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Effect of Virtual Reality-Based Breathing Training on Trunk Control in Children With Spastic Diplegic Cerebral Palsy: A Randomised Controlled Trial

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Abstract

Background

Children with spastic diplegic cerebral palsy commonly have impaired trunk control and respiratory dysfunction, which reduce functional performance and quality of life. Virtual reality-based breathing training is a promising adjunct to paediatric neurorehabilitation, but has not been compared directly with conventional diaphragmatic breathing exercises. This trial compared the two approaches, each delivered alongside conventional physiotherapy, on trunk control, respiratory function and quality of life.

Methods

In this two-arm, parallel-group, single-centre randomised controlled trial, 60 children aged 6–12 years with spastic diplegic cerebral palsy (Gross Motor Function Classification System levels I–III) were allocated 1:1 to virtual reality-based breathing training (n = 30) or diaphragmatic breathing exercises (n = 30). Both arms received 60-minute sessions comprising 30 minutes of conventional physiotherapy and a 30-minute breathing block, five days per week for eight weeks (40 sessions). The primary outcome was the Trunk Control Measurement Scale; secondary outcomes were maximum inspiratory pressure, maximum voluntary ventilation and the caregiver-reported Cerebral Palsy Quality of Life Questionnaire. A single assessor, blinded to allocation, performed the performance-based assessments. Between-group differences were analysed using independent t-tests.

Results

All 60 randomised participants completed the intervention and were analysed. Post-intervention scores were higher in the experimental group on all four outcomes: Trunk Control Measurement Scale (mean difference 5.86 points, 95% CI 2.87–8.85), maximum inspiratory pressure (8.20 cmH_2O, 95% CI 3.91–12.49), maximum voluntary ventilation (8.88 L/min, 95% CI 5.24–12.52) and quality of life (8.02 points, 95% CI 4.40–11.64), with large between-group effect sizes (Cohen's d 0.99–1.26). Both groups improved significantly from baseline on all outcomes. No intervention-related adverse events were observed in either group.

Conclusions

Virtual reality-based breathing training combined with conventional physiotherapy produced greater short-term improvements in trunk control, respiratory function and caregiver-reported quality of life than diaphragmatic breathing exercises combined with conventional physiotherapy. Given the single-centre design, pragmatic sample size and absence of long-term follow-up, larger multicentre trials are required to confirm these findings.

Trial registration

Trial registration: this trial was not registered in a clinical trial registry.

BACKGROUND

Cerebral palsy is a group of permanent disorders of movement and posture resulting from non-progressive disturbances in the developing fetal or infant brain [1]. Spastic diplegia is one of the most common clinical subtypes and is characterised predominantly by motor impairment of the lower limbs, often accompanied by deficits in trunk control [2]. Adequate trunk control is essential for postural stability, balance and coordinated limb movement, and its impairment adversely affects functional mobility, activities of daily living and participation [3]. The Trunk Control Measurement Scale is a reliable and valid clinical tool for evaluating static and dynamic trunk control in this population [4].

In addition to motor impairment, children with spastic diplegic cerebral palsy frequently exhibit respiratory dysfunction, including reduced inspiratory muscle strength, decreased ventilatory capacity and altered breathing patterns [5]. These impairments are associated with poor postural alignment, respiratory muscle weakness, decreased thoracic mobility and impaired neuromuscular control [6]. Respiratory muscle performance is commonly assessed using maximum inspiratory pressure and maximum voluntary ventilation, recommended by the American Thoracic Society and the European Respiratory Society as standardised measures of inspiratory muscle strength and ventilatory capacity [7]. Beyond its respiratory function, the diaphragm contributes to trunk stabilisation by regulating intra-abdominal pressure and coordinating with the deep trunk musculature during postural activity [8].

Conventional physiotherapy remains central to paediatric rehabilitation and aims to improve postural control, movement quality and functional performance [9]. Diaphragmatic breathing exercises are frequently incorporated to improve respiratory muscle strength and breathing efficiency [10], and a systematic review and meta-analysis has reported improvements in inspiratory muscle strength and pulmonary function when respiratory exercise is added to conventional rehabilitation in children with cerebral palsy [18]. More recently, virtual reality-based rehabilitation has emerged as an interactive approach combining task-specific practice with real-time visual feedback to facilitate motor learning, repetitive practice and active participation [11,12].

