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Article in *Brain Disorders* · March 2025

DOI: 10.1016/j.dscb.2025.100213

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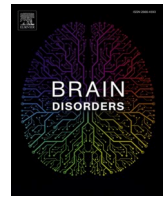


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The effectiveness of the Halliwick concept hydrotherapy and Bobath (Neurodevelopmental Treatment-NDT) in the treatment of children with cerebral palsy—A randomised controlled trial

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ARTICLE INFO

Keywords:

Cerebral palsy
Halliwick concept
Hydrotherapy
Bobath concept
Paediatric rehabilitation
Aquatic therapy

ABSTRACT

Background: Children with cerebral palsy (CP) often face challenges in motor function, balance, and daily activities. While land-based therapies such as the Bobath concept are widely used, complementary water-based therapies, including the Halliwick concept, offer unique opportunities to enhance rehabilitation outcomes.

Objective: This study aimed to evaluate the effectiveness of Halliwick concept hydrotherapy on gross motor function, balance, speed, and daily life skills in children with CP. A secondary objective was to compare the combined intervention of Halliwick hydrotherapy and Bobath therapy (NDT) with Bobath therapy (NDT) alone.

Methods: A total of 80 children with CP (mean age: 7.53 years) participated in this 9-month long randomised controlled trial. Participants were divided into three groups: the intervention group ($n = 40$), which received one session per week of both Halliwick hydrotherapy and Bobath therapy; control group 1 ($n = 35$), which received two sessions of Bobath therapy (NDT) per week; and control group 2 ($n = 5$), which did not receive any intervention. Two-way repeated measures ANOVA was conducted to compare the GMFM, PEDI, PBS, and TUG between time and groups, while a paired t -test to assess water-based (WOTA 1 & 2, SWIM, HAAR) through time.

Results: Statistically significant improvements were observed in the intervention group when compared with control groups across all measures. The intervention group demonstrated greater gains in gross motor function, balance, daily activities, and speed, using the TUG test, compared to control group 1, with minimal changes observed in control group 2. Notable improvements included increased GMFM scores (6 points improvement in the intervention group compared to 3.36 in control group 1 (Wilks's Lambda = 0.807, $F = 9.222$, partial $\eta^2 = 0.193$, $p < 0.001$)), balance (PBS: +3.8 points (Wilks's Lambda = 0.778, $F = 11.002$, partial $\eta^2 = 0.222$, $p < 0.001$)), and daily activities (PEDI: +6.32 points (Wilks's Lambda = 0.849, $F = 6.854$, partial $\eta^2 = 0.151$, $p = 0.002$)). Water-based assessments further highlighted substantial improvements in aquatic skills.

Conclusion: Incorporating Halliwick hydrotherapy into rehabilitation programs for children with CP yields significant benefits, enhancing motor skills, balance, and daily functioning beyond what is achieved with land-based interventions alone. These findings highlight the importance of integrating complementary aquatic therapies into routine clinical practice for children with CP. Further research with larger, homogeneous samples and extended intervention durations is recommended to refine these therapeutic approaches.

1. Introduction

Cerebral palsy (CP) is the most common physical disability that manifests early in life and persists throughout an individual's lifetime

[1]. The term "cerebral palsy" denotes brain damage caused by oxygen deprivation at birth and is associated with a spectrum of neuromuscular disorders in neonates [2,3]. Prevalence rates have been estimated to be about 2–2.5 per 1000 live births, making CP the most common motor

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<https://doi.org/10.1016/j.dscb.2025.100213>

Available online 18 March 2025

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disability in childhood [4]. CP is characterised as a static, non-progressive neurological condition, with the primary lesion typically occurring during early childhood, often within the first two years of life [5]. The clinical presentation of CP varies depending on the timing of central nervous system (CNS) damage, the underlying pathophysiology, the topographical distribution of the lesion, and the presence of associated disorders [6].

The annual cost for the health care system and the governments, to provide care to these children rises, respectively, to 66,000 euros per year [7]. This cost differs for ambulatory and non-ambulatory children, due to the walking independency the first ones have. Children with GMFCS levels III-V, have more expenses when referring for independency supplies (seating, wheelchairs) [8,9].

Multiple interventions are used to alleviate symptoms of CP including medicine, surgery, therapeutic approaches such as physical therapy, speech therapy, occupational therapy etc. [10]. Among these interventions, Bobath/NDT is also used commonly and widely, and it's recognised across the globe. The Neuro-Developmental Treatment (NDT) - Bobath concept developed following extensive clinical observations by Bertha and Karel Bobath [11]. This approach postulates that CNS lesions result in impairments in coordination, mobility, and muscle tone, ultimately leading to functional limitations [12]. The Bobath concept adopts a holistic framework, addressing not only sensory and motor deficits but also perceptual, cognitive, emotional, social, and functional domains of daily living [13]. It is a problem-solving methodology designed to identify aberrant or incomplete movement patterns and to facilitate developmental progress in children with diverse disorders [14,15].

