical historical data. The conclusions are based on objective measurement indicators, reducing subjective bias.

However, as a retrospective study, its limitations must be acknowledged:

1) Limitations in Causal Inference: The cross-sectional design cannot determine the causal relationship between cervical proprioceptive abnormality and visuo-vestibular functional dysfunction. Although the pathological mechanism supports the logic of the former causing the latter, both may also be driven by common unknown factors, or bidirectional influence may exist.

2) Potential for Selection Bias: The study only included patients with complete medical and examination records. This group may represent patients who seek medical care more regularly, whose condition receives more attention, or who are more willing to undergo detailed assessments. Therefore, caution is needed when extrapolating the conclusions to all CGD patients.

3) Control of Confounding Factors: Retrospective data analysis makes it difficult to completely control all potential

confounding factors, such as the degree of pain, anxiety state, or previous rehabilitation experience at the time of assessment, which may simultaneously affect proprioception and balance function.

4.4 Future Research Directions

Based on the findings and limitations of this study, future research could explore the following directions in depth:

Conduct Prospective Intervention Studies: Design randomized controlled trials to verify whether comprehensive rehabilitation protocols targeting "sensory integration" are superior to conventional treatment in improving objective functional indicators (JPS, CDP) and subjective symptoms, thereby providing stronger evidence for causality.

Explore Central Mechanisms: Utilize functional magnetic resonance imaging or electroencephalography techniques to investigate whether characteristic changes occur in the activation patterns or functional connectivity of sensory integration-related brain regions (e.g., insula, anterior cingulate cortex, intraparietal sulcus) in CGD patients when performing relevant sensorimotor tasks.

Develop Simplified Assessment Tools: Develop low-cost and reliable cervical proprioception and simple balance screening tools suitable for community or primary healthcare institutions to promote the objective identification and early intervention of this condition on a broader scale.

5. Summary

This retrospective study confirms that patients with cervicogenic dizziness exhibit abnormal cervical proprioceptive input, and this abnormality is significantly correlated with impairment in visuo-vestibular central integration function and spatial perception. Error. Cervical proprioceptive error can serve as an objective biological indicator for predicting patients' subjective dizziness disability. These findings provide solid clinical data support for the pathological mechanism of CGD from the perspective of sensory integration and lay an important theoretical and practical foundation for promoting the objectification of its diagnostic assessment and the precision of rehabilitation treatment. Future research should focus on developing and validating comprehensive intervention strategies based on this mechanism to improve the long-term prognosis of patients.

Fund Project

"Correlation Study on Regional Cerebral Blood Flow (rCBF) Changes in Patients with Cervical Vertigo and the Impact of Li's Manipulation Therapy in Guanzhong", Shaanxi Provincial Key Research and Development Program (2024SF-YBXM-501).

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