Research Article

Cervical and Ocular Vestibular Evoked Myogenic Potentials in Children with Speech Sound Disorder

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Short running title: Cervical and Ocular Vestibular Evoked…

Highlights:
- Children with SSD exhibit diminished otolithic reflexes, evidenced by VEMPs
- Amplitude asymmetry ratios are higher in children with SSD than in controls
- Reduced vestibular reflex in SSD could influence head-neck muscle tone

ABSTRACT

Background and Aim: Speech Sound Disorder (SSD) is a developmental communication disorder characterised by children's difficulties in producing speech sounds clearly. Auditory deficits, sensory integration issues and motor execution difficulties are reported in children with SSD. The vestibular system, being in proximity to the auditory system and important in sensory integration, requires exploration of its function in children with SSD. The study compared latency and amplitude parameters of Vestibular Evoked Myogenic Potentials (VEMPs) in children with SSD and typically developing children to assess otolithic function.

Methods: The study employed a standard group comparison, involving 10 children with SSD and 10 typically developing children matched for age and gender in the 6–11 years age range (7 boys). Participants underwent cervical VEMP and ocular VEMP testing in a sound-treated room, with appropriate strategies in place to ensure their cooperation with the test procedures.

Results: Statistically significantly higher peak-to-peak amplitude for cVEMP and oVEMP was observed in typically developing children, whereas the amplitude asymmetry ratio was statistically higher in children with SSD. Both findings suggest possible alterations in vestibular function among children with SSD, a finding reported for the first time in the literature.

Conclusion: Alterations in sacculo-collic and utriculo-ocular pathway function might be concomitant in children with SSD. This may influence sensory information related to relative position, movement of articulators, as well as the muscle tone of the neck and head, including articulators. The findings pave the way for exploring adjunct vestibular rehabilitation with speech-language intervention in children with SSD.

Keywords: Vestibular evoked myogenic potential; speech sound disorder; vestibular function tests; reolithic organ

Introduction

Speech Sound Disorder (SSD) is a developmental communication disorder where children experience difficulties in clearly producing speech sounds, affecting the intelligibility of speech and their social participation [1]. While various anatomical, auditory, and motor factors have been reported, the disorder often remains functionally classified when no identifiable structural or neurological cause is established [2]. Prevalence estimates vary widely, with developmental SSD being the most common type of speech impairment in school-aged children [3]. Globally, several authors have reported varying prevalence rates of SSD, with estimates ranging from 8% to 9% [3], depending on region and methodology. In India, studies have reported a prevalence rate of 18.6% [4-5].

Speech Sound Disorders (SSDs) are broadly classified as either organic or idiopathic [6]. Organic SSDs arise from identifiable conditions such as motor or neurological disorders (e.g. apraxia of speech, dysarthria), structural abnormalities (e.g. cleft palate or other orofacial anomalies), or sensory and perceptual deficits (e.g. hearing loss). In contrast, idiopathic SSDs have no established cause. When these difficulties occur during the course of development without a known aetiology, they are referred to as developmental SSDs. This neutral terminology has been adopted to move beyond the traditional articulation-phonology distinction [7]. Developmental SSD is therefore defined as a heterogeneous set of speech production difficulties in children, potentially reflecting limitations in perceptual, motor, linguistic, or combined processes of unknown origin [7]. The symptoms of SSD may present as sound omissions or deletions, substitutions that reduce phonemic contrast, additions of extra sounds, or distortions of existing sounds. Errors can also occur at the syllable level, such as the deletion of weak syllables, or through inconsistent productions of the same word. These features may appear as isolated articulation errors or as phonological rule-based patterns, and in some cases, children may also develop unique error patterns not typically observed [6].

Several researchers have highlighted the role of sensory integration, particularly the vestibular system, in shaping speech and motor functions [8]. The vestibular system, responsible for balance, spatial orientation, and coordination, contributes to head stabilization and postural control which are essential for precise articulatory movements. When the child has deficits in postural control and head stabilization it affects the spatial orientation of articulators within the oral cavity, coordinated movement of muscles with appropriate tone, synchrony with respiratory muscles and overall coordination leading to possible errors in articulation. Children with communication disorders, including developmental SSD, often display co-occurring motor deficits, suggesting that disruptions in sensory-motor integration may underlie or exacerbate speech difficulties [9]. Studies have documented vestibular dysfunction in children with various neurodevelopmental conditions such as Attention Deficit Hyperactivity Disorder (ADHD), Autism, and Specific Learning Disorder (SLD) [10-12], prompting a detailed analysis of vestibular involvement in SSD.

