

EFFECTS OF PROGRESSIVE RESISTANCE EXERCISE ON SPASTICITY AND SMARTPHONE-MEASURED GAIT PARAMETERS IN CHILDREN WITH SPASTIC DIAPLEGIC CEREBRAL PALSY

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Keywords

Cerebral Palsy; Dynamic Gait Index; Gait Parameters; Gross Motor Function; Muscle Strength; Progressive Resistance Exercise; Rehabilitation; Spastic Diaplegia; Spasticity; Smartphone Based Gait Analysis.

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Abstract

Background: CP affects the muscle tone, strength, balance and walking. Spastic diaplegic CP primarily involves the lower limbs and may cause restricted functional mobility. Progressive resistance exercise could be beneficial in enhancing gait and strength in addition to conventional physiotherapy.

Objective: To assess the impact of PRES on spasticity, gross motor function and functional gait parameters in children with cerebral palsy (CP) spastic diaplegia.

Methods: We randomly selected 40 children aged 1 to 7 with spastic diaplegic cerebral palsy. The subjects were randomly divided into Group A (n=20) who were treated with progressive resistance exercise along with conventional therapy and Group B (n=20) who were treated with conventional therapy only. The intervention was 6 weeks in length with 3 sessions a week for about 45 minutes each session. Evaluation was done before and following intervention. The Modified Ashworth Scale (MAS), the Gross Motor Function Measure (GMFM-66), Dynamic Gait Index, and Gait Parameters were used to assess spasticity, gross motor function, dynamic gait and gait parameters, respectively, using a smartphone.

Results: Group A demonstrated greater improvement than Group B. Right lower-limb MAS decreased from 2.10 ± 0.45 to 1.25 ± 0.44 in Group A and from 2.15 ± 0.49 to 1.90 ± 0.46 in Group B ($p < 0.001$). GMFM-66 increased from 52.80 to 63.90 in Group A compared with 51.90 to 55.20 in Group B. Walking speed improved from 0.76 to 0.97 m/s in Group A and from 0.74 to 0.80 m/s in Group B. Post-intervention cadence, right stride length, left stride length, and gait symmetry were 114.3 steps/min, 86.8 cm, 86.1 cm, and 93.1% in Group A, compared with 104.7 steps/min, 77.6 cm, 76.8 cm, and 86.5% in Group B.

Conclusion: Conventional therapy alone was not as effective as progressive resistance exercise and conventional therapy in reducing spasticity, gross motor function and gait performance in children with spastic diaplegic cerebral palsy.

1. Introduction

Cerebral palsy (CP) is a group of permanent disorders affecting movement and posture that result from disturbances occurring in the developing brain. Although the primary neurological lesion is non-progressive, children with CP may experience persistent limitations in motor function, balance, coordination, and mobility. The clinical presentation varies considerably among individuals, with spastic forms representing an important proportion of affected children. [1,5]

Spastic diplegic cerebral palsy is characterized predominantly by motor impairment of the lower limbs. Children with this presentation commonly demonstrate increased muscle tone, reduced muscle strength, impaired selective motor control, and altered muscle-tendon function. These neuromuscular impairments can contribute to abnormal gait patterns and limitations in functional mobility. [5,7] The thesis similarly identifies muscle weakness, impaired motor control, and altered neuromuscular characteristics as important contributors to gait abnormalities in children with cerebral palsy.

Muscle weakness is an important factor contributing to reduced functional performance in children with cerebral palsy. Reduced force-generating capacity may affect standing, transitional movements, balance, and walking. Previous research has demonstrated relationships between muscle volume, strength, and functional performance in children with cerebral palsy, supporting the importance of strengthening as part of rehabilitation. [10]

Progressive resistance exercise involves the gradual increase of resistance placed on muscles according to an individual's capacity and tolerance. Exercise-based interventions have received increasing attention in pediatric cerebral palsy rehabilitation. Systematic reviews have reported beneficial effects of exercise interventions on motor function, balance, and functional outcomes in children with CP. [2-4]

Resistance and strengthening interventions may be particularly useful because they directly target muscle weakness while supporting functional movement. Evidence summarized in the literature indicates that appropriately prescribed exercise can improve physical function without

necessarily increasing spasticity. [7,12,13] The thesis also emphasizes the potential value of integrating resistance exercise into multidisciplinary rehabilitation programs.

Conventional physiotherapy remains an important component of cerebral palsy management. Stretching, range-of-motion activities, balance exercises, postural training, and functional mobility activities are commonly incorporated to maintain movement and support functional independence. However, adding structured strengthening may provide additional benefits beyond conventional therapy alone. [12,13]

Gait performance is an important functional outcome in ambulatory children with spastic diplegic cerebral palsy. Abnormal muscle tone, weakness, impaired motor control, and reduced postural stability may contribute to slower walking speed, altered cadence, reduced stride length, and gait asymmetry. [5,16] These abnormalities can affect mobility and participation in daily activities.

Quantitative gait assessment can provide additional information beyond routine observational assessment. Technology-assisted rehabilitation and digital assessment approaches have increasingly been explored in pediatric rehabilitation. [13] Smartphone-based gait assessment may offer a relatively accessible approach for measuring selected walking characteristics and monitoring changes over time.

The present study therefore investigated whether progressive resistance exercise combined with conventional physiotherapy could produce greater improvements in spasticity, lower-limb muscle strength, gross motor function, dynamic balance, and smartphone-measured gait parameters than conventional physiotherapy alone in children with spastic diplegic cerebral palsy.

2. Materials and Methods

2.1 Study Design

A randomized controlled study was conducted to determine the effects of progressive resistance exercise combined with conventional physiotherapy on spasticity, muscle strength, gross motor function, dynamic balance, and gait parameters in children with spastic diplegic

cerebral palsy. A total of 40 participants were included and randomly allocated into two equal groups. Group A received progressive resistance exercise in addition to conventional physiotherapy, whereas Group B received conventional physiotherapy alone.

2.2 Participants

Children aged 5–15 years diagnosed with spastic diplegic cerebral palsy were recruited according to the predefined eligibility criteria. Participants were ambulatory and able to follow simple verbal instructions. Children with conditions that could interfere with participation in the intervention or assessment were excluded.

Before participation, written informed consent was obtained from the parents or legal guardians, and assent was obtained from children where appropriate. Demographic information, including age, gender, weight, height, and functional classification, was recorded at baseline.

2.3 Randomization and Group Allocation

After baseline assessment, participants were randomly allocated into two groups of 20 participants each. Group A was designated as the experimental group and received progressive resistance exercise combined with conventional physiotherapy. Group B served as the control group and received conventional physiotherapy alone.

Random allocation was used to reduce the possibility that pre-existing differences between participants would influence the comparison of treatment outcomes.

