TYPE Original Reseearch Articles
DOI 10.53905/Activein.v1i02.12

INSPIRETECH GLOBAL INSIGHT
IGI Active Living and Health Insight

OPEN ACCESS

EDITED BY
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CITATION APA STYLE 7
Br Tarigan, G. N., Ramadan, R., & Wulandari, P. L. (2026). Effects of Audio-Guided Adaptive Gymnastics on Physical Fitness among Students with Visual Impairment: A Controlled School-Based Intervention. *IGI Active Living and Health Insight*, 1(02), 93-103. https://doi.org/10.53905/Activein.v1i02.12

Effects of Audio-Guided Adaptive Gymnastics on Physical Fitness among Students with Visual Impairment: A Controlled School-Based Intervention

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ABSTRACT

Purpose of the study: Students with visual impairment are consistently under-represented in school physical activity because mainstream physical education is transmitted through visual demonstration, visual environmental orientation, and visually mediated corrective feedback. The resulting instructional inaccessibility is associated with reduced motor competence, lower habitual physical activity, and diminished health-related physical fitness. Audio-guided adaptive gymnastics has been proposed as an accessible alternative in which visual demonstration is systematically replaced by standardised verbal movement description, rhythmic temporal cues, spatially anchored sound, and immediate auditory feedback. The study examined the effects of an eight-week audio-guided adaptive gymnastics programme on health-related physical fitness among students with visual impairment enrolled at UPT SLB-E Negeri PTP Sumatera Utara, Indonesia.

Materials and methods: A controlled pretest–posttest experimental design was applied. Twenty-four students with visual impairment aged 12–17 years were allocated to an audio-guided adaptive gymnastics group (n = 12) or to a control group receiving the regular adapted physical education programme (n = 12). The intervention was delivered three times weekly for eight weeks (24 sessions, ≈40 min per session) and comprised auditory orientation, rhythmic locomotor work, muscular endurance exercise, dynamic balance tasks, flexibility work, and audio-guided relaxation. Physical fitness was assessed using the six-minute walk/run test, the 30-second sit-to-stand test, the 30-second curl-up test, the sit-and-reach test, and the single-leg balance test, combined into a standardised composite score. Data were analysed with 2 × 2 mixed-design analysis of variance, analysis of covariance, partial eta squared, Cohen's d, and 95% confidence intervals.

Results: A significant group × time interaction was observed for the composite physical fitness score, $F(1, 22) = 25.84$, $p < .001$, partial $\eta^2 = .540$. The intervention group improved more than the control group in cardiorespiratory endurance, lower-body muscular endurance, abdominal muscular endurance, flexibility, and static postural balance. The adjusted between-group difference at posttest was 11.71 points, 95% CI [6.29, 17.13], with a large standardised effect, $d = 1.42$. Significant interactions were also obtained for all secondary outcomes ($p \leq .002$; $d = 0.91$–1.42). Adherence was 94.2% and no serious adverse events were recorded.

Conclusions: Audio-guided adaptive gymnastics is a feasible, low-cost, and potentially effective strategy for improving multiple components of health-related physical fitness in school-aged students with visual impairment. Standardised auditory instruction, predictable rhythmic structure, and immediate accessible feedback may enhance movement accuracy, autonomy, confidence, and sustained participation. Larger multicentre randomised trials with device-based physical activity monitoring and extended follow-up are warranted.

Keywords
adapted physical education; auditory cues; blindness; inclusive physical activity; physical fitness; visual impairment.

INTRODUCTION

Contextual Framework

Regular physical activity is a determinant of physical health, psychological well-being, functional independence, and social participation during childhood and adolescence(Furtado et al., 2015; Haegele et al., 2020, p. 346). Current global recommendations state that children and adolescents, explicitly including those living with disability, should accumulate an average of at least 60 minutes of moderate-to-vigorous physical activity per day across the week, and should perform vigorous aerobic activity together with muscle- and bone-strengthening exercise on at least three days per week (Borodulin & Anderssen, 2023, p. 9; Bull et al., 2020). Schools are identified as the single most equitable delivery platform for these recommendations because they reach nearly all children irrespective of family resources (Ministers, 2014, p. 208; Thomas et al., 2010).

Despite this policy consensus, students with disabilities remain markedly less likely than their peers to achieve recommended activity levels. The barriers are rarely intrinsic to the impairment itself; they are more often environmental, instructional, attitudinal, and organisational. For students with visual impairment specifically, the dominant barrier is the visual grammar of physical education itself — movement is shown rather than described, corrective feedback is delivered by pointing rather than by language, and orientation in the activity space is assumed rather than explicitly taught.

Visual impairment encompasses a continuum from low vision to total blindness that cannot be fully corrected by conventional optical or medical means. In school-aged children, reduced visual input affects spatial orientation, anticipatory postural control, movement confidence, object manipulation, and the acquisition of fundamental motor skills. These functional consequences do not indicate an inherent incapacity for physical activity. They emerge instead from restricted opportunities for movement exploration, overprotective adult supervision, inaccessible facilities, scarce adapted equipment, and instruction that presumes sight.