The vestibular apparatus shares close anatomical and physiological proximity with the auditory system, particularly at the level of the inner ear and brainstem. This association has led to the hypothesis that vestibular dysfunction may subtly accompany auditory processing deficits, which are consistently observed in children with SSD [13]. Moreover, the influence of the vestibular system on oromotor control is increasingly recognized [14]. Research shows that complex vestibular inputs reaching to head and neck (including tongue, eyes and facial muscles) may affect some of the vital components of fluent speech including muscle tone, ocular tracking, and even respiratory coordination [15]. Animal studies have demonstrated a convergence of visual and vestibular inputs on hypoglossal motor pathways. For instance, in rabbits, a majority of hypoglossal neurons exhibited responses to both retinal photic stimulation and labyrinthine stimulation, suggesting sensory integration that may modulate tongue posture and motor control [16]. Despite these theoretical links, empirical data on vestibular function in children with SSD remain largely unknown. This could be attributed to multifaceted reasons, including children being unaware of this as a problem, unable to express their sensations, ignoring it as a very minute balance-related issues or unable to characterise such feelings [17]. When balance problems are not severe, these children still develop basic walking abilities on par with typically developing children, tolerate symptoms of balance deficits better, and remain asymptomatic in many instances [17]. Additionally, children's brain plasticity remains stronger, leading to better adaptation and compensation for balance problems, which can even cause parents to overlook balance-related issues in children. Hence, an objective method of assessing vestibular function in children with SSD may reveal physiological alterations in the otolith organ and its pathway, if any.

Clinical assessment tools, such as cervical Vestibular Evoked Myogenic Potentials (cVEMP) and ocular Vestibular Evoked Myogenic Potentials (oVEMP), offer non-invasive methods to measure the functional integrity of the saccule and utricle (otolith organs), respectively, along with their respective pathways. These tests have been reliably used in pediatric populations and can detect subtle vestibular asymmetries or response magnitude differences that may not present as overt balance issues in children [18]. Thus, using VEMP protocols provides an objective means to explore otolith organs involvement in children with SSD. Although VEMP testing requires specialized equipment and trained personnel, it remains a relatively low-cost and non-invasive clinical tool compared to imaging or balance lab evaluations. Evaluating its utility in SSD could help justify its incorporation into broader clinical assessments. The purpose of this study was to compare the otolithic pathway function of children with SSD and typically developing children. To achieve this aim, we have utilised cervical and ocular VEMP as objective tools to measure the Vestibulo-Spinal Reflex (VSR) and Vestibulo-Ocular Reflex (VOR), respectively, to assess the functioning of the sacculo-collic and utriculo-ocular pathways. The objectives were to compare the peak-peak amplitude, amplitude asymmetric ratio between ears and latencies of cVEMP and oVEMP between children with SSD and typically developing children.

Methods

The present study employed a standard group comparison design. The participants consisted of 10 children in each of the two groups, group 1, consisting of children with Speech Sound Disorder (SSD) and group 2, consisting of age-matched Typically Developing (TD) children. The participants were recruited for the study using a purposive sampling method. All the participants were in the age range of 6–11 years. This age range was adopted as no age-related changes were observed in cVEMP and oVEMP parameters [19], in the selected age range, and hence, a further subgroup was not done.

Participants in the SSD group were diagnosed as having developmental SSD based on Diagnostic and Statistical Manual of Mental Disorders-fifth edition (DSM-5) criteria (details provided in Appendix 1), evaluated by an expert panel of three speech-language pathologists with experience of more than 5 years. This assessment procedure included a detailed case history, oromotor examination, and diadochokinetic (DDK) rate, articulation test, discrimination ability, stimulability, speech intelligibility rating, and consistency of errors. In addition to the diagnosis of developmental SSD, other inclusion criteria for the SSD group were 1) hearing sensitivity of <25 dB HL for both air conduction across 250 to 8000 Hz frequencies and bone conduction across 250 to 4000 Hz audiometry with an air bone gap ≤10 dB HL. The hearing sensitivity criteria were chosen based on the prior reports of minimal hearing loss in children with SSD [13], 2) “A” or “As” type of tympanogram with the presence of acoustic reflexes at 500 and 1000 Hz was considered, as it rules out middle ear pathology, which might alter the VEMP results.

The inclusion criteria for participants in TD group were 1) typically developing children without having any speech, language, or motor delay/disorder as diagnosed by the same three speech-language pathologists using the same assessment tools used for SSD group, 2) no report of any vestibular symptoms as per the detailed case history and Pediatric Vestibular Symptom Questionnaire (PVSQ) [20], in Kannada language (Questionnaire provided in Appendix 2), and 3) matching with the SSD group participants on their air conduction and bone conduction thresholds, as well as immittance test results.

The exclusion criteria of the SSD and TD groups participants included having any complaint or history of middle ear problems, undergoing any medication for psychological/psychiatric disorders, or taking any kind of ototoxic medications. Children with a history of head injuries were also excluded from the study.

Procedure for cervical vestibular evoked myogenic potentials

The VEMP recordings were carried out using calibrated Neuro-audio auditory evoked potentials equipment (Neurosoft, Ivanovo, Russia) in an electrically and acoustically shielded room. The protocol implemented to record cVEMP and oVEMP were adopted from Rodriguez et al [19]. The cVEMPs were obtained by administering high-intensity acoustic stimuli to one ear and recorded from the same side sternocleidomastoid. To start off the cVEMP recording procedure, the children were seated in an upright position. The recording electrode sites were meticulously cleaned, electrodes placed and then their impedance levels were maintained at 5 k ohms. To capture the cVEMP, the non-inverting electrode was positioned on the upper one-third of the sternocleidomastoid, the inverting electrode placed at the upper sternum of same side, and the ground electrode attached on the forehead.

