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Effectiveness of a School-based Cardiorespiratory Endurance Training Programme on Motor Coordination, Functional Endurance, Sleep Quality, and Health-Related Quality of Life in Children with Developmental Coordination Disorder: A Randomised Controlled Trial

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ABSTRACT:

Introduction: Developmental Coordination Disorder (DCD) is characterised by motor coordination difficulties that secondarily impair cardiorespiratory fitness, sleep quality, and health-related quality of life. Targeted cardiorespiratory endurance training (CRET) may address these multi-domain impairments simultaneously; however, evidence from randomised controlled trials, particularly from Indian school settings, remains scarce.

Aim: To evaluate the effectiveness of an eight-week school-based gamified CRET programme compared to a general exercise (GE) programme on motor coordination, cardiorespiratory endurance, sleep quality, and health-related quality of life in children with DCD.

Materials and Methods: A randomised controlled trial with a pre-test and two post-test design was conducted in selected schools of Kanyakumari district, Tamil Nadu, India. Eighty children aged 9–15 years with confirmed DCD were randomly allocated to either the CRET group (n=40) or GE group (n=40). The CRET group received three weekly sessions of structured, gamified aerobic training for eight weeks. The GE group received equivalent-duration coordination and balance-focused exercise. Outcome measures — Developmental Coordination Disorder Questionnaire (DCDQ'07), Six-Minute Walk Test (6MWT), Sleep Disturbance Scale for Children (SDSC), and Paediatric Quality of Life Inventory (PedsQL 4.0) — were assessed at baseline, four weeks, and eight weeks. Repeated measures ANOVA with Bonferroni post hoc correction and independent samples t-tests were used for analysis.

Results: The CRET group demonstrated significant within-group improvements in all four outcomes: DCDQ (F=9.91, p=0.01), 6MWT (F=13.957, p=0.001), SDSC (F=12.1, p<0.001), and PedsQL (F=7.632, p=0.001). The GE group showed improvement only in motor coordination (F=3.005, p=0.043). Between-group comparisons at eight weeks

significantly favoured CRET for coordination ($p=0.001$), endurance ($p<0.001$), and sleep quality ($p=0.003$).

Conclusion: A school-based CRET programme significantly improves motor coordination, cardiorespiratory endurance, sleep quality, and quality of life in children with DCD, with benefits substantially exceeding those of general exercise. These findings support integration of aerobic training into DCD management protocols.

INTRODUCTION

Developmental Coordination Disorder (DCD) is a prevalent neurodevelopmental condition characterised by marked and persistent difficulties in the acquisition and performance of coordinated motor skills that are substantially below what is expected for a child's chronological age and level of education [1]. Affecting approximately 5–6% of school-aged children globally, DCD impacts fundamental daily activities including handwriting, dressing, sports participation, and classroom mobility [2]. Despite being one of the most common childhood developmental conditions, it remains under-recognised and frequently unmanaged, particularly in low- and middle-income country settings where specialist paediatric services are limited [3].

The consequences of DCD extend well beyond the motor domain. Children with DCD demonstrate significantly lower cardiorespiratory fitness compared to typically developing peers, a deficit compounded by avoidance of physical activity stemming from repeated motor failure and diminished perceived motor competence [4,5]. This physical inactivity creates a self-reinforcing cycle in which reduced fitness further limits motor participation, accelerating the gap between children with DCD and their typically developing counterparts over time [6]. Several population-based longitudinal studies have confirmed that this fitness deficit, if unaddressed, persists into adolescence and contributes to elevated cardiovascular risk in later life [7].

Sleep disturbance is an increasingly recognised secondary consequence of DCD. Children with motor coordination difficulties frequently report difficulties initiating and maintaining sleep, night waking, and daytime fatigue [8]. Poor sleep in school-aged children has broad negative consequences for cognitive performance, emotional regulation, behavioural functioning, and academic participation — all domains already compromised in DCD [9,10]. Furthermore, health-related quality of life (HRQoL) is markedly reduced in children with DCD across physical, emotional, social, and school functioning domains [11,12]. The cumulative burden of motor impairment, reduced fitness, disturbed sleep, and diminished quality of life makes DCD a condition demanding multi-domain therapeutic strategies.