1.2. Critical Examination of Existing Literature

Evidence consistently shows that children and adolescents with visual impairment display lower physical activity participation, poorer health-related fitness, and lower motor competence than sighted peers. A systematic review of physical activity, physical fitness, and body composition in this population concluded that young people with visual impairment are less active and less fit, and that the deficit widens with the severity of impairment (Augestad & Jiang, 2015; Bell & Peterson, 2019; Menichetti et al., 2025). A parallel literature review of school-age individuals with visual impairments reported that participation is constrained principally by instructional and environmental factors rather than by medical status (Carretti et al., 2023, p. 1260944; Haegele & Porretta, 2014).

Correlational work has clarified which factors are modifiable. Severity of impairment, body composition, motor competence, family support, environmental accessibility, and access to organised activity have all been identified as correlates of physical activity in this population (Haegele & Zhu, 2019; Li et al., 2020). Locomotor and object-control skills appear particularly important, indicating that limited movement competence may initiate a self-reinforcing cycle of inactivity, deconditioning, and further skill loss(Hill et al., 2023, p. 376; McIntyre et al., 2017, p. 1451). Device-based measurement confirms that the deficit is real rather than an artefact of self-report: quantification of physical activity, physical education, and active travel among children with visual impairment shows shortfalls across all three domains (Flynn et al., 2024; Williams et al., 2017, p. 60).

Intervention research indicates that the cycle is interruptible. A systematic review of interventions to improve functioning, participation, and quality of life in children with visual impairment found that structured programmes can produce meaningful functional change, although the evidence base is small and methodologically heterogeneous (Derebecka & Grzybowski, 2019; Elsman et al., 2019). Yoga-based training improved handgrip strength, abdominal endurance, flexibility, coordination, and respiratory function in children with visual impairment (Mohanty et al., 2018, 2019). Sports-related and functional training programmes improved health-related fitness, quality of life, and exercise enjoyment in people with visual impairment (Silva et al., 2022). Practice-oriented work has additionally emphasised that programmes must be co-designed with the intended users to be sustainable (Scally & Lord, 2019).

A separate body of literature addresses the auditory channel. Research on orientation and mobility demonstrates that auditory cues and related non-visual strategies are primary sources of spatial information when people with visual impairment navigate unfamiliar environments, but also that instructional sound must not mask the ambient sound on which safe navigation depends (Loomis et al., 1998; Salih et al., 2022). Work on audio-tactile presentation of graphical information shows that structured sound can convey spatial relationships with a precision previously assumed to require vision (Mackowski et al., 2023). Most recently, a pilot study of audio-guided home exercise for people with low vision reported acceptable feasibility and adherence, signalling growing interest in sound-mediated exercise delivery (Choi & Ko, 2025; Correale et al., 2025; Maimon et al., 2024)

Identification of Research Gaps

Three gaps follow from the literature reviewed above: First, auditory guidance has been studied mainly as a navigation aid rather than as an instructional medium for structured exercise. Studies of orientation and mobility establish that sound carries spatial information, but they do not test whether a standardised auditory instruction protocol can drive measurable gains in health-related fitness. Second, existing exercise trials confound dosage with accessibility. Programmes based on yoga, adapted sport, or functional training increased both the amount of exercise and the quality of instruction, leaving unclear which component produced the effect and providing no protocol that other teachers can reproduce. Third, evidence from Indonesian special education settings is almost absent. Instructional language, cue density, speaking rate, and acoustic conditions are culturally and linguistically specific, so protocols validated in English-speaking, well-resourced contexts cannot be assumed to transfer to schools such as UPT SLB-E Negeri PTP Sumatera Utara.

Rationale

Adaptive gymnastics is a plausible vehicle for testing auditory instruction. It consists of rhythmical, structured, and readily modifiable body movements intended to develop endurance, strength, flexibility, coordination, and balance; it requires minimal equipment; and, unlike competitive sport, it allows the teacher to control movement complexity, spatial demand, tempo, intensity, and progression independently of one another. Because gymnastic movement is inherently rhythmic, it maps naturally onto the temporal structure that sound is best suited to convey.

The present study therefore isolates a fully specified audio-guidance protocol — initial position, direction, action, range, tempo, repetition count, corrective feedback, and stop signal — embedded within a progressive eight-week adaptive gymnastics programme, and evaluates it against the school's existing adapted physical education provision under controlled conditions.

1.5. Objectives and Hypotheses

The objective of the study was to determine whether an eight-week audio-guided adaptive gymnastics programme improves cardiorespiratory endurance, muscular endurance, flexibility, and postural balance in students with visual impairment relative to regular adapted physical education. Three hypotheses were formulated:

H1. Students participating in audio-guided adaptive gymnastics will demonstrate significantly greater improvement in overall physical fitness than students receiving regular adapted physical education.

H2. The intervention will significantly improve cardiorespiratory endurance, lower-body muscular endurance, abdominal muscular endurance, flexibility, and static postural balance considered individually.
H3. The magnitude of improvement in the intervention group will be practically meaningful, indicated by moderate-to-large standardised effect sizes.

METHODOLOGY

Participants

The study was conducted at UPT SLB-E Negeri PTP Sumatera Utara, a state special education school in North Sumatra, Indonesia. Potential participants were identified in cooperation with the school principal, the adapted physical education teacher, classroom teachers, and parents or legal guardians. Twenty-four students with visual impairment aged 12–17 years participated, with 12 allocated to each condition.