A tone burst stimulus was presented through Etymotic ER-3 insert earphones to one ear, and the child was instructed to turn their head in the opposite direction to generate the appropriate muscle tension. To ensure the turning of the head, an attractive toy/cartoon video was displayed at an angle suitable to obtain appropriate muscle tension. The children were asked to maintain this head position until the stimulus ended.

Procedure for ocular vestibular evoked myogenic potentials

The oVEMPs were obtained by delivering a high-intensity acoustic stimulus to one ear while simultaneously recording surface Electromyography (EMG) signals from the opposite side inferior oblique muscle. During the oVEMP recording process, the children were seated in an upright position. The locations of the recording electrodes were meticulously cleaned, and their impedance was maintained within 5 k ohms. To capture the oVEMP, the non-inverting electrode was positioned 1 cm below the eye (at the centre of the eye below the pupil when it is at rest looking straight), the inverting electrode situated 2 cm below the non-inverting electrode, and the ground electrode affixed to the forehead. The children were instructed to gaze upward by at least 30 degrees and maintain their eye position in this direction until the stimulus concluded. To ensure appropriate muscle tension, an attractive toy/cartoon video was displayed at a 30-degree angle upward, which was ensured before initiating each recording.

cVEMP and oVEMP recordings were obtained using one recording channel for each response type. For both tests, tone bursts of 500 Hz frequency were delivered at an intensity of 125 dB peSPL with alternating polarity and a repetition rate of 5.1 stimuli per second. Each response was averaged over 200 sweeps with an epoch duration of 64 ms. Artifact rejection criteria were maintained between 30–100 µV for cVEMP and 0–30 µV for oVEMP recordings. Signals were amplified by a factor of 5000 for cVEMP and 30,000 for oVEMP. The band-pass filter for cVEMP recordings was set between 10 and 1500 Hz, whereas for oVEMP, it ranged from 0.1 to 1000 Hz. These parameters were standardized across participants to ensure optimal signal clarity and reproducibility of vestibular evoked myogenic potentials.

Electromyographic rectification

Amplitude rectification method was used to overcome the effect of the varying EMG levels maintained by each child. The recording equipment automatically averaged EMG in the pre-stimulus level in each trial, and the entire response waveform is scaled according to this average EMG level [21]. The corresponding value is divided into each of the 256 points along the collected VEMP waveform to obtain new rectified waveforms. Throughout this study, rectified EMG is used for all types of peak-to-peak amplitude comparisons of cVEMP and oVEMP.

For both cVEMP and oVEMP, the consistency and repeatability of the response were assessed by recording the response at least two times. A minimum of 2-minute rest period was provided between successive recordings. To reduce biases and increase reliability, the peaks were marked by two experienced audiologists (with a minimum of three years' experience) independently on the screen. Whenever there was a discrepancy in the markings, an average point was taken for further analysis. The latency and amplitude parameters of cVEMP and oVEMP were noted based on these markings.

Grand average waveform preparation

To provide a representative visual display of VEMP responses, grand average waveforms were generated. The original recordings were first exported in ASCII format. For each participant, two reproducible waveforms were averaged to obtain a single trace per recording. These individual participant traces were then plotted together in Microsoft Excel 2016, and an overall average across participants was computed to derive the grand average waveform, which is highlighted in the figures.

Statistical analysis

The tabulated VEMP parameters were analysed using IBM SPSS Statistics for Windows, Version 26.0 (IBM Corp., Armonk, NY, USA). The VEMP parameters from the two ears were compared using paired t-tests, while independent t-tests were applied to examine differences between the SSD and TD groups. Effect sizes were estimated using Cohen’s d.

Results

The average age of the children in the SSD group was 7 years 6 months (± 1.4), and in the TD group, it was 7 years 7 months (± 1.4). In both groups, there were seven boys and three girls. The average neck length of the children in the SSD group was (12.8 ± 1.1 cm), and that of the TD group was (12.5 ± 1.14 cm). The statistical analysis revealed no significant difference between the SSD and TD groups in terms of age ($p<0.05$), and having equal gender in each group ensured age-gender matching.

The Shapiro-Wilk test was performed, and it revealed a normal distribution of the data for all parameters considered in both groups ($p>0.05$). Hence, the parametric tests were used for further statistical analysis. In the SSD group, cVEMP and oVEMP responses showed similar latencies between ears, with slightly longer n23 and n10 latencies in some cases. The left ear displayed marginally higher cVEMP amplitudes (1.66 ± 0.64 μV), whereas oVEMP amplitudes were greater on the right (0.77 ± 0.25 μV). In the TD group, both cVEMP and oVEMP responses were symmetrical across ears, showing minimal latency differences. Amplitudes were comparable between sides, with a slight tendency for higher values in the left ear for both cVEMP (2.42 ± 0.66 μV) and oVEMP (1.18 ± 0.27 μV).

