Effect of designed aerobic exercise program on cardiopulmonary fitness in children with hemiparetic cerebral palsy. A randomized controlled trial

Efecto del programa de ejercicio aeróbico diseñado sobre la aptitud cardiopulmonar en niños con parálisis cerebral hemiparética. Un ensayo controlado aleatorio

Authors

Hamada S. Ayoub [1]
Emad M. Taha [1]
Rania M. Tawfik [1, 2]
Shereen Mohamed Said [3]
Sara Rabie El-Hadad [3]
Dany Alphonse Anwar Habib [4]
Doaa A. Sanad [1]

[1] Cairo University (Egypt)
[2] Pharos University (Egypt)
[3] Misr University for Science and Technology (Egypt)
[4] Suez University (Egypt)

Corresponding author:
Hamada S. Ayoub
h.ayoub@cu.edu.eg

Received: 12-02-26
Accepted: 19-03-26

How to cite in APA

Ayoub, H. S., Taha, E. M., Tawfik, R. M., Said, S. M., El-Hadad, S. R., Anwar Habib, D. A., & Sanad, D. A. (2026). Effect of designed aerobic exercise program on cardiopulmonary fitness in children with hemiparetic cerebral palsy. A randomized controlled trial. *Retos, 78*, 843-853. https://doi.org/10.47197/retos.v78.118796

Abstract

Background: Children with hemiparetic cerebral palsy (CP) often experience reduced cardiopulmonary fitness, limiting functional mobility and participation. Aerobic exercise has been shown to enhance fitness in pediatric CP.
Objective: To investigate the effect of a designed aerobic exercise program on walking energy expenditure, aerobic capacity, and functional walking endurance in children with hemiparetic CP.
Methods: Forty children with hemiparetic CP participated in this randomized controlled study, their age from 7–12 years and GMFCS I–II. They were randomly assigned to a study group (n = 20) and a control group (n = 20). The control group received the conventional physiotherapy program based on the neuro-developmental technique 45 minutes (3 sessions/week), while the study group received the same conventional physiotherapy program provided to control group besides a supervised designed 12-weeks aerobic exercise program for 45 minutes (3 sessions/week). Outcome measures included Energy Expenditure Index (EEI), maximal oxygen uptake (VO_2 max), and the Six-Minute Walk Test (6MWT), assessed pre- and post-intervention. Data was analyzed using mixed-design MANOVA.
Results: There was a significant reduction in EEI ($p < 0.001$), a significant increase in VO_2 max ($p < 0.001$), and a significant improvement in 6MWT distance ($p < 0.001$) in the study group, whereas changes in the control group were not significant.
Conclusion: The study findings support the integration of designed aerobic exercise training into pediatric rehabilitation programs to enhance cardiopulmonary fitness and functional outcomes in hemiparetic CP children.

Keywords

Cerebral palsy, Hemiparesis, aerobic exercise, cardiopulmonary fitness, VO_2 max, six-minute walk test.

Resumen

Fundamento: Los niños con parálisis cerebral hemiparética (PC) a menudo experimentan una aptitud cardiopulmonar reducida, lo que limita la movilidad funcional y la participación. Se ha demostrado que el ejercicio aeróbico mejora la condición física en la PC pediátrica.
Objetivo: Investigar el efecto de un programa de ejercicio aeróbico diseñado sobre el gasto energético al caminar, la capacidad aeróbica y la resistencia funcional al caminar en niños con parálisis cerebral hemiparética.
Métodos: En este estudio controlado aleatorizado participaron cuarenta niños con PC hemiparética, de 7 a 12 años de edad y GMFC I–II, asignados aleatoriamente a un grupo de estudio (n = 20) y a un grupo de control (n = 20). El grupo de control recibió el programa de fisioterapia convencional basado en la técnica de neurodesarrollo de 45 minutos (3 sesiones / semana), mientras que el grupo de estudio recibió el mismo programa de fisioterapia convencional proporcionado al grupo de control además de un programa de ejercicio aeróbico supervisado diseñado de 12 semanas durante 45 minutos (3 sesiones / semana). Las medidas de resultado incluyeron el Índice de Gasto Energético(IEE), el consumo máximo de oxígeno (VO_2 máx.) y la Prueba de Caminata de Seis Minutos (6 MWT), evaluada antes y después de la intervención. Los datos se analizaron mediante MANOVA de diseño mixto.
Resultados: Hubo una reducción significativa en la IEE ($p < 0{,}001$), un aumento significativo en el VO_2 máx ($p < 0{,}001$) y una mejora significativa en la distancia 6MWT ($p < 0{,}001$) en el grupo de estudio, mientras que los cambios en el grupo de control no fueron significativos.
Conclusión: Los hallazgos del estudio respaldan la integración del entrenamiento con ejercicios aeróbicos diseñados en los programas de rehabilitación pediátrica para mejorar la aptitud cardiopulmonar y los resultados funcionales en niños con parálisis cerebral hemiparética.