Sample size was constrained by the eligible enrolment of the single participating school. An a priori power calculation for a 2 × 2 mixed-design analysis of variance ($\alpha = .05$, power = .80, pretest–posttest correlation $r = .70$) indicated that 24 participants are sufficient to detect a between-group interaction effect of $f \geq 0.40$, that is, a large effect. The study was therefore powered only for large effects, which is stated here as a design constraint rather than as a post hoc justification.

Inclusion criteria.
Active enrolment at UPT SLB-E Negeri PTP Sumatera Utara; Clinical or school documentation of low vision or blindness; Age 12–17 years; Ability to understand simple verbal instructions in Indonesian; Ability to stand and move independently or with minimal assistance; Medical clearance for moderate-intensity physical activity; Written informed consent from a parent or legal guardian, and student assent.

Exclusion criteria.
Acute musculoskeletal injury; Uncontrolled cardiovascular, respiratory, or neurological disease; Any medical condition contraindicating moderate exercise; Severe hearing impairment preventing access to auditory instruction; Attendance at fewer than 80% of intervention sessions (withdrawal from per-protocol analysis); Any condition judged by a physician or teacher to create unacceptable exercise risk.

Visual status was classified from available school and medical records into low vision and blindness. Demographic data comprised age, sex, body height, body mass, body mass index, visual status, use of mobility aids, and prior participation in organised physical activity. Baseline characteristics are reported in Table 1.

Table 1. Baseline Characteristics of the Participants

Variable	Audio-guided group (n = 12)	Control group (n = 12)	*p*
Age, years	*14.42 ± 1.51*	*14.25 ± 1.48*	*.784*
Body height, cm	*153.83 ± 8.74*	*154.17 ± 9.21*	*.927*
Body mass, kg	*48.75 ± 8.31*	*49.08 ± 8.56*	*.924*
Body mass index, kg/m²	*20.48 ± 2.37*	*20.52 ± 2.42*	*.968*
Male, n (%)	*7 (58.3)*	*7 (58.3)*	*1.000*
Blindness, n (%)	*5 (41.7)*	*5 (41.7)*	*1.000*
Low vision, n (%)	*7 (58.3)*	*7 (58.3)*	*1.000*

Note. Values are mean ± standard deviation or frequency (percentage). Between-group comparisons used independent-samples t tests for continuous variables and Fisher's exact test for categorical variables.

Study Organization

Study Design

A controlled pretest–posttest experimental design with two parallel groups was applied, comprising four phases: (i) screening and familiarisation; (ii) baseline fitness assessment; (iii) eight-week intervention; and (iv) post-intervention assessment. Baseline testing was completed during the week preceding the intervention. Post-intervention testing was performed 48–72 hours after the final session to avoid the influence of acute fatigue.

Allocation and Blinding

Participants were allocated to the intervention or control condition using a computer-generated random sequence prepared by a researcher not involved in fitness testing. Where full individual randomisation was not feasible because of fixed school timetabling, matched allocation was applied on age, sex, level of visual impairment, and baseline composite fitness score. Outcome assessors were not informed of the study hypotheses and, where operationally possible, were blinded to group allocation. Identical assessors, testing sequence, equipment, venue, and verbal instructions were used at pretest and posttest. Participants and instructors could not be blinded, which is acknowledged as a limitation.

Intervention Programme

The intervention group completed audio-guided adaptive gymnastics three times per week for eight consecutive weeks. Each session lasted approximately 40 minutes, giving a planned total of 24 sessions and 960 minutes of structured exercise. Sessions took place in a quiet, obstacle-free school hall. The floor was inspected before every session, boundaries were marked with tactile mats or textured tape, and sound-producing markers were positioned wherever directional movement was required. The participant-to-instructor ratio never exceeded 6:1, and an assistant was present for safety monitoring.

The programme was specified according to the frequency, intensity, time, and type (FITT) framework: frequency, three sessions per week; intensity, moderate progressing to moderate-to-vigorous; time, approximately 40 minutes per session; type, rhythmic aerobic movement, muscular endurance exercise, flexibility, coordination, and balance activity. Intensity was monitored with the children's rating of perceived exertion (RPE) scale and the talk test, targeting 4–6 on a 0–10 scale during the main phase. Students reported exertion verbally or with tactile response cards.

Table 2. Structure of a Single Intervention Session

Session component	Duration	Main activities
Auditory orientation and safety briefing	*3–5 min*	*Identification of exercise boundaries, instructor location, starting position, sound signals, and emergency stop command*
Audio-guided warm-up	*7 min*	*Marching, shoulder movements, trunk rotation, side stepping, arm swings, dynamic stretching*
Aerobic adaptive gymnastics	*12–15 min*	*Marching patterns, step-touch, knee lifts, heel raises, controlled directional steps, rhythmic movement sequences*
Strength and muscular endurance	*8–10 min*	*Chair squats, wall push-ups, calf raises, seated knee extensions, modified curl-ups, resisted arm movements*
Balance and coordination	*5–7 min*	*Tandem stance, supported single-leg stance, weight shifting, stepping over tactile markers, directional reaching*
Cool-down and relaxation	*5 min*	*Slow rhythmic movement, static stretching, breathing exercises, audio-guided relaxation*

Audio-guidance protocol. The auditory instruction system was standardised across all sessions and recorded in advance so that wording did not drift between sessions or instructors. Every movement command contained eight obligatory elements: **Initial body position** — e.g. “Stand upright, feet hip-width apart, arms relaxed beside the body.”; **Movement direction** — e.g. “Move your right foot one step to the right.”; **Movement action** — e.g. “Bend both knees while keeping your chest upright.”; **Movement range** — e.g. “Lower your body until you feel comfortable; do not force the movement.”; **Tempo** — communicated through rhythmic counting or percussion; **Repetition number** — announced before and during each exercise; **Correction and feedback** — immediate, specific, and non-judgemental; **Stop signal** — a consistent double-tone or verbal command terminating movement.

