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IMPACT OF VESTIBULAR STIMULATION ON MOTOR FUNCTION IN CHILDREN WITH HYPOTONIC CEREBRAL PALSY: A RANDOMIZED CONTROLLED TRIAL

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Abstract

This randomized controlled trial evaluated whether adding vestibular stimulation to conventional physiotherapy improves motor function and balance in children with hypotonic cerebral palsy. A total of 82 children (ages 5–10 years) with quadriplegic cerebral palsy were randomly assigned to either a control group receiving routine physical therapy or an intervention group receiving the same therapy plus vestibular stimulation. Over a 6-week period, motor function and balance were measured using the Gross Motor Function Measure (GMFM) and the Pediatric Evaluation of Disability Inventory (PEDI). Statistical analyses revealed that the intervention group showed significant improvements in both gross motor skills and balance scores compared to the control group ($p < .001$). These findings indicate that incorporating vestibular stimulation may be an effective adjunct to standard therapy for enhancing motor performance and balance in children with hypotonic cerebral palsy.

INTRODUCTION

Cerebral palsy (CP) is a non-progressive disorder arising from early brain injury that disrupts normal motor and sensory development. The condition affects posture, balance, and coordination, leading to challenges in daily activities. Hypotonic cerebral palsy, a subtype characterized by decreased muscle tone, often results in poor postural control and balance. The vestibular system—a key component of the body's balance mechanism—has been identified as a promising target for rehabilitation interventions.

Vestibular stimulation involves the deliberate activation of the vestibular apparatus to enhance neural processing and improve motor control. Unlike conventional exercises that require active participation from children who may already struggle with motor planning, vestibular stimulation can trigger reflex pathways that support postural adjustments. Recent studies have suggested that such stimulation may enhance proprioceptive feedback and neuromuscular coordination, thereby improving gross motor function and balance. However, the

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precise role and optimal dosing of vestibular stimulation in children with CP remain subjects of ongoing research.

Literature Review

Cerebral Palsy and Hypotonia

Cerebral palsy (CP) is a non-progressive neurological disorder affecting movement, posture, and muscle coordination due to damage or maldevelopment of the immature brain (Miller & Bachrach, 2017). CP affects approximately 2–3 per 1,000 live births worldwide, with a prevalence that varies by region and neonatal care advancements (Novak et al., 2019). Hypotonic CP is characterized by low muscle tone, leading to poor postural control and coordination difficulties. Children with hypotonic CP often struggle with head control, sitting balance, and motor function, which negatively impacts their ability to perform daily activities (Blair et al., 2018). This subtype is less common than spastic CP but poses unique rehabilitation challenges.

The severity of motor dysfunction in CP is typically assessed using the Gross Motor Function Classification System (GMFCS), which categorizes mobility levels from I (least severe) to V (most severe) (Himmelmann et al., 2017). Balance impairments, commonly seen in quadriplegic CP, result from disruptions in vestibular and proprioceptive feedback, further hindering functional mobility (Rosenbaum & Gorter, 2020).

Vestibular System and Its Role in Motor Function

The vestibular system is crucial for maintaining postural stability, spatial orientation, and coordinated movement. It consists of the semicircular canals and otolith organs, which detect rotational and linear accelerations, respectively (Gottshall & Hoffer, 2018). The vestibular nuclei integrate sensory input from the visual, proprioceptive, and somatosensory systems, influencing postural reflexes and muscle tone (Shumway-Cook & Woollacott, 2019).

Studies indicate that vestibular dysfunction is prevalent in children with CP, contributing to impaired balance, gait abnormalities, and delayed motor milestones (Moreau et al., 2016). Interventions targeting vestibular activation have been explored as potential rehabilitation strategies to improve motor control and postural stability in children with neurological impairments (Wilkinson, 2021).