Palabras clave

Parálisis cerebral, hemiparesia, ejercicio aeróbico, aptitud cardiopulmonar, VO_2 máx., prueba de caminata de seis minutos.

Introduction

Cerebral palsy (CP) is the most common physical disability in childhood, affecting approximately 2–3 per 1,000 live births worldwide. (McIntyre et al., 2022; Oskoui et al 2013; Graham, et al 2016) Among the various clinical presentations, hemiparetic CP accounts for approximately 30-40% of all cases and is characterized by unilateral motor impairment affecting one side of the body. (Hollung et al., 2021; Himmelmann & Uvebrant, 2014; Krägeloh-Mann & Cans, 2009)

Children with hemiparetic CP typically demonstrate better ambulatory capacity than those with bilateral involvement, with the majority classified as Gross Motor Function Classification System (GMFCS) levels I or II. (Palisano et al 1997). Despite this relative functional advantage, these children have significant deficits in cardiopulmonary fitness as diminished maximal oxygen uptake (VO_2 max), elevated energy expenditure during ambulation, and decreased walking endurance and physical activity participation that can profoundly impact their long-term health and quality of life. (Wijnhoud et al. 2024; Verschuren et al 2016; Fowler et al 2007; Verschuren et al 2006; Maltais et al 2014; Bjornson et al 2007)

Reduced fitness levels are associated with decreased participation in physical education and recreational activities, increased risk of secondary health conditions including obesity and cardiovascular disease, and lower health-related quality of life. (Santos et al., 2023; Shikako-Thomas et al 2008; Rimmer & Rowland 2008; Verschuren et al 2012)

Aerobic exercise training has been developed as a promising intervention to address cardiopulmonary deficits in children with CP. The theoretical rationale is grounded in well-established principles of exercise physiology as the repetitive, submaximal aerobic activity stimulates cardiovascular adaptations including increased stroke volume, improved cardiac output, enhanced peripheral oxygen extraction, and increased oxidative enzyme capacity in skeletal muscle. (Wasserman et al 2012; Rogers et al 2008) These physiological adaptations translate into improved VO_2 max, reduced energy cost of movement, and enhanced functional endurance. (Tauro, Ganesh & Vincent 2024; Damiano & DeJong 2009; Dodd & Foley 2007)

Although aerobic interventions have been studied in mixed CP cohorts including spastic diplegia, quadriplegia, and hemiplegia without subgroup analyses specific to hemiparetic presentations, relatively few trials have focused specifically on hemiparetic CP, despite its unique gait asymmetry and unilateral weakness that may differentially influence training response. (Slaman et al 2013; Reedman et al 2017, Reedman et al 2022)

Moreover, previous studies have often emphasized either functional measures (e.g., 6-minute walk test; 6MWT) or laboratory-based outcomes (VO_2 peak) in isolation, with limited integration of both physiological and functional endpoints in the same protocol. (Santos et al., 2023; Nsenga et al 2012; Verschuren & Takken 2010).

Regular physical activity plays a central role in the development and maintenance of cardiorespiratory fitness. Repeated engagement in aerobic activity stimulates cardiovascular and muscular adaptations that improve oxygen transport and utilization, thereby enhancing maximal oxygen uptake and exercise tolerance. In children with cerebral palsy, reduced participation in physical activity due to motor impairments and fatigue often leads to physical deconditioning and lower aerobic capacity. Increasing opportunities for structured aerobic activity can help reverse this cycle by improving movement efficiency, endurance, and overall functional mobility. Consequently, promoting regular aerobic exercise is considered an important strategy for improving cardiorespiratory fitness and physical functioning in children with cerebral palsy (Verschuren et al., 2016; Reedman et al., 2022).

The conceptual framework guiding this study suggests that a designed aerobic exercise program, tailored to the needs of children with hemiparetic CP, may reduce walking energy cost (EEI), enhance maximal oxygen uptake (VO_2 max), and improve functional walking capacity (6MWT).

By focusing exclusively on the hemiparetic subtype and using a comprehensive group of validated cardiopulmonary outcome measures. Therefore, the present study was conducted to investigate the effect of a designed aerobic exercise program on cardiopulmonary fitness measures in children with hemiparetic cerebral palsy.

Method

Study Design

This randomized pre–post controlled trial was conducted from May to August 2025 to investigate the effects of a designed aerobic exercise program on cardiopulmonary fitness in children with hemiparetic CP.

Sample Size Calculation

The sample size was calculated using G*Power 3.1 software (Heinrich Heine University, Düsseldorf, Germany). Based on previous exercise intervention studies in children with CP, a mean improvement in VO_2 max. of 4-6 $mL.kg^{-1}.min^{-1}$ is considered clinically meaningful. (Lauglo et al 2016). Using an expected moderate effect size (f = 0.25), α = 0.05, and power (1–β) = 0.80 for MANOVA (within and between interaction, 2 groups × 2 time points), the required sample size was 34 participants (17 per group).