The Halliwick concept, introduced in 1949 by James and Phyl McMillan, emphasises teaching swimming to individuals with disabilities. By incorporating principles of hydrostatics and hydrodynamics, the Halliwick approach addresses balance and movement challenges encountered in aquatic environments, particularly among individuals with severe disabilities. The core components of the Halliwick concept include: (1) familiarisation with water to promote enjoyment, (2) emphasis on motor deficits, (3) progressive swimming instruction tailored to personal potential and positive encouragement, (4) a focus on individual achievements, and (5) the promotion of systematic cooperation and competition through group activities [16].

Halliwick concept was specifically chosen for this study due to its structured, progressive, and adaptable nature, which allows individuals with varying levels of CP to develop core stability, postural control, and movement coordination in a safe and supportive aquatic environment. Unlike other aquatic therapies that primarily focus on passive movement facilitation or hydrostatic benefits, Halliwick concept integrates active participation, independence, and motor learning principles, which align with key rehabilitation goals for children with CP.

It is well-documented that complementary therapeutic approaches, when integrated with physiotherapy, can enhance therapeutic outcomes in children with CP during both early interventions and follow-up care. This study was driven by the observed underutilisation of these approaches. Moreover, the number of published studies investigating the therapeutic benefits of the Halliwick concept as a hydrotherapeutic modality remains limited.

This randomised controlled trial aimed to evaluate the effectiveness of the addition of Halliwick-based hydrotherapy to the rehabilitation programme of children with CP. A secondary objective was to compare the contribution of aquatic interventions to motor development compared to only land-based Bobath concept (NDT) intervention, with a particular focus on the attainment of gross motor milestones over time.

2. Methods

This study was approved by the Ethics Committee of the Department of Physical Education and Sport Sciences, University of Thessaly (3-3/15-7-2015). Written informed consent was obtained from parents or

caregivers for their child's participation in the assessments and video recordings. The research adhered to the ethical principles outlined in the World Medical Association's Declaration of Helsinki, which governs medical research involving human participants. The study was registered with ClinicalTrials.gov (NCT04770298).

2.1. Sample

Based on prior aquatic therapy studies in cerebral palsy, we anticipated a moderate intervention effect; accordingly, we assumed a medium effect size (Cohen's $f \approx 0.25$, corresponding to ~6 % variance explained). Using G*Power (version 3.1) to model a 3-arm repeated-measures ANOVA (between-group factor with 3 groups and a within-subject factor with pre- and post-intervention measurements), we determined that roughly 66 participants in total would be required to achieve 80 % power at $\alpha = 0.05$ for detecting a significant group $\times$ time interaction. To safeguard against attrition over the 9-month study (estimated dropout ~15 %), the sample size was inflated to a target of approximately 78.

A total of 80 children (aged 3–14 years; mean age: 7.53 years) with cerebral palsy (CP) were enrolled using the Gross Motor Function Classification System (GMFCS) across all five levels (I–V). The GMFM comprises 88 subtests assessing five domains of gross motor function [17]. To streamline test administration and prioritise subtests based on difficulty for children with CP, Russell et al. developed a shortened version, the GMFM-66, which consists of 66 prioritised subtests [18]. The GMFM has been reliably applied to classify children with CP in Greece [19]. Of the 80 children included, 43 (53.75 %) were boys and 37 (46.25 %) were girls. Classification of CP was based on the distribution of spasticity: (a) 41 children (51.25 %) presented with quadriplegia, (b) 23 children (28.75 %) with right or left hemiplegia, and (c) 16 children (20 %) with diplegia.

Eligibility criteria were a diagnosis of CP, GMFCS level I–V, age 3–15 years, general good health, following a Bobath concept (NDT) rehabilitation programme, without following any rehabilitation program. Exclusion criteria encompassed children with autism, those who had undergone surgery or received botulinum toxin injections within the past year, children with severe vision impairments, and those unable to follow verbal instructions or replicate the test procedures. Participants absent from the treatment programme for more than one week were also excluded. A total of 75 participants completed the treatment programme under the consistent supervision of the same therapist and 5 children were the second control group that did not follow any intervention (Fig. 1).