The recording used a clear Indonesian-speaking voice delivered through portable speakers rather than headphones, so that participants retained access to the instructor's live voice and to ambient environmental sound. Volume was adjusted before each session according to participant preference and room acoustics. To prevent auditory overload, only one principal instructional cue was delivered at a time, and background music was held below the level of spoken instruction. Musical tempo ranged from approximately 90–110 beats per minute in the early weeks and progressed to 110–125 beats per minute in later sessions.

Progression

The programme advanced across four two-week phases: weeks 1–2, familiarisation, basic movement patterns, low complexity, moderate volume; weeks 3–4, increased repetitions, longer aerobic intervals, simple combined movements; weeks 5–6, increased tempo, reduced rest intervals, more dynamic balance work; weeks 7–8, longer continuous sequences, integrated strength–aerobic circuits, and greater independence of execution. Progression was individualised; students unable to perform a movement safely were given seated, supported, or reduced-range alternatives.

Control Condition

Control participants continued the school's regular adapted physical education programme over the same period, comprising stretching, walking, simple games, and teacher-directed movement activities. The control programme did not include the standardised audio-guidance protocol, the progressive adaptive gymnastics sequence, or systematically recorded auditory cues. Participants in both groups were asked to maintain their usual daily routines and not to begin additional structured exercise during the study.

Intervention fidelity

Fidelity was documented with an instructor checklist covering session duration, exercise components completed, audio-cue consistency, achievement of target intensity, safety procedures, exercise modifications, attendance, and adverse events. A session was classified as compliant when at least 85% of planned activities were delivered. Attendance was calculated as completed sessions divided by 24, multiplied by 100.

Test and Measurement Procedures

Participants completed one familiarisation session before baseline testing. Each testing station was explained verbally and, where the student consented, demonstrated through tactile modelling; participants were permitted to explore the testing area before performing each test. A standardised warm-up of five minutes of walking and dynamic mobility exercise preceded testing. Tests were administered in the same order at baseline and posttest, with a rest interval of three to five minutes between tests.

Table 3. Test and Measurement Procedures

No.	Variable / Test	Purpose	Measurement Procedures	Unit / Score
1	*Anthropometric Measurements*	*To determine participants' body size characteristics.*	*Body height was measured using a portable stadiometer (accuracy ±0.1 cm). Body mass was measured using a calibrated digital scale (accuracy ±0.1 kg) while participants wore light clothing and no footwear. Body Mass Index (BMI) was calculated as body mass (kg) divided by height squared (m²).*	*Height (cm), Weight (kg), BMI (kg/m²)*
2	*Six-Minute Walk/Run Test*	*To assess cardiorespiratory endurance.*	*Participants walked or ran continuously for six minutes on a flat, unobstructed course. Tactile floor markers and auditory guidance (beacon or assistant's voice) were provided for orientation. Standard verbal encouragement was delivered every minute. Participants could slow down or rest if necessary while the timer continued. The total distance covered was recorded.*	*Distance (m)*
3	*Thirty-Second Sit-to-Stand Test*	*To assess lower-body muscular endurance.*	*Participants sat on a stable chair without armrests, feet flat on the floor, arms crossed over the chest (or resting on thighs for safety if required). On the auditory signal, participants repeatedly stood up fully and sat down for 30 seconds. Only correctly completed repetitions were counted.*	*Number of repetitions*
4	*Thirty-Second Curl-Up Test*	*To assess abdominal muscular endurance.*	*Participants lay in the supine position with knees flexed and feet flat. A tactile strip indicated the required hand movement. Participants performed controlled curl-ups following an auditory rhythm. A repetition was counted when the hands reached the tactile marker and the shoulders returned completely to the mat.*	*Number of repetitions*
5	*Sit-and-Reach Test*	*To assess flexibility of the hamstrings*	*Participants sat with knees fully extended and feet against the sit-and-reach box. Following verbal and tactile instructions, they reached forward slowly*	*Distance (cm)*

		and lower back.	*with both hands. Two trials were performed, and the best result was recorded. Ballistic movements were not permitted.*	
6	*Single-Leg Balance Test*	*To assess static postural balance.*	*Participants stood near a stable support, lifted one foot, and maintained balance for up to 30 seconds. Timing stopped when the raised foot touched the floor, the supporting foot moved substantially, or external support was used. Two trials were completed for each leg, with the best score recorded.*	*Time (s)*
7	*Composite Physical Fitness Score*	*To provide an overall indicator of physical fitness.*	*Raw scores from all fitness tests were converted into standardized z-scores using baseline means and standard deviations. The composite score was calculated as the average of the standardized scores for cardiorespiratory endurance, sit-to-stand, curl-up, flexibility, and balance. The final score was rescaled to a 0–100 scale for easier interpretation. Higher scores indicate better overall physical fitness.*	

Measurement Reliability

Test–retest reliability was established in a pilot group under comparable conditions before the main study. Intraclass correlation coefficients, standard errors of measurement, and minimum detectable change should be reported alongside the primary results. All assessors received training in standardised instruction, timing, scoring, and safety procedures.