Current clinical practice guidelines for DCD, including those published by the European Academy of Childhood Disability, endorse task-oriented motor learning approaches as the primary intervention strategy [13]. While these approaches produce meaningful motor skill gains, they do not directly address the secondary impairments of cardiorespiratory deconditioning, sleep disturbance, and reduced quality of life that substantially determine a child's overall functional status and wellbeing. This gap between motor-focused intervention and the broader needs of children with DCD is an important clinical problem [14].

Aerobic exercise has well-established effects on neuroplasticity, cerebellar function, and basal ganglia activity — the very neural systems implicated in the motor planning and automatization deficits characteristic of DCD [15]. Exercise-induced upregulation of brain-derived neurotrophic factor (BDNF) promotes synaptic strengthening in motor circuits, providing a neurobiological rationale for aerobic training as an indirect motor rehabilitation modality [16]. Additionally, regular aerobic exercise is among the most consistently effective non-pharmacological interventions for improving sleep quality in children [17], and improvements in physical fitness are independently associated with better HRQoL in paediatric populations [18].

Despite this compelling theoretical basis, few randomised controlled trials have examined the effectiveness of structured cardiorespiratory endurance training in children with DCD, and none to the best of the authors' knowledge have been conducted in Indian school settings. The present study was designed to address this gap. It builds upon a preceding cross-sectional phase (Phase 1) that established significant interrelationships among coordination, endurance, sleep quality, and HRQoL in children with DCD from Kanyakumari district, and which confirmed that sleep disturbance and cardiorespiratory deconditioning were the strongest predictors of quality of life in this population [19]. These findings provided the scientific rationale for a targeted cardiorespiratory endurance training intervention.

This paper reports the randomised controlled trial (Phase 2) comparing the effects of an eight-week school-based gamified cardiorespiratory endurance training programme with a general exercise programme on all four outcome domains. The primary hypothesis was that the CRET programme would produce significantly greater improvements than general exercise across motor coordination, cardiorespiratory endurance, sleep quality, and health-related quality of life in children with DCD.

MATERIALS AND METHODS

Study Design

This study was designed as a two-group, pre-test and two post-test randomised controlled trial. Assessments were conducted at three time points: baseline (pre-test), after four weeks (post-test 1), and after eight weeks (post-test 2). The trial was conducted in accordance with the CONSORT 2010 reporting guidelines for randomised controlled trials [20]. The study was approved by the Institutional Ethics Committee of Madhav University, Rajasthan, India [IEC Ref: MUEC/2023/XXX] and was conducted in accordance with the Declaration of Helsinki (2013 revision). The trial was registered in the clinical trial registry prior to commencement.

Setting and Participants

The study was conducted in selected government and private schools in Kanyakumari district, Tamil Nadu, India, between [Month/Year] and [Month/Year]. Schools were selected based on administrative permission, availability of safe physical activity spaces, and feasibility of intervention delivery. Participants were recruited from children previously identified as having DCD during the Phase 1 screening assessment.

Children were eligible for inclusion if they were aged 9–15 years, had been identified with DCD features during Phase 1 screening, demonstrated mild-to-moderate coordination impairment, were enrolled as regular students in participating schools, were medically fit to participate in moderate-intensity physical activity, had parental written consent and personal assent, and could commit to at least 80% of intervention sessions. Children were excluded if they had known cardiovascular or respiratory disorders limiting exercise tolerance, musculoskeletal injuries or deformities, cognitive impairments precluding comprehension of instructions, participation in external structured athletic training, or acute illness during the intervention period.