The rationale for delivering breathing training through virtual reality rests on principles of motor learning. Systematic reviews in children with cerebral palsy indicate that virtual reality interventions commonly provide enhanced feedback, motivating tasks and opportunities for intensive repetitive practice, which may facilitate motor learning and engagement [20,21]. Visual biofeedback and game-based breathing tasks may therefore help sustain attention, reinforce performance through immediate feedback, and elicit greater repetition of the breathing task than conventional breathing training alone. Diaphragmatic breathing was selected as an active comparator because it is a simple intervention targeting the same physiological mechanism, allowing the trial to test whether the visual feedback and game-based delivery confer benefit beyond breathing exercise itself [19].

Although both approaches aim to improve respiratory function, direct comparative evidence in children with spastic diplegic cerebral palsy remains limited, and their effects on trunk control and health-related quality of life have not been adequately established. This trial therefore compared virtual reality-based

breathing training with diaphragmatic breathing exercises, both combined with conventional physiotherapy, on trunk control, respiratory muscle strength, ventilatory capacity and quality of life. It was hypothesised that virtual reality-based breathing training would produce greater improvement in trunk control than diaphragmatic breathing exercises.

METHODS

Trial design and reporting

This was a two-arm, parallel-group, single-centre randomised controlled trial with a 1:1 allocation ratio and a pre-test–post-test design, conducted in the Physiotherapy Division of the National Institute for Empowerment of Persons with Multiple Disabilities (Divyangjan), Chennai, Tamil Nadu, India. Participant enrolment was conducted from July 2025 to January 2026, and final outcome assessment was completed in March 2026. The trial ended as planned once the target sample had been recruited and all participants had completed the eight-week intervention. No changes were made to the methods or to the trial outcomes after commencement. The trial is reported in accordance with the CONSORT 2010 statement (Additional file 1) [22], and the interventions are reported in accordance with the Template for Intervention Description and Replication (TIDieR) checklist (Additional file 2) [23].

Ethics approval and consent

The study was approved by SRM Medical College Hospital & Research Center's Institutional Ethics Committee (IEC No: 8944; 28.08.2024) and was conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from the parents or legal guardians of all participants prior to enrolment and assent obtained from participating children as well.

Participants

Children aged 6–12 years with a diagnosis of spastic diplegic cerebral palsy were assessed for eligibility. Children classified at Gross Motor Function Classification System levels I–III [13] who were able to understand and follow simple verbal instructions were included. Children with a history of recent orthopaedic surgery, uncontrolled epilepsy, severe cardiopulmonary disorders, or other neurological or musculoskeletal conditions that could interfere with participation were excluded.

Sample size

The sample size of 60 participants (30 per arm) was determined pragmatically based on participant availability and clinical feasibility at the study centre, rather than by an *a priori* statistical power calculation. Consequently, the trial was not formally powered to detect a pre-specified difference on the primary outcome (Trunk Control Measurement Scale), and the magnitude of the observed effects should be interpreted with appropriate caution.

Randomisation and allocation concealment

Simple randomisation with a 1:1 allocation ratio was used. The allocation sequence was generated by the principal researcher using a computer-based random number generator. Allocation was concealed in sequentially numbered, sealed, opaque envelopes held off site by an independent officer with no role in recruitment, intervention delivery or outcome assessment. Eligible participants were enrolled by the principal researcher. After eligibility had been confirmed, consent obtained and baseline assessment completed, the principal researcher contacted the independent officer by telephone; the officer opened the next envelope in sequence and communicated the assigned group. The sequence therefore remained concealed from the enrolling investigator until the moment of assignment.

Blinding

Outcome assessments at baseline and after the intervention were performed by a physiotherapist who was blinded to group allocation and took no part in delivering either intervention. Blinding of participants, caregivers and treating therapists was not feasible given the nature of the interventions. Both arms received identical total contact time, so exposure was matched between groups and any between-group difference is attributable to the content of the breathing intervention rather than to therapy dose.

