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The Effect of Combined Vestibular-Proprioceptive Training on Postural Control in Children with Visual Impairment: A Quasi-Experimental Study

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Original Article

Abstract

Introduction: Reduced visual input in children with visual impairments can negatively affect postural control and motor performance. In such conditions, the vestibular and proprioceptive systems play a crucial compensatory role. This study aimed to investigate the effects of combined vestibular-proprioceptive training conducted in a school setting on postural control, knee joint position sense, and locomotor skills in children with visual impairment, as well as the retention of these effects after a two-month follow-up period.

Materials and Methods: This quasi-experimental study included 20 boys with visual impairment aged 7-10 years who were randomly assigned to experimental and control groups. The experimental group participated in combined vestibular-proprioceptive exercises for eight weeks, while the control group received no intervention. Outcome measures were assessed at pre-test, post-test, and two-month follow-up. Data were analyzed using repeated measures analysis of variance (ANOVA) with a significance level of $P \leq 0.05$.

Results: Significant intergroup differences were observed for group effect, time effect, and group × time interaction ($P \leq 0.001$), with medium to large effect sizes. In the experimental group, significant improvements were found in postural control, knee joint position sense, and locomotor skills in both pre-test to post-test and pre-test to follow-up comparisons ($P \leq 0.050$). However, no significant difference was observed between post-test and follow-up for locomotor skills ($P = 0.580$). In the control group, no significant changes were found across assessment times in any of the studied variables ($P \geq 0.050$).

Conclusion: Combined vestibular-proprioceptive training implemented in school settings can effectively improve postural control and locomotor skills in children with visual impairment and may be incorporated into daily rehabilitation programs in schools for students with visual impairments. Nevertheless, further studies are required to confirm and generalize these findings.

Keywords: Postural control; Joint position sense; Locomotor skills; Children with low vision

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Introduction

The visual system plays a pivotal role in guiding cognitive, social, and motor development from birth. Consequently, visual impairments can exert significant consequences on motor performance and social interactions (1). A reduction or absence of visual input disrupts postural control, subsequently leading to complications in orientation and postural stability (2).

Postural control emerges from the dynamic interplay between three primary sensorimotor systems: the visual, vestibular, and proprioceptive systems (3). Specifically, the vestibular system governs cephalic orientation and gravitational alignment, while the proprioceptive system regulates appendicular

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positioning and the base of support. Concurrently, the visual system facilitates the body's spatiotemporal relationship with the environment. According to Systems Theory, the relative contribution of each sensory input undergoes context-dependent modulation, a phenomenon that underscores the capacity for central neuroplasticity and adaptive integration (4, 5).

In children with congenital visual impairment, postural control is primarily achieved through compensatory reliance on the vestibular and proprioceptive systems, with the capacity for postural maintenance developing through motor coordination and synergistic muscle activation (6). Nevertheless, empirical evidence suggests that, despite enhanced proprioceptive sensitivity in this population, such compensation remains insufficient to reach the postural control threshold exhibited by their sighted peers (7).

While the proprioceptive system plays a critical compensatory role during visual deprivation or vestibular dysfunction (8), these adaptations often fail to fully restore postural control (9). Children with visual impairments consistently exhibit diminished performance in static balance assessments (10) and experience heightened postural sway (11). Age and the severity of visual deficit are key determinants of balance proficiency, with the most pronounced impairments reported in the 7-to-11-year age cohort (12). Furthermore, the sedentary lifestyle and low physical activity levels prevalent during the school years may exacerbate dynamic postural instability (13) and delay the acquisition of gross motor skills, such as running, jumping, and grasping (14). Regular engagement in structured physical activities, specifically gross motor training involving gait and jumping, plays a fundamental role in enhancing motor function (15), postural stability (16), ambulation (16), and overall quality of life in this population (17). Consequently, to optimize postural control and motor efficacy, these children require targeted interventions to augment proprioceptive acuity and spatial awareness (18).

Previous investigations have demonstrated that vestibular-based stimulation (19) and structured balance training (20) can significantly enhance static and dynamic balance and mitigate fall risk among individuals with visual impairments. These improvements are fundamentally underpinned by neural adaptations (20). Nevertheless, solitary reliance on a single sensory modality is insufficient to fully compensate for the absence of visual input (8, 20). Consequently, the synergistic integration of vestibular and proprioceptive afferents may offer a more efficacious strategy for optimizing postural stability and motor proficiency (8, 21).