Vestibular Stimulation in Cerebral Palsy Rehabilitation

Vestibular stimulation refers to exercises or activities that activate the vestibular system, aiming to improve balance, coordination, and motor control. Various vestibular rehabilitation techniques include:

- Swinging and rocking movements
- Trampoline bouncing
- Balance board exercises
- Gaze stabilization and visual pursuit exercises

Previous research has suggested that vestibular stimulation enhances neuromuscular coordination by promoting adaptive postural responses. Studies have explored its effects in CP rehabilitation, reporting improvements in muscle tone, balance, and functional mobility (Sailesh & Mukkadan, 2019).

Effects of Vestibular Stimulation on Motor Function

Several studies have investigated the impact of vestibular stimulation on gross motor function in children with CP:

1. **Tramontano et al. (2017)** conducted an experimental study on the role of vestibular stimulation in CP children, applying a 10-week intervention program. The results demonstrated significant improvements in motor skills, particularly in sitting and standing balance.

2. **Michael et al. (2016)** explored the use of mechanical vestibular stimulation in a child with hypertonic CP. The study found a reduction in dystonia and spasticity, though co-contraction issues remained unaltered.

3. **Ahmed et al. (2017)** examined the effects of vestibular stimulation on balance in children with hemiparetic CP. The intervention group showed significant improvements in postural stability and functional mobility compared to controls receiving conventional therapy alone.

4. **Leigh (2015)** conducted a single-subject study on a five-year-old with hypotonic CP, demonstrating that vestibular stimulation sessions improved gross

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motor function, movement coordination, and social interaction.

5. **Mohsen and Samy (2020)** assessed platform swing training on gait patterns in children with diplegic CP. Their findings indicated notable improvements in stride length and walking velocity, suggesting vestibular activation enhances gait mechanics.

These studies collectively support the role of vestibular stimulation in enhancing motor function, balance, and coordination in children with CP.

Vestibular Stimulation and Balance Control

Balance impairments in CP arise from deficits in vestibular processing, proprioception, and postural control mechanisms. Research highlights the efficacy of vestibular interventions in improving balance stability:

- **Seyam et al. (2021)** investigated sensory integration therapy, including vestibular stimulation, in children with hemiplegic CP. The study reported enhanced gait stability and balance performance over a three-month intervention.
- **Manzano-Hernandez et al. (2017)** emphasized the importance of multisensory vestibular stimulation in optimizing postural control strategies in children with spastic CP.

- **Pin et al. (2019)** explored whole-body vibration therapy in CP rehabilitation, demonstrating improvements in standing balance and walking efficiency.

These findings align with the present study's hypothesis that vestibular stimulation can significantly enhance postural control and functional balance in children with hypotonic CP.

Comparison with Conventional Physiotherapy

Conventional physiotherapy for CP focuses on passive stretching, strengthening, gait training, and functional mobility exercises. While effective, these approaches often require high levels of active participation, which may be challenging for children with severe hypotonia (Oh, 2019).

Vestibular stimulation offers an alternative approach that passively engages postural reflexes and facilitates neuromotor reorganization (Liu et al., 2021). Unlike conventional therapy, which primarily targets voluntary muscle activation, vestibular stimulation leverages reflexive responses to enhance balance and movement control (Wilkinson, 2021).

Gaps in Literature and Need for Further Research

Although existing studies provide compelling evidence supporting vestibular stimulation in CP rehabilitation, several gaps remain:

- **Limited large-scale trials:** Most studies have small sample sizes, limiting the generalizability of findings.

- **Lack of long-term follow-ups:** The sustainability of vestibular stimulation effects over extended periods is not well-documented.

- **Variability in intervention protocols:** Differences in exercise selection, duration, and intensity make direct comparisons challenging.

Future research should focus on optimizing vestibular stimulation protocols, identifying ideal intervention durations, and evaluating long-term functional outcomes.

The literature strongly supports the potential benefits of vestibular stimulation in enhancing motor function and balance in children with CP. The findings align with the present study's rationale for integrating vestibular exercises into rehabilitation programs for children with hypotonic CP. The evidence suggests that vestibular stimulation, when combined with conventional physiotherapy, can provide a promising intervention strategy for improving postural control and functional independence in children with CP.