To assess the ear effect across the parameters investigated in this study (except for the amplitude asymmetric ratio, as it is a single value for each participant), a series of paired samples t-tests was performed for each parameter, comparing the respective pairs of responses from the right and left ears. For cVEMP, the mean differences in p13 latency, n23 latency, and p13-n23 amplitude showed no significant difference between left and right ear responses ($p>0.05$). Similarly, for oVEMP, no significant side-related differences were observed for n10 latency, p16 latency, or n10-p16 amplitude ($p>0.05$). These findings suggest symmetrical responses between the right and left ears across all vestibular measures examined. Henceforth, the responses from the right and left ears were combined for all parameters of cVEMP and oVEMP, except for the Amplitude Asymmetric Ratio (AAR), for further analysis. The mean and standard deviation of the responses of cVEMP and oVEMP parameters under analysis, along with AAR, are provided in Table 1. The ear-wise comparison was done for the combined data of the SSD and TD groups.

The individual waveforms and grand average wave of cVEMP responses from the TD group and the SSD group are provided in Figure 1, whereas Figure 2 represents the individual waveforms and grand average wave of oVEMP responses from the TD group and the SSD group, respectively. The morphological and amplitude differences between the responses from the TD group and the SSD group are noticeable in these figures.

After combining the right and left responses group-wise, to understand the significance of the difference between the SSD and TD groups, independent t-tests were conducted across all parameters. The statistical details of the independent t-tests are presented in Table 2. The table clearly shows a significantly higher peak-peak amplitude of cVEMP and oVEMP ($p<0.05$) in typically developed children compared to children with speech sound disorders. The asymmetry ratio was significantly higher ($p<0.05$) in children with speech sound disorders compared to typically developing children. Due to high standard deviation while comparing the asymmetric ratio, we performed a non-parametric Mann-Whitney U test also to account for this, and the results again showed statistically significant difference between the two groups with higher asymmetry observed for cVEMP ($z=2.41$, $p=0.016$) and oVEMP ($z=2.01$, $p=0.048$) in the SSD group when compared to the TD group.

Figure 3 graphically compares the mean and standard deviation of the p13-n23 peak-to-peak amplitude of cVEMP and the n10-p16 peak-to-peak amplitude of oVEMP for the SSD and TD groups. Similarly, Figure 4 graphically depicts the comparison of the mean and standard deviation of AAR of cVEMP and oVEMP for SSD and TD groups.

The effect size of this difference was evaluated using Cohen's d, and it revealed a large effect size for peak-to-peak amplitudes of cVEMP and oVEMP and amplitude asymmetric ratios of cVEMP, and oVEMP [22]. However, there was no significant difference between the latency parameters of cVEMP and oVEMP ($p>0.05$).

The EMG potential alone was analysed separately across the groups, which showed no difference between ears ($p>0.05$), no correlation between rectified amplitudes and EMG potentials across groups ($p>0.05$) and significantly higher values in SSD group than TD group ($p<0.05$), in contrast, the rectified amplitude was high in TD group. Hence, all these findings suggest that the difference observed in our study is unrelated to the voluntary EMG potential induced by children, but rather related to the changes in otolithic pathway activity of VCR and t-VOR elicited by an acoustic stimulus.

Discussion

This study investigated vestibular function in children with speech sound disorder and typically developing peers using cervical Vestibular Evoked Myogenic Potentials (cVEMP) and ocular Vestibular Evoked Myogenic Potentials (oVEMP). The key findings showed that children with SSD exhibited significantly reduced peak-to-peak amplitudes in both cVEMP and oVEMP, along with higher Amplitude Asymmetry Ratios (AAR) compared to the TD group, while no group differences were observed in latency measures. Together, these results suggest that SSD may be associated with reduced vestibular response strength and increased asymmetry of otolithic pathway activity, indicating subtle yet measurable alterations in vestibular processing.

The peak-to-peak amplitudes of cervical and ocular vestibular evoked myogenic potentials

The SSD group demonstrated significantly reduced amplitudes in both cVEMP (p13-p23) and oVEMP (n10-p16) compared to the TD group. This suggests a reduced magnitude of vestibular response, potentially reflecting impaired saccular and utricular function or a deficit in the peripheral and central processing of vestibular input.

Reduced VEMP amplitudes have been associated with vestibular hypofunction in pediatric populations with neurodevelopmental disorders. In particular, Goulardins et al. [23] highlighted that children with developmental coordination disorder exhibited abnormal postural and vestibular responses, supporting a possible sensorimotor integration deficit as proposed by Ayres [24]. Our findings extend this evidence to children with SSD, implying that motor speech deficits may be linked to broader deficits in sensory-motor integration, including vestibular processing.

Speech development begins with ample sensory and motor experiences during early childhood. Many young children with speech disorders have reduced functions in the vestibular, proprioceptive, and tactile sensory systems compared to typically developing children [25]. When a child has defects in sensory systems, such as auditory perception or the vestibular system, speech development will be affected, causing problems such as delay in speech development and articulation disorders [26]. Articulation disorders in young children could also be due to defects occurring at a certain stage in sensory and motor development [27]. Sensory integration involves the ability to perform motor actions after integrating sensory input. The integration of these sensory inputs is essential for self-motion, postural stability, and spatial orientation. The reduced amplitude responses in children with SSD might also reflect diminished vestibular afferent activity, which could impair the sensory-motor integration. The vestibular system's influence on muscle tone, balance, and head stabilization, especially of Vestibulo-Collic Reflex (VCR) measured through cVEMP in this study, plays a crucial role in oral-motor control. Additionally, the reduction in otolith organ activity may, in turn, affect the brain's ability to accurately detect the location and movement of articulators in the oral cavity. Thus, disruptions in vestibular feedback may contribute to difficulties in articulatory precision and motor timing observed in SSD.

The transalational-Vestibulo Ocular Reflex (t-VOR) which is measured through oVEMP in this study, is important in the precise observation of the position and movement of articulators by maintaining a stable image at the fovea [28]. During the development from infant to childhood, as the head position in relation to gravity varies across lying down, sitting, and standing, an accurate t-VOR is essential for learning the articulatory movements in the early stage of speech-language development. Reduced t-VOR is reported in children with speech-language disorders [29] and our findings extend this as a possible concomitant factor in children with SSD.

The amplitude asymmetry ratio of cervical and ocular vestibular evoked myogenic potentials

A significant group difference in AAR was observed for both cVEMP and oVEMP, with the SSD group exhibiting higher asymmetry values than the TD group. Elevated AARs may indicate lateralized vestibular dysfunction or asymmetric peripheral and central processing [28]. In clinical contexts, asymmetry values exceeding normative ranges are often considered indicative of pathology.

The mean AAR of cVEMP and oVEMP among young children of less than 12 years reported in the literature varies from 2.07-17.6% [18] and the results found in our study fall within this range for typically developing children (mean 12.21%), and it is clearly out of the range for children with SSD (mean 21.13%). The high variation in the normative of AAR could be attributed to differences in the sample size of the population studied, variation in the age range considered, and differences in amplitude rectification across the equipment used. The abnormal AAR is also reported among children with specific learning disorder and attention deficit hyperactive disorder [30].

Asymmetrical vestibular input may lead to instability in postural control and reduced coordination of structures, potentially influencing speech articulation. Studies have shown the influence of vestibular system activity on tongue muscles, arising from the close connectivity of the trigeminal and solitary nuclei with vestibular nuclei at the brainstem level, where most of the afferent projections from the tongue reach [31]. Changes in body position are reported to have an influence on the muscle activities of the tongue and muscles of the upper respiratory tract [32]. Diminished or asymmetric vestibular inputs may alter the sensory integration process, eventually leading to defects in motor planning and execution through brainstem reflexes that involve the head, neck, and facial muscles. Since precise movement of articulators, including the tongue, is essential for the accurate production of various speech sounds, alterations in the vestibular inputs diminish Vestibulo-Collic Reflexes (VCR), and thereby plausibly reduce the inputs to muscles, which might contribute to errors in speech sound production.

The presence of significant asymmetry in both cVEMP and oVEMP reinforces the hypothesis of multisystem involvement in SSD. Importantly, these physiological markers could potentially serve as objective biomarkers to identify subclinical vestibular dysfunction in children with SSD.

The latencies of cervical and ocular vestibular evoked myogenic potentials

No statistically significant differences were observed in the latencies of cVEMP (p13 and n23) or oVEMP (n10 and p16) between the SSD and TD groups. This suggests that the neural conduction time along the vestibulo-collic and vestibulo-ocular pathways remains intact in children with SSD. Though there are no previous studies done on children with SSD, these findings align with previous studies that have reported preserved latency measures in children with developmental language disorders [23], indicating that conduction delays across the cVEMP and oVEMP pathway may not be a primary feature in these populations.

Our findings suggest that vestibular dysfunction, particularly in terms of response magnitude and amplitude symmetry, may be a previously underrecognized component in the neurophysiological profile of children with SSD. Incorporating vestibular assessments, such as VEMPs, as supplementary tools into multidisciplinary diagnostic protocols may enhance the understanding of SSD pathophysiology and aid in developing holistic intervention approaches.

Intervention studies have demonstrated that vestibular stimulation, when integrated into sensory integration therapy, can lead to measurable improvements in balance, postural control and motor coordination among children with balance issues [33]. Through a randomised controlled trial Schaaf et al. [33] reported that children with autism spectrum disorder who received sensory integration therapy (including structured vestibular activities) exhibited measurable improvements in questionnaire scores targeting the conception, planning, and organisation of motor actions. Ray et al. [34] highlighted the possible role of vestibular stimulation in the improved speech production of a child with autism. Taken together, these evidences suggest vestibular-based therapies may serve as beneficial adjuncts to conventional speech-language interventions among children with SSD who report vestibular deficits. Furthermore, this may potentially enhance adequate and symmetrical sensory inputs, facilitate more stable articulatory movements, and augment fine motor coordination for speech targets in children with SSD.

Conclusion

Reduced cervical Vestibular Evoked Myogenic Potentials (cVEMP) and ocular Vestibular Evoked Myogenic Potentials (oVEMP) amplitudes, as observed in this study, may reflect diminished afferent vestibular input or inefficiencies in central and peripheral sensory processing. These physiological changes could impact oromotor stability, head posture, and coordination which are critical elements in speech production. High amplitude asymmetric ratios may indicate unilateral vestibular hypofunction or asymmetric central and peripheral vestibular integration, both of which alter the vestibular-related muscle reflexes affecting the head and neck, including articulators, which in turn may contribute to a lack of precision in speech sound production. Notably, these results align with previous literature documenting sensorimotor deficits in developmental speech and language disorders, although this is one of the first studies to extend the possibility of altered vestibular sensory inputs in children with Speech Sound Disorder (SSD). By incorporating VEMP protocols into the evaluation of children with SSD, this study underscores the potential role of diminished vestibular-related reflexes as a possible concomitant factor in children with SSD. However, this study has limitations such as a small sample size, addressed only the otolith organ and its pathway function; Future studies may focus on the functioning of other structures involved in balance and correlations between VEMP measures, behavioural balance function, severity and types of SSD, and reproducibility of the findings using other methods of electromyography monitoring.

Ethical Considerations

Compliance with ethical guidelines

All procedures performed in this study were in accordance with the ethical standards of the institutional review board (SH/IRB/M.1-31/2024-25 dated 23/12/2024) of All India Institute of Speech and Hearing (AIISH), Mysuru, India, as per the guidelines of the Ethical principles for Bio-Behavioural research involving human subjects. The participants were informed about the entire procedure, and informed consent was obtained from all participants.

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Authors' contributions

PT: Data collection, drafting the manuscript, interpretation of the results, statistical analysis; AB: Study design, interpretation of the results, reviewing the manuscript, statistical analysis.

Conflict of interest

There is no conflict of interest declared by the authors.

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Table 1. The mean and standard deviation of cervical and ocular vestibular evoked myogenic potentials response parameters obtained from speech sound disorder and typically developing group

		SSD group		TD group	
	Parameter analyzed	**Mean**	**SD†**	**Mean**	**SD†**
cVEMP	**p13 latency (ms)***	13.28	0.56	13.31	0.76
	n23 latency (ms)*	20.44	1.66	20.52	1.60
	p13-n23 amplitude (μV)*	1.51	0.31	2.32	0.56
	Amplitude asymmetric ration of cVEMP (%)	30.08	18.27	12.21	8.53
oVEMP	**n10 latency (ms)***	10.14	0.66	9.80	0.62
	p16 latency (ms)*	15.72	0.67	15.33	1.11
	n10-p16 amplitude (μV)*	0.67	0.27	1.16	0.29
	Amplitude asymmetric ration of oVEMP (%)	29.91	23.98	12.35	5.89

SSD; speech sound disorder, TD; typically developing, cVEMP; cervical vestibular evoked myogenic potentials, oVEMP; ocular vestibular evoked myogenic potentials

* Combined response of left and right ears, † SD – Standard deviation

Table 2. Depicting the results of independent t-tests by averaging the responses of right and left ear stimulation across the parameters

Parameter	**t(18)-value**	**p**	**Cohen's d**
p13 latency	–0.11	0.91	-
n23 latency	–0.10	0.92	-
p13-n23 amplitude	–3.80	0.001*	1.70
n10 latency	1.11	0.28	-
p16 latency	0.93	0.37	-
n10-p16 amplitude	–3.66	0.002*	1.64
cVEMP amplitude asymmetric ratio	2.66	0.016*	1.19
oVEMP amplitude asymmetric ratio	2.13	0.047*	0.95

cVEMP; cervical vestibular evoked myogenic potentials, oVEMP; ocular vestibular evoked myogenic potentials

* Statistically significant differences

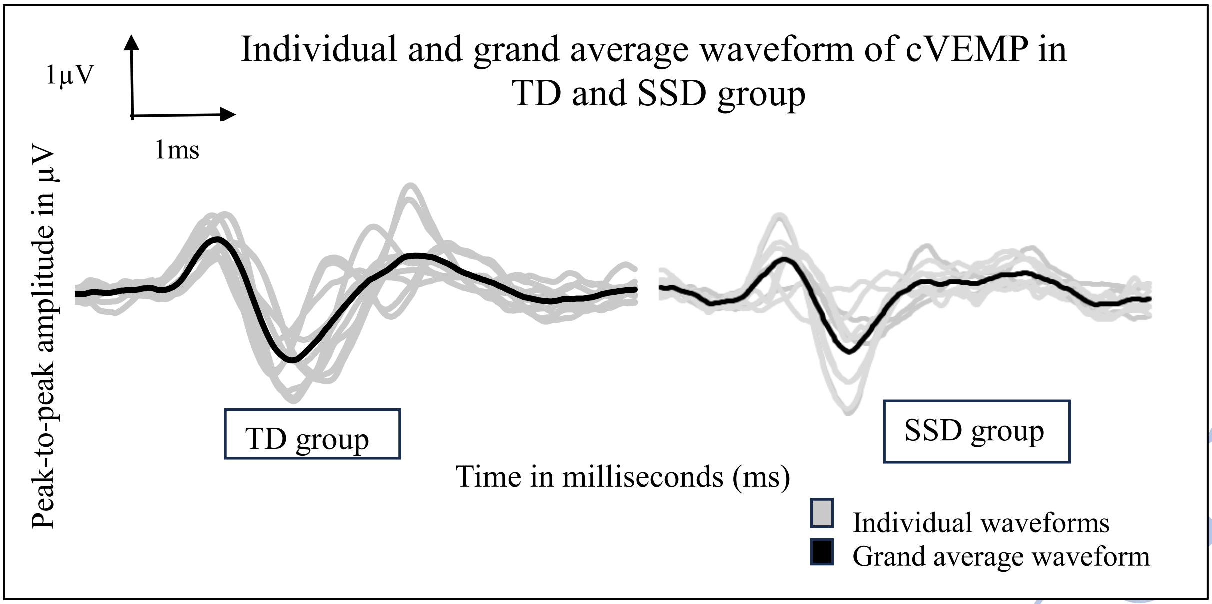

Figure 1. Represents the individual and grand average waveforms of cervical vestibular evoked myogenic potential recorded from children with speech sound disorder and typically developing children. cVEMP; cervical vestibular evoked myogenic potentials, TD; typically developing, SSD; speech sound disorder

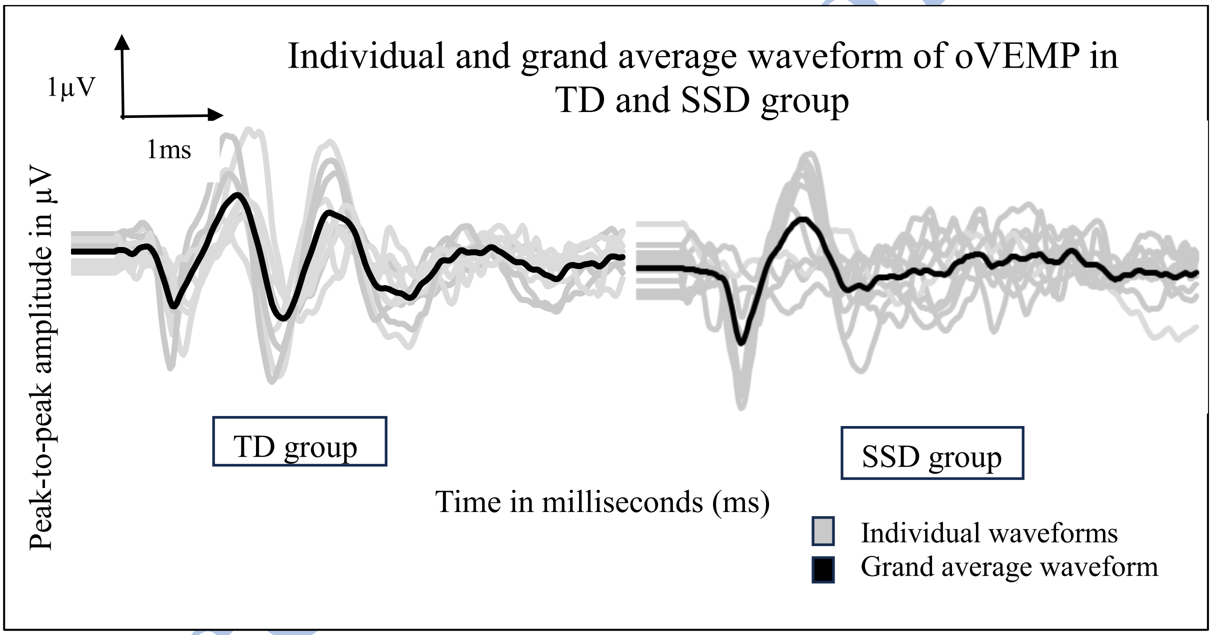

Figure 2. Represents the individual and grand average waveforms of ocular vestibular evoked myogenic potential recorded from typically developing children. oVEMP; ocular vestibular evoked myogenic potentials, TD; typically developing, SSD; speech sound disorder

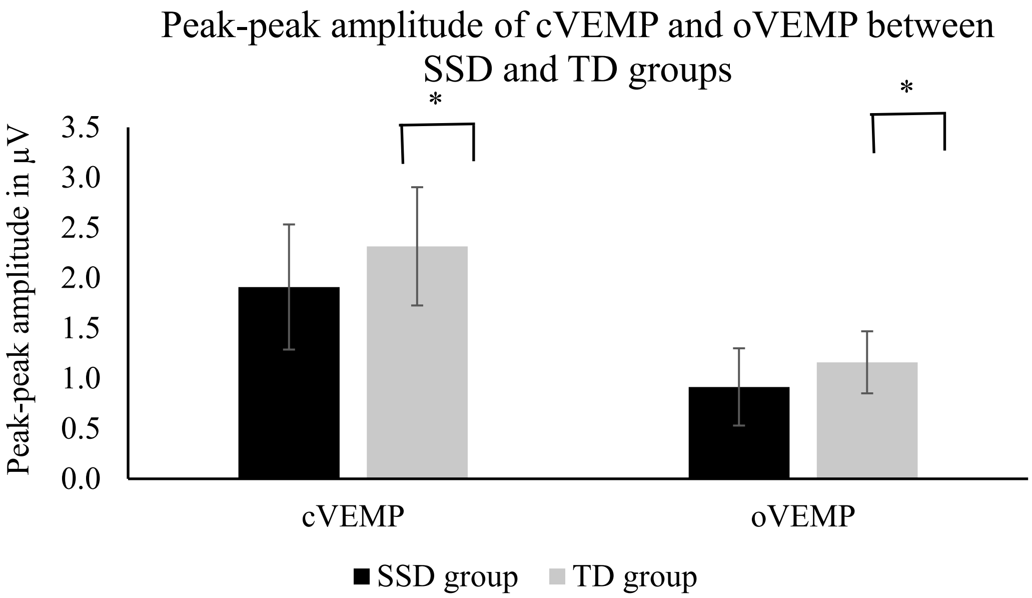

Figure 3. Represents the comparison of mean and standard deviation of peak-to-peak amplitudes of cervical and ocular vestibular evoked myogenic potentials between speech sound disorder and typically developing groups. cVEMP; cervical vestibular evoked myogenic potentials, oVEMP; ocular vestibular evoked myogenic potentials, SSD; speech sound disorder, TD; typically developing

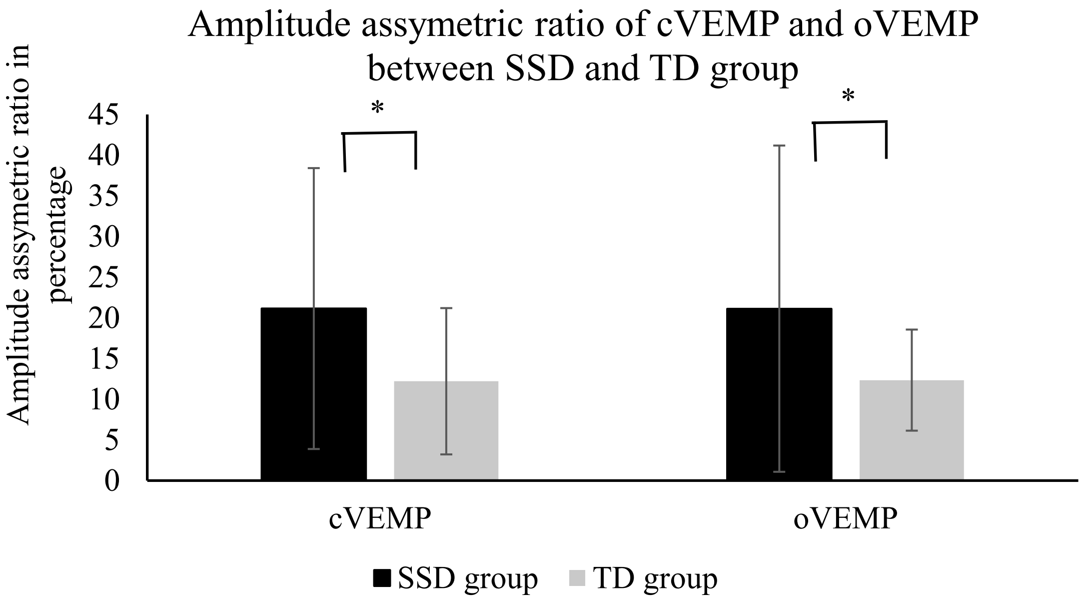

Figure 4. Represents the comparison of mean and standard deviation of cervical and ocular vestibular evoked myogenic potentials amplitude asymmetric ratio between Speech sound disorder group and Typically developing group. cVEMP; cervical vestibular evoked myogenic potentials, oVEMP; ocular vestibular evoked myogenic potentials, SSD; speech sound disorder, TD; typically developing

Appendix 1. The DSM-V (Diagnostic and Statistical Manual of Mental Disorders, fifth edition) criteria to diagnose Developmental Speech Sound Disorder.

There are four criteria to diagnose Developmental Speech Sound Disorder:

Criteria	**Description**
1	Persistent unintelligible speech consisting of phoneme addition, omission, distortion, or substitution, which interferes with verbal communication
2	There is interference with either social participation, academic performance, or occupational performance (or any combination thereof)
3	The onset of symptoms is during childhood
4	The symptoms cannot be accounted for by another medical or neurological condition, including TBI (Traumatic Brain Injury)