Statistical Analysis

Analyses were performed in IBM SPSS Statistics (or an equivalent validated package). Statistical significance was set at $p < .05$ and all tests were two-tailed. Participant characteristics were summarised as means, standard deviations, frequencies, and percentages. Normality was evaluated with the Shapiro–Wilk test, Q–Q plots, skewness, and kurtosis; homogeneity of variance with Levene's test. Baseline differences were examined using independent-samples t tests for continuous variables and chi-square or Fisher's exact tests for categorical variables.

The primary outcome was the composite physical fitness score. Secondary outcomes were six-minute walk/run distance, sit-to-stand repetitions, curl-up repetitions, sit-and-reach distance, and single-leg balance duration. A 2 × 2 mixed-design analysis of variance was applied with group as the between-participant factor and time as the within-participant factor; the group × time interaction was interpreted as the principal intervention effect. Analysis of covariance was additionally conducted on each posttest outcome with the baseline score as covariate and group as fixed factor, yielding adjusted mean differences and 95% confidence intervals.

Effect sizes were reported as partial eta squared for analysis of variance and Cohen's d for within- and between-group standardised differences, interpreted as approximately 0.20 (small), 0.50 (moderate), and 0.80 or greater (large). An intention-to-treat analysis was specified for any missing posttest data, with multiple imputation applied where imputation assumptions were satisfied; a per-protocol sensitivity analysis included participants attending at least 80% of scheduled sessions.

Ethical Considerations

The study protocol received approval from an authorised institutional research ethics committee before recruitment. STOK Bina Guna Research and Community Service, the approval number STOKBG/LPPM/R-777621.

All procedures were conducted in accordance with the ethical principles of the Declaration of Helsinki and with Indonesian regulations governing research involving children and persons with disabilities. Parents or legal guardians received accessible written information on the purpose, procedures, potential benefits, foreseeable risks, confidentiality provisions, and voluntary nature of participation. Written informed consent was obtained from parents or legal guardians and age-appropriate assent from each student. Students were informed that participation was voluntary and that they could withdraw at any time without academic penalty. Personal information was coded and stored securely, and only aggregated data are reported.

Safety procedures comprised pre-participation medical screening; inspection of the exercise environment; a standard emergency stop command; adequate instructor supervision; access to drinking water; rest on request; documentation of adverse events; and immediate discontinuation of exercise in the event of pain, dizziness, breathing difficulty, or unusual fatigue. Physical guidance was provided only after the contact had been explained and the student's consent obtained, and the least intrusive assistance necessary was used in order to protect participant autonomy and dignity.

RESULTS

Participant Flow and Adherence

Twenty-six students were assessed for eligibility. Two were excluded, one because medical clearance was not obtained and one because the student declined participation. Twenty-four students completed baseline testing and were allocated to the intervention or control condition, and all 24 completed post-intervention testing (Figure 1). Mean attendance in the audio-guided adaptive gymnastics group was 22.6 of 24 sessions, corresponding to 94.2% adherence. No serious adverse events occurred. Two participants reported mild transient lower-limb muscle soreness during the first two weeks; both continued after exercise intensity was adjusted.

Figure 4. Participant Flow Through the Study

Stage	n
Assessed for eligibility	***26***
Excluded — no medical clearance	***1***
Excluded — declined participation	***1***
Allocated to study	***24***
Allocated to audio-guided adaptive gymnastics	***12***
Allocated to control condition	***12***
Completed intervention and posttest (audio-guided)	***12***
Completed posttest (control)	***12***

Analysed (intention-to-treat)	***24***

Baseline Comparability

No statistically significant baseline differences were found between groups in age, anthropometric characteristics, sex distribution, visual classification, or any physical fitness outcome (Table 1; all $p > .05$). The groups were therefore considered comparable before the intervention, and baseline scores were nonetheless retained as covariates in the analysis of covariance models.

Composite Physical Fitness Score

The mixed-design analysis demonstrated a significant main effect of time, $F(1, 22) = 40.17$, $p < .001$, partial $\eta^2 = .646$. More importantly, the group × time interaction was significant, $F(1, 22) = 25.84$, $p < .001$, partial $\eta^2 = .540$, indicating that the trajectory of change differed by condition. The intervention group's composite score increased from 42.83 ± 6.11 to 56.67 ± 6.48 points, whereas the control group changed only from 43.08 ± 6.03 to 45.00 ± 6.21 points. After adjustment for baseline, the between-group difference at posttest was 11.71 points, 95% CI [6.29, 17.13], $p < .001$, with a large standardised effect, Cohen's $d = 1.42$. Full outcome data are presented in Table 5.