To account for an estimated 15% dropout rate, the target recruitment was increased to 40 participants (20 per group). This sample size was considered adequate to detect significant changes across the three dependent variables (EEI, VO_2 max, 6MWT), while maintaining appropriate statistical power.

Subjects

Forty children diagnosed as hemiparetic CP were recruited from the outpatient clinic, Faculty of Physical Therapy, Cairo University according to the following criteria that align with previous aerobic training trials in CP that emphasized safety, ambulatory status, and ability to complete exercise assessments. (Verschuren et al 2016)

Inclusion Criteria

• Their age ranged from 7–12 years.

• Their GMFCS levels were I–II (ambulant without assistive devices).

• They can follow simple verbal instructions and complete treadmill/field assessments.

• Have stable medical condition with no orthopedic surgery or botulinum toxin injections within the past 6 months.

Exclusion Criteria

• Severe cognitive impairment that may interfere with test compliance.

• Epilepsy, cardiopulmonary, or metabolic disease contraindicating exercise.

• Orthopedic deformities or musculoskeletal injuries limiting safe participation.

• Participation in another structured exercise or rehabilitation research trial during the study period.

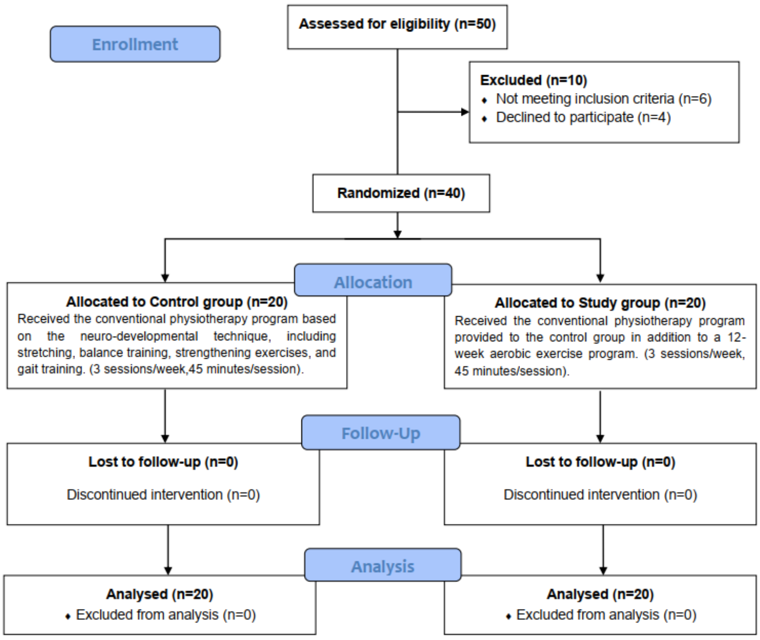
Randomization and Allocation

Following baseline testing, participants were randomly assigned to either the intervention or control group using a computer-generated randomization sequence with a 1:1 allocation ratio. The randomization sequence was generated by a researcher not involved in participant recruitment or assessment and was concealed using sequentially numbered, opaque, sealed envelopes. (Fig. 1). Due to the ethical considerations, there were no participants blinding as the children's parents signed informed consent form after clear explanation of the study protocol, in addition the treating therapists were not blinded to group allocation.

Ethical Considerations

This randomized controlled trial was registered at (ClinicalTrials.gov.ID: NCT06423476). Ethical approval was obtained from the Ethical Committee, Faculty of Physical Therapy, Cairo University (No. P.T.REC/012/004368). The study was conducted in accordance with the principles outlined in the Declaration of Helsinki for human research. Informed consent was obtained from the parents of each child, who were thoroughly informed on the study protocol, objectives, and potential benefits along with their right to decline participation or withdraw at any time, with a commitment to maintaining the confidentiality of their information. Participants were monitored throughout for safety, and sessions were supervised by experienced pediatric physiotherapists.

Figure 1. CONSORT Flow diagram



Outcome Measures

1. Energy Expenditure Index (EEI)

EEI was calculated as the ratio of walking heart rate minus resting heart rate to walking speed (beats/m), obtained during a standardized 6-minute submaximal treadmill walk. This measure has been validated for assessing walking economy in children with CP. (García et al 2016)

2. Maximal Oxygen Uptake (VO_2 max)

VO_2 max was measured using a metabolic cart (breath-by-breath gas analysis) during a graded treadmill exercise test. The modified Balke protocol adapted for children with CP was used, which is feasible and reliable in this population. Criteria for VO_2 max attainment included volitional fatigue, plateau in VO_2 despite workload increase, respiratory exchange ratio ≥1.0, and peak HR ≥85% of age-predicted maximum. (Marinov et al 2003).