Sample Size

The sample size was calculated using G*Power software (version 3.1.9) for a repeated measures ANOVA design. Based on a medium effect size ($f=0.25$), alpha level of 0.05, power of 0.80, three measurement time points, and two groups, the estimated sample size was 34 per group. To account for a potential 15% attrition rate, 40 participants per group were recruited, yielding a total sample of 80 children.

Randomisation and Allocation Concealment

Following baseline assessment, eligible participants were randomly allocated to either the CRET group or the GE group using a random number table method, ensuring an equal probability of assignment to either group. The allocation sequence was generated prior to enrolment and was concealed from participants and school teachers involved in intervention delivery. Allocation concealment was maintained using sealed opaque envelopes opened sequentially at the time of group assignment. Due to the nature of the physical exercise intervention, blinding of participants and therapists was not feasible; however, the outcome assessor was blinded to group allocation.

Intervention Protocols

Cardiorespiratory Endurance Training Group (CRET): The CRET group received a structured, school-based gamified cardiorespiratory endurance training programme over eight weeks, with three sessions per week (total 24 sessions). Each 45-minute session was structured into four phases. The warm-up phase (five minutes) comprised light marching, gentle jogging, arm swings, and joint mobility exercises to prepare the cardiovascular and musculoskeletal systems. The main aerobic training phase (25 minutes) included: (a) run-and-play circuits with cone zig-zag runs, shuttle runs, and ladder-running patterns for 10 minutes; (b) structured jogging-walking intervals alternating one minute of jogging with one minute of walking for 10 minutes; and (c) team-based relay activities with short-distance running for five minutes. A gamified endurance phase (10 minutes) followed, in which children maintained continuous movement within a defined area while responding to verbal and visual cues from the instructor, sustaining elevated heart rate through variability in movement direction and pattern. The cool-down phase

(five minutes) comprised slow walking and static stretching of major muscle groups. Training intensity was maintained at 60–75% of maximum effort, monitored using the talk test and a simplified perceived exertion scale appropriate for children. Progressive overload was applied across weeks, with rest intervals reducing and continuous activity duration increasing from weeks three onwards.

General Exercise Group (GE): The GE group received an equivalent-duration programme over eight weeks, three sessions per week, focusing on coordination, balance, and functional movement rather than sustained cardiovascular stimulus. Each session included: skipping exercise for 10 minutes targeting rhythmic coordination and bilateral motor control; balloon volleyball for 10 minutes promoting upper limb coordination and reaction time; modified push-up conditioning for 10 minutes addressing upper limb strength and trunk stability; tandem walking for 10 minutes targeting postural balance and proprioceptive awareness; and breathing exercises for five minutes promoting relaxation and respiratory control. Warm-up and cool-down with joint mobility exercises and active stretching were included in every session. Progression was achieved through gradual increases in repetitions and reduction in rest intervals.

Outcome Measures

Motor coordination was assessed using the Developmental Coordination Disorder Questionnaire 2007 version (DCDQ'07), a validated 15-item parent-reported instrument with scores from 15 to 75; lower scores indicate greater coordination difficulty [21]. Cardiorespiratory endurance was assessed using the Six-Minute Walk Test (6MWT), conducted according to American Thoracic Society guidelines; the total distance walked in metres was recorded [22]. Sleep disturbance was assessed using the Sleep Disturbance Scale for Children (SDSC), a 26-item parent-reported instrument with scores from 26 to 130; higher scores indicate greater disturbance [23]. Health-related quality of life was assessed using the Paediatric Quality of Life Inventory Version 4.0 Generic Core Scales (PedsQL 4.0), a validated 23-item instrument covering physical, emotional, social, and school functioning domains, linearly transformed to a 0–100 scale with higher scores indicating better HRQoL [24]. All assessments were administered at baseline, four weeks, and eight weeks by the same trained assessor, blinded to group allocation.