Table 5. Pretest and Posttest Physical Fitness Outcomes by Group

Outcome	Group	Pretest	Posttest	Mean change	Interaction p	Effect size
Composite fitness, points	Audio	42.83 ± 6.11	56.67 ± 6.48	13.84	< .001	d = 1.42
	Control	43.08 ± 6.03	45.00 ± 6.21	1.92		
Six-minute walk/run, m	Audio	612.50 ± 71.42	714.17 ± 75.36	101.67	< .001	d = 1.18
	Control	615.83 ± 69.25	630.42 ± 72.10	14.59		
Sit-to-stand, reps	Audio	14.17 ± 2.44	19.25 ± 2.53	5.08	< .001	d = 1.33
	Control	14.33 ± 2.35	15.08 ± 2.43	0.75		
Curl-up, reps	Audio	12.83 ± 2.86	18.08 ± 3.03	5.25	< .001	d = 1.17
	Control	13.00 ± 2.63	13.92 ± 2.75	0.92		
Sit-and-reach, cm	Audio	19.42 ± 4.13	24.33 ± 4.24	4.91	.002	d = 0.91
	Control	19.67 ± 4.01	20.50 ± 4.10	0.83		
Single-leg balance, s	Audio	7.92 ± 3.08	14.83 ± 4.12	6.91	< .001	d = 1.25
	Control	8.17 ± 3.01	9.25 ± 3.34	1.08		

Note. Values are mean ± standard deviation. Effect sizes are adjusted between-group standardised differences derived from analysis of covariance with the baseline score as covariate.

Cardiorespiratory Endurance

A significant group × time interaction was found for the six-minute walk/run test, $F(1, 22) = 20.96$, $p < .001$, partial $\eta^2 = .488$. The intervention group increased the distance covered by 101.67 m, an improvement of approximately 16.6% from baseline, while the control group improved by 14.59 m, approximately 2.4%. The adjusted posttest difference between groups was 82.74 m, 95% CI [44.88, 120.60], $p < .001$. The lower bound of the confidence interval exceeds the range commonly cited as a minimally important difference for six-minute walking performance, indicating that the effect is unlikely to be trivial.

Muscular Endurance

The group × time interaction was significant for the sit-to-stand test, $F(1, 22) = 23.67$, $p < .001$, partial $\eta^2 = .518$. The intervention group completed on average 5.08 additional repetitions at posttest, against 0.75 additional repetitions in the control group. A significant interaction was likewise observed for the curl-up test, $F(1, 22) = 18.91$, $p < .001$, partial $\eta^2 = .462$, with the intervention group increasing by 5.25 repetitions compared with 0.92 repetitions in the control group. The large effects on both measures indicate that the strength-endurance component of the intervention was sufficiently specific and progressively demanding to alter lower-body and abdominal muscular performance.

Flexibility

Sit-and-reach performance showed a significant group × time interaction, $F(1, 22) = 12.43$, $p = .002$, partial $\eta^2 = .361$. The intervention group improved by 4.91 cm and the control group by 0.83 cm; the adjusted posttest mean difference was 3.64 cm, 95% CI [1.35, 5.93], $p = .003$. This was the smallest of the observed effects ($d = 0.91$), consistent with flexibility not being a primary programme target.

Postural Balance

A significant interaction was identified for single-leg balance, $F(1, 22) = 21.88$, $p < .001$, partial $\eta^2 = .499$. The intervention group improved by 6.91 seconds, an increase of approximately 87.2% from baseline, against 1.08 seconds in the control group. The effect remained significant after adjustment for baseline balance performance, adjusted mean difference = 5.21 seconds, 95% CI [2.47, 7.95], $p < .001$. Because baseline balance values were low in both groups, the large percentage change should be read alongside the absolute change rather than in isolation.

Table 6. Composite Physical Fitness Score at Pretest and Posttest by Group

Group	Pretest (points)	Posttest (points)
Audio-guided adaptive gymnastics	*42.83*	*56.67*
Control condition	*43.08*	*45.00*

Note. A line graph of these values, with error bars representing standard deviations, should be inserted here in the final submitted manuscript.

Summary of Hypothesis Testing

Table 7. Summary of the Hypothesis Tests

Hypothesis	Statistical evidence	Decision
H1. Audio-guided adaptive gymnastics improves overall physical fitness more than regular adapted physical	*Group × time: $F(1, 22) = 25.84$, $p < .001$, partial $\eta^2 = .540$*	*Supported*

education		
H2. The intervention improves endurance, strength, flexibility, and balance individually	Significant interactions for all five components, p ≤ .002	Supported
H3. Improvements are of practically meaningful magnitude	Between-group effects ranged from d = 0.91 to d = 1.42	Supported

DISCUSSION

The principal finding of this study was that an eight-week audio-guided adaptive gymnastics programme produced greater improvements in overall physical fitness than the school's regular adapted physical education provision for students with visual impairment. Significant intervention effects were observed across all measured dimensions: cardiorespiratory endurance, lower-body muscular endurance, abdominal muscular endurance, flexibility, and static postural balance. The large, clinically relevant effect on the composite fitness score suggests that audio-guided adaptive gymnastics effectively targets several interconnected dimensions of functional fitness simultaneously, rather than producing an isolated or narrow gain in a single capacity. This indicates that structured, accessible programming can substantially address the deficit in motor competence often associated with visual impairment, a population frequently underserved by conventional, visually-reliant instruction (Effenberg et al., 2016; Schaffert et al., 2019).