Interventions

Both groups attended sessions five days per week for eight consecutive weeks, giving 40 sessions in total. Each session lasted 60 minutes and comprised 30 minutes of conventional physiotherapy followed by a 30-minute breathing block, amounting to approximately 40 contact hours per participant. All sessions were delivered face-to-face and individually, at a 1:1 therapist-to-participant ratio.

Conventional physiotherapy (both groups). The 30-minute conventional physiotherapy programme was identical in both arms and focused on trunk alignment, postural control, weight shifting, balance reactions and functional movement patterns.

Experimental group: virtual reality-based breathing training. Training was delivered using the Breathing+ system (Breathing Labs, Ljubljana, Slovenia), comprising the Breathing Headset 2.0 and the Breathing+ breathing-game software version 1.1.0. The headset uses a microphone-based sensor positioned near the mouth to detect respiratory activity and provide real-time control of the games. The software was operated on an Android mobile device with microphone input, the mobile display providing the visual feedback; no dedicated virtual reality computer or head-mounted display was used. The breathing activities comprised windmill blowing, kite flying, balloon blowing and aeroplane-based games.

The 30-minute block was divided into 5 minutes of preparation and familiarisation and 25 minutes of active training. During preparation, the child was positioned in supported sitting and the equipment fitted and adjusted for comfort and clear visualisation (1 minute); the therapist explained and demonstrated the breathing task, emphasising slow inhalation followed by prolonged, controlled exhalation guided by the visual biofeedback (2 minutes); and the child practised the task while becoming familiar with the environment and breathing cues, with verbal instruction and encouragement (2 minutes). The active

training period consisted of three sets of ten breathing repetitions, each repetition comprising slow inhalation followed by prolonged, controlled exhalation, with a 30-second rest between repetitions and approximately one minute of rest after each set; each set took approximately eight minutes. No fixed respiratory rate, inspiratory or expiratory duration, pressure or flow target was prescribed. Throughout, the therapist monitored the child's breathing pattern, posture, ability to follow the visual feedback and tolerance. The task was considered successfully performed when the participant controlled the game through the required respiratory input. Participants remained in a stable, well-supported seated position in an armchair with appropriate trunk support throughout.

Control group: diaphragmatic breathing exercises. The 30-minute block followed the same structure of 5 minutes of preparation and familiarisation and 25 minutes of active exercise. During preparation, the child was positioned in supported sitting and instructed to maintain an upright, relaxed posture (1 minute); the therapist explained and demonstrated diaphragmatic breathing, emphasising slow inspiration with abdominal expansion followed by slow, controlled expiration (2 minutes); and the child practised the pattern under supervision, with verbal and tactile cues used to facilitate abdominal breathing and reduce unnecessary upper-chest movement (2 minutes). The active period consisted of three sets of ten repetitions, each comprising slow diaphragmatic inhalation followed by prolonged, controlled expiration through pursed lips, with a 30-second rest between repetitions and approximately one minute of rest after each set; each set took approximately eight minutes. The therapist monitored the child's breathing pattern, abdominal movement, posture and tolerance throughout. All exercises were performed in supported sitting. No spirometry device or other specialised respiratory equipment was used, and no caregiver handout, home-programme sheet or training diary was provided, so that the amount and mode of breathing practice were standardised across participants.

Progression. In the experimental group, progression was determined by the principal investigator on the basis of the participant's ability to perform and maintain the prescribed breathing pattern and to complete the assigned virtual reality tasks. Performance was reviewed at every session and task difficulty adjusted when the participant demonstrated adequate control and consistent task completion. Breathing targets were individualised to each participant's capacity for controlled inhalation and prolonged expiration. In the control group, progression was determined by the treating physiotherapist from observed performance, and was considered when the child could consistently perform the prescribed breathing pattern, maintain adequate breathing control and complete the assigned functional breathing activity without difficulty or loss of technique.

Intervention providers. The study procedures were conducted by total of three physiotherapists holding postgraduate qualifications, each with more than five years of experience in paediatric neurological rehabilitation, particularly cerebral palsy. A physiotherapist assigned to conduct blinded outcome assessments (pre and post assessment). Another physiotherapist was assigned to administer the intervention for experimental group and the third physiotherapist was assigned to control group. One Neurodevelopmental treatment certification was not an eligibility requirement for the treating physiotherapists. Before the intervention began, the physiotherapists received standardised training in

the outcome-measure procedures to ensure consistent baseline and post-intervention assessment; those delivering the virtual reality intervention were additionally familiarised with the Breathing+ system and the standardised protocol before participant training commenced.

Setting and infrastructure. Virtual reality-based breathing training was conducted in a dedicated physiotherapy room of approximately 20 × 10 feet, with ambient lighting maintained and clear space around the participant to facilitate supervision. Because the system was operated on a mobile device, no specialised virtual reality computer or high-power infrastructure was required. The comparator intervention was delivered in the same department, in a separate room of approximately 20 × 40 feet arranged to provide adequate space and safe conditions. In both arms, training was conducted in sitting under continuous physiotherapist supervision, minimising fall risk; participants were positioned securely before each activity, and sessions were to be stopped if discomfort, dizziness or other adverse symptoms occurred.

Adherence and fidelity. Attendance was recorded for every scheduled session and each participant was individually monitored by the treating physiotherapist throughout. Intervention delivery was monitored directly by the treating physiotherapist against the standardised protocol, which specified session duration, exercise sequence, repetitions, breathing instructions and supervision. Sessions were not video-recorded and no independent or external fidelity audit was performed. Missed sessions were documented and, where feasible, rescheduled and completed within the study period. No minimum attendance threshold was pre-specified. No modifications were made to either intervention during the course of the trial.

Outcome measures

All outcomes were recorded at baseline and after completion of the eight-week intervention. The primary outcome was trunk control; respiratory muscle strength, ventilatory capacity and quality of life were secondary outcomes. Trunk control was assessed using the Trunk Control Measurement Scale [4], which comprises three subscales: static sitting balance, selective movement control and dynamic reaching. The total score ranges from 0 to 58, with higher scores indicating better trunk control. Maximum inspiratory pressure was measured using a Sonmol (B Arm) respirometer; three attempts were performed with adequate rest between attempts and the highest value retained, expressed in cmH_2O. Maximum voluntary ventilation was measured using an RMS spirometer; three attempts were performed and the highest value retained, expressed in L/min [7].

Quality of life was assessed using the Cerebral Palsy Quality of Life Questionnaire for Children, Primary Caregiver Questionnaire, appropriate for children aged 4–12 years [14]. The questionnaire uses a nine-point response scale, with domain scores transformed to a 0–100 scale where higher scores indicate better quality of life.

Statistical analysis

Analyses were performed using IBM SPSS Statistics version 23(IBM Corp., Armonk, NY, USA). The normality of continuous variables was assessed using the Shapiro–Wilk test, with data considered normally distributed at $p > 0.05$. Descriptive statistics summarised participant characteristics. Within-group comparisons used paired t-tests and between-group comparisons used independent t-tests. Between-group effect sizes were calculated as Cohen's d using the pooled standard deviation, with 95% confidence intervals for mean differences [15]. Statistical significance was set at $p < 0.05$. All randomised participants completed the intervention and provided complete outcome data; there were no missing data, and the per-protocol and intention-to-treat populations were therefore identical. No subgroup or adjusted analyses were performed. No interim analyses were conducted and no stopping guidelines were applied. Interventions are reported in accordance with the Template for Intervention Description and Replication (TIDieR) checklist (Additional file 2).

RESULTS

Participant flow

Seventy children were assessed for eligibility. Of these, five did not meet the inclusion criteria, three declined to participate and two were excluded for other reasons, leaving 60 eligible participants who were randomly allocated 1:1 to the experimental group (n = 30) or the control group (n = 30). All 60 participants received their allocated intervention, completed the eight-week programme and the post-intervention assessment, and were included in the analysis. No participants were lost to follow-up or discontinued the intervention. Participant flow is shown in Fig. 1.

Adherence

In the experimental group, participants attended a mean of 38.97 (SD 0.93) of the 40 scheduled sessions, with attendance ranging from 92.5% to 100%; ten of 30 participants (33.3%) attended all sessions as originally scheduled and the remainder completed their sessions after rescheduling. Thirty-one sessions were made up and none were forfeited. In the control group, participants attended a mean of 38.77 (SD 1.01) of 40 scheduled sessions, with the same attendance range; eight of 30 participants (26.7%) attended all sessions as originally scheduled, 37 sessions were made up and none were forfeited. Across the whole sample, the mean was 38.87 (SD 0.96) sessions attended as scheduled, 18 of 60 participants (30.0%) attended all sessions as originally scheduled, and all 68 missed sessions were subsequently made up. All participants therefore completed the full 40-session intervention. No protocol deviations were recorded.

Harms

No serious adverse events or intervention-related harms were observed in either group. Participants in the experimental group were monitored during and after each session for virtual reality-specific effects including dizziness, nausea, headache, eye strain and discomfort; any adverse events were recorded in the session records by the treating therapist. No virtual reality-related adverse events requiring

discontinuation of treatment were reported. The control group was monitored in the same way and no adverse effects were reported.

Baseline characteristics

The two groups were comparable at baseline in age, sex, height, weight and Gross Motor Function Classification System distribution (Table 1).

Within-group outcomes

Both groups improved significantly on all four outcomes (Table 2). In the experimental group, Trunk Control Measurement Scale scores increased from 35.12 ± 5.82 to 47.24 ± 5.96, maximum inspiratory pressure from 43.18 ± 8.12 to 58.42 ± 8.47 cmH_2O, maximum voluntary ventilation from 39.82 ± 6.85 to 58.34 ± 7.18 L/min, and quality of life scores from 55.42 ± 7.31 to 71.84 ± 6.94 (all $p < 0.001$). In the control group, the corresponding changes were from 35.46 ± 5.91 to 41.38 ± 5.62, from 42.96 ± 8.28 to 50.22 ± 8.11 cmH_2O, from 39.64 ± 7.02 to 49.46 ± 6.92 L/min, and from 55.76 ± 7.18 to 63.82 ± 7.05 (all $p < 0.001$).

Between-group outcomes

After eight weeks, post-intervention scores were significantly higher in the experimental group on all four outcomes (Table 3). The mean difference was 5.86 points for the Trunk Control Measurement Scale (95% CI 2.87–8.85; $t = 3.92$; $p < 0.001$), 8.20 cmH_2O for maximum inspiratory pressure (95% CI 3.91–12.49; $t = 3.83$; $p < 0.001$), 8.88 L/min for maximum voluntary ventilation (95% CI 5.24–12.52; $t = 4.88$; $p < 0.001$) and 8.02 points for quality of life (95% CI 4.40–11.64; $t = 4.44$; $p < 0.001$). Between-group effect sizes were large throughout: Cohen's d 1.02 for trunk control, 0.99 for maximum inspiratory pressure, 1.26 for maximum voluntary ventilation and 1.14 for quality of life. Analysis of mean change scores confirmed greater improvement in the experimental group, with between-group differences of 6.20 points, 7.98 cmH_2O, 8.70 L/min and 8.36 points respectively (all $p < 0.001$; Table 4).

Table 1. Baseline demographic and clinical characteristics (N = 60)

Variable	Experimental (n = 30)	Control (n = 30)
Age (years), mean ± SD	8.42 ± 1.71	8.58 ± 1.83
Male, n (%)	17 (56.7)	16 (53.3)
Female, n (%)	13 (43.3)	14 (46.7)
Height (cm), mean ± SD	124.8 ± 9.5	125.3 ± 8.9
Weight (kg), mean ± SD	25.8 ± 5.3	26.2 ± 5.7
GMFCS level I, n (%)	8 (26.7)	9 (30.0)
GMFCS level II, n (%)	13 (43.3)	13 (43.3)
GMFCS level III, n (%)	9 (30.0)	8 (26.7)

Table 2. Within-group comparison of outcome measures

Outcome	Exp. Pre	Exp. post	p	Control pre	Control post	p
TCMS (score)	35.12 ± 5.82	47.24 ± 5.96	<0.001	35.46 ± 5.91	41.38 ± 5.62	<0.001
MIP (cmH_2O)	43.18 ± 8.12	58.42 ± 8.47	<0.001	42.96 ± 8.28	50.22 ± 8.11	<0.001
MVV (L/min)	39.82 ± 6.85	58.34 ± 7.18	<0.001	39.64 ± 7.02	49.46 ± 6.92	<0.001
CP-QOL (score)	55.42 ± 7.31	71.84 ± 6.94	<0.001	55.76 ± 7.18	63.82 ± 7.05	<0.001

Values are mean ± SD. TCMS Trunk Control Measurement Scale; MIP maximum inspiratory pressure; MVV maximum voluntary ventilation; CP-QOL Cerebral Palsy Quality of Life Questionnaire.

Table 3. Between-group comparison after eight weeks

Outcome	Experimental	Control	Mean difference (95% CI)	t	p
TCMS (score)	47.24 ± 5.96	41.38 ± 5.62	5.86 (2.87–8.85)	3.92	<0.001
MIP (cmH_2O)	58.42 ± 8.47	50.22 ± 8.11	8.20 (3.91–12.49)	3.83	<0.001
MVV (L/min)	58.34 ± 7.18	49.46 ± 6.92	8.88 (5.24–12.52)	4.88	<0.001
CP-QOL (score)	71.84 ± 6.94	63.82 ± 7.05	8.02 (4.40–11.64)	4.44	<0.001

Values are mean ± SD unless stated. Between-group effect sizes (Cohen's d): TCMS 1.01; MIP 0.99; MVV 1.26; CP-QOL 1.15.

Table 4. Mean change scores following intervention

Outcome	Experimental, mean change ± SD	Control, mean change ± SD	P
TCMS	12.12 ± 4.24	5.92 ± 3.68	<0.001
MIP (cmH_2O)	15.24 ± 5.32	7.26 ± 4.61	<0.001
MVV (L/min)	18.52 ± 5.61	9.82 ± 4.93	<0.001
CP-QOL	16.42 ± 5.14	8.06 ± 4.72	<0.001

DISCUSSION

This randomised controlled trial compared virtual reality-based breathing training with diaphragmatic breathing exercises, both delivered alongside an identical conventional physiotherapy programme, in children with spastic diplegic cerebral palsy. Both interventions improved trunk control, respiratory muscle strength, ventilatory capacity and quality of life, but improvements were significantly greater in the experimental group across all four outcomes. Because total contact time was matched between arms, the difference is attributable to the content of the breathing intervention rather than to therapy dose.

The principal finding was greater improvement in trunk control. The between-group mean difference of 5.86 points on the Trunk Control Measurement Scale (95% CI 2.87–8.85) corresponded to a large effect size (Cohen's d = 1.01). Enhanced trunk control may be explained by improved diaphragmatic activation and regulation of intra-abdominal pressure, which contribute to postural stability and coordinated trunk muscle activity [8]. The interactive nature of the intervention may additionally have facilitated motor learning through repetitive, task-oriented practice with continuous visual feedback [16].

Respiratory outcomes followed the same pattern, with between-group effect sizes of 0.99 for maximum inspiratory pressure and 1.26 for maximum voluntary ventilation. Real-time visual biofeedback allows participants to modify breathing patterns immediately, which may improve diaphragmatic recruitment, breathing coordination and respiratory muscle performance [17]. Previous systematic reviews have reported that virtual reality-based rehabilitation enhances motor performance, motivation and treatment engagement in children with cerebral palsy [12].

The concurrent improvement in trunk control and respiratory function is consistent with the biomechanical relationship between the respiratory and postural systems. The diaphragm acts not only as the primary inspiratory muscle but also as a stabiliser of the trunk during functional activity [8], so improvements in inspiratory muscle performance may enhance postural control through better trunk stability and neuromuscular coordination. These findings support integrating respiratory muscle training into paediatric neurorehabilitation programmes [9].

Quality of life improved in both groups, with a between-group effect size of 1.15 favouring the experimental group. Improved respiratory function and trunk stability are likely to facilitate greater

independence in daily activities, reduce fatigue and enhance participation. The interactive and motivating nature of virtual reality-based rehabilitation may also improve treatment adherence and engagement, contributing to better functional and psychosocial outcomes [12].

Generalisability

Participants were children at Gross Motor Function Classification System levels I–III, selected for their ability to participate in structured breathing and trunk-control training and to follow the intervention procedures with supervision. The findings should not be generalised directly to children at levels IV–V, who have more severe motor limitations and may require greater physical assistance, modified positioning and individualised protocols. Extension to other cerebral palsy subtypes, such as spastic hemiplegia, spastic quadriplegia, dyskinetic or ataxic cerebral palsy, should also be made cautiously, since differences in motor impairment, trunk control, movement patterns and functional ability may influence the response. The trial was conducted at a single tertiary specialist centre, and its applicability to community or resource-limited settings is uncertain.

Several trials in virtual reality and cerebral palsy rehabilitation have used paired and independent t-tests to evaluate pre-post and between-group data. In paediatric populations, research examining therapeutic interventions for functional mobility in children with spastic diplegic cerebral palsy has employed paired t-tests to assess within-group change [24]. Trials of virtual reality-based training protocols have similarly used paired t-tests to assess functional change before and after training, alongside independent t-tests for between-group comparison [25]. The analysis in the present trial therefore follows the pre-specified statistical plan and provides a transparent evaluation of both within-group trajectories and comparative treatment effects, although analysis of covariance would have afforded greater precision.

Clinical implications

Virtual reality-based breathing training may serve as an effective adjunct to conventional physiotherapy for improving trunk control and respiratory function in children with spastic diplegic cerebral palsy, providing structured visual feedback, increased engagement and task-specific practice. These potential benefits should be weighed against the practical burden of the intervention, including the cost and availability of hardware and software, the need for trained therapists and technical support, appropriate clinical space and supervised delivery. Although the system used here ran on a mobile device rather than dedicated virtual reality hardware, which lowers the infrastructure requirement, accessibility may still be limited in resource-constrained settings.

Limitations

This trial has several limitations. It was conducted at a single centre with an eight-week intervention period and no long-term follow-up, so the sustainability of the treatment effects could not be determined. Participants, caregivers and treating therapists could not be blinded, which introduces a risk of performance bias, and outcome assessment relied on a single blinded assessor. Four outcomes were

analysed without adjustment for multiplicity. There was no attention-matched or sham comparator, so a novelty or engagement effect cannot be excluded. Only trunk control, respiratory function and quality of life were assessed; functional mobility, participation and respiratory health outcomes were not measured. The sample size was determined pragmatically based on participant availability and clinical feasibility at the study centre. Finally, the magnitude of the observed effect sizes should be interpreted cautiously, and the minimal clinically important difference for the Trunk Control Measurement Scale, maximum inspiratory pressure and maximum voluntary ventilation should be considered when judging whether the statistically significant differences are clinically meaningful. Larger, adequately powered multicentre trials with extended follow-up are required to confirm the effectiveness, safety and cost-effectiveness of virtual reality-based breathing training.

CONCLUSIONS

Both virtual reality-based breathing training and diaphragmatic breathing exercises, delivered alongside conventional physiotherapy, improved trunk control, respiratory muscle strength, ventilatory capacity and quality of life in children with spastic diplegic cerebral palsy. Virtual reality-based breathing training produced significantly greater improvement across all outcomes, with large between-group effect sizes. These findings suggest that virtual reality-based breathing training is a promising adjunct to conventional paediatric neurorehabilitation, although larger multicentre trials with long-term follow-up are required to confirm its clinical effectiveness.

Declarations

Ethics approval and consent to participate

Approved by SRM Medical College Hospital & Research Center's Institutional Ethics Committee, reference no 8944, on 28.08.2024. Conducted in accordance with the Declaration of Helsinki. Written informed consent obtained from parents or legal guardians; assent obtained from participating children. All other institutional clearance was obtained from participating institute NIEPMD.

Consent for publication

Not applicable

Availability of data and materials

The data generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

S R: Conception and design of the study, participant recruitment and data collection, data analysis, interpretation of results, and drafting of the manuscript. V K: Conception and design, supervision of the study, interpretation of findings, critical revision of the manuscript for important intellectual content, and final approval of the manuscript. B S S K: Methodological guidance, data interpretation, critical revision of the manuscript, and final approval of the manuscript.

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During preparation of this manuscript the authors used AI tools to assist with restructuring and drafting sections of the text, checking reporting-guideline compliance, and preparing the CONSORT and TIDieR checklists. The authors reviewed and edited all output and take full responsibility for the content of the published article.

Trial protocol

A separate trial protocol was not published. The full study protocol, including methodology, intervention procedures, outcome measures and the statistical analysis plan, is available from the corresponding author on reasonable request.

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Figures

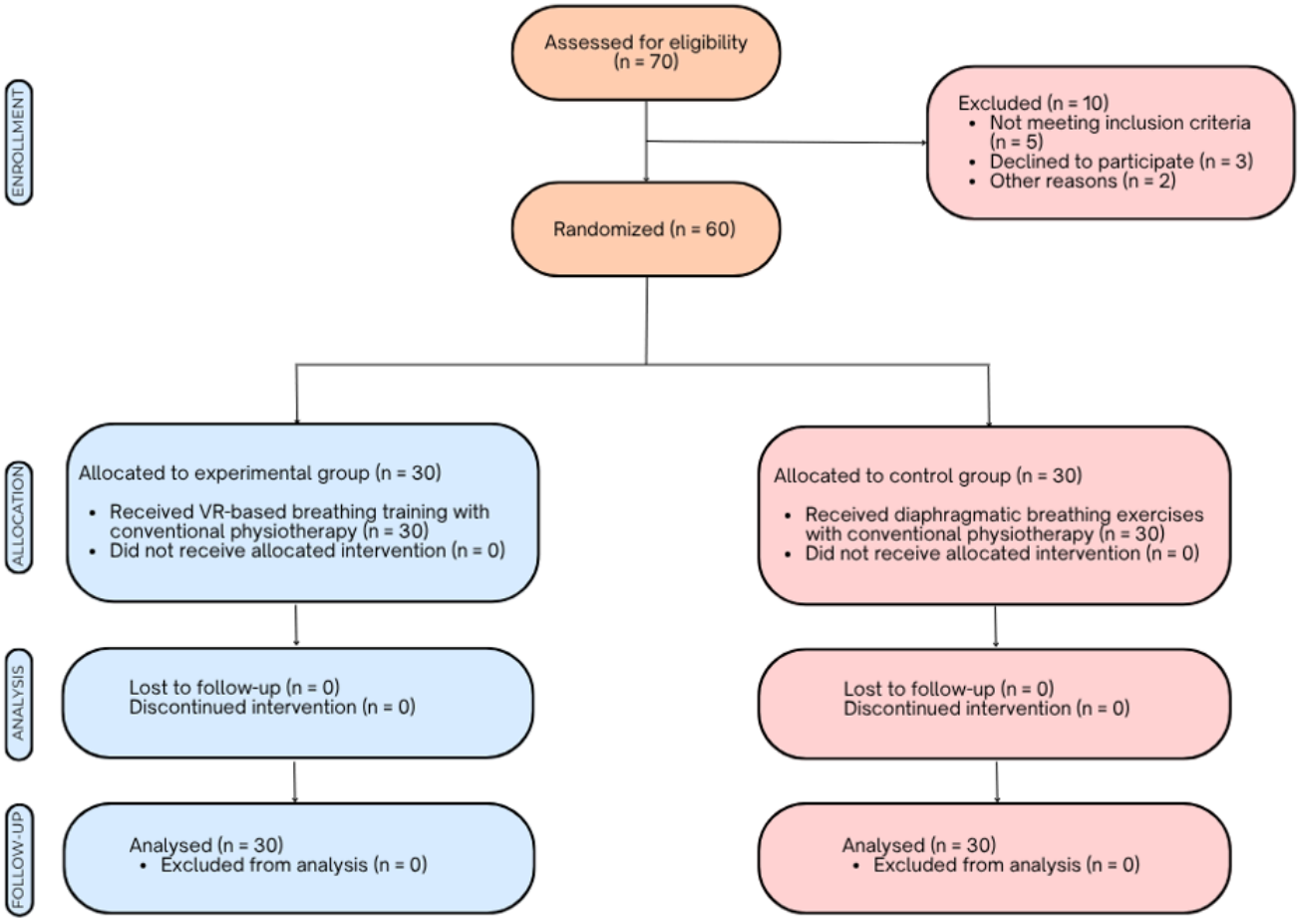


Fig. 1 CONSORT flow diagram

Figure 1

CONSORT flow diagram of participant enrolment, allocation, follow-up and analysis

Supplementary Files

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