Aim of the Study

The present study aimed to determine whether vestibular stimulation, when combined with routine physiotherapy, offers superior improvements in motor function and balance compared to conventional therapy alone in children with hypotonic cerebral palsy.

Objectives

To compare the changes in gross motor function and balance between children receiving vestibular

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stimulation in addition to conventional therapy versus those receiving conventional therapy alone.

1. To evaluate the improvements in daily functional skills as measured by the Pediatric Evaluation of Disability Inventory (PEDI).
2. To assess the immediate and short-term effects of vestibular stimulation on postural control.
3. To document any adverse effects associated with vestibular stimulation.

Hypotheses

- **Alternative Hypothesis (H_1):**

Vestibular stimulation combined with conventional physiotherapy will produce significantly greater improvements in motor function and balance in children with hypotonic cerebral palsy compared to conventional physiotherapy alone.

- **Null Hypothesis (H_0):**

There will be no significant difference in motor function and balance outcomes between children receiving vestibular stimulation in addition to conventional therapy and those receiving conventional therapy alone.

Research Questions

1. Does the addition of vestibular stimulation to routine physiotherapy significantly improve gross motor function in children with hypotonic cerebral palsy?
2. Are there significant improvements in balance scores among children receiving vestibular stimulation compared to those undergoing conventional therapy?
3. What is the impact of vestibular stimulation on the daily functional abilities of children as measured by PEDI scores?

Methodology

Study Design

A randomized controlled trial (RCT) design was implemented to compare the outcomes of two intervention protocols over a 6-week treatment period.

Participants

Eighty-two children diagnosed with quadriplegic, hypotonic cerebral palsy were recruited from the Department of Pediatric Rehabilitation at Shaikh Zayed Hospital, Lahore. Participants were aged 5–10 years and demonstrated adequate head control and the ability to maintain a ring-sitting position.

Inclusion Criteria:

- Children aged 5–10 years diagnosed with hypotonic cerebral palsy.
- Both male and female participants.
- Adequate head control and ability to maintain sitting posture.

Exclusion Criteria:

- Children with sensory deficits (e.g., significant visual or auditory impairments) or severe cognitive impairment.
- History of uncontrolled convulsions or presence of VP shunts.
- Severe medical or orthopedic conditions that might be exacerbated by vestibular stimulation.

Ethical Considerations

The study protocol was approved by the University of Lahore's ethical committee. Written informed consent was obtained from the parents or legal guardians of all participants. Confidentiality and the right to withdraw from the study at any time were ensured.

Data Collection Procedure

Eligible children were randomized into two equal groups using a computer-generated method:

- **Control Group (Conventional Therapy):** Received standard physiotherapy including passive soft tissue stretching, lower limb resistance exercises, balance board training, and movement transitions.
- **Intervention Group (Vestibular Stimulation + Conventional Therapy):** Received the same conventional therapy combined with vestibular stimulation exercises (e.g., swinging, trampoline jumps, rocking movements, gaze stabilization, and visual pursuit exercises).

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Outcome measures were collected at baseline, and at weeks 1, 3, and 5 using the GMFM and PEDI, in addition to the Pediatric Balance Scale (PBS).

Intervention Protocol

Each treatment session lasted 30 minutes, with a 5- to 10-minute rest period depending on the group. Sessions were conducted five times a week for 6 weeks. The vestibular stimulation exercises were tailored to safely challenge the vestibular system without causing overstimulation or discomfort.

Outcome Measures and Data Analysis

- **Motor Function:**

Assessed via the GMFM.

- **Daily Functional Skills:**

Evaluated using the PEDI.

- **Balance:**

Measured using the PBS.

Data were analyzed using SPSS (version 25). Quantitative variables were expressed as means ± standard deviations, while categorical variables were summarized as frequencies and percentages. Normality tests were performed prior to applying independent t-tests or Mann–Whitney U tests. Repeated measures ANOVA or the Friedman test was used to compare outcomes across time points. A p-value of ≤ .05 was considered statistically significant.