2.4 Intervention

Group A: Progressive Resistance Exercise Combined with Conventional Physiotherapy

Participants in Group A received progressive resistance exercise in addition to conventional physiotherapy. The resistance program targeted major lower-limb muscle groups, including the quadriceps, hamstrings, hip abductors, hip extensors, and ankle dorsiflexors. Exercises included sit-to-stand exercises, step-ups, resisted walking, and Theraband-based strengthening. The training began with low resistance and was progressively increased according to each child's tolerance and functional ability. Participants

performed approximately 2–3 sets of 8–12 repetitions, three times per week for six weeks. Conventional physiotherapy included stretching, balance training, and functional mobility exercises. [25,26]

Group B: Conventional Physiotherapy

Participants in Group B received conventional physiotherapy alone. The treatment included stretching exercises, range-of-motion exercises, balance training, and gait training without progressive resistance exercise. The duration and frequency of treatment sessions were matched with Group A to maintain consistency between the groups. [27]

2.5 Outcome Measures

2.5.1 Modified Ashworth Scale

Spasticity of the lower limbs was assessed using the Modified Ashworth Scale (MAS). The MAS is commonly used to assess resistance to passive movement and the degree of muscle hypertonia in individuals with neurological conditions. [28]

2.5.2 Gross Motor Function Measure-66

Gross motor function was assessed using the Gross Motor Function Measure-66 (GMFM-66). The GMFM is a standardized clinical measure designed to evaluate changes in gross motor function in children with cerebral palsy. The assessment includes functional activities related to lying and rolling, sitting, crawling and kneeling, standing, and walking/running/jumping. [29]

2.5.3 Dynamic Gait Index

Dynamic gait performance and balance were evaluated using the Dynamic Gait Index (DGI). The DGI assesses an individual's ability to modify gait in response to different task demands, including changes in gait speed, horizontal and vertical head movements, pivot turning, stepping over and around obstacles, and stair negotiation. [30]

2.5.4 Smartphone-Based Gait Assessment

Gait parameters were assessed using a smartphone-based gait analysis application in a controlled walking environment. The assessment included walking speed, cadence, stride length, and gait symmetry. Smartphone-

based gait assessment was selected to provide quantitative information regarding walking performance in addition to the clinical outcome measures. [31]

2.6 Data Collection Procedure

Data were collected from children with spastic diplegic cerebral palsy who fulfilled the inclusion criteria and attended the selected rehabilitation setting. Baseline assessments were performed before commencement of the intervention.

Group A (Experimental Group): Participants in Group A received progressive resistance exercise along with conventional physiotherapy. Progressive resistance training targeted lower limb muscle groups including quadriceps, hamstrings, hip abductors, hip extensors, and ankle dorsiflexors. Exercises included sit-to-stand, step-ups, resisted walking, and theraband-based strengthening. Training intensity began at

low resistance and gradually increased based on the child's tolerance, with 2–3 sets of 8–12 repetitions performed three times per week for six weeks. Conventional therapy included stretching, balance training, and functional mobility exercises(25, 26).

Group B (Control Group): Participants in Group B received conventional physiotherapy alone, including stretching exercises, range of motion exercises, balance training, and gait training without progressive resistance exercise. The duration and frequency of sessions were matched with Group A to maintain consistency(27).

Post-intervention assessments were conducted using the same outcome measures to evaluate changes in spasticity, gait parameters, muscle strength, and functional mobility. All interventions and assessments were conducted by trained physiotherapists to ensure consistency and reliability.



Figure 1: Sit-to-Stand with Resistance



Figure 2: Step-Up Exercise



Figure 3: Theraband lower-Limb Strengthening



Figure 4: Theraband lower-Limb Strengthening



Figure 5: Placement of smartphone at the waist using a belt pouch for BGait gait assessment.

2.7 Statistical Analysis

Data were analyzed using statistical software. Descriptive statistics were presented as mean and standard deviation for continuous variables and frequencies and percentages for categorical variables. Normality was assessed using the Shapiro-Wilk test. Paired comparisons were used for pre- and post-intervention changes, while independent-samples t-tests were used for between-group comparisons. Statistical significance was set at $p < 0.05$.

For the post-intervention independent-samples t-tests, Levene's test was also examined. The reported significance values were greater than 0.05 for the assessed outcomes, supporting the equal-variance assumption used for interpretation.

2.8 Ethical Considerations

The study was conducted according to the ethical requirements of the relevant institutional ethical committee. Written informed consent was obtained from the parents or legal guardians of participants. Participant information was kept confidential, and participants remained anonymous throughout the study. Participants were informed about their voluntary participation and their right to withdraw from

the study at any time.

3. Results

Forty children with spastic diaphragic cerebral palsy were equally partitioned into 2 groups. One hundred and twenty children of spastic diaphragic cerebral palsy were equally divided into 2 groups. Group A was given progressive resistance exercise combined with the conventional therapy, and Group B was given conventional therapy alone. The groups were similar at the beginning of the study. Following treatment, both groups had improved, but more improvement was seen in Group A with progressive resistance train. Progressive resistance exercise led to a decrease in the levels of spasticity, increase in muscle strength in the lower limb, an increase in GMFM-66 score, an improvement in Dynamic Gait Index score, and improvement in gait parameters such as gait symmetry, walking speed, cadence, and stride length. In general, the results suggest that the addition of progressive resistance exercise to standard therapy yields further benefits in reducing spasticity, increasing muscle strength, balance, gross motor function and gait performance in children with spastic diaphragic cerebral palsy.

Table 1 Age Distribution of Participants (N = 40)

Age Group (Years)	Frequency (n)	Percentage (%)
5-7	10	25.0
8-10	16	40.0
11-13	9	22.5
14-15	5	12.5
Total	40	100.0

The participants were 5 to 15 years old. Most participants were in the 8-10 years age group (40%), while 25% were aged 5-7 years, 22.5% were 11-13 years, and 12.5% were 14-15 years.

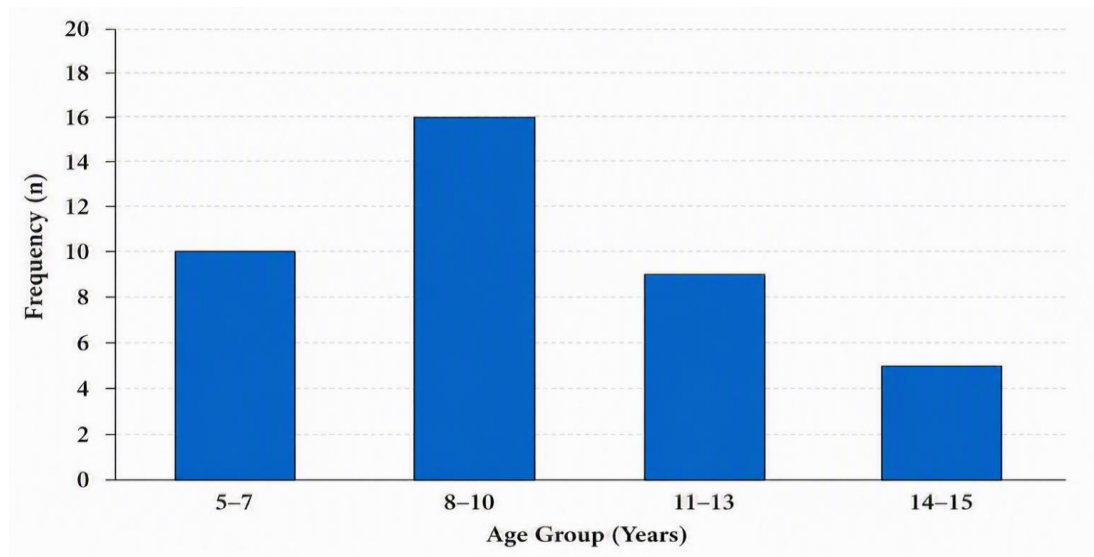


Figure 1 Age Distribution of Participants

Table 2. Distribution of Participants According to Gender

Gender	Frequency (n)	Percentage (%)
Male	23	57.5
Female	17	42.5
Total	40	100.0

Among the 40 participants, 23 (57.5%) were male and 17 (42.5%) were female. Thus, males made up a slightly larger proportion of the study sample.