3. Six-Minute Walk Test (6MWT)

The 6MWT was performed according to the American Thoracic Society guidelines on a 30-meter indoor track. Distance walked was recorded in meters. The 6MWT has demonstrated strong reliability and validity in ambulant children with CP. (Romeo et al 2022)

Intervention: Designed Aerobic Exercise Program

The control group received the conventional physiotherapy program based on the neuro-developmental technique, including stretching, balance training, strengthening exercises, and gait training (3 sessions/week, 45 minutes/session).

The intervention group received the conventional physiotherapy program provided to the control group in addition to a 12-week aerobic exercise program (3 sessions/week, 45 minutes/session). (Tauro, Ganesh & Vincent 2024). The sessions were conducted individually under physiotherapist supervision and structured as follows:

Each session initiated with a five-minute warm-up that included stretching exercises targeting the legs, thighs, and arms, along with breathing exercises. This was followed by 35 minutes of cardiovascular endurance training, which included 15 minutes on the treadmill, 15 minutes utilizing a gym ball, and 5 minutes of using a bicycle ergometer, ending with a five-minute cooldown. The intensity of the exercises was in accordance with the guidelines set by the American College of Sports Medicine (ACSM), with HRmax progressively increasing from 64% to 95% throughout the duration of the program. Specifically, HRmax was established at 65% during the first and second weeks, 70% during the third and fourth weeks, 75% during the fifth and sixth weeks, 80% during the seventh and eighth weeks, 85% during the ninth and tenth weeks, and 90% during the eleventh and twelfth weeks. (Mendola, 2025)

Statistical Analysis

Data was analyzed using SPSS version 12. Normality was checked with Shapiro–Wilk tests. Descriptive statistics (mean + SD) were calculated. Multivariate analysis of variance (MANOVA) was used because the study involved several correlated dependent variables measured repeatedly over time. MANOVA accounts for intercorrelations among outcomes, reduces the risk of Type I error, and allows evaluation of group, time, and interaction effects within a single statistical model. Statistical significance was set at $p < 0.05$. All analyses were conducted on an intention-to-treat basis, with participants analyzed according to their randomized group assignment. In the event of missing data, multiple imputation procedures would be employed; however, complete data were obtained for all participants who completed the study.

Results

Demographic Data

The study included forty children with hemiparetic CP, evenly distributed between the control and study groups. The demographic characteristics indicated that there were no statistically significant differences observed between groups, which confirmed that both groups were well-matched at baseline. (Table 1).

Table 1. Demographic characteristics

Variable	Control (mean ± SD)	Study (mean ± SD)	p-value
Age (years)	8.9 ± 1.5	9.1 ± 1.6	0.68
Gender (M/F)	12/8	11/9	0.75
Height (cm)	131.8 ± 8.2	132.4 ± 7.5	0.81
Weight (kg)	30.9 ± 5.9	31.5 ± 6.1	0.74
GMFCS I/II	12/8	13/7	0.74

Inferential Analysis

A 2 × 2 mixed multivariate analysis of variance (MANOVA) was conducted to examine the effects of group (study vs. control) and time (pre- vs. post-treatment) on the outcome variables. Because aerobic capacity may naturally change with growth and maturation in children, participants in both groups were closely matched for age, and the short intervention period minimized the likelihood that maturational changes substantially influenced VO_2 max values. Thus, any observed differences between groups over time should be interpreted within the context of this controlled design rather than attributed solely to age-related physiological development.

The multivariate analysis demonstrated a significant overall effect of time (Wilks' $\Lambda = 0.42$, $F(3, 33) = 15.2$, $p < 0.001$, $\eta^2 = 0.58$), indicating that the combined outcome variables changed across the intervention period. A significant group effect was also identified (Wilks' $\Lambda = 0.77$, $F(3, 33) = 3.3$, $p = 0.03$, $\eta^2 = 0.23$), suggesting differences between the study and control groups across the measured variables. Importantly, a significant group × time interaction was observed (Wilks' $\Lambda = 0.48$, $F(3, 33) = 11.8$, $p < 0.001$, $\eta^2 = 0.52$), indicating that the pattern of change over time differed between groups.

For the Energy Expenditure Index (EEI), no statistically significant difference was detected between the groups at baseline ($p = 0.73$). Following the intervention period, a significant between-group difference emerged ($p < 0.001$), with the study group demonstrating lower EEI values compared with the control group. The MANOVA interaction effect indicated that the reduction in EEI across time was significantly greater in the study group, suggesting improved gait efficiency associated with participation in the intervention program (Table 2).

Similarly, baseline VO_2 max values did not differ significantly between the study and control groups ($p = 0.78$). Post-treatment comparisons revealed a significant difference between-group favoring the study group ($p < 0.001$). The significant interaction effect from the MANOVA analysis indicated that changes in aerobic capacity over time differed between groups, with the study group demonstrating a greater increase in VO_2 max relative to the control group (Table 2). These findings should be interpreted as an association between participation in the intervention and improvements in aerobic capacity, rather than as direct causal evidence.

For the Six-Minute Walk Test (6MWT), baseline walking distance did not differ significantly between the groups ($p = 0.85$). After the treatment period, a highly significant difference between-groups was observed ($p < 0.001$). The MANOVA interaction effect demonstrated that functional walking capacity improved to a greater extent in the study group, whereas the control group showed minimal change over the same period (Table 2).

These results indicate that participants in the intervention group exhibited greater improvements in gait efficiency, aerobic capacity, and functional walking performance across the study period compared with the control group, while controlling baseline equivalence and potential confounding related to age-matched participant characteristics.

Table 2. Pre and post treatment comparison of EEI, VO2 max, and 6 MWT in both groups A, and B.

		1. EEI, (Beat/m)		
Group	Pre	Post	Mean Diff	P Value
Control	0.64 ± 0.10	0.61 ± 0.12	- 0.03	0.21
Study	0.65 ± 0.11	0.49 ± 0.09	- 0.16	<0.001*
Mean Diff	- 0.01	0.12		
P-value	0.73	<0.001*		
		2. VO_2 max, (ml/kg/min)		
Group	Pre	Post	Mean Diff	P- value
Control	27.6 ± 5.0	28.1 ± 4.8	0.5	0.42
Study	27.2 ± 4.6	33.5 ± 5.2	6.3	<0.001*
Mean Diff	0.4	-5.4		
P-value	0.78	<0.001*		
		3. 6MWT, (meters)		
Group	Pre	Post	Mean Diff	P- value
Control	373.1 ± 40.8	379.8 ± 39.2	6.7	0.18
Study	375.6 ± 42.1	431.2 ± 44.7	55.6	<0.001*
Mean Diff	-2.5	-51.4		
P-value	0.85	<0.001*		

Discussion

The present study examined the effects of a specifically designed aerobic exercise program on cardiopulmonary fitness in children with hemiparetic CP who have been underrepresented in previous exercise intervention studies. The results demonstrate that children in the study group achieved significant improvements in all measured outcomes with reduced EEI, increased VO_2 max, and greater distance in the 6MWT compared with the control group. These findings support the hypothesis that structured aerobic exercise provides meaningful physiological and functional benefits in this population.

The significant reduction in EEI observed in the study group represents a clinically important improvement in walking efficiency that address one of the most functionally limiting impairments in children with hemiparetic CP who demonstrate an elevated energy cost of ambulation which contributes to rapid fatigue during community mobility, and limited participation in physical activities, thereby perpetuating a cycle of deconditioning. (Balemans et al 2017; Carlon et al 2013)

The study indicates that the aerobic exercise program significantly reduces EEI, this can be induced by promoting physiological adaptations which include enhanced cardiovascular fitness, improved gait mechanics, and reduced cardiovascular stress during walking. Alongside, the neuromuscular adaptations such as better motor unit recruitment and decreased co-contraction of antagonist muscles contribute to these improvements, resulting in efficient movement strategies and enhanced lower limb strength, which minimize compensatory movements and energy expenditure.

Our findings are supported by Abd El-Nabie and Abd El-Monem (2019), who reported that there was an improvement in energy efficiency following twelve weeks of treadmill training in a mixed sample of children with hemiparetic and diplegic CP. Similarly, our findings are parallel with Mukherjee et al., (2025), who indicated that integrated aerobic exercise into rehabilitation programs for a mixed cohort of children with CP significantly improved cardiopulmonary endurance and physical fitness with significant reduction of EEI.

The considerable improvement in VO_2 max may be achieved through enhancing both central oxygen delivery and peripheral oxygen utilization. These adaptations may include allowing the heart to pump more oxygenated blood per beat while lowering the resting heart rate and the heart rate response to submaximal tasks. (Wasserman et al 2012; Rogers et al 2008). Associated by improved ability of muscular system to extract oxygen and increases mechanical efficiency, which reduces the energy cost required for movements.

This comes in agreement with Nsenga et al, (2013), who reported that children with CP who engaged in aerobic training program had a significant improvement in oxygen consumption highlighting the importance of integrating that type of exercise into the regular rehabilitation for such population. In addition, this is supported by a systematic review and meta-analysis study conducted by Soares et al., (2023) and highlighted that aerobic exercises are more effective than usual care or other interventions in improving mobility, aerobic capacity, and balance in CP.

The significant improvement in 6MWT distance in the study group represented a clinically significant enhancement in functional walking endurance, that correlates strongly with community mobility, participation in physical activities, and health-related quality of life. This is likely induced by both physiological factors represented by improved aerobic capacity and reduced energy expenditure that delay onset of fatigue while walking alongside with the biomechanical factors represented by enhanced muscular endurance and potentially enhanced gait efficiency that may contribute to the ability to maintain walking speed over the six-minute test duration. (Scholtes et al 2012)

This is consistent with Chrysagis et al. (2012), who reported significant improvements in both walking speed and endurance following a structured treadmill training program in ambulatory adolescents with CP, suggesting that repetitive, submaximal aerobic loading can enhance locomotor efficiency and cardiovascular tolerance during ambulation. In addition, Nsenga et al. (2012), documented significant improvements in 6MWT performance after an aerobic conditioning program in children with CP classified as GMFCS levels I and II, indicating enhanced functional walking capacity following cardiovascular training.