Despite extant evidence on the efficacy of isolated balance, vestibular, or proprioceptive interventions (19-22), limited data are available on the long-term retention of these effects in authentic educational settings, such as schools. To date, there appears to be a paucity of systematic research investigating the concurrent, synergistic effects of feasible vestibular and proprioceptive exercises implemented in real-world school environments for children with visual impairments. This knowledge gap is particularly critical given the significant pragmatic implications of such interventions, including their ease of implementation in daily educational routines, cost-effectiveness, and minimal equipment requirements. Moreover, their potential for integration into school-based physical education programs and, crucially, the sustainability of therapeutic gains during the sensitive period of motor development (ages 7–10) underscore the imperative for the present study.

Accordingly, the present study aimed to evaluate the efficacy and retention of a school-based, integrated vestibular-proprioceptive training program on postural control, knee joint position sense, and locomotor skills in children aged 7 to 10 years with visual impairments.

Materials and Methods

Study Design: The present research employed a quasi-experimental design featuring a pre-test, post-test, and a two-month follow-up assessment. The study was conducted during the 2023–2024 academic year at a specialized school for the visually impaired in Mashhad, Razavi Khorasan Province, Iran. The participants comprised male students aged 7 to 10 years with visual impairments. Following an initial screening, subjects were randomly allocated—via a simple lottery method—into two groups: an experimental group (n = 10) and a control group (n = 10). The impact of the intervention on the research variables was evaluated across three distinct time points.

Randomization and Allocation Concealment: Randomization was performed via a manual lottery system using sequentially numbered, opaque, sealed envelopes (SNOSE) containing numbers 1-20. To ensure allocation concealment and minimize selection bias, the envelopes were opened in sequential order by an independent investigator who was not involved in the screening, initial assessments, or the administration of the interventions (45). This procedure ensured that the allocation sequence remained concealed from both the participants and the primary researchers until the point of assignment.

The number of participants was determined based on comparable studies and the logistical constraints of accessing eligible students. The sample size for this study was calculated using G*Power software (Version 3.1.9.2, Kiel University, Germany). For a predefined alpha level of 0.05 and a statistical power (1-β) of 0.80, the analysis was conducted to ensure sufficient sensitivity to detect the intervention's effects (33).

This study was conducted in strict adherence to the Declaration of Helsinki and the ethical principles governing human research. Official authorization was obtained from the General Directorate of Education of Razavi Khorasan Province (Mashhad District) under internal permit No. 1401/1617/30/d/109841, dated March 13, 2023. Prior to the commencement of the study, the research objectives and protocols were comprehensively explained to both parents and students, and written informed consent was secured from all legal guardians. The study protocol was approved by the Institutional Review Board (IRB) of the University of Guilan and was subsequently registered with the Clinical Trials Registry. Participation was entirely voluntary, with subjects retaining the right to withdraw at any stage without prejudice. To ensure confidentiality, all personal data were anonymized. Furthermore, all intervention sessions were supervised by the researchers and certified specialists in Adapted Physical Activity (APA) and disability sports within the school environment to mitigate any potential risks and ensure participant safety.

Participants: The participants were male students aged 7 to 10 years with mild-to-moderate visual impairment, categorized according to the World Health Organization (WHO) classification and corresponding Class B3 in the International Blind Sports Federation (IBSA) system. To identify eligible candidates, medical records and optometric assessments were reviewed in collaboration with the school's optometrist. During the initial screening of 100 students, 19 were excluded due to intellectual disability, 37 due to age (over 10), and 9 due to total blindness. Consequently, 35 students met the inclusion criteria, of whom 24 volunteered to participate. Prior to the primary intervention, a pilot study was conducted with 4 volunteers to refine the experimental protocol, assess subject capabilities, and optimize exercise timing; data from this pilot phase were excluded from the final analysis. Ultimately, 20 eligible participants were randomly allocated into the experimental and control groups. The Participant screening flow diagram is shown in Figure 1.

Inclusion and Exclusion Criteria: Inclusion criteria for the study included a confirmed diagnosis of visual impairment verified by an optometrist, the ability to walk without assistance, and age within the specified range.