The study initially began with 96 children with CP; however, 16 were excluded from the final analysis. Three (3) were excluded due to chlorine allergies, two (2) due to a deterioration in their condition, one (1) due to surgery, three (3) due to the parents' inconsistency in attending the treatment program, and seven (7) due to non-participation in the intervention for more than a week. The characteristics of the final sample are presented in Table 1.

2.2. Design

Seventy-five children with cerebral palsy (CP) were randomised into two groups: 40 children formed the intervention group, 35 comprised control-intervention group 1, and 5 children constituted the non-intervention control group 2. The classification of children was based on the severity of their clinical condition, as determined by GMFCS (Table 1).

The Halliwick hydrotherapy programme emphasised improving balance, coordination, and muscle control through structured, progressive water-based activities. The therapeutic use of water buoyancy was central to promoting relaxation, joint unloading, and the facilitation of movement, allowing children to explore and develop motor patterns in a gravity-reduced environment. The natural resistance of water was

CONSORT Flow Diagram

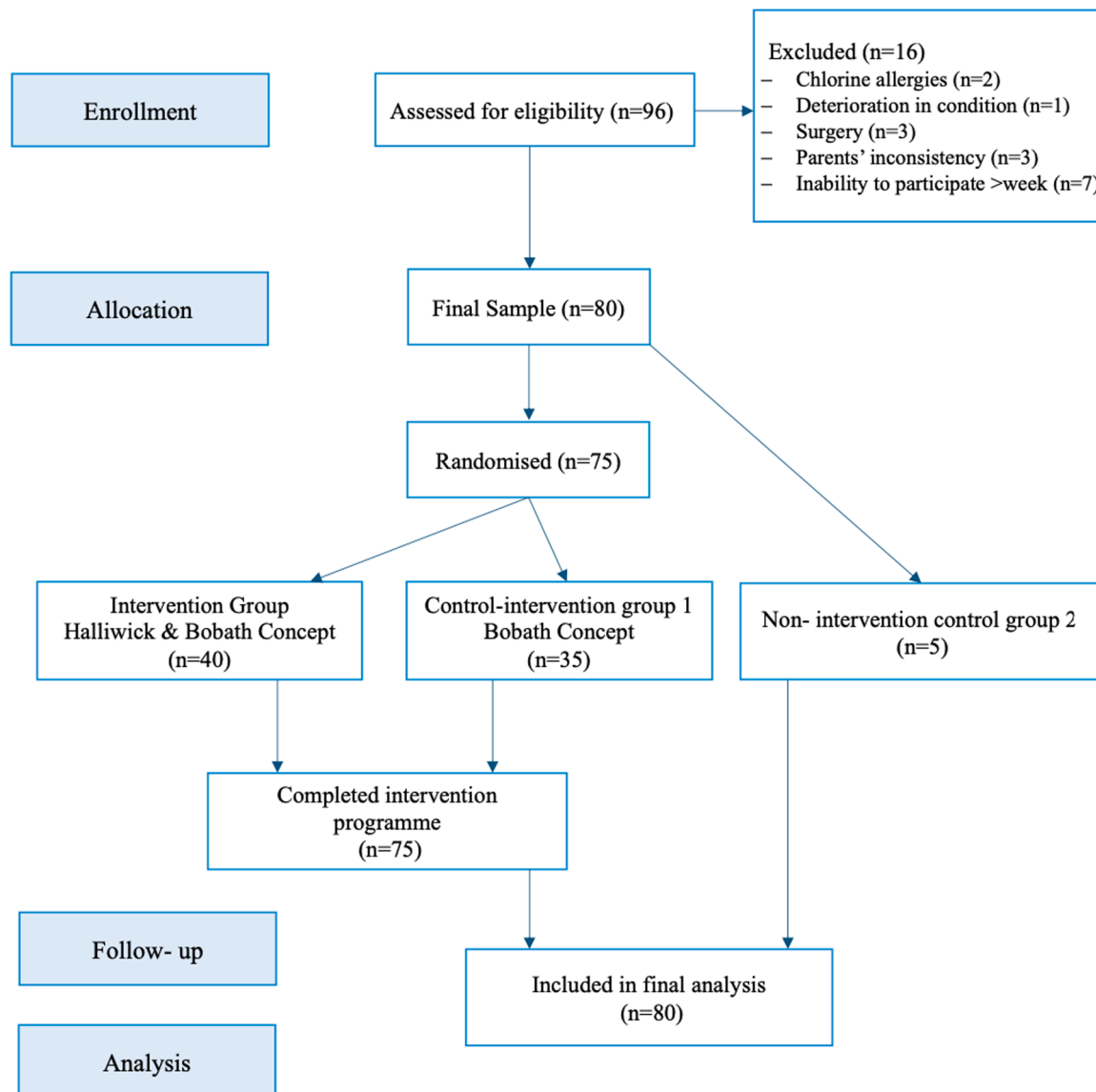


Fig. 1. CONSORT flow diagram. Flow-chart showing inclusion, randomization and participation throughout the study.