Statistical Analysis

Data were analysed using IBM SPSS Statistics Version 26.0. The normality of all outcome variables at each time point was verified using Shapiro–Wilk and Kolmogorov–Smirnov tests. All variables were normally distributed at all time points, supporting the use of parametric tests. Within-group changes across three time points were analysed using one-way repeated measures ANOVA. Where significant F-values were obtained, Bonferroni post hoc correction was applied to identify specific time-point differences. Between-group comparisons at each assessment point were conducted using independent samples t-tests. Baseline homogeneity of demographic and potential confounding variables between groups was verified using independent t-tests for continuous variables and chi-square tests for categorical variables. Statistical significance was set at $p < 0.05$ for all analyses. Effect sizes were calculated using partial eta-squared (η^2).

RESULTS

Participant Flow and Baseline Characteristics

Eighty children (CRET: $n=40$; GE: $n=40$) completed the study with no dropouts recorded. The mean age was 11.83 ± 1.97 years in the CRET group and 11.79 ± 1.95 years in the GE group. Both groups were well-matched at baseline across all demographic and potential confounding variables including age, gender distribution, hand dominance, nutritional status, physical activity level, school type, and socioeconomic status, with no statistically significant differences observed (all $p > 0.05$), confirming baseline homogeneity. Detailed baseline characteristics are presented in Table/Fig-1.

Table 1: Baseline Homogeneity of Demographic and Potential Confounding Variables Between CRET and GE Groups ($n=80$)

Variable	CRET (n=40)	GE (n=40)	Test	Statistic	p
Age (years, Mean $\pm$ SD)	11.83 $\pm$ 1.97	11.79 $\pm$ 1.95	t-test	0.09	0.93
Gender (Male/Female)	22/18	21/19	χ^2	0.10	0.75
Hand Dominance (R/L)	37/3	36/4	χ^2	0.12	0.73

Nutritional Status (N/U/Ov)	28/10/2	26/8/6	χ^2	0.18	0.91
Physical Activity (L/M/H)	12/20/8	13/19/8	χ^2	0.22	0.89
School Type (Govt/Pvt)	20/20	19/21	χ^2	0.05	0.83
Socioeconomic (L/M/H)	15/18/7	16/17/7	χ^2	0.14	0.93

R: Right; L: Left; N: Normal; U: Underweight; Ov: Overweight; Govt: Government; Pvt: Private; L: Low; M: Middle; H: High. All variables $p > 0.05$ confirm baseline equivalence.

Normality Testing

Shapiro–Wilk and Kolmogorov–Smirnov tests confirmed normal distribution for all four outcome variables across all three time points in both groups (all Shapiro–Wilk W values > 0.980 , all $p > 0.05$). This supported the application of parametric statistical tests throughout the analysis.

Motor Coordination Outcomes (DCDQ'07)

Within the CRET group, repeated measures ANOVA revealed a statistically significant improvement in motor coordination scores across the three time points ($F=9.91$, $p=0.01$). Mean scores improved from 45.94 ± 4.72 at baseline to 48.72 ± 5.04 at post-test 1, and further to 50.91 ± 5.22 at post-test 2. Bonferroni post hoc analysis confirmed significant differences between pre-test and post-test 1 (mean difference=2.78, $p=0.043$) and between pre-test and post-test 2 (mean difference=4.96, $p=0.001$). The difference between post-test 1 and post-test 2 did not reach significance ($p=0.16$), suggesting that the primary coordination gains occurred within the first four weeks and thereafter stabilised.

In the GE group, a statistically significant but smaller improvement was also observed ($F=3.005$, $p=0.043$). Mean scores progressed from 46.38 ± 4.34 at baseline to 47.69 ± 4.94 at post-test 1, and 49.04 ± 5.21 at post-test 2. Post hoc analysis revealed significance only between pre-test and post-test 2 (mean difference=2.66, $p=0.047$), with no significant difference between pre-test and post-test 1 ($p=0.689$).

Between-group comparisons confirmed baseline equivalence ($t=0.299$, $p=0.766$). Significant between-group differences emerged at post-test 1 ($t=2.438$, $p=0.017$) and post-test 2 ($t=3.886$, $p=0.001$), with mean differences of 2.77 and 4.51 points respectively, both favouring the CRET group. Full data are presented in Table/Fig-2.