Several limitations should be considered when interpreting these findings, including restricted generalizability due to the inclusion of only children with hemiparetic CP classified as GMFCS I–II, complete participant and treating therapists blinding were not feasible due to ethical and practical considerations related to the nature of the intervention, which may have introduced potential expectancy or performance bias, the absence of long-term follow-up to determine maintenance or detraining effects, and the lack of broader patient-centered outcomes assessment such as participation, quality of life, and psychosocial functioning. These factors highlighted the need for larger, multi-centered trials including diverse CP subtypes and severity levels, long-term follow-up studies, comprehensive outcome measures, mechanistic assessments, and scalable intervention models.

Conclusions

This study provides evidence that a structured 12-week aerobic exercise program, an evidence-based, safe, and effective intervention significantly improved cardiopulmonary fitness in children with hemiparetic cerebral palsy. This support integrating structured aerobic exercise program into pediatric rehabilitation practice has the potential to enhance functional outcomes, prevent secondary complications, and improve long-term health conditions for children with hemiparetic CP.

Acknowledgements

The authors would like to sincerely thank all the children and their parents who agreed to participate in this study. In addition, they extend their gratitude to all individuals who assisted in evaluating the children and in the random distribution of samples for this research.

Conflict of Interest

The authors declare no conflict of interest.

Financing

None to report.

References

Abd El-Nabie, W. A., & Abd El-Monem, A. M. (2019). Effect of treadmill training on energy cost of walking, functional walking capacity and postural stability in children with cerebral palsy: A randomized controlled trial. International Journal of Physiotherapy, 6(3), 116–122. http://dx.doi.org/10.7243/2055-2386-6-5

Balemans, A. C., Bolster, E. A., Brehm, M. A., & Dallmeijer, A. J. (2017). Physical Strain: A New Perspective on Walking in Cerebral Palsy. Archives of physical medicine and rehabilitation, 98(12), 2507–2513. https://doi.org/10.1016/j.apmr.2017.05.004

Bjornson, K. F., Belza, B., Kartin, D., Logsdon, R., & McLaughlin, J. F. (2007). Ambulatory physical activity performance in youth with cerebral palsy and youth who are developing typically. Physical therapy, 87(3), 248–257. https://doi.org/10.2522/ptj.20060157

Carlon, S. L., Taylor, N. F., Dodd, K. J., & Shields, N. (2013). Differences in habitual physical activity levels of young people with cerebral palsy and their typically developing peers: a systematic review. Disability and rehabilitation, 35(8), 647–655. https://doi.org/10.3109/09638288.2012.715721

Chrysagis, N., Skordilis, E. K., Stavrou, N., Grammatopoulou, E., & Koutsouki, D. (2012). The effect of treadmill training on gross motor function and walking speed in ambulatory adolescents with cerebral palsy: a randomized controlled trial. American journal of physical medicine & rehabilitation, 91(9), 747–760. https://doi.org/10.1097/PHM.0b013e3182643eba

Damiano, D. L., & DeJong, S. L. (2009). A systematic review of the effectiveness of treadmill training and body weight support in pediatric rehabilitation. Journal of neurologic physical therapy : JNPT, 33(1), 27–44. https://doi.org/10.1097/NPT.0b013e31819800e2

Dodd, K. J., & Foley, S. (2007). Partial body-weight-supported treadmill training can improve walking in children with cerebral palsy: a clinical controlled trial. Developmental medicine and child neurology, 49(2), 101–105. https://doi.org/10.1111/j.1469-8749.2007.00101.x

Fowler, E. G., Kolobe, T. H., Damiano, D. L., Thorpe, D. E., Morgan, D. W., Brunstrom, J. E., Coster, W. J., Henderson, R. C., Pitetti, K. H., Rimmer, J. H., Rose, J., Stevenson, R. D., Section on Pediatrics Research Summit Participants, & Section on Pediatrics Research Committee Task Force (2007). Promotion of physical fitness and prevention of secondary conditions for children with cerebral palsy: section on pediatrics research summit proceedings. Physical therapy, 87(11), 1495–1510. https://doi.org/10.2522/ptj.20060116

García, C. C., Alcocer-Gamboa, A., Ruiz, M. P., Caballero, I. M., Faigenbaum, A. D., Esteve-Lanao, J., Saiz, B. M., Lorenzo, T. M., & Lara, S. L. (2016). Metabolic, cardiorespiratory, and neuromuscular fitness performance in children with cerebral palsy: A comparison with healthy youth. Journal of exercise rehabilitation, 12(2), 124–131. https://doi.org/10.12965/jer.1632552.276