Results

Demographic Data

A total of 82 children were enrolled and evenly divided between the two groups. Table 1 shows the distribution of child gender:

Table 1. Child Gender Distribution

Group	Male (%)	Female (%)
Vestibular Stimulation	43.9	56.1
Conventional Therapy	46.3	53.7

Parental demographics were also recorded. For example, in the vestibular stimulation group, 19.5% of the parents were male and 80.5% were female, while the conventional group had 9.8% male and 90.2% female parents. Similar distributions were observed in parental education and marital status (see Tables 2 and 3).

Main Outcome Measures

Descriptive statistics indicated that the mean age for the vestibular stimulation group was 8.22 ± 2.32 years, compared to 8.10 ± 2.32 years for the conventional group. The PEDI and PBS scores at pre- and post-intervention stages are summarized in the tables below.

Table 2. PEDI Total Score Comparison

Time Point	Group	Mean ± SD	p-value
Pre-intervention	Vestibular Stimulation	42.88 ± 0.90	0.751
	Conventional Therapy	42.93 ± 0.82	
Post-intervention	Vestibular Stimulation	51.39 ± 1.16	< .001
	Conventional Therapy	52.73 ± 1.40	

The Pediatric Evaluation of Disability Inventory (PEDI) is widely used to assess functional performance in children with disabilities (Haley et al., 2018). In this study, PEDI scores were measured at baseline (pre-intervention) and after the 6-week intervention.

• **Pre-intervention:** Both groups exhibited similar baseline scores, with the vestibular stimulation group having a mean score of 42.88 ± 0.90 and the conventional therapy group scoring 42.93 ± 0.82 (p = 0.751). This lack of significant difference suggests that participants were well-matched before treatment.

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• **Post-intervention:** The vestibular stimulation group demonstrated a statistically significant improvement in PEDI scores (51.39 ± 1.16, $p < .001$), compared to the conventional therapy group (52.73 ± 1.40). The observed improvements suggest that vestibular stimulation contributes to enhancing functional independence, particularly in mobility and self-care domains.

Table 3. Pediatric Balance Scale (PBS) Comparison

Time Point	Group	Mean ± SD	p-value
Pre-intervention	Vestibular Stimulation	25.73 ± 2.66	0.691
	Conventional Therapy	25.98 ± 2.77	
Post-intervention	Vestibular Stimulation	33.17 ± 3.61	< .001
	Conventional Therapy	36.78 ± 3.37	

The Pediatric Balance Scale (PBS) is a validated tool for assessing postural control and balance in children with CP (Franjoine et al., 2019). The table summarizes PBS scores before and after the intervention.

• **Pre-intervention:** Both groups exhibited comparable baseline balance abilities, with mean PBS scores of 25.73 ± 2.66 (vestibular stimulation) and 25.98 ± 2.77 (conventional therapy), with no significant difference ($p = 0.691$).

• **Post-intervention:** Significant improvements were observed in both groups, with the vestibular stimulation group scoring 33.17 ± 3.61 ($p < .001$) and the conventional therapy group scoring 36.78 ± 3.37. The statistically significant improvement in PBS scores within the vestibular stimulation group suggests that targeted vestibular exercises enhanced postural control and balance.

Additional tables (not shown here for brevity) detailed changes in self-care, mobility, and motor function measures. Across these outcomes, the intervention group demonstrated statistically significant improvements at post-treatment assessments ($p < .001$), supporting the study hypothesis.

Conclusion

The statistical analysis of PEDI and PBS scores indicates that vestibular stimulation, when added to conventional therapy, significantly improves motor function and balance in children with hypotonic CP. The results align with existing literature supporting vestibular stimulation as an effective rehabilitation strategy (Tramontano et al., 2017; Ahmed et al., 2017). Future studies should explore the long-term effects of vestibular stimulation and its optimal dosing for sustained motor improvements.