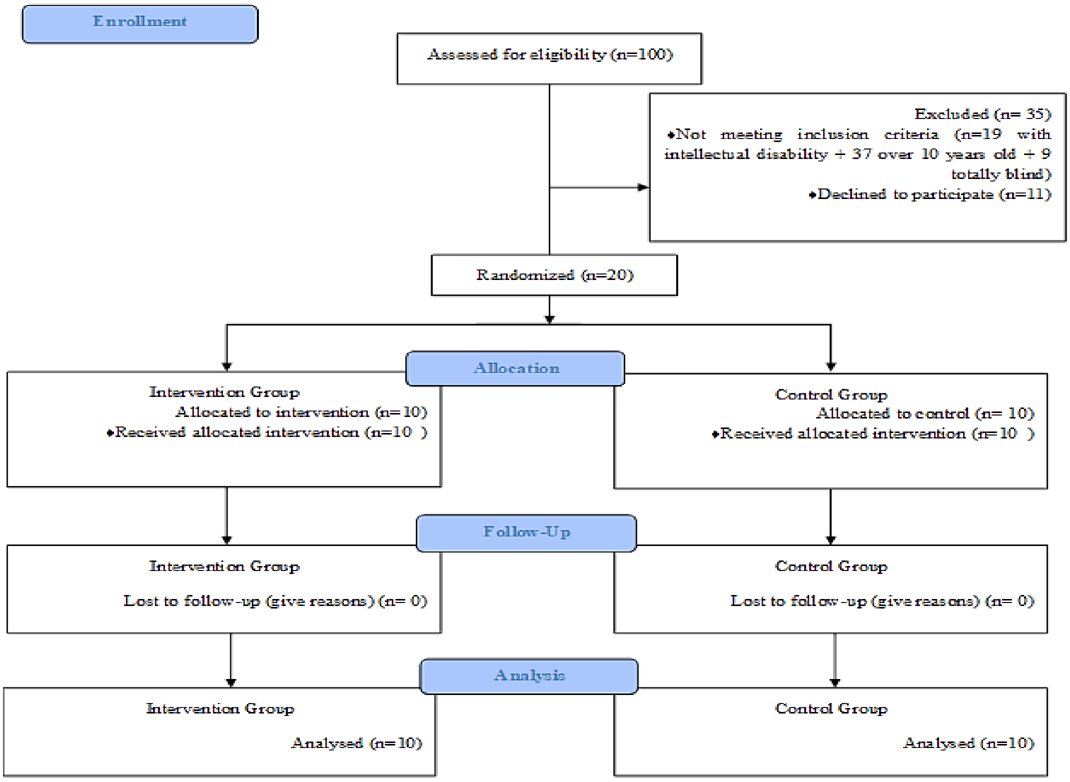

Figure 1. CONSORT Flow Diagram of Participants

Exclusion criteria included total blindness (Class B1), a history of lower-limb injury or surgery, concurrent participation in similar training programs, absence from more than 3 training sessions, engagement in structured sports activities outside the research, and illness during the intervention. These criteria were implemented to enhance sample homogeneity and control for confounding factors.

Implementation Method: After subjects were allocated to experimental and control groups, pre-test assessments were conducted over five consecutive days. These evaluations included the single-leg stance test under four sensory conditions, the active joint position sense reconstruction test of the knee at a target angle of 45-degree flexion, and the locomotor subtests of the Test of Gross Motor Development. To mitigate participant fatigue and prevent test interference, the assessment sequence remained consistent across all participants. Before the training began, an orientation session was held for parents and students. The post-test was administered two days after the completion of the eight-week training period to evaluate the short-term effects of the intervention. To assess retention of training effects, a 2-month follow-up phase was conducted using the same assessment protocols as the pre-test and post-test. All evaluations were conducted by a trained examiner under identical environmental conditions to minimize measurement error. The experimental group performed integrated vestibular-proprioceptive exercises in the school environment for 8 weeks (3 sessions per week, 60 minutes per session), while the control group was instructed to refrain from participating in structured training programs during this period and to engage only in routine daily activities.

Vestibular-Proprioceptive Training Protocol: The selected exercises were designed according to validated protocols (22, 23) and finalized by experts after assessing the students' ages and functional capabilities. Following the pre-test, the experimental group attended the school gymnasium for eight weeks, three sessions per week, from 11:00 AM to 12:00 PM. Each 60-minute session included a 5-minute warm-up, 50 minutes of protocol execution, and a 5-minute cool-down. Approximately 20 minutes were allocated to vestibular exercises and 30 minutes to proprioceptive exercises (22, 23). To prevent fatigue and control for the order effect of exercises on the results, the sequence of vestibular and proprioceptive activities was alternated in each session. The principle of progressive overload was strictly followed, and if a participant was unable to perform a specific movement, that exercise was excluded. Progression was determined based on individual tolerance (duration of balance maintenance, number of repetitions without loss of balance, or instructor observation of readiness for a higher level). Certified instructors in adapted physical activity and disability sports were present at all sessions to guarantee participant safety. No adverse events, such as falls, injuries, or extreme fatigue, were reported. All sessions were conducted under direct supervision, and additional rest periods were provided upon signs of fatigue. Motivation was enhanced through positive reinforcement and high-contrast color visual aids. During this period, the control group refrained from regular physical activity.