Table 1
Final sample's characteristics.

	Intervention group	Control group 1	Control group 2
Boys	18	20	3
Girls	22	15	2
Mean age	7.36	7.86	12
Mean height (cm)	117.5	119.2	128.0
Mean weight (kg)	23.8	24.5	31.2
Medications (%)	40.0	35	45
GMFCS I	8	7	1
GMFCS II	13	12	–
GMFCS III	7	8	1
GMFCS IV	8	6	1
GMFCS V	4	2	2
Bobath-NDT session/week	1	2	–
Hydrotherapy/Halliwick session/week	1	–	–

utilised to enhance muscle strengthening, build endurance, and improve motor control. Sessions included specific activities aimed at enhancing postural stability, facilitating transitions between movements (e.g., sitting to standing), and practising functional skills such as walking or floating. Additionally, the therapy addressed breathing control through water immersion, which contributed to improved respiratory function and better coordination during movement.

The Bobath concept (NDT) programme focused on improving postural alignment, regulating abnormal muscle tone, and facilitating functional movement patterns critical for gross motor skill development. Hands-on therapeutic techniques were employed to guide the child's movements, promoting active participation while minimising compensatory patterns. The therapy targeted trunk control, weight shifting, and coordination of the upper and lower limbs to support key transitions such as sitting, crawling, and standing. Sessions were designed to incorporate play-based and task-specific exercises, fostering engagement and enabling functional improvements tailored to each child's

needs.

2.2.1. Intervention group program

The 40 children in the intervention group participated in a combined therapeutic programme comprising Halliwick hydrotherapy in a pool and Bobath concept (NDT) sessions on land. Each therapy session was conducted once weekly for nine months, from September 2023 to May 2024. The aquatic therapy was delivered by a physiotherapist certified in the Halliwick concept, while the land-based therapy was conducted by a certified physiotherapist in the Bobath concept (NDT). Each session lasted 35 to 40 min and focused on individualised therapeutic activities tailored to the child's needs and goals. The rehabilitation programme was slightly adapted throughout the 9-month period, gradually advancing in complexity as the child's motor skills improved, ensuring individualised progression according to their abilities and therapeutic goals.

2.2.2. Control groups' program

Control group 1 participated in a Bobath concept (NDT) programme conducted on land, delivered by a Bobath concept certified physiotherapist. The intervention consisted of two sessions per week, each lasting 45 min. This group was utilised as the standard for comparison, aiming to test the hypothesis that combining Halliwick hydrotherapy with land-based intervention leads to superior therapeutic outcomes. Control group 2, which did not receive any intervention, was included to further validate the assumption regarding the progression of children with cerebral palsy who do not undergo therapeutic intervention. However, the size of this group was limited due to the difficulty in identifying children with CP who were not receiving any form of treatment.

2.3. Assessment

This study utilised three assessment tools in the aquatic environment and four on land. The selected tools included the Water Orientation Test of Alyn 1 (WOTA 1) [20,21], Water Orientation Test of Alyn 2 (WOTA 2) [20,21], Swim with Independent Measure (SWIM) [22,23], Humphries' Assessment of Aquatic Readiness (HAAR) [24], Gross Motor Function Measure (GMFM) [25], Pediatric Evaluation of Disability Inventory (PEDI) [26], Pediatric Balance Scale (PBS) [27], and Timed Up & Go test (TUG) [28,29]. Three experienced paediatric physiotherapists-hydrotherapists were involved in the administration of these assessments. For the water intervention group, the WOTA 1, WOTA 2, SWIM, HAAR, GMFM, PEDI, PBS, and TUG tests were applied. In contrast, for control group 1 (land-based intervention) and control group 2 (no intervention), the GMFM, PEDI, PBS, and TUG tests were used.

All assessments were conducted by two assessors, both of whom were paediatric physiotherapists-hydrotherapists with over 10 years of clinical experience. Baseline and follow-up assessments were recorded by one of three assessors, who did not participate in grading the tests. The other two assessors, who were blinded to the intervention groups, graded the tests independently by reviewing the recorded videos. To ensure consistency, all assessments were conducted at approximately the same time each morning, prior to the child's participation in any therapy session.