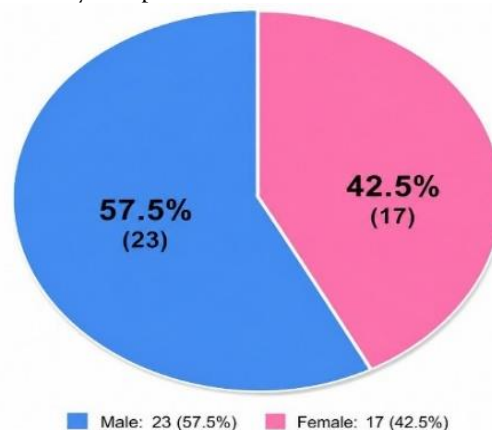


Figure 1. Distribution of Participants According to Gender

Table 2 Demographic Characteristics of Participants (N = 40)

Variable	Group A (n = 20) Mean $\pm$ SD / n (%)	Group B (n = 20) Mean $\pm$ SD / n (%)	Total (N = 40) Mean $\pm$ SD / n (%)	p-value
Weight (kg)	24.8 $\pm$ 3.2	25.3 $\pm$ 3.5	25.1 $\pm$ 3.3	0.641
Height (m)	1.269 $\pm$ 0.071	1.278 $\pm$ 0.075	1.274 $\pm$ 0.072	0.713
BMI (kg/m ²)	15.4 $\pm$ 1.1	15.5 $\pm$ 1.0	15.5 $\pm$ 1.0	0.821
Age at Diagnosis (Years)	2.1 $\pm$ 0.7	2.2 $\pm$ 0.8	2.2 $\pm$ 0.7	0.754
Male	12 (60.0%)	11 (55.0%)	23 (57.5%)	0.749

Female	8 (40.0%)	9 (45.0%)	17 (42.5%)	
GMFCS Level I	5 (25.0%)	4 (20.0%)	9 (22.5%)	0.921
GMFCS Level II	11 (55.0%)	12 (60.0%)	23 (57.5%)	
GMFCS Level III	4 (20.0%)	4 (20.0%)	8 (20.0%)	
Previous Physiotherapy (Yes)	17 (85.0%)	16 (80.0%)	33 (82.5%)	0.677
Previous Physiotherapy (No)	3 (15.0%)	4 (20.0%)	7 (17.5%)	
AFO Users	15 (75.0%)	14 (70.0%)	29 (72.5%)	0.723
Non-AFO Users	5 (25.0%)	6 (30.0%)	11 (27.5%)	

The two groups had similar baseline characteristics. No significant differences were found in weight, height, BMI, age at diagnosis, gender, GMFCS level, previous physiotherapy, or AFO use ($p > 0.05$).

3.1 Within-Group Changes in Group A

Group A demonstrated substantial improvements following six weeks of progressive resistance exercise combined with conventional therapy.

Table 3. Within-Group Comparison of Major Outcomes in Group A

Outcome	Pre-intervention Mean $\pm$ SD	Post-intervention Mean $\pm$ SD	Mean Change	p-value
GMFM-66 Total	52.80 $\pm$ 5.42	63.90 $\pm$ 5.81	+11.10	<0.001
GMFM-66 Dimension D	58.60 $\pm$ 7.20	71.80 $\pm$ 6.94	+13.20	<0.001
GMFM-66 Dimension E	42.50 $\pm$ 6.80	56.90 $\pm$ 7.02	+14.40	<0.001
DGI	11.80 $\pm$ 2.10	18.40 $\pm$ 1.90	+6.60	<0.001
Walking Speed (m/s)	0.76 $\pm$ 0.09	0.97 $\pm$ 0.08	+0.21	<0.001
Cadence (steps/min)	101.5 $\pm$ 7.6	114.3 $\pm$ 6.9	+12.8	<0.001
Right Stride Length (cm)	74.5 $\pm$ 5.1	86.8 $\pm$ 5.3	+12.3	<0.001
Left Stride Length (cm)	73.9 $\pm$ 5.0	86.1 $\pm$ 5.1	+12.2	<0.001
Gait Symmetry (%)	84.8 $\pm$ 4.8	93.1 $\pm$ 3.9	+8.3	<0.001

The reported values demonstrate significant improvement across the assessed functional and gait outcomes in Group A.

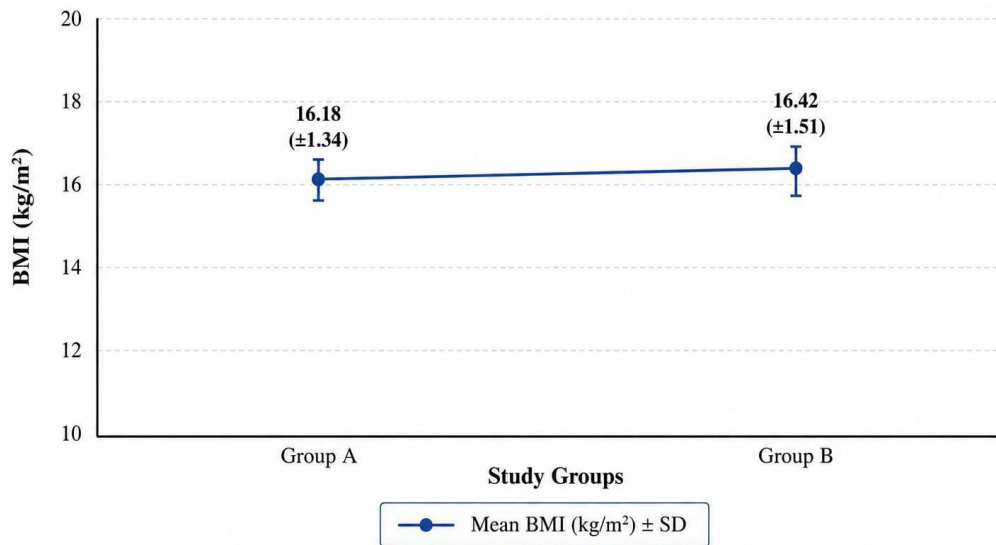


Figure 3 BMI (kg/m²)

Figure 4. Pre- and Post-Intervention GMFM-66 Total Score

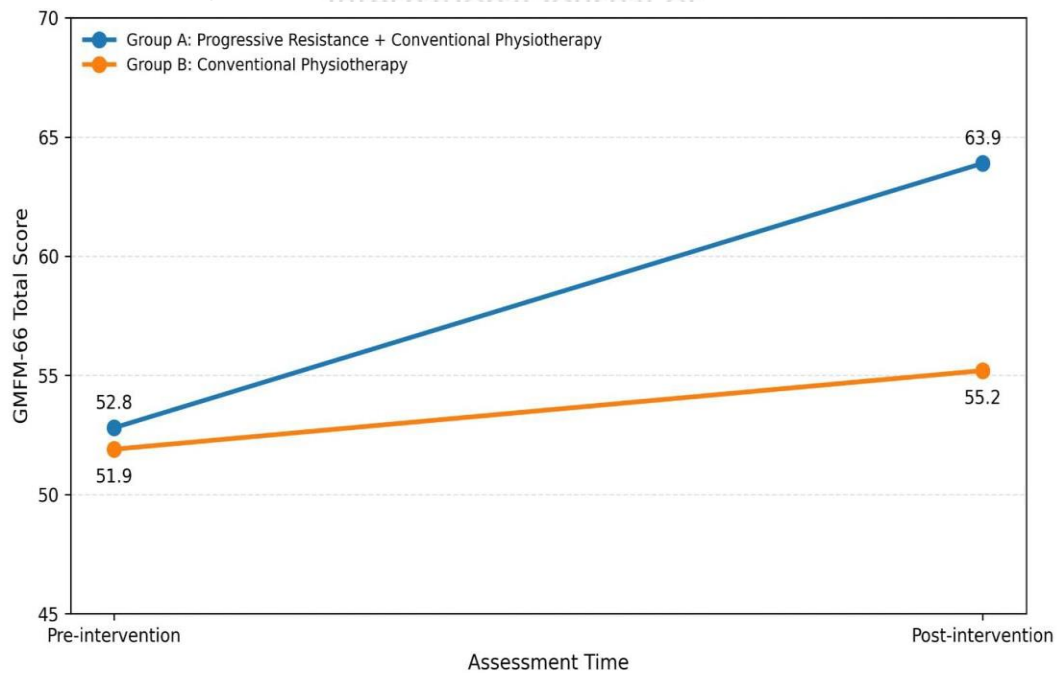


Figure 4. Mean GMFM-66 total scores before and after intervention in Group A.

Figure 5. Pre- and Post-Intervention Dynamic Gait Index

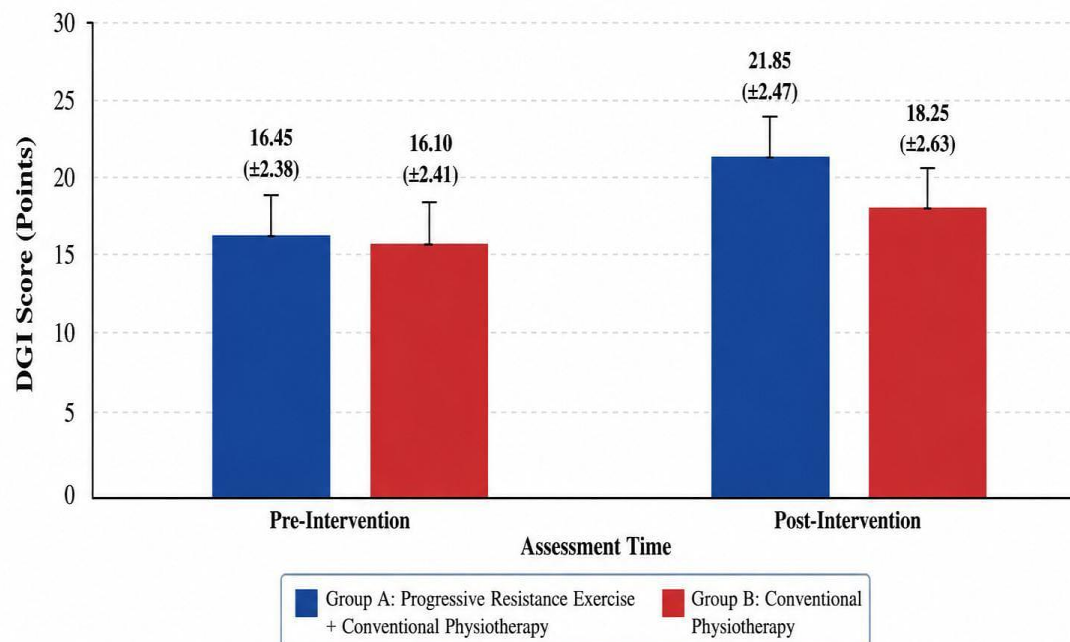


Figure 5. Mean Dynamic Gait Index scores before and after intervention in Group A
Figure 6. Pre- and Post-Intervention Walking Speed

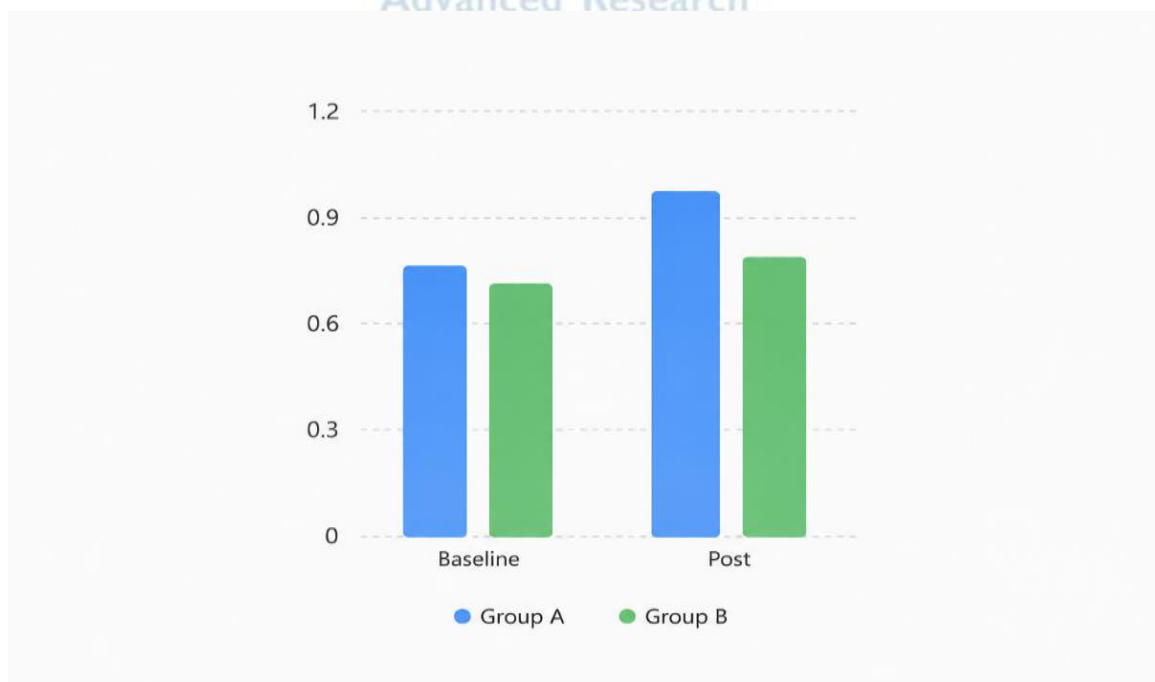


Figure 6. Mean walking speed before and after intervention in Group A.

3.2 Within-Group Changes in Group B

Group B also demonstrated statistically significant improvements after six weeks of conventional physiotherapy, although the magnitude of improvement was smaller than that observed in Group A.