Protocol fidelity and participant adherence were as follows: all 24 planned sessions were completed; the average attendance rate in the experimental group was 100%. Sets and repetitions were executed precisely according to the training protocol. Gradual progression was observed in all participants, and no deviations from the intended protocol occurred.

Execution of the Vestibular-Proprioceptive Training Protocol: Vestibular exercises focused on head rotations, tandem walking (pivoting), static balance, sit-to-stand transitions, and combined movements, all of which were executed in a group format. Representative vestibular exercises included single-leg static balance, tandem turns, head rotations (45–90 degrees), and sit-to-stand repetitions (5-20 seconds or 5-15 repetitions).

Proprioceptive exercises emphasized unstable surfaces (tilt boards, Bosu balls, Swiss balls, parallel bars, and wobble boards) and were performed individually in a station-based format. These exercises included maintaining balance on a tilt board (various directions), standing on Swiss and Bosu balls, Swiss ball bridges, wall presses with a ball, and tandem walking. The progressive program advanced incrementally from foundational exercises (Weeks 1–2 with full support) to advanced levels (Weeks 7–8 with minimal or no support, alongside increased duration/repetitions).

Postural Control: Postural control was assessed using the single-leg stance test under four distinct sensory conditions: 1) standing on a stable surface with eyes open and no sensory interference; 2) standing on an unstable surface created by foam; 3) standing on a stable surface with eyes closed; and 4) standing on an unstable surface created by foam with eyes closed (23). The unstable surface was established using a polyfoam block measuring 50 × 50 cm and 10 cm high. Each condition was performed for 20 seconds, and the number of subject errors was recorded as the balance score. Errors were defined as: lifting hands off the waist, the non-supporting foot touching the ground, remaining out of the standard position for more than five seconds, stepping, or hip flexion/abduction exceeding 30 degrees. Each condition was repeated three times with a 30-second rest interval between trials, and a two-minute rest period was provided between different conditions (23). The test-retest reliability of this assessment is reported at 0.59, with inter-rater reliability ranging from 0.89 to 0. (24). To enhance safety and ensure correct execution, two specialists in adapted physical activity and disability sports were present throughout all stages of the assessment.

Knee Joint Position Sense: To assess knee joint position sense, the active joint angle reconstruction test was employed at a target angle of 45 degrees of flexion. The procedure utilized skin markers, digital photography, and angular analysis via AutoCAD software (Version 2023, Autodesk Inc., USA) to minimize physical skin contact (25). Skin markers (black adhesive circles, 1 cm in diameter) were placed on specific anatomical landmarks of the dominant limb, including the greater trochanter, popliteal crease, fibular head, and lateral malleolus. Markers on the greater trochanter and popliteal crease served as femoral segment indicators, while markers on the fibular head and lateral malleolus indicated the tibial segment (25). Participants were seated on a standard examination table with their knees at 90 ° of flexion and their feet hanging freely. A universal goniometer (the validity and reliability of which have been established (46)) was used to determine the starting and target angles, and a blindfold was used to occlude visual input. Initially, with eyes open, the target angle of 45 degrees of knee flexion was performed three times to facilitate short-term memory encoding. Subsequently, with eyes closed, the subject reconstructed the target angle and verbally signaled "reached" to indicate the completion of the reconstruction to control for compensatory pelvic and trunk movements (which can compromise measurement accuracy), the examiner provided visual and verbal monitoring; if compensations such as pelvic rotation or trunk leaning were observed, the trial was repeated to ensure the movement isolated the knee joint. The camera was mounted on a tripod at knee height, positioned perpendicularly at a distance of 185 cm. Each reconstruction was captured using a 10-megapixel Canon digital camera (Intraclass Correlation Coefficient (ICC) $\geq$ 0.79). The captured images were then imported into AutoCAD software to calculate the absolute error angle. The mean of three error measurements was recorded as the final score and primary index for statistical analysis (25).

Locomotor Skills: To assess locomotor skills, the locomotor subtests of the Test of Gross Motor Development-Second Edition (TGMD-2) were utilized, specifically adapted for the functional capabilities of children with visual impairments (26). The locomotor subtests comprised six skills: running, galloping, hopping, leaping, horizontal jumping, and sliding. This test is designed for children aged 3 to 10 years, with each skill consisting of three to five performance criteria. The examiner records scores over two trials for each criterion: a score of one is assigned for correct execution, and a score of zero for incorrect performance. In this study, the scores were calculated and analyzed as a total raw score. To adapt the assessment to visual limitations, several modifications were implemented, including the use of high-contrast red and orange equipment (cones and floor markings), verbal guidance or sound boxes to indicate paths, and the provision of a practice trial for each skill following verbal instruction and a physical demonstration by the examiner. After the practice trial, children performed two primary trials, and the score for each skill was documented on the test record sheet (26). The validity and reliability of this assessment have been established for children with visual impairments (27). Furthermore, research by Ghasemi-Fard et al. (2020) demonstrated that this test serves as a standardized tool for evaluating gross motor skills in the Iranian population with visual impairments (28). Consequently, the use of this instrument in the present study enhances the validity of the findings and facilitates comparison with international literature.