To minimise distractions, assessments were performed in the absence of observers, relatives, or other children. However, parents were required to be present during all assessments to ensure the child's safety and facilitate cooperation. The assessments were carried out in the same controlled environment at the "Laboratory of Movement" Developmental Physiotherapy Centre, which was equipped with standardised materials, including mattresses, staircases, adjustable seating, rods, toys, and balls. The equipment arrangement remained consistent across all measurements to ensure standardisation. Special attention was given to maintaining a comfortable room temperature, allowing children to wear

minimal clothing during the assessments. All procedures strictly adhered to the test manual instructions, with oral explanations and demonstrations provided when necessary for children with lower cognitive abilities. Any such adaptations were documented by the first assessor to ensure consistency in the approach followed by the second assessor. Each child was given three attempts to perform each test.

For the water intervention group, assessments were conducted in the same indoor heated swimming pool, measuring 8 meters in length, 4 m in width, and with a depth ranging from 0.80 m to 1.50 m. The water temperature was maintained between 32 °C and 33 °C, and the pool was illuminated exclusively by external lighting. No flotation aids were used during the assessments. Children wore swimsuits, except those without sphincter muscle control, who were provided with specialised water diapers or swimsuits.

Reassessments for the water group were conducted two days later, and all participants were reassessed at the conclusion of the nine-month intervention programme using the same assessment tools. The identical videotaping procedure was followed for both baseline and follow-up assessments to ensure consistency.

2.4. Statistical analysis

The Statistical Package for the Social Sciences (IBM SPSS, version 21.0) was utilised for all statistical analyses. Normal distribution of each variable was assessed using the Shapiro-Wilk test (table 2). Levene's Test for Equality of Variances was applied to evaluate homogeneity of variance. Descriptive statistics, including mean, standard deviation, median, maximum, and minimum values, were calculated. Paired samples *t*-test was conducted to evaluate the effect of time (1st day, 9th month) on WOTA 1, WOTA 2, SWIM and HAAR.

The effects of the intervention programs were analysed by examining two factors—time and group—on the GMFM, PEDI, PBS, and TUG scale measurements.

These factors were defined as follows:

- The time factor included two levels, corresponding to the two measurement points.
- The group factor comprised three levels: (1) Intervention group, (2) Control group 1, and (3) Control group 2.

A two-way Repeated Measures ANOVA was conducted to evaluate the effect of time and group on GMFM, PEDI, PBS, and TUG scale measurements, as well as to assess the interaction between time and group. Bonferroni corrections were made to adjust for multiple comparisons. The level of statistical significance was set at $p < 0.05$.

3. Results

Using the paired samples *t*-test the hypothesis that there is no statistically significant difference in WOTA 1 between the measurements taken at the first and second time points (after nine months) is rejected (*t* statistic value = -12.28, $p < 0.001$). Specifically, the mean WOTA 1 score recorded at the second measurements were higher, clearly indicating an improvement in the children's aquatic abilities (Table 3).

Table 2
p-values from Shapiro-Wilk test.

	1st day	9th month	Difference
WOTA 1	0.561	0.634	0.489
WOTA 2	0.721	0.958	0.836
SWIM	0.438	0.725	0.589
HAAR	0.884	0.826	0.694
GMFM	0.200	0.073	0.089
PEDI	0.348	0.077	0.067
PBS	0.200	0.189	0.365
TUG	0.286	0.316	0.165

Table 3

Descriptive statistics pre-test and post-test of WOTA 1, WOTA 2, SWIM, HAAR for the Intervention group.

	Descriptives								p-value
	Mean	95 % Confidence interval for mean		Median	Variance	Std. deviation	Min	Max	
		Lower bound	Upper bound						
WOTA1 - 1st Day	22,65	19,5223	25,7777	21	44,661	6,68,285	16	38	<0.001
WOTA1 –9 months	32,1	28,8085	35,3915	30,5	49,463	7,03,300	22	46	
WOTA2–1st Day	25,7	20,7004	30,6996	25,5	114,116	10,6820	12	57	<0.001
WOTA2 –9 months	44,6	40,0386	49,1613	44,5	94,989	9,74,625	21	66	
SWIM –1st Day	30,45	27,9360	32,9640	28,5	61,792	7,86,081	19	49	<0.001
SWIM - 9 months	41,125	39,2251	43,0249	40	35,292	5,94,068	32	54	
HAAR –1st Day	18,075	17,0072	19,1428	17	11,148	3,33,887	13	24	<0.001
HAAR - 9 months	23,4	22,2462	24,5538	23,5	13,015	3,60,768	16	30	

Similarly, the paired samples *t*-test rejected the hypothesis of no statistically significant difference in WOTA 2 between the first and second time points (after nine months) (*t* statistic value= 16.55, $p < 0.001$). Consequently, the mean WOTA 2 measurements after nine months were higher than those recorded at the initial measurement, reflecting improvement (Table 3).