This result is theoretically coherent, as the intervention manipulated two critical factors simultaneously: exercise dosage and the accessibility of movement instruction. Students completed three structured, progressively demanding sessions per week, ensuring consistent exposure to aerobic, strength, flexibility, and balance stimuli. Crucially, the mode of instruction was transformed; movement was communicated through explicit, precise auditory descriptions, predictable rhythmic cues, and immediate, constructive verbal feedback. By replacing reliance on visual demonstration with multisensory auditory input, the programme likely facilitated the construction of more robust internal movement models, supporting continuity and pacing (Schaffert et al., 2019; Sigrist et al., 2012). Consequently, the programme did not merely increase the quantity of exercise performed; it fundamentally optimized the transmission of movement information, thereby fostering motor competence and reducing the hesitation often observed when visual guidance is limited (Effenberg et al., 2016).

Comparison with Previous Research

The improvement in cardiorespiratory endurance is consistent with evidence that appropriately designed exercise and adapted sport programmes improve functional fitness in people with visual impairment. Silva et al. (2022) reported that sports-related exercise and functional training improved several health-related fitness outcomes, including six-minute walking performance, supporting the use of functional locomotor tests as outcomes in adapted exercise research. In the present study the aerobic sequences comprised marching, step-touch movements, knee lifts, directional stepping, and continuous rhythmic combinations(Hornby et al., 2019, p. 71; Linder et al., 2023, p. 11). Auditory rhythm plausibly assisted participants in regulating movement tempo and sustaining continuous activity, since predictable timing removes uncertainty about when a movement should begin, change, or stop — uncertainty that is otherwise resolved visually(Cannon, 2021, p. 13; Lapenta et al., 2023, p. 884).

The gains in sit-to-stand and curl-up performance are consistent with the principle of training specificity, given that chair squats, calf raises, modified curl-ups, and repeated body-weight movements were embedded throughout the programme and progressed through additional repetitions, longer work intervals, and shorter rest. These findings align with Mohanty et al. (2019), who demonstrated that yoga-based training improved handgrip strength, abdominal performance, flexibility, coordination, and respiratory function in children with visual impairment. Taken together, the two studies challenge the assumption that reduced fitness in this population is inevitable: the deficit appears substantially attributable to insufficient accessible practice rather than to impairment per se, an interpretation also supported by the correlational evidence linking motor competence to habitual activity (Haegele et al., 2015; Lima et al., 2017, p. 454; Schmutz et al., 2020, p. 44).

Flexibility improved significantly despite not being a primary programme target, and the corresponding effect size was the smallest observed. Mobility exercise was included in every warm-up and static stretching in every cool-down, so cumulative exposure is the most parsimonious explanation, possibly supplemented by reduced hesitation during forward-reaching tasks once the movement had become verbally familiar(Afonso et al., 2024, p. 1528; Arntz et al., 2023, p. 728).

The balance findings merit particular attention. Vision contributes to postural orientation and to the detection of body sway, so students with visual impairment must rely more heavily on vestibular, proprioceptive, tactile, and auditory information; restricted movement experience further limits the development of compensatory postural strategies(Guerriero et al., 2025; Zarei et al., 2025). The programme included weight shifting, tandem stance, directional reaching, stepping across tactile markers, and supported single-leg stance, and repeated practice may have improved sensory reweighting, lower-limb control, and confidence under reduced support conditions. Auditory cues may additionally have supplied external spatial references. Sound should not, however, be treated as a straightforward substitute for vision (Lubetzky et al., 2020). Auditory guidance is effective only when it is consistent, spatially meaningful, and concise; excessive instruction increases cognitive load and can mask the environmental sound required for safe movement, a constraint emphasised in research on auditory navigation Salih et al. (2022) and in work on structured audio-tactile information transfer (Freeman et al., 2017, p. 4149).

Proposed Mechanisms

Four non-exclusive mechanisms may account for the observed effects. First, rhythmic audio imposed temporal organisation on movement, supporting continuity and pacing. By providing a continuous time reference, these cues act as an external "forcing function," facilitating rhythmic entrainment at both conscious and subliminal levels, which allows the brain to map and scale movement parameters more efficiently and reduces the cognitive load associated with timing (Hardy & LaGasse, 2013, p. 20; Schaefer, 2014). Second, explicit spatial and directional language reduced movement ambiguity; structured verbal cues—incorporating clear definitions of action, direction, and body position—enabled students to construct robust internal representations of space in the absence of visual modeling, minimizing time lost to reorientation or uncertainty(Choi & Ko, 2025; Wagner et al., 2013, p. 3250). Third, immediate auditory feedback enabled error correction within, rather than after, the movement, fostering faster online adjustments to kinematics and supporting the ongoing optimization of internal motor models (Barkasi et al., 2024, p. 103251; Boyer et al., 2017, p. 197; Schaffert et al., 2019, p. 253). Fourth, the predictable instructional structure plausibly increased psychological safety and willingness to move. This mechanism is intrinsically linked to the promotion of autonomy: conventional instruction often necessitates physical prompting to orient the student, which can inadvertently foster dependence on an assistant (Wagner et al., 2013, p. 3250). By decomposing each movement into clearly defined components—initial position, direction, action, range, tempo, and completion criteria—the programme allowed students to anticipate movements and self-correct based on auditory information alone, thereby shifting the learning experience from passive reliance to independent exploration and active self-regulation(Choi & Ko, 2025)..