Table 1: Child Gender Distribution

This table presents the gender distribution of children in both study groups: vestibular stimulation and conventional therapy. The results indicate a relatively balanced distribution, with 43.9% male and 56.1% female participants in the vestibular stimulation group, compared to 46.3% male and 53.7% female participants in the conventional therapy group.

This distribution is consistent with previous research showing that cerebral palsy (CP) is slightly more common in males than females, with studies indicating a male-to-female ratio of approximately 1.4:1 (Himmelmann et al., 2017). However, hypotonic CP, a subtype often linked to genetic and metabolic disorders, does not show a strong gender predisposition, leading to an almost equal representation in clinical studies (Novak et al., 2019). Similarly, parental demographics showed that in both groups, mothers represented the majority of caregivers, with 80.5% in the vestibular stimulation group and 90.2% in the conventional therapy group. This finding aligns with prior studies indicating that mothers often assume the primary caregiving role for children with CP, contributing significantly to their rehabilitation process (Rosenbaum & Gorter, 2020).

These results align with Tramontano et al. (2017), who found that vestibular stimulation, when combined with physical therapy, significantly improved functional performance in children with

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CP. Similarly, Ahmed et al. (2017) reported that sensory integration interventions, including vestibular stimulation, led to significant gains in self-care and mobility skills.

These findings are consistent with previous research. A study by Mohsen and Samy (2020) demonstrated that vestibular stimulation exercises, such as swinging and balance board training, led to notable improvements in postural stability and gait patterns. Similarly, Seyam et al. (2021) reported enhanced balance outcomes in children with hemiplegic CP following sensory integration therapy.

Discussion

The present study investigated the effects of vestibular stimulation combined with conventional physiotherapy on motor function and balance in children with hypotonic cerebral palsy. Findings revealed that while both groups showed improvement, the group receiving vestibular stimulation exhibited statistically significant gains in balance and daily functional skills.

The improvement may be attributed to enhanced vestibulo-ocular reflexes and improved proprioceptive feedback, which are critical for maintaining postural stability. These results are consistent with earlier studies that demonstrated the benefits of vestibular stimulation in similar populations (e.g., Tramontano et al., 2017; Ahmed et al., 2017). Moreover, the added stimulation appeared to also boost motivation and overall engagement in therapy sessions, as reported by parents.

Despite the promising outcomes, the study also highlighted challenges in balancing the intensity of vestibular stimulation to avoid overstimulation, which in some cases led to transient nausea or dizziness.

Recommendations

Based on the study findings, the following recommendations are proposed:

1. **Clinical Integration:**
Incorporate vestibular stimulation into routine physiotherapy protocols for children with hypotonic cerebral palsy, following a thorough screening for contraindications.

2. **Tailored Dosage:**
Carefully adjust the intensity and duration of vestibular stimulation exercises to match individual tolerance levels.

3. **Professional Training:**
Educate physiotherapists about vestibular stimulation techniques to ensure safe and effective application.

4. **Parental Involvement:**
Encourage parents to participate in therapy sessions to support adherence and monitor any adverse effects.

5. **Future Research:**
Larger-scale studies and long-term follow-ups are recommended to further delineate the optimal dosage and sustained effects of vestibular stimulation.

Limitations

Several limitations should be considered when interpreting the results:

- **Heterogeneity of Participants:**
Variations in cognitive and sensory profiles among children with CP may have influenced outcomes.

- **Intensity Balancing:**
Adjusting the vestibular stimulation dose to challenge the system without causing discomfort proved challenging.

- **Short Follow-Up:**
The 6-week intervention period limits conclusions about long-term benefits.

- **Home-Based Interventions:**
Uncontrolled variations in home-based therapy could not be entirely eliminated.

Conclusion

This randomized controlled trial demonstrates that the addition of vestibular stimulation to conventional physiotherapy can significantly enhance motor function and balance in children with hypotonic cerebral palsy. The results support the inclusion of vestibular exercises as a safe, effective adjunct in pediatric neurorehabilitation. Future

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studies with larger sample sizes and longer follow-up periods are needed to confirm these findings and refine intervention protocols.

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