For the SWIM scale, the paired samples *t*-test similarly rejected the null hypothesis of no statistically significant difference between the first and second time points (*t* statistic value= 13.84, $p < 0.001$). The mean SWIM measurements after nine months were higher than those recorded initially (Table 3).

The HAAR scale also demonstrated statistically significant differences between the first and second measurements, as confirmed by the paired samples *t*-test (*t* statistic value= 13.71, $p < 0.001$). Table 2 shows that the mean HAAR scores after nine months were statistically significantly higher than the initial measurements (Table 3).

Additionally, there was a statistically significant effect of the time factor (Wilks' Lambda= 0.722, $F = 26.699$, $p < 0.001$) and a significant interaction effect between time and group (Wilks' Lambda= 0.807, $F = 9.222$, $p < 0.001$) on GMFM. The intervention group demonstrated the most significant progress from the baseline assessment to the nine-month follow-up.

The statistical tables (Table 4) indicate a general improvement between the first and post-nine-month measurements, with the greatest improvement observed in the intervention group (Table 5).

Furthermore, there was a significant effect of the time factor (Wilks' Lambda= 0.750, $F = 26.620$, $p < 0.001$) and a significant interaction between time and group (Wilks' Lambda= 0.849, $F = 6.854$, $p = 0.002$) on PEDI. These results demonstrate that the intervention group exhibited the most notable improvement in measurements after nine months compared to the control groups (Table 5).

Table 4 illustrates statistically significant differences in PBS between the two-time measurements (Wilks's Lambda= 0.709, $F = 31.645$, $p < 0.001$) and by the interaction of time and group (Wilks's Lambda=

0.778, $F = 11.002$, $p < 0.001$). The intervention group showed the greatest improvement, with substantial gains in scores between the initial measurement and the nine-month follow-up (Table 5).

For the TUG scale, the time factor did not demonstrate a statistically significant effect (Wilks' Lambda= 0.935, $F = 3.729$, $p = 0.059$), nor did the interaction between time and group (Wilks' Lambda= 0.985, $F = 0.424$, $p = 0.657$). However, the lack of significance may be attributed to the small sample size. Despite this, Table 5 reveals a reduction in TUG scale times for the intervention group, indicating improvement over the nine-month period (Table 5).

4. Discussion

The purpose of this study was to evaluate the clinical utility of incorporating the Halliwick concept into treatment programs for children with disabilities, with the aim of improving therapeutic outcomes. The primary patient group included children with cerebral palsy (CP). The Halliwick concept and Bobath (NDT) treatment were selected as therapeutic interventions, as they represent two of the most commonly utilised rehabilitation approaches for children with CP, both on land and in aquatic settings.

The relatively small sample size in studies with children with cerebral palsy is characteristic of applied research involving specific populations. In clinical research, particularly where small sample sizes and additional factors may influence therapeutic effects and validity, even non-statistically significant or moderately significant findings can hold clinical relevance [30]. As a result, some researchers have questioned whether statistical significance alone should be the sole criterion of importance. Instead, they suggest that non-statistically significant differences may still provide meaningful insights [31]. Sutlive and Ulrich [30] argue that even moderate effects, without statistically significant differences, can contribute valuable evidence and generate hypotheses for further exploration of independent variables.

The results for the 40 children, assessing the development of swimming skills over a 9-month period, are presented below. A statistically significant improvement in swimming skills was observed across all measures. Specifically, WOTA 1 scores increased from a pre-intervention mean of 22.65 (SD: 6.68) to 32.1 (SD: 7.03) post-intervention. Similarly, WOTA 2 scores improved from 25.7 (SD: 10.68) before the intervention to 44.6 (SD: 9.75) afterward. The SWIM scores demonstrated comparable gains, increasing from 30.45 (SD: 7.86) pre-intervention to 41.125 (SD: 5.94) post-intervention. Additionally, HAAR scores rose from 18.075 (SD: 3.34) before the intervention to 23.4 (SD: 3.61) afterward. These tools consistently captured changes in swimming skill and water-related abilities over time. The improvements in WOTA 1 and WOTA 2 align with findings reported by the original authors, who noted similar changes after a 3-month intervention period, 1 session per week, duration 60 min each.

In the current study, the extended intervention period of 9 months revealed that the group of 40 children participating in the Halliwick

Table 4

Descriptive statistical measures on the time factor in the first (1), (1st Day) and second (2), (9 Months) measurements with GMFM, PEDI, PBS and TUG for the whole sample of children.