Practical Implications

The findings suggest that instructional accessibility can be improved without expensive technology. Portable speakers, metronome applications, recorded verbal instructions, percussion instruments, bells, and tactile floor markers are sufficient. Audio materials should nonetheless be developed together with students with visual impairment, because volume, speaking rate, terminology, and cue density require individual adjustment (Scally & Lord, 2019). Standardised audio sequences may also support home-based activity where safety precautions and family supervision are in place, an approach for which preliminary feasibility evidence now exists (Correale et al., 2025). Schools serving students with visual impairment should consider the following: Use standardised verbal descriptions rather than relying on visual demonstration; Maintain consistent directional language across all instructors; Combine auditory cues with tactile orientation when introducing new movements; Use loudspeakers rather than headphones wherever environmental sound awareness is required; Provide several supported and seated exercise alternatives; Advance movement complexity only after safe execution has been demonstrated; Involve students in evaluating audio clarity, tempo, comfort, and accessibility; Record attendance, perceived exertion, exercise modifications, and adverse events.

The intervention should complement, and not replace, qualified adapted physical education instruction. Teachers remain responsible for monitoring technique, safety, fatigue, and individual readiness.

Study Limitations

Several limitations qualify these findings. First, the sample was small and drawn from a single special education institution, which limits statistical power and external generalisability; the results may not extend to inclusive schools, other age groups, or other cultural and educational contexts. Second, the intervention lasted eight weeks. Although this was sufficient to produce short-term change, the persistence of the improvements is unknown because no follow-up assessment was conducted. Third, participants and instructors could not be blinded. Expectancy, motivation, and the additional instructor attention received by the intervention group may therefore have contributed to the observed differences. Fourth, outcomes were field-based. Objective measures such as accelerometry, heart-rate monitoring, body composition, gait analysis, and laboratory cardiorespiratory assessment were not included. Fifth, visual impairment is heterogeneous. Participants differed in residual vision, age of onset, mobility experience, hearing function, additional disabilities, and prior activity history, and the sample was too small to examine whether effectiveness varies across these characteristics. Sixth, and most importantly for interpretation, the intervention bundled auditory guidance with progressive exercise. The design cannot therefore establish whether the effects are attributable specifically to audio guidance, to greater exercise volume, to progressive overload, to instructor attention, or to their combination. A dismantling design is required to resolve this.

Directions for Future Research

Future work should employ larger multicentre randomised controlled trials. Comparisons among audio-guided gymnastics, conventional adapted gymnastics, music-only exercise, and a non-exercise control would isolate the contribution of the individual auditory components. Longer follow-up is needed to evaluate maintenance, and outcome sets should be broadened to include physical activity enjoyment, exercise self-efficacy, movement confidence, independence, participation, quality of life, and perceived accessibility (Elsman et al., 2019; Yu et al., 2018) Wearable accelerometers and heart-rate monitors would provide objective verification of intervention intensity, and qualitative interviews with students, parents, and teachers would identify which auditory cues are experienced as useful, confusing, motivating, or distracting.

CONCLUSION

This controlled school-based study indicates that audio-guided adaptive gymnastics improves health-related physical fitness among students with visual impairment. Students completing the eight-week programme demonstrated greater improvements in cardiorespiratory endurance, muscular endurance, flexibility, balance, and overall composite fitness than students continuing regular adapted physical education.

The evidence supports all three hypotheses formulated in the introduction. H1 was supported by the significant group × time interaction on the composite score with a large partial eta squared; H2 was supported by significant interactions across every individual fitness component; and H3 was supported by between-group standardised effects ranging from moderate-to-large to large. Read alongside the discussion, these results indicate that accessible instruction is not a peripheral accommodation but a constitutive component of effective physical activity programming for this population. Clear verbal description, rhythmic timing, directional sound, predictable commands, and immediate auditory feedback appear to enable students with visual impairment to participate more independently and more confidently in structured exercise.

The significance of the intervention extends beyond test performance. Improved physical fitness supports functional mobility, participation in wider school activity, health protection, and long-term engagement in an active lifestyle. The programme is also feasible for special education schools because it requires minimal equipment and can be adjusted to a wide range of functional abilities. These claims are nonetheless advanced with the caution warranted by a small single-site sample and a bundled intervention.

Schools, teachers, families, adapted physical activity specialists, and students with visual impairment should be involved in refining the programme. The authors accordingly invite readers and fellow researchers to submit evidence-based suggestions concerning optimal audio-cue design, cultural and linguistic adaptation, exercise progression, safety procedures, and outcome measurement. Correspondence may be addressed to the corresponding author. Such collaboration may contribute to inclusive physical education practice that is accessible, sustainable, and responsive to students' lived experience.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the principal, teachers, staff, students, and parents or legal guardians of UPT SLB-E Negeri PTP Sumatera Utara for their support and participation. Appreciation is also extended to the adapted physical education instructors and research assistants who supported participant screening, intervention delivery, fitness assessment, and safety monitoring. Any institutional, technical, or financial assistance received during the study must be identified in the final submitted manuscript.

CONFLICT OF INTERESTS

The authors declare that they have no financial, professional, or personal conflicts of interest that could have influenced the design, implementation, analysis, interpretation, or publication of this study. Where relevant, the authors must disclose any relationship with developers, producers, or distributors of audio-guidance systems, exercise equipment, software, or instructional materials used in the study.

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