The Shapiro-Wilk test was employed to assess the normality of the data distribution. Descriptive statistics were reported as means and standard deviations (SD), and demographic characteristics between groups were compared using independent t-tests. For inferential statistics, a repeated-measures analysis of variance (RM-ANOVA) was used to compare the means of the research variables across time points. Where significant interactions were observed, the Bonferroni post hoc test was applied for pairwise comparisons. All hypotheses were tested at the $p \leq 0.05$ significance level. Data analysis was performed using SPSS software (Version 23; IBM Corp., Armonk, NY, USA).

Results

In this section, the individual characteristics of the subjects, including age, weight, height, body mass index (BMI), and leg length, are presented separately for each group in Table 1.

Table 1. Demographic Characteristics of the Subjects

Variable	Experimental Group (mean ± SD)	Control Group (mean ± SD)	P-value
Age (years)	7.80 ± 1.03	8.50 ± 0.97	0.13
Height (m)	1.33 ± 0.10	1.31 ± 0.12	0.72
Weight (kg)	34.20 ± 7.63	31.07 ± 6.20	0.32
BMI (kg/m²)	19.06 ± 2.38	17.99 ± 2.68	0.35
Leg Length (cm)	67.50 ± 5.28	66.20 ± 6.44	0.62

The results of the independent t-test indicated that there were no significant differences between the groups in demographic variables, and the groups were homogeneous with respect to their demographic characteristics.

Test Results for Intra-Group and Inter-Group Sections: The mean and standard deviation of the research variables across the three assessment periods, pre-test, post-test, and follow-up, for both the experimental and control groups are presented in Table 2 and Figure 2. Given the normality of the data distributions within the groups, a repeated-measures analysis of variance (RM-ANOVA) was used for the statistical analysis.

The results of the repeated measures ANOVA for the mean scores of postural controls (across four sensory conditions), knee joint position sense, and locomotor skills at all three time points (pre-test, post-test, and follow-up) revealed that the within-group effect, between-group effect, and interaction effect were all statistically significant ($p \leq 0.001$).

In accordance with the reported significance, the results of the Bonferroni post-hoc test are presented in Table 3. The results in Table 3 indicate that there were no significant differences between the groups at pre-test, confirming that the groups were homogeneous at the baseline.

The results indicated that for all variables, the group effect, time effect, and time × group interaction were statistically significant ($P < 0.001$). Bonferroni post hoc tests revealed that the experimental group showed significant improvements compared to the control group immediately after the intervention and at the 2-month follow-up. After implementing the vestibular-proprioceptive training program, the experimental group demonstrated significant enhancements in postural control across all four sensory conditions, knee joint position sense, and locomotor skills relative to the control group. These improvements were largely maintained during the 2-month follow-up period, indicating the intervention's effectiveness and relative stability in the short term.