Table 4. Within-Group Comparison of Major Outcomes in Group B

Outcome	Pre-intervention Mean $\pm$ SD	Post-intervention Mean $\pm$ SD	Mean Change	p-value
GMFM-66 Total	51.90 $\pm$ 5.67	55.20 $\pm$ 5.70	+3.30	0.012

GMFM-66 Dimension D	57.90 ± 7.10	61.30 ± 6.90	+3.40	0.021
GMFM-66 Dimension E	41.80 ± 6.95	45.60 ± 6.70	+3.80	0.018
DGI	11.40 ± 2.20	13.20 ± 2.10	+1.80	0.029
Walking Speed (m/s)	0.74 ± 0.10	0.80 ± 0.09	+0.06	0.037
Cadence (steps/min)	100.8 ± 7.9	104.7 ± 7.4	+3.90	0.031
Right Stride Length (cm)	73.8 ± 5.4	77.6 ± 5.5	+3.80	0.026
Left Stride Length (cm)	73.2 ± 5.2	76.8 ± 5.3	+3.60	0.032
Gait Symmetry (%)	84.0 ± 5.1	86.5 ± 4.8	+2.50	0.040

These results indicate that conventional physiotherapy alone also improved functional and gait outcomes, but the observed changes were smaller than those in Group A.

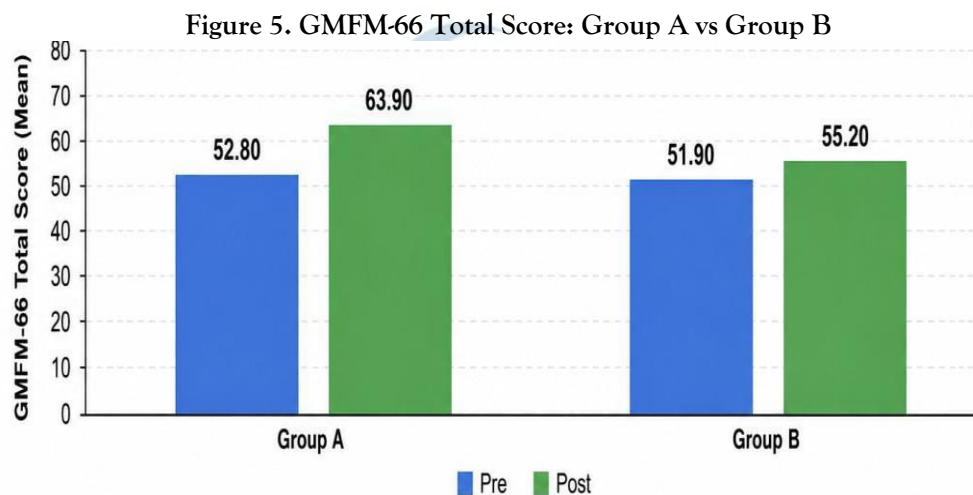


Figure 5. Comparison of mean GMFM-66 total scores between Group A and Group B before and after intervention.

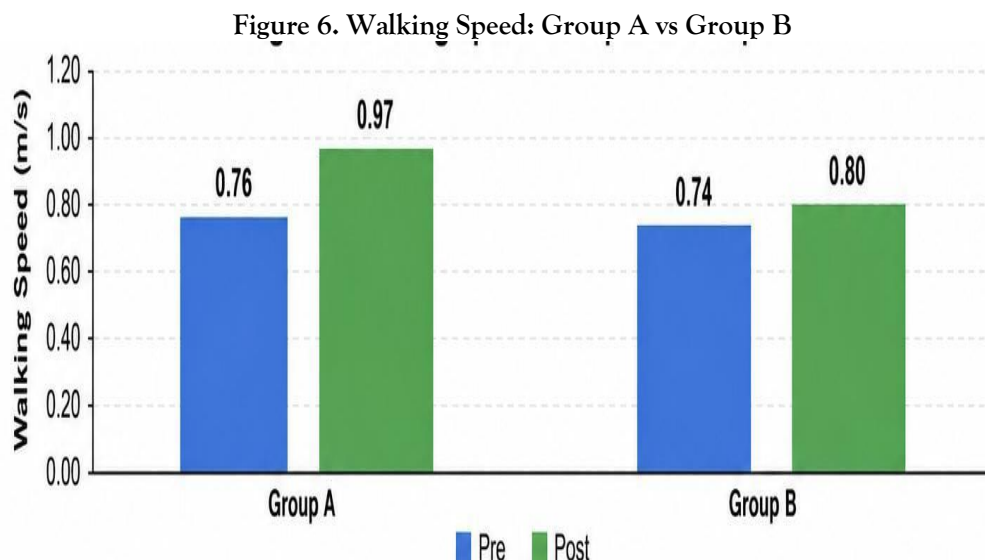


Figure 6. Comparison of mean walking speed between groups before and after intervention.

3.3 Between-Group Post-Intervention Comparison

Table 5. Between-Group Comparison of Post-Intervention Outcomes

Outcome Measure	Group A Mean $\pm$ SD	Group B Mean $\pm$ SD	Mean Difference	t-value	p-value
MAS Right Lower Limb	1.25 $\pm$ 0.44	1.90 $\pm$ 0.46	-0.65	-4.56	<0.001
MAS Left Lower Limb	1.20 $\pm$ 0.41	1.88 $\pm$ 0.42	-0.68	-5.12	<0.001
Hip Flexor Strength Right	4.55 $\pm$ 0.51	4.05 $\pm$ 0.50	0.50	3.18	0.003
Hip Flexor Strength Left	4.50 $\pm$ 0.49	4.00 $\pm$ 0.48	0.50	3.26	0.002
Hip Extensor Strength Right	4.40 $\pm$ 0.50	3.90 $\pm$ 0.47	0.50	3.24	0.002
Hip Extensor Strength Left	4.35 $\pm$ 0.48	3.85 $\pm$ 0.49	0.50	3.19	0.003
Knee Flexor Strength Right	4.30 $\pm$ 0.47	3.75 $\pm$ 0.51	0.55	3.52	0.001
GMFM-66 Total	63.90 $\pm$ 5.81	55.20 $\pm$ 5.70	8.70	4.81	<0.001
GMFM-66 Dimension D	71.80 $\pm$ 6.94	61.30 $\pm$ 6.90	10.50	4.82	<0.001
GMFM-66 Dimension E	56.90 $\pm$ 7.02	45.60 $\pm$ 6.70	11.30	5.19	<0.001
DGI	18.40 $\pm$ 1.90	13.20 $\pm$ 2.10	5.20	8.30	<0.001
Walking Speed (m/s)	0.97 $\pm$ 0.08	0.80 $\pm$ 0.09	0.17	6.23	<0.001
Cadence (steps/min)	114.3 $\pm$ 6.9	104.7 $\pm$ 7.4	9.60	4.26	<0.001
Right Stride Length (cm)	86.8 $\pm$ 5.3	77.6 $\pm$ 5.5	9.20	5.40	<0.001
Left Stride Length (cm)	86.1 $\pm$ 5.1	76.8 $\pm$ 5.3	9.30	5.64	<0.001
Gait Symmetry (%)	93.1 $\pm$ 3.9	86.5 $\pm$ 4.8	6.60	4.82	<0.001

The between-group results demonstrate significantly better outcomes in Group A across the assessed clinical and gait variables.

3.6 Main Gait Outcomes

Table 6. Smartphone-Measured Gait Parameters After Intervention

Gait Parameter	Group A	Group B	Mean Difference	p-value
Walking Speed (m/s)	0.97 $\pm$ 0.08	0.80 $\pm$ 0.09	0.17	<0.001
Cadence (steps/min)	114.3 $\pm$ 6.9	104.7 $\pm$ 7.4	9.60	<0.001
Right Stride Length (cm)	86.8 $\pm$ 5.3	77.6 $\pm$ 5.5	9.20	<0.001
Left Stride Length (cm)	86.1 $\pm$ 5.1	76.8 $\pm$ 5.3	9.30	<0.001
Gait Symmetry (%)	93.1 $\pm$ 3.9	86.5 $\pm$ 4.8	6.60	<0.001

The intervention group demonstrated superior walking speed, cadence, stride length, and gait symmetry compared with the control group.

Figure 7. Smartphone-Measured Walking Speed

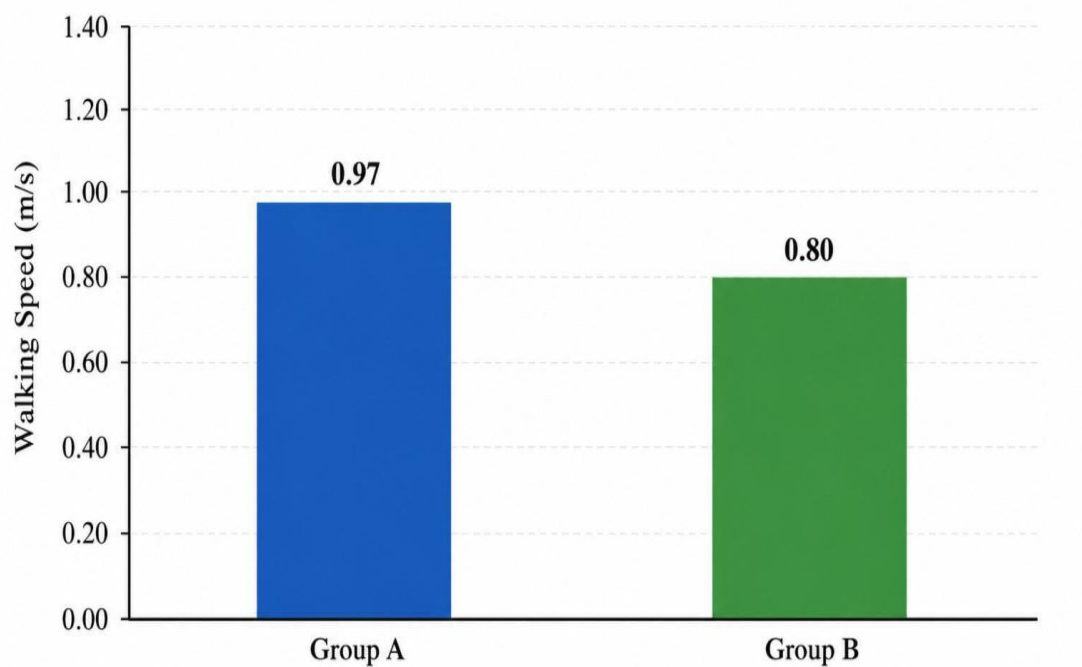


Figure 7. Post-intervention comparison of walking speed between the progressive resistance exercise and conventional therapy groups.

Figure 8. Smartphone-Measured Cadence

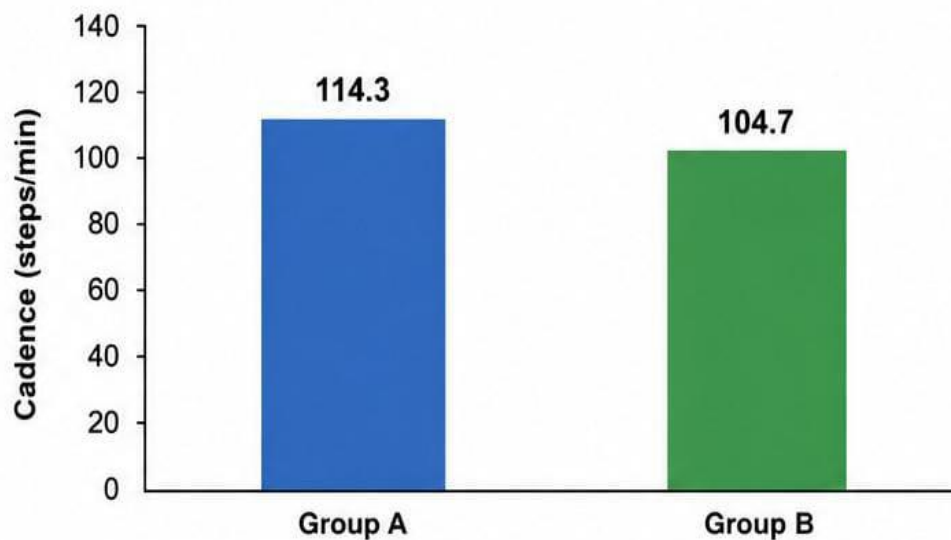


Figure 8. Post-intervention comparison of cadence between groups.

Figure 9. Right and Left Stride Length

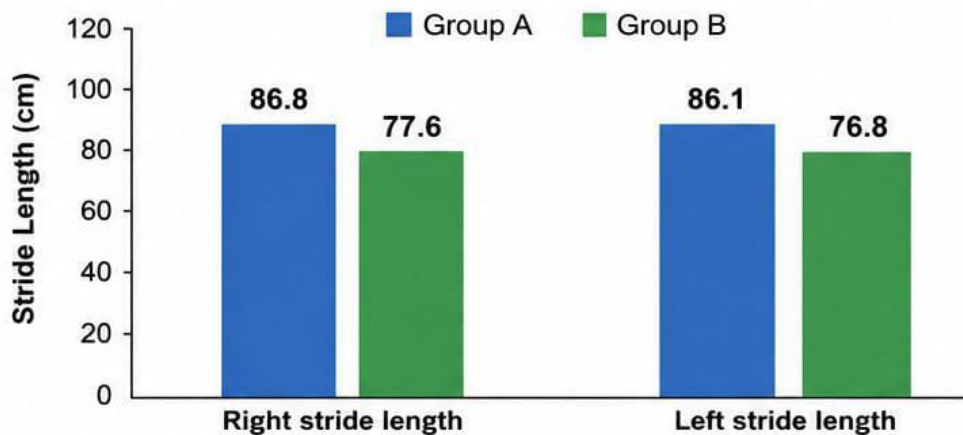


Figure 9. Post-intervention comparison of right and left stride length between groups.

Figure 10. Gait Symmetry

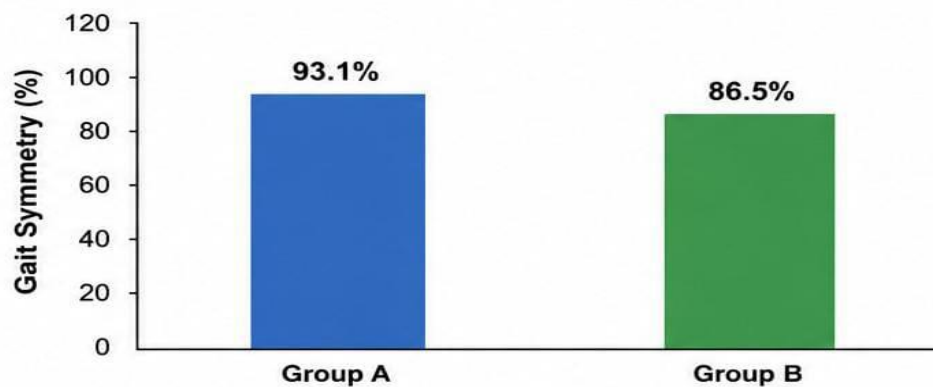


Figure 10. Post-intervention comparison of gait symmetry between groups.

3.6 Safety and Adverse Events

Table 7. Adverse Events During the Intervention

Adverse Event	Group A n (%)	Group B n (%)	Total n (%)
No adverse events	16 (80.0)	17 (85.0)	33 (82.5)
Mild muscle soreness	3 (15.0)	2 (10.0)	5 (12.5)
Mild fatigue	1 (5.0)	1 (5.0)	2 (5.0)
Muscle cramp	0 (0.0)	0 (0.0)	0 (0.0)
Fall during therapy	0 (0.0)	0 (0.0)	0 (0.0)
Joint pain	0 (0.0)	0 (0.0)	0 (0.0)
Skin irritation	0 (0.0)	0 (0.0)	0 (0.0)
Serious adverse events	0 (0.0)	0 (0.0)	0 (0.0)

The majority of participants experienced no adverse events. Mild muscle soreness and mild fatigue were the only reported treatment-related events, and no serious adverse event was documented.

4. Discussion

The present study demonstrated that progressive resistance exercise combined with conventional physiotherapy produced greater improvements than conventional physiotherapy alone across the major clinical and gait outcomes.

Participants in Group A demonstrated significantly greater reductions in lower-limb spasticity and greater improvements in muscle strength, gross motor function, dynamic balance, walking speed, cadence, stride length, and gait symmetry.

Spasticity and Muscle Strength

A major finding of the study was the greater reduction in lower-limb spasticity in the progressive resistance exercise group. Post-intervention MAS scores were significantly lower in Group A than Group B for both the right and left lower limbs, with both comparisons reaching $p < 0.001$. The findings suggest that appropriately prescribed resistance exercise did not aggravate spasticity and may have contributed to improved neuromuscular performance.

The improvement in gait-related outcomes observed in the present study is consistent with previous research showing that structured walking training can improve functional mobility in children with spastic cerebral palsy [21]. This supports the role of targeted physical rehabilitation in improving walking-related functional performance.

The reduction in spasticity observed in the present study is consistent with evidence supporting exercise and strengthening interventions as components of cerebral palsy rehabilitation. Previous literature has indicated that structured exercise can improve functional performance and muscle strength without producing detrimental increases in muscle tone. [7,12,13] The relationship between muscle strength and functional ability in children with cerebral palsy further supports the use of strengthening interventions. [10]

The intervention group also demonstrated significantly greater gains in lower-limb muscle strength. This improvement may be related to progressive overload, repeated activation of the targeted muscle groups, and gradual adaptation to resistance. Strengthening of the hip, knee, and ankle musculature can improve the capacity of the lower limbs to stabilize the body and generate controlled movement during functional activities.

Gross Motor Function

The study demonstrated a significant improvement in gross motor function following the intervention. The GMFM-66 total score was 63.90 ± 5.81 in Group A compared with 55.20 ± 5.70 in Group B, producing an 8.70-point between-group difference ($p < 0.001$).

Dimension D and Dimension E also significantly favored Group A.

These findings suggest that improvements in muscle strength were translated into meaningful functional changes. Stronger lower-limb muscles may facilitate standing, weight transfer, transitional movements, and walking-related activities. Exercise-based rehabilitation has previously been associated with improvements in motor and functional outcomes in children with cerebral palsy. [2-4]

The findings are also consistent with evidence summarized by Novak et al., which supports appropriately selected rehabilitation interventions for improving functional outcomes in children with cerebral palsy. [7] The present findings therefore strengthen the argument for including progressive strengthening within comprehensive pediatric rehabilitation programs.

Dynamic Balance

Dynamic balance also improved significantly following treatment. The post-intervention DGI score was 18.40 ± 1.90 in Group A compared with 13.20 ± 2.10 in Group B, resulting in a 5.20-point between-group difference ($p < 0.001$). Improved dynamic balance may be related to increased lower-limb strength and better neuromuscular control. During walking and other functional activities, adequate strength around the hip, knee, and ankle joints contributes to postural stability and controlled weight transfer. Exercise interventions have previously demonstrated beneficial effects on balance in children with cerebral palsy. [3,4]

The improvement in DGI scores is clinically relevant because dynamic balance is required for activities such as changing walking direction, adjusting walking speed, negotiating environmental obstacles, and performing functional mobility tasks. Thus, the greater DGI improvement observed in Group A indicates that the intervention may have provided benefits beyond isolated muscle strengthening.

Smartphone-Measured Gait Parameters

An important feature of the present study was the use of smartphone-based gait assessment. The intervention group demonstrated significantly greater improvements in walking

speed, cadence, stride length, and gait symmetry than the conventional therapy group. Walking speed was 0.97 ± 0.08 m/s in Group A compared with 0.80 ± 0.09 m/s in Group B. Cadence was 114.3 ± 6.9 steps/min compared with 104.7 ± 7.4 steps/min, respectively.

Right and left stride lengths were also greater in Group A, while gait symmetry reached $93.1 \pm 3.9\%$ compared with $86.5 \pm 4.8\%$ in Group B. All between-group comparisons were statistically significant at $p < 0.001$.

The improved gait performance may be explained by the combined effects of increased lower-limb strength, improved dynamic balance, and enhanced neuromuscular coordination. Children with spastic diplegic cerebral palsy commonly exhibit gait abnormalities associated with weakness, spasticity, and impaired motor control. [5,16] Strengthening the muscles responsible for propulsion and limb stabilization may therefore contribute to more efficient walking.

The findings are consistent with the thesis discussion, which describes improvements in walking speed, cadence, stride length, and symmetry following progressive resistance exercise. Evidence concerning task-specific and technology-assisted rehabilitation also supports the broader use of objective approaches for monitoring functional mobility in children with cerebral palsy. [13,16].

Role of Smartphone-Based Assessment

The use of smartphone-based gait assessment is particularly relevant in clinical environments where sophisticated three-dimensional gait laboratories may not be readily available. Technology-assisted rehabilitation has been increasingly explored as a means of supporting assessment and treatment monitoring in children with cerebral palsy. [13]

In the present study, the smartphone-based assessment detected differences between the intervention and control groups across several gait variables. This suggests that smartphone-based measurements may provide useful quantitative information alongside standardized clinical outcome measures. However, the findings should be interpreted within the limitations of smartphone-based assessment, which does not provide the complete

biomechanical information available through laboratory-based motion analysis.

Overall Interpretation

The overall pattern of results indicates that progressive resistance exercise provided additional benefits when combined with conventional physiotherapy. Both groups improved after treatment, but the magnitude of improvement was consistently greater in Group A. This pattern was observed for spasticity, muscle strength, GMFM-66, DGI, and all smartphone-measured gait parameters.

These findings are broadly consistent with systematic reviews reporting positive effects of exercise interventions on balance and motor function in children with cerebral palsy. [2-4] They also support the use of strengthening as an adjunct rather than a replacement for conventional physiotherapy.

The results should nevertheless be interpreted with consideration of the study's relatively small sample size and six-week intervention period. Longer follow-up and larger multicenter studies would be useful for determining whether the observed improvements are maintained over time.

5. Conclusion

Progressive resistance exercise combined with conventional physiotherapy was more effective than conventional physiotherapy alone in improving spasticity, lower-limb muscle strength, gross motor function, dynamic balance, and gait performance in children with spastic diplegic cerebral palsy.

The intervention group demonstrated significantly greater improvements in GMFM-66 scores, DGI scores, walking speed, cadence, stride length, and gait symmetry. The smartphone-based assessment also demonstrated its usefulness for quantifying clinically relevant changes in gait performance.

These findings suggest that progressive resistance exercise can be incorporated into conventional pediatric rehabilitation programs to provide additional benefits in functional mobility and walking performance.

6. Clinical Implications

The findings have several clinical implications:

1. Progressive resistance exercise can be incorporated into conventional physiotherapy for ambulatory children with spastic diplegic cerebral palsy.
2. Strengthening should target the major hip, knee, and ankle muscle groups.
3. Exercise intensity should be progressively adjusted according to the child's tolerance and functional ability.
4. Functional strengthening exercises such as sit-to-stand, step-ups, and resisted walking may be useful additions to rehabilitation.
5. Smartphone-based gait assessment can provide quantitative information regarding walking speed, cadence, stride length, and gait symmetry.
6. Combining clinical outcome measures with quantitative gait assessment may provide a broader picture of rehabilitation progress.

7. Limitations

The study had several limitations. The sample size was relatively small, with only 40 participants, which may limit generalizability. The intervention period was limited to six weeks, and long-term retention of treatment effects was not evaluated. Participants were children with spastic diplegic cerebral palsy, so the findings may not be directly applicable to other cerebral palsy subtypes. In addition, smartphone-based gait assessment provides selected gait parameters but does not provide the comprehensive biomechanical information available from laboratory-based three-dimensional gait analysis.

8. Recommendations

Future studies should:

- Include larger sample sizes.
- Recruit participants from multiple rehabilitation centers.
- Include longer intervention and follow-up periods.
- Examine whether improvements are maintained after cessation of supervised treatment.
- Compare progressive resistance exercise with other active rehabilitation approaches.
- Investigate home-based strengthening programs.

- Further evaluate smartphone-based gait applications against laboratory-based gait analysis.
- Explore the effects of different resistance-training intensities and frequencies.

REFERENCES

- Dhondt E, Dan B, Plasschaert F, Degelaen M, Dielman C, Dispa D, et al. Prevalence of cerebral palsy and factors associated with cerebral palsy subtype: a population-based study in Belgium. *Eur J Paediatr Neurol.* 2023;46:8-23.
- Soares EG, Gusmão CHV, Souto DO. Efficacy of aerobic exercise on functioning and quality of life of children with cerebral palsy: a systematic review and meta-analysis. *Dev Med Child Neurol.* 2023;65(10):1292-1307.
- Xiao J, Liu L, Tang N, Yi C, et al. Effects of exercise intervention on balance function in children with cerebral palsy: a systematic review and meta-analysis of randomized controlled trials. *BMC Sports Sci Med Rehabil.* 2024;16:164.
- Wang B, Huang H. Effects of various exercise interventions on motor function in cerebral palsy patients: a systematic review and network meta-analysis. *Neurol Sci.* 2024;45(12):5915-5927.
- Clewes K, Hammond C, Dong Y, Meyer M, Lowe E, Rose J. Neuromuscular impairments of cerebral palsy: contributions to gait abnormalities and implications for treatment. *Front Hum Neurosci.* 2024;18:1445793.
- Palisano R, Rosenbaum P, Bartlett D, Livingston M. Content validity of the expanded and revised Gross Motor Function Classification System. *Dev Med Child Neurol.* 2018;60(10):1112-1117.
- Novak I, Morgan C, Fahey M, Finch-Edmondson M, Galea C, Hines A, et al. State of the Evidence Traffic Lights: systematic review of interventions for preventing and treating children with cerebral palsy. *Curr Neurol Neurosci Rep.* 2020;20:3.

- Moll F, Kessel A, Bonetto A, Stresow J, Herten M, Dudda M, et al. Use of robot-assisted gait training in pediatric patients with cerebral palsy in an inpatient setting: a randomized controlled trial. *Sensors (Basel)*. 2022;22(24):9946.
- Verschuren O, Peterson MD, Balemans ACJ, Hurvitz EA. Exercise and physical activity recommendations for people with cerebral palsy. *Dev Med Child Neurol*. 2016;58(8):798-808.
- Handsfield GG, Meyer CH, Hart JM, Abel MF, Blemker SS. Relationships of muscle volume, strength, and function in children with cerebral palsy. *Muscle Nerve*. 2016;53(5):769-775.
- Novak I, Morgan C, Adde L, Blackman J, Boyd RN, Brunstrom-Hernandez J, et al. Early, accurate diagnosis and early intervention in cerebral palsy: advances in diagnosis and treatment. *JAMA Pediatr*. 2017;171(9):897-907.
- Ryan JM, Cassidy EE, Noorduyt SG, O'Connell NE. Exercise interventions for cerebral palsy. *Cochrane Database Syst Rev*. 2017;(6):CD011660.
- Bartlett DJ, Chiarello LA, McCoy SW, Palisano RJ. Technology-assisted rehabilitation for children with cerebral palsy: current evidence and future directions. *Dev Med Child Neurol*. 2021;63(10):1153-1160.
- Rosenbaum P, Paneth N, Leviton A, Goldstein M, Bax M, Damiano D, et al. A report: the definition and classification of cerebral palsy. *Dev Med Child Neurol Suppl*. 2007;109:8-14.
- Manikowska F, et al. Robot-assisted gait therapy and gait parameters in children with bilateral spastic cerebral palsy. *Gait Posture*. 2021.
- Novak I, Morgan C, Fahey M, et al. Task-specific gait training in children with cerebral palsy: current evidence and clinical implications. *Dev Med Child Neurol*. 2021;63(8):899-908.
- Kim SJ, Lee BH, Park ES, et al. Exoskeleton-assisted gait training improves gross motor function in children with spastic diplegic cerebral palsy. *Children (Basel)*. 2020;7(11):210.
- Friel KM, Kuo HC, Carmel JB, et al. Robotic-assisted treadmill training compared with conventional treadmill training in children with cerebral palsy. *Dev Neurorehabil*. 2021;24(5):321-329.
- Bar-On L, Molenaers G, Aertbeliën E, et al. Exoskeleton-assisted gait rehabilitation in children with cerebral palsy: effects on walking endurance and functional mobility. *Gait Posture*. 2023;102:180-186.
- Yang JH, Lee BH, Kim TH, et al. Short-term exoskeleton-assisted gait training improves functional mobility and lower limb strength in children with cerebral palsy. *Sensors (Basel)*. 2023;23(11):5148.
- Siddique H, Ijaz MJ, Kiran Q, Shahid Z, Rehmat S, Parveen S, et al. Effects of backward walking training versus forward walking training program to improve balance and mobility in children with cerebral palsy. [Journal details]. doi:10.64105/njwdsj53.