Table 2: Mean DCDQ'07 Scores and Between-Group Comparisons at Each Assessment Point (n=80)

Assessment Point	CRET Mean ($\pm$ SD)	GE Mean ($\pm$ SD)	Mean Diff	t	p
Pre-test	45.94 ± 4.72	46.38 ± 4.34	0.33	0.299	0.766
Post-test 1 (4 weeks)	48.72 ± 5.04	47.69 ± 4.94	2.77	2.438	0.017*
Post-test 2 (8 weeks)	50.91 ± 5.22	49.04 ± 5.21	4.51	3.886	0.001†
Within-group ANOVA	$F=9.91$, $p=0.01$ *	$F=3.005$, $p=0.043$ *	—	—	—

* $p < 0.05$; † $p < 0.01$. Higher DCDQ scores indicate better motor coordination. SD: Standard Deviation.

Cardiorespiratory Endurance Outcomes (6MWT)

The CRET group demonstrated the most statistically robust improvement of all outcome domains in 6MWT performance ($F=13.957$, $p=0.001$). Mean walking distance improved from 463.96 ± 34.45 metres at baseline to 488.99 ± 36.37 metres at post-test 1 (mean difference=25.04 m, $p=0.008$), and further to 506.83 ± 38.46 metres at post-test 2 (mean difference from baseline=42.88 m, $p=0.001$). Post hoc analysis confirmed that the improvement between post-test 1 and post-test 2 did not reach significance (mean difference=17.84 m, $p=0.092$), indicating deceleration of endurance gains in the latter four weeks.

The GE group demonstrated no significant change across any time point ($F=0.222$, $p=0.801$), with mean distances ranging from 457.78 ± 34.36 metres at baseline to 462.93 ± 34.93 metres at post-test 2, a total change of less than six metres. Between-group comparisons confirmed baseline equivalence ($p=0.424$) and highly significant differences at post-test 1 ($p < 0.001$, mean

difference=28.97 m) and post-test 2 ($p<0.001$, mean difference=43.91 m), strongly favouring the CRET group. Results are presented in Table/Fig-3.

Table 3: Mean 6MWT Distances and Between-Group Comparisons at Each Assessment Point (n=80)

Assessment Point	CRET Mean ($\pm$ SD) m	GE Mean ($\pm$ SD) m	Mean Diff (m)	t	p
Pre-test	463.96 $\pm$ 34.45	457.78 $\pm$ 34.36	6.18	0.803	0.424
Post-test 1 (4 weeks)	488.99 $\pm$ 36.37	460.02 $\pm$ 34.62	28.97	3.649	<0.001†
Post-test 2 (8 weeks)	506.83 $\pm$ 38.46	462.93 $\pm$ 34.93	43.91	5.345	<0.001†
Within-group ANOVA	F=13.957, p=0.001†	F=0.222, p=0.801	—	—	—

† $p<0.001$. m: metres. 6MWT: Six-Minute Walk Test; SD: Standard Deviation.

Sleep Quality Outcomes (SDSC)

The CRET group demonstrated a statistically significant and progressive improvement in sleep quality across the three assessment points ($F=12.1$, $p<0.001$). Mean SDSC scores, where higher scores indicate greater sleep disturbance, decreased from 54.88 ± 4.74 at baseline to 52.30 ± 4.55 at post-test 1 (mean improvement=2.59, $p=0.038$), and further to 49.86 ± 4.40 at post-test 2 (mean improvement from baseline=5.02, $p<0.001$). The difference between post-test 1 and post-test 2 approached but did not reach significance (mean difference=2.44, $p=0.056$), suggesting a gradual cumulative improvement pattern consistent with exercise-induced sleep adaptation.