Graham, H. K., Rosenbaum, P., Paneth, N., Dan, B., Lin, J. P., Damiano, D. L., Becher, J. G., Gaebler-Spira, D., Colver, A., Reddihough, D. S., Crompton, K. E., & Lieber, R. L. (2016). Cerebral palsy. Nature reviews. Disease primers, 2, 15082. https://doi.org/10.1038/nrdp.2015.82

Himmelmann, K., & Uvebrant, P. (2014). The panorama of cerebral palsy in Sweden. XI. Changing patterns in the birth-year period 2003-2006. Acta paediatrica (Oslo, Norway: 1992), 103(6), 618–624. https://doi.org/10.1111/apa.12614

Hollung, S.J., Hägglund, G., Gaston, M.S., Seid, A.K., Lydersen, S., Alriksson-Schmidt, A.I. and Andersen, G.L. (2021), Point prevalence and motor function of children and adolescents with cerebral palsy in Scandinavia and Scotland: a CP-North study. Dev Med Child Neurol, 63: 721-728. https://doi.org/10.1111/dmcn.14764

Krägeloh-Mann, I., & Cans, C. (2009). Cerebral palsy update. Brain & development, 31(7), 537–544. https://doi.org/10.1016/j.braindev.2009.03.009

Lauglo, R., Vik, T., Lamvik, T., Stensvold, D., Finbråten, A. K., & Moholdt, T. (2016). High-intensity interval training to improve fitness in children with cerebral palsy. BMJ open sport & exercise medicine, 2(1), e000111. https://doi.org/10.1136/bmjsem-2016-000111

Maltais, D. B., Wiart, L., Fowler, E., Verschuren, O., & Damiano, D. L. (2014). Health-related physical fitness for children with cerebral palsy. Journal of child neurology, 29(8), 1091–1100. https://doi.org/10.1177/0883073814533152

Marinov, B., Kostianev, S., & Turnovska, T. (2003). Modified treadmill protocol for evaluation of physical fitness in pediatric age group--comparison with Bruce and Balke protocols. Acta physiologica et pharmacologica Bulgarica, 27(2-3), 47–51.

McIntyre, S., Goldsmith, S., Garcia, A., Badawi, N., & Blair, E. (2022). Global prevalence of cerebral palsy: A systematic analysis. Developmental Medicine & Child Neurology, 64(12), 1494–1506. https://doi.org/10.1111/dmcn.15346

Mendola, N. (2025). Exercise Evolved: Exciting New Updates in ACSM's Guidelines for Exercise Testing and Prescription, 12th Edition. ACSM'S Health & Fitness Journal, 29(2), 44–47. https://doi.org/10.1249/fit.0000000000001036

Mukherjee, P., Das, P. R., Pradhan, D. K., Sahoo, R., & Mishra, P. (2025). Effectiveness of aerobic training on cardiopulmonary function and quality of life in children with cerebral palsy: A single-blinded randomized trial. J Clin Biomed Sci, 15(3), 163–171. https://doi.org/10.58739/jcbs/v15i3.24.221

Nsenga Leunkeu, A., Shephard, R. J., & Ahmaidi, S. (2012). Six-minute walk test in children with cerebral palsy gross motor function classification system levels I and II: reproducibility, validity, and training effects. Archives of physical medicine and rehabilitation, 93(12), 2333–2339. https://doi.org/10.1016/j.apmr.2012.06.005

Oskoui, M., Coutinho, F., Dykeman, J., Jetté, N., & Pringsheim, T. (2013). An update on the prevalence of cerebral palsy: a systematic review and meta-analysis. Developmental medicine and child neurology, 55(6), 509–519. https://doi.org/10.1111/dmcn.12080

Palisano, R., Rosenbaum, P., Walter, S., Russell, D., Wood, E., & Galuppi, B. (1997). Development and reliability of a system to classify gross motor function in children with cerebral palsy. Developmental medicine and child neurology, 39(4), 214–223. https://doi.org/10.1111/j.1469-8749.1997.tb07414.x

Reedman, S., Boyd, R. N., & Sakzewski, L. (2017). The efficacy of interventions to increase physical activity participation of children with cerebral palsy: a systematic review and meta-analysis. Developmental medicine and child neurology, 59(10), 1011–1018. https://doi.org/10.1111/dmcn.13413

Reedman, S. E., Sakzewski, L., McNamara, L., Sherrington, C., Beckman, E., West, K., Trost, S. G., Thomas, R., Chatfield, M. D., Dutia, I., Gennen, A., Dodds, B., Cotton, Z., & Boyd, R. N. (2022). Study protocol for Running for health (Run4Health CP): a multicentre, assessor-blinded randomised controlled trial of 12 weeks of two times weekly Frame Running training versus usual care. BMJ Open, 12(6). https://doi.org/10.1136/bmjopen-2021-057668

Rimmer, J. A., & Rowland, J. L. (2008). Physical activity for youth with disabilities: a critical need in an underserved population. Developmental neurorehabilitation, 11(2), 141–148. https://doi.org/10.1080/17518420701688649

Rogers, A., Furler, B. L., Brinks, S., & Darrah, J. (2008). A systematic review of the effectiveness of aerobic exercise interventions for children with cerebral palsy: an AACPDM evidence report. Developmental medicine and child neurology, 50(11), 808–814. https://doi.org/10.1111/j.1469-8749.2008.03134.x

Romeo, D. M., Venezia, I., De Biase, M., Sini, F., Velli, C., Mercuri, E., & Brogna, C. (2022). The Use of the 6MWT for Rehabilitation in Children with Cerebral Palsy: A Narrative Review. Journal of personalized medicine, 13(1), 28. https://doi.org/10.3390/jpm13010028

Santos, K. P., Silva, V. M., Reis, I. F., Aquino, M. R., Lana, M. R., & Teixeira, M. F. (2023). Physical conditioning in children and adolescents with cerebral palsy: Systematic review and meta-analysis. Journal of Bodywork and Movement Therapies. https://doi.org/10.1016/j.jbmt.2023.04.036

Scholtes, V. A., Becher, J. G., Janssen-Potten, Y. J., Dekkers, H., Smallenbroek, L., & Dallmeijer, A. J. (2012). Effectiveness of functional progressive resistance exercise training on walking ability in children with cerebral palsy: a randomized controlled trial. Research in developmental disabilities, 33(1), 181–188. https://doi.org/10.1016/j.ridd.2011.08.026

Shikako-Thomas, K., Majnemer, A., Law, M., & Lach, L. (2008). Determinants of participation in leisure activities in children and youth with cerebral palsy: systematic review. Physical & occupational therapy in pediatrics, 28(2), 155–169. https://doi.org/10.1080/01942630802031834

Slaman, J., Bussmann, J., van der Slot, W. M., Stam, H. J., Roebroeck, M. E., van den Berg-Emons, R. J., & Transition and Lifespan Research Group South West Netherlands (2013). Physical strain of walking relates to activity level in adults with cerebral palsy. Archives of physical medicine and rehabilitation, 94(5), 896–901. https://doi.org/10.1016/j.apmr.2012.11.005

Soares, E. G., Gusmão, C. H. V., & Souto, D. O. (2023). Efficacy of aerobic exercise on the functioning and quality of life of children and adolescents with cerebral palsy: A systematic review and meta-analysis. Developmental medicine and child neurology, 65(10), 1292–1307. https://doi.org/10.1111/dmcn.15570

Tauro, R., Ganesh, S., & Vincent, J. G. (2024). Effect of Cardiovascular Endurance Training on the Exercise Capacity and Endurance in Children With Cerebral Palsy. Cureus, 16(6), e61595. https://doi.org/10.7759/cureus.61595

Verschuren, O., & Takken, T. (2010). Aerobic capacity in children and adolescents with cerebral palsy. Research in developmental disabilities, 31(6), 1352–1357. https://doi.org/10.1016/j.ridd.2010.07.005

Verschuren, O., Peterson, M. D., Balemans, A. C., & Hurvitz, E. A. (2016). Exercise and physical activity recommendations for people with cerebral palsy. Developmental medicine and child neurology, 58(8), 798–808. https://doi.org/10.1111/dmcn.13053

Verschuren, O., Takken, T., Ketelaar, M., Gorter, J. W., & Helders, P. J. (2006). Reliability and validity of data for 2 newly developed shuttle run tests in children with cerebral palsy. Physical therapy, 86(8), 1107–1117. https://doi.org/10.1093/ptj/86.8.1107

Verschuren, O., Wiart, L., Hermans, D., & Ketelaar, M. (2012). Identification of facilitators and barriers to physical activity in children and adolescents with cerebral palsy. The Journal of pediatrics, 161(3), 488–494. https://doi.org/10.1016/j.jpeds.2012.02.042

Wasserman, K., Hansen, James, Sue, D.Y., Stringer, William, Sietsema, Kathy, Sun, Xing-Guo & Whipp, B.J. (2012). Principles of exercise testing and interpretation: Including pathophysiology and clinical applications: Fifth edition. Philadelphia, PA: Lippincott Williams & Wilkins.

Wijnhoud, L., Takken, T., & Verschuren, O. (2024). Aerobic fitness in children with cerebral palsy compared to typically developing peers: A systematic review and meta-analysis. Revista Brasileira De Fisioterapia. https://doi.org/10.1016/j.bjpt.2024.101142

Authors and translators' details:

Hamada S. Ayoub	h.ayoub@cu.edu.eg	Author
Emad M. Taha	Dr.3mad79@gmail.com	Author
Rania M. Tawfik	dr.rania_mohamed@cu.edu.eg	Author
Shereen Mohamed Said	Shereen.said@must.edu.eg	Author
Sara Rabie El-Hadad	Sara.rabee@must.edu.eg	Author
Dany Alphonse Anwar Habib	Dany.alphonse@the.suezuni.edu.eg	Author
Doaa A. Sanad	dr.doaa.sanad@gmail.com	Author