Time	Mean	Std. error	95 % confidence interval		p-value
			Lower bound	Upper bound	
GMFM					
1	54.488	4.282	45.960	63.015	<0.001
2	57.702	4.419	48.903	66.501	
PEDI					
1	47.086	3.402	40.312	53.860	<0.001
2	50.691	3.543	43.636	57.746	
PBS					
1	19.879	2.661	14.580	25.177	<0.001
2	21.869	2.755	16.383	27.355	
TUG					
1	19,034	2718	13,585	24,483	0.059
2	18,142	2780	12,569	23,715	

Table 5

Descriptive statistical measures about the interaction of factors group and time in the first (1), (1st Day) and second (2), (9 Months) measurements with GMFM, PEDI, PBS and TUG.

Group * Time						
Group	Time	Mean	Std. error	95 % confidence interval		p-value (for the interactiongroup*time)
				Lower bound	Upper bound	
GMFM						<0.001
Intervention group	1	57,276	3645	50,017	64,534	
	2	63,156	3761	55,666	70,646	
ControlGroup 1	1	58,637	3945	50,781	66,493	
	2	62,000	4071	53,894	70,106	
ControlGroup 2	1	47,550	11,670	24,311	70,789	
	2	47,950	12,042	23,972	71,928	
PEDI						<0.001
Intervention group	1	52,090	3205	45,709	58,471	
	2	58,408	3337	51,762	65,053	
Control Group 1	1	52,429	3426	45,607	59,250	
	2	55,546	3568	48,441	62,650	
Control Group 2	1	36,740	9064	18,692	54,788	
	2	38,120	9439	19,324	56,916	
PBS						0.002
Intervention group	1	23.750	2.507	18.759	28.741	
	2	27.550	2.595	22.382	32.718	
Control Group 1	1	23.086	2.680	17.750	28.422	
	2	25.057	2.774	19.533	30.582	
Control Group 2	1	12.800	7.090	-1.317	26.917	
	2	13.000	7.340	-1.616	27.616	
TUG						0.657
Intervention group	1	16,250	2036	12,168	20,332	
	2	14,964	2082	10,789	19,139	
Control Group 1	1	17,852	2074	13,695	22,009	
	2	16,963	2121	12,711	21,214	
Control Group 2	1	23,000	7619	7726	38,274	
	2	22,500	7792	6879	38,121	

concept programme exhibited the most substantial improvement in GMFM scores, with an average increase of 6 units, compared to 3.36 units in the group of 35 children who participated exclusively in the land-based intervention. By contrast, the 5 children who did not participate in any therapeutic programme showed minimal improvement, with an average change of only 0.40 units. Specifically, the water intervention group demonstrated an increase in mean GMFM scores from 57.28(SD: 23.05) pre-intervention to 63.16 (SD: 23.79) post-intervention. The land-based intervention group showed an improvement from 58.64 (SD: 23.34) to 62.00 (SD: 24.08) after 9 months of Bobath (NDT) therapy. In comparison, the non-intervention group exhibited a marginal increase in mean GMFM scores, rising from 47.55 (SD: 26.09) to 47.95 (SD: 26.93) over the same 9-month period.

These findings align with a study involving 27 children with cerebral palsy (CP), which reported significant improvements in gross mobility following a six-week programme comprising two 55-minute sessions per week [32]. Similarly, a randomised controlled trial (RCT) involving 34 independently walking children with CP, aged 3 to 5 years, demonstrated improvements in walking, jumping, and running activities. This improvement was observed in the group performing Halliwick-based exercises in water three times per week for 45 min over a 12-week period [33]. Another study corroborates these findings, showing enhancements in overall gross motor functionality among independently walking children. This study included seven children with functional CP (GMFCS levels I–III) who participated in six weeks of therapeutic swimming based on the Halliwick philosophy, attending two 45-minute sessions per week [34].

In contrast, some studies did not find statistically significant differences in GMFM scores. One such study involved 19 children aged 3 to 6 years, who participated in 30 min Halliwick interventions twice weekly for four months [35]. Similar results were observed in a follow-up study by the same research team [36], which included 16 children aged 3 to 6 years. While the study concluded that aquatic therapy reduced metabolic costs compared to physiotherapy alone, it did not demonstrate a

significant impact on movement. This lack of statistical significance may be attributed to several factors, including the relatively short intervention duration, the small sample size, and the potential variability in participants' baseline functional levels. Additionally, it is also possible that improvements in movement efficiency and energy expenditure did not immediately translate into measurable changes in gross motor function within the study period.