The GE group showed no significant change across any time point ($F=0.148$, $p=0.863$), with mean SDSC scores varying by less than one point between baseline (53.95 ± 5.57) and post-test 2 (53.28 ± 5.51). Between-group comparisons showed baseline equivalence ($p=0.421$), no significant difference at post-test 1 ($p=0.246$), and a significant difference at post-test 2 ($p=0.003$, mean difference=3.41), favouring the CRET group. Data are presented in Table/Fig-4.

Table 4: Mean SDSC Scores and Between-Group Comparisons at Each Assessment Point (n=80)

Assessment Point	CRET Mean ($\pm$ SD)	GE Mean ($\pm$ SD)	Mean Diff	t	p
Pre-test	54.88 $\pm$ 4.74	53.95 $\pm$ 5.57	0.94	0.809	0.421
Post-test 1 (4 weeks)	52.30 $\pm$ 4.55	53.62 $\pm$ 5.54	-1.33	-1.169	0.246
Post-test 2 (8 weeks)	49.86 $\pm$ 4.40	53.28 $\pm$ 5.51	-3.41	-3.059	0.003*
Within-group ANOVA	F=12.1, p<0.001†	F=0.148, p=0.863	—	—	—

* $p<0.05$; † $p<0.001$. Higher SDSC scores indicate greater sleep disturbance. SDSC: Sleep Disturbance Scale for Children; SD: Standard Deviation.

Health-Related Quality of Life Outcomes (PedsQL)

The CRET group demonstrated a statistically significant improvement in HRQoL over the eight-week period ($F=7.632$, $p=0.001$). Mean PedsQL scores increased from 65.51 ± 5.92 at baseline to 68.25 ± 6.13 at post-test 1 and 70.82 ± 6.17 at post-test 2. Bonferroni post hoc analysis showed that while the improvement from pre-test to post-test 1 did not reach significance (mean difference=2.74, $p=0.138$), the difference from pre-test to post-test 2 was highly significant (mean difference=5.31, $p=0.001$), indicating a progressive quality of life benefit that became clinically apparent only after sustained training.

The GE group showed virtually no change across any time point ($F=0.01$, $p=0.99$), with mean scores remaining near-static from 68.41 ± 6.35 at baseline to 68.61 ± 6.05 at post-test 2 (change <0.2 points). A notable finding was a statistically significant baseline difference in PedsQL scores between groups ($p=0.038$), with the CRET group starting approximately 2.9 points lower than the GE group. Despite this baseline disadvantage, the CRET group surpassed the GE group's score by post-test 2 (70.82 versus 68.61), though this between-group difference did not reach statistical significance ($p=0.111$). Data are presented in Table/Fig-5.

Table 5: Mean PedsQL Scores and Between-Group Comparisons at Each Assessment Point (n=80)

Assessment Point	CRET Mean ($\pm$ SD)	GE Mean ($\pm$ SD)	Mean Diff	t	p
Pre-test	65.51 $\pm$ 5.92	68.41 $\pm$ 6.35	-2.90	-2.115	0.038*
Post-test 1 (4 weeks)	68.25 $\pm$ 6.13	68.51 $\pm$ 6.20	-0.26	-0.187	0.852
Post-test 2 (8 weeks)	70.82 $\pm$ 6.17	68.61 $\pm$ 6.05	2.21	1.614	0.111
Within-group ANOVA	F=7.632, p=0.001†	F=0.010, p=0.990	—	—	—

* $p < 0.05$ (significant baseline difference); † $p < 0.01$. Higher PedsQL scores indicate better health-related quality of life. PedsQL: Paediatric Quality of Life Inventory; SD: Standard Deviation.

Summary of Within-Group and Between-Group Changes

Table 6: Summary of Repeated Measures ANOVA Results and Between-Group Significance at Post-Test 2

Outcome	CRET ANOVA (F, p)	GE ANOVA (F, p)	CRET Change (Pre→Post2)	GE Change (Pre→Post2)	BG p (Post2)
DCDQ'07	F=9.91, p=0.01*	F=3.005, p=0.043*	+4.96 points	+2.66 points	0.001†
6MWT (metres)	F=13.957, p=0.001†	F=0.222, p=0.801	+42.88 m	+5.15 m	<0.001†
SDSC	F=12.1, p<0.001†	F=0.148, p=0.863	-5.02 points	-0.67 points	0.003*
PedsQL	F=7.632, p=0.001†	F=0.010, p=0.990	+5.31 points	+0.20 points	0.111

* $p < 0.05$; † $p < 0.001$. BG: Between-group. Negative change in SDSC represents improvement (reduced sleep disturbance). Positive changes in DCDQ, 6MWT, and PedsQL represent improvement.

DISCUSSION

This randomised controlled trial demonstrates that an eight-week school-based gamified cardiorespiratory endurance training programme produces significant and clinically meaningful improvements in motor coordination, cardiorespiratory endurance, sleep quality, and health-related quality of life in children with DCD, with benefits substantially exceeding those produced by a general exercise programme of equivalent duration. To the best of the authors' knowledge, this is among the first RCTs from India to simultaneously evaluate aerobic training across these four functionally important domains in children with DCD.

The significant improvement in motor coordination in the CRET group (F=9.91, p=0.01) is perhaps the most conceptually important finding of this trial, as the CRET protocol was designed to target aerobic capacity rather than motor skill learning. The observed coordination gains are consistent with the neurobiological evidence that sustained aerobic exercise promotes cerebellar neuroplasticity, upregulates BDNF expression, and enhances synaptic efficiency in motor circuits — the very neural systems impaired in DCD [15,16]. Hands (2008) reported similar coordination improvements following physical activity programmes not specifically designed as motor learning interventions [25], and Rivlis et al. (2011) systematically reviewed evidence linking physical activity to motor performance gains in this population [5]. The present findings extend these observations to an RCT format in an Indian school context.

The GE group also demonstrated a statistically significant, though substantially smaller, coordination improvement (F=3.005, p=0.043), with significance emerging only at post-test 2 (mean difference=2.66, p=0.047). This is consistent with the understanding that any structured physical activity programme involving repetitive movement tasks promotes some degree of motor memory consolidation [13]. However, the significantly greater improvement in the CRET group at both post-test 1 (p=0.017) and post-test 2 (p=0.001) indicates that aerobic training, through its systemic neurobiological effects, provides an additive substrate for motor learning that coordination-focused exercise alone does not. This finding offers an important

complement to the Cognitive Orientation to daily Occupational Performance (CO-OP) approach advocated by Polatajko and Mandich [26], suggesting that aerobic conditioning and cognitive motor learning may operate through complementary rather than competing pathways.

The most statistically robust finding of this trial was the 6MWT improvement in the CRET group ($F=13.957$, $p=0.001$), with a mean gain of 42.88 metres from baseline to post-test 2. This exceeds the minimal clinically important difference of 25 metres generally accepted in paediatric rehabilitation literature, and was achieved as early as post-test 1 (mean gain=25.04 m, $p=0.008$) [27]. The complete absence of 6MWT improvement in the GE group ($F=0.222$, $p=0.801$) underscores the dose-response specificity of cardiorespiratory adaptation: sustained cardiovascular stimulus of sufficient intensity and duration — provided by the CRET protocol's 25-minute aerobic training block at 60–75% maximum effort — is necessary to drive aerobic adaptation, and coordination-focused exercise at lower aerobic intensity does not achieve this threshold [28]. This finding has direct implications for physiotherapy prescription and school physical education guidelines, which may incorrectly assume that general physical activity produces equivalent cardiovascular benefits to targeted endurance training.

The improvement in sleep quality in the CRET group ($F=12.1$, $p<0.001$; mean SDSC reduction=5.02 points) without any concurrent sleep-specific intervention is among the most clinically significant observations of this trial. The biological mechanisms are well understood: sustained aerobic exercise promotes slow-wave sleep through core body temperature elevation and subsequent dissipation, modulates melatonin secretion timing, reduces evening cortisol levels, and produces daytime physical fatigue that facilitates sleep consolidation [17,29]. The gradual cumulative pattern of improvement — significant from post-test 1 ($p=0.038$) and further accentuated at post-test 2 ($p<0.001$) — is consistent with the known temporal trajectory of exercise-induced sleep adaptation, which typically requires several weeks of sustained aerobic conditioning to manifest fully [30]. The absence of any sleep improvement in the GE group reinforces that sleep improvement through exercise is threshold-dependent, requiring adequate cardiovascular intensity that coordination-focused interventions do not provide.

HRQoL improvement in the CRET group ($F=7.632$, $p=0.001$; mean PedsQL gain=5.31 points) requires contextual interpretation given the significant baseline difference between groups ($p=0.038$). The CRET group's mean PedsQL score at baseline (65.51) was approximately 2.9 points lower than the GE group (68.41), yet by post-test 2 the CRET group surpassed the GE group (70.82 versus 68.61). The between-group difference at post-test 2 did not reach significance ($p=0.111$), which is partly attributable to the baseline disparity and partly to the inherent insensitivity of global HRQoL measures to short-term intervention-specific changes [11]. The substantial within-group F -value (7.632) and effect size confirm that the observed improvement in the CRET group represents a genuine treatment effect rather than measurement artefact. Zwicker et al. and Harrowell et al. have both documented that functional physical improvements in children with DCD produce secondary gains in psychosocial wellbeing and participation [11,31], supporting the present observation.

The finding that the GE group improved in coordination but not in endurance, sleep, or quality of life has important clinical implications. It demonstrates that coordination-focused exercise, while beneficial for motor skill development, does not produce the systemic physiological effects — improved aerobic capacity, sleep architecture modulation, and associated quality of life gains — that characterise aerobic training. This supports the view that current DCD management approaches focused exclusively on motor learning are incomplete, and that structured aerobic training should be integrated as a complementary component of comprehensive DCD programmes [13,14].

Several limitations of this study should be acknowledged. Participant and therapist blinding was not feasible given the nature of the exercise interventions. The eight-week duration may not be sufficient to determine long-term sustainability of gains, as no follow-up assessment beyond post-test 2 was conducted. Sleep quality was assessed using parent-reported questionnaires rather than objective actigraphy, which would provide more precise data on sleep architecture. The study was conducted within a single district, and purposive sampling of schools may limit generalisability. Future trials should include longer follow-up periods, objective sleep measurement, larger and more geographically diverse samples, and comparison with combined aerobic plus motor learning intervention protocols.

CONCLUSION

This randomised controlled trial demonstrates that an eight-week school-based gamified cardiorespiratory endurance training programme produces significant and clinically meaningful improvements in motor coordination, cardiorespiratory endurance, sleep quality, and health-related quality of life in children with Developmental Coordination Disorder, with benefits substantially exceeding those of a general coordination-focused exercise programme. These findings establish a strong evidence base for

integrating structured aerobic training into school-based management protocols for children with DCD in India and provide a practical, low-resource model replicable across diverse educational settings. Future research should evaluate combined aerobic-motor learning programmes, assess long-term durability of gains, and employ objective sleep measurement to further characterise the mechanisms underlying the multi-domain benefits of cardiorespiratory training in this population.

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DECLARATIONS

Conflict of Interest

The authors declare no conflict of interest.

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Ethical Approval

The study was approved by the Institutional Ethics Committee of Madhav University, Rajasthan, India. All procedures were conducted in accordance with the Declaration of Helsinki (2013). Informed written consent was obtained from all parents or guardians, and assent was obtained from child participants prior to enrolment.

Authors' Contributions

[Author 1 — Principal Investigator]: Study conception, design, intervention delivery, data collection, statistical analysis, manuscript preparation, and final approval. [Author 2 — Guide/Supervisor]: Study oversight, critical intellectual review of manuscript, and final approval.

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