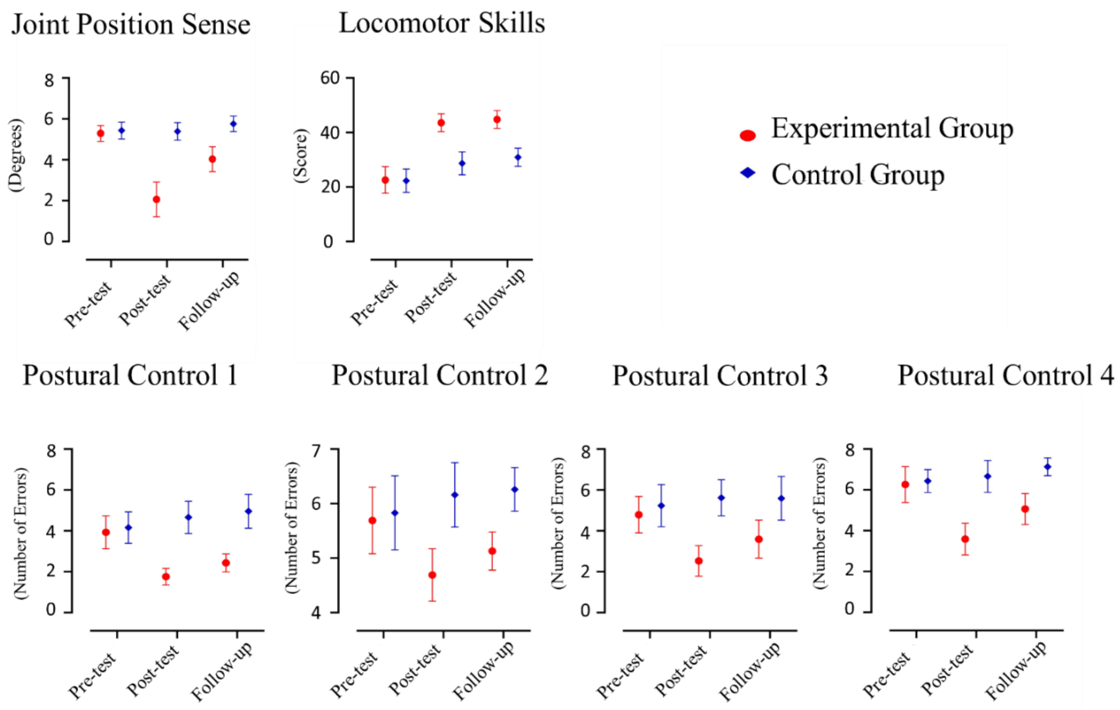

Figure 2. Mean and standard deviation of the research variables

Table 2. Results of Repeated Measures ANOVA

Variable	Group	F	Pre vs. Post	Pre vs. Follow-up	Post vs. Follow-up	Sphericity (P-value)	Group Effect					
			P-value				Significance (df)			Effect Size		
							Group Effect	Time Effect	Interaction Effect	Group Effect	Time Effect	Interaction Effect
Postural Control (Cond. 1-Errors)	Exp.	65.145	0.001*	0.001*	0.005*	0.276	0.001* (1)	0.001* (2)	0.001* (2)	0.735	0.483	0.736
	Cont.	5.450	0.047*	0.011*	0.344							
Postural Control (Cond. 2-Errors)	Exp.	59.805	0.001*	0.001*	0.001*	0.076	0.001* (1)	0.001* (2)	0.001* (2)	0.480	0.375	0.699
	Cont.	6.000	0.001*	0.012*	0.776							
Postural Control (Cond. 3-Errors)	Exp.	93.55	0.001*	0.001*	0.099	0.099	0.001* (1)	0.001* (2)	0.001* (2)	0.573	0.492	0.664
	Cont.	3.33	0.079	0.421								
Postural Control (Cond. 4-Errors)	Exp.	136.49	0.001*	0.001*	0.703	0.703	0.001* (1)	0.001* (2)	0.001* (2)	0.672	0.756	0.802
	Cont.	7.87	0.466	0.002*								
Knee Flexion Position Sense (Deg.)	Exp.	86.81	0.001*	0.001*	0.142	0.142	0.001* (1)	0.001* (2)	0.001* (2)	0.873	0.748	0.729
	Cont.	2.00	> 0.999	0.200								
Locomotor Skills (Score)	Exp.	102.39	0.001*	0.001*	0.072	0.072	0.001* (1)	0.001* (2)	0.001* (2)	0.741	0.894	0.662
	Cont.	26.66	0.001*	0.001*								

*Significant at $p \leq 0.05$

Table 3. Results of Bonferroni Post-hoc Test for Between-Group Comparisons Across Three Time Points

Variable	Time	Group Comparison	Mean Difference	P-value
Postural Control (Condition 1)	Pre-test	Experimental-Control	-0.235	0.516
	Post-test	Experimental-Control	-2.899	0.001*
	Follow-up	Experimental-Control	-2.533	0.001*
Postural Control (Condition 2)	Pre-test	Experimental-Control	-0.134	0.651
	Post-test	Experimental-Control	-1.466	0.001*
	Follow-up	Experimental-Control	-1.134	0.001*
Postural Control (Condition 3)	Pre-test	Experimental-Control	-0.435	0.326
	Post-test	Experimental-Control	-3.098	0.001*
	Follow-up	Experimental-Control	-2.002	0.001*
Postural Control (Condition 4)	Pre-test	Experimental-Control	-0.168	0.620
	Post-test	Experimental-Control	-3.067	0.001*
	Follow-up	Experimental-Control	-2.065	0.001*
Knee Joint Position Sense (Degrees)	Pre-test	Experimental-Control	-0.134	0.470
	Post-test	Experimental-Control	-3.330	0.001*
	Follow-up	Experimental-Control	-1.730	0.001*
Locomotor Skills (Score)	Pre-test	Experimental-Control	0.300	0.880
	Post-test	Experimental-Control	14.900	0.001*
	Follow-up	Experimental-Control	13.900	0.001*

*Significant at $p \leq 0.05$

Discussion

The findings of the present study demonstrated that eight-week combined vestibular-proprioceptive training in a school environment leads to improvements in postural control, knee joint position sense, and locomotor skills in children with visual impairment, and these effects are largely maintained during a two-month follow-up period. The stability of the observed effects can be attributed to neural adaptations (20, 44); such that combined vestibular-proprioceptive training likely improved multisensory integration and the accuracy of body position representation by increasing plasticity in cerebellar networks, the posterior parietal cortex, and vestibular nuclei.

In this regard, recent evidence of exercise-induced neuroplasticity suggests that balance training increases neural flexibility in brain regions involved in visual and vestibular motion perception. Such exercises can lead to increased cortical thickness in areas associated with sensory system processing and increased thickness of the precentral cortex, along with improved functional connectivity in the cerebellum and parietal cortex (44). These structural and functional changes explain the maintenance of long-term effects (such as the two-month follow-up), as the combined training likely strengthens vestibular and proprioceptive pathways and reduces dependence on visual input; and since these areas are known for their role in spatial orientation and movement (20, 44), the stimulation of these pathways during movement itself may be due to the effects of the exercises. This explanation highlights the main innovation of the present study, namely the implementation of a combined program in a real school environment and the maintenance of effects during follow-up, and shows that such a program can be used as a feasible strategy in the educational environment. However, given that the intervention was implemented as a combination (vestibular-proprioceptive), it is not clear which part of the exercise (vestibular or proprioceptive) the observed effect is primarily related to, or whether there are synergistic or merely additive effects. This limitation can be investigated in future studies by using a separate-group design.

The severity of visual impairment and low levels of physical activity exacerbate postural sway (29). Individuals with visual impairment primarily rely on non-visual systems to maintain balance, and strengthening these systems can play an effective compensatory role (8). Structured exercises can reinforce compensatory mechanisms and improve orientation, a function of the vestibular system (30). Vestibular exercises, by stimulating sensory pathways related to orientation, retrain the central nervous system and create a representation of head and body position in space, ultimately improving balance and postural control (19). The proprioceptive system also plays an important role in postural control, and stimulating joint and muscular mechanoreceptors through proprioceptive exercises (31) strengthens multisensory integration and increases postural stability (32). These changes are associated with neuro-muscular mechanisms in the cerebellum (20). On the other hand, given the weakness of lower-limb muscle strength in children with blindness compared to their sighted peers (33), it appears that the combination of sensory exercises is more effective than isolated exercises, because, in addition to increasing the compensatory capacity of the nervous system, it can help improve postural control by strengthening the lower-limb muscles.

The improvement in knee joint position sense in the experimental group indicates that the combined exercises led to an increase in motor reconstruction accuracy, a finding consistent with the greater reliance of individuals with visual impairment on the proprioceptive system (33). The simultaneous stimulation of mechanoreceptors in the knee joint facilitates neuromuscular retraining (32) and compensates for the lack of visual inputs. Evidence shows that structured exercises with moderate intensity have the greatest impact in this field (34). Accordingly, the present study's findings can explain their positive response to sensory exercises, as they show that physical exercises can reduce the negative effects of visual deprivation on mobility and motor performance and increase individuals with visual impairment's independence (35). Clinically, improving the accuracy of knee joint position sense (reducing absolute error) can reduce the risk of falls and increase stability during daily activities, such as walking on uneven surfaces or sitting and standing. These changes, even if moderate, have a significant impact on the independence and safety of these individuals, who are at higher risk of falling. However, because the intervention was implemented as a combination, the relative contribution of vestibular and proprioceptive exercises to improvements in knee joint position sense is unclear. Future research with multi-group designs can investigate the role of each exercise component separately.

Guerriero et al. (2025) showed that even a single weekly session of proprioceptive and plyometric training can improve stability indices and motor performance in children with visual impairment (36). Other positive effects of balance training on improving dynamic balance (37), reducing postural sway, and increasing functional independence in these children aged 6 to 16 have been reported (38). Rogue et al. (2021) considered regular physical activity beneficial for walking and orientation (16). Furthermore, perturbation and vestibular exercises have produced significant improvements in postural control in blind individuals, and these effects have been maintained during follow-up (22). Findings from a clinical trial by Toledo et al. (2025) also showed that combining transcranial direct current stimulation with proprioceptive exercises improved balance and walking in blind children (39). This evidence suggests that simultaneous stimulation of vestibular and proprioceptive pathways, whether through traditional exercises or neuro-rehabilitation technologies, can increase the nervous system's compensatory capacity and improve factors related to maintaining postural control in these individuals.

The improvement in locomotor skills indicates that combined vestibular-proprioceptive training enhances motor performance and postural control in children with visual impairment. Given the developmental delay in the motor skills of these children compared to their sighted peers (40), this finding is of high importance for the design of motor and rehabilitation interventions. Although the learning effect of the tests may explain part of this improvement, as subjects became familiar with the tests after initial attempts and test repetition improves performance (27, 41), the time × group interaction analysis showed that the intervention played the primary role in these changes. From a practical perspective, improvements in locomotor skills can lead to increased motor self-confidence, improved orientation in the school environment, and greater participation in physical activities, which are considered the primary goals of rehabilitation for these individuals.

In this regard, evidence shows that the average developmental age of gross motor skills in children with visual impairment is approximately 4 to 5 years lower than their chronological age, and this delay results from limited motor experience and reduced visual feedback (41). Increasing proprioceptive sensitivity and creating spatial awareness can enhance balance and locomotor skills (18). Other studies have also reported the positive effects of balance training on the motor skills of children with visual impairment (42, 43).

The findings of this study showed that the implementation of an eight-week school-based combined vestibular-proprioceptive training program leads to significant improvements in postural control, knee joint position sense, and locomotor skills of students with visual impairment, and these effects remain largely stable during the two-month follow-up period. These results are consistent with previous studies on balance training (16, 22). Simultaneous strengthening of the vestibular and proprioceptive systems increases the compensatory capacity of the nervous system and improves multisensory integration for postural control and motor performance, suggesting that simultaneous stimulation of these systems can reinforce each other's mechanisms. The practical importance of these findings in school-based rehabilitation is significant, as these exercises are low-cost, do not require complex equipment, and can be implemented under the supervision of physical education instructors and teachers, becoming part of the daily programs in schools for the blind. Short-term training for special education teachers (such as 2–4-hour briefing sessions) can facilitate integration of this program into the daily physical education curriculum and increase regular physical activity among children with visual impairment. However, due to the combined nature of the intervention, the relative contribution of each system is unclear, and part of the observed improvement, especially in locomotor skills, may have been influenced by the learning effect of the tests; however, supplementary studies are needed for definitive conclusions.

Limitations

This research was limited in several respects, which should be considered when interpreting and generalizing the results. Among the main limitations, the small sample size, limited age range, inclusion of only one gender, and short follow-up period stand out. The heterogeneity of visual impairment types in the subgroup analyses based on reported visual acuity, visual field, and comorbidities was not fully presented. Additionally, characteristics such as fatigue, level of attention, motivation, and history of medication use were not controllable. The possibility of a learning effect due to subjects' familiarity with the tasks, the potential for some subjects to err during test execution, the lack of complete control over physical activities outside the program, and the use of field-based tools instead of laboratory equipment could also affect the results to some extent.

Recommendations

Future research should include larger samples, both genders, different severities of visual impairment, and longer follow-up periods. Utilizing advanced tools such as force plates, electromyography, electroencephalography, and 3D motion analysis can more accurately clarify neuromuscular mechanisms. Additionally, comparing the effects of combined training with isolated training and using modern rehabilitation technologies, such as transcranial or magnetic stimulation, could determine the relative contributions of each system to motor performance improvement. Furthermore, it is recommended that future studies record direct and functional motor performance measures (such as walking speed, functional tests like the Timed Up and Go, or the 6-minute walk test) to better clarify the transfer of joint position-sense findings to the actual performance of these children in daily environments. Investigating broader outcomes, including social participation, functional independence, and the prevention of motor problems in adulthood, is also recommended to provide a more comprehensive picture of the long-term effects of these interventions and to develop more effective rehabilitation strategies.

Conclusion

School-based combined vestibular-proprioceptive training, a low-cost, safe intervention that can be implemented by school instructors, can be an effective option for improving postural control, joint position-sense accuracy, and locomotor skills in children with visual impairment. This approach not only strengthens the compensatory capacity of non-visual systems and enhances motor performance but also, given its relative stability during the follow-up period, has high potential for integration into the daily programs of special schools for the blind and even regular schools with students who have visual impairments. Such interventions can reduce the risk of falls, motor delays, and limitations in social participation, thereby increasing independence and quality of life for these children. Therefore, the development and implementation of similar programs at the school level, through teacher and instructor training, can be an important step toward inclusive rehabilitation and the prevention of long-term motor problems in children with visual impairment.

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Conflict of Interest

The authors did not have a conflict of interest.

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