In terms of daily life activities, as assessed by the PEDI tool, the Halliwick-based intervention group outperformed the other two groups after the nine-month intervention period. Specifically, the water intervention group exhibited an average improvement of 6.32 units, with PEDI scores increasing from a baseline mean of 52.09 (SD: 20.14) to 58.41(SD: 21.21). The Bobath (NDT) concept group showed an average improvement of 3.12 units, with scores rising from 52.43 (SD: 19.24) to 55.54(SD: 19.72) over the same period. By contrast, the group of children who did not receive any intervention demonstrated only a minor improvement of 1.38 units, with scores increasing from 36.74 (SD: 28.33) to 38.12 (SD: 28.49).

These findings are consistent with the study by Getz [35], which involved 19 children aged 3–6 years who participated in a 30-minute Halliwick therapeutic programme twice weekly for four months, demonstrating statistically significant improvements in PEDI scores. Conversely, Fragala-Pinkham et al. [37] did not observe statistically significant changes in PEDI scores following a water aerobics intervention in children with functional CP. Similarly, another study involving 17 children who completed 32 sessions of combined land-based and aquatic therapy reported no significant improvements in daily life activities [36]. The lack of statistical significance in these studies could be attributed to factors such as short intervention durations, small sample sizes, and the non-functional nature of aerobic activities.

In terms of balance, as assessed by the PBS after nine months, the Halliwick-based intervention group showed greater statistical improvements compared to the other two groups. Specifically, the water intervention group's average score increased from 23.75 (SD: 16.30)

pre-intervention to 27.55 (SD: 17.18) post-intervention. The Bobath (NDT) group improved from a mean score of 23.09 (SD: 15.00) to 25.06 (SD: 15.19) after nine months of neurodevelopmental treatment. By contrast, the group of children who did not receive any treatment exhibited only a marginal change, with scores increasing from an average of 12.80 (SD: 18.30) to 13.00 (SD: 18.62).

Most existing studies investigating balance changes through aquatic interventions have focused on adult patients recovering from stroke, frequently using the Berg Balance Scale as the primary evaluation tool. For this research, the Pediatric Balance Scale (PBS), an adaptation of the Berg Balance Scale for paediatric populations, was employed. These findings align with the results of Mackinnon [38], who assessed an 8-year-old boy with CP (spastic diplegia) before and after a water-based intervention, demonstrating improved upright balance. Similarly, a case study involving an 11-year-old girl with Rett syndrome reported improvements in balance following an 8-week aquatic therapy programme [39]. A comparable result was observed in a 14-year-old with spastic quadriplegia after 8 weeks of aquatic therapy [40]. Additionally, a study conducted in Greece demonstrated positive effects of hydrotherapy on balance and gross mobility in 10 children with CP who participated in an 8-week traditional physiotherapy programme. These improvements were attributed to the dynamic changes in the base of support provided by aquatic therapy, in contrast to conventional physiotherapy [41].

Regarding speed, as assessed by the TUG test, only children classified as GMFCS levels I to III were included, as the test requires independent walking. After the 9-month intervention, the Halliwick-based programme demonstrated superior statistical outcomes compared to the other two groups. Specifically, in the water intervention group, 28 children exhibited a decrease in TUG execution time from a pre-intervention average of 16.25 s (SD: 10.78) to 14.96 s (SD: 11.01) post-intervention. In the Bobath concept (NDT) group, 27 ambulatory children showed a reduction in TUG time from 17.85 s (SD: 10.26) to 16.96 s (SD: 10.69) following treatment. By contrast, the group of five children who did not receive any intervention displayed only a minor change, with TUG times decreasing from 23.00 s (SD: 19.80) to 22.50 s (SD: 17.68) over the 9-month period.

These findings align with the results reported by Kelly and Darrah [42], who reviewed studies focusing on intervention programs lasting 6 to 10 weeks. Their analysis found no significant differences across studies during the intervention period, although pre-test and post-test measurements consistently demonstrated increases in muscle strength and speed among children with CP.

However, the present study faced certain limitations. It was not feasible to restrict parental involvement in therapeutic activities conducted at home, potentially influencing the outcomes. Additionally, the control group of children who did not receive any intervention was limited in size due to the difficulty in identifying a sufficient number of children not participating in any treatment programme.

5. Conclusion

Using the Halliwick concept in hydrotherapy has demonstrated potential benefits for children with cerebral palsy (CP), particularly in improving water skills and adaptability. This method may contribute to enhancements in gross motor function, daily living activities, balance, and speed. Specifically, 67.5 % of participants exhibited improvements in motor function, 62.5 % in daily activities, 72.5 % in balance, and 64 % in speed. These findings should be interpreted with caution, as factors such as baseline functional variability, differences in individual responsiveness to therapy, and the influence of additional interventions may have contributed to the observed outcomes. It appears, however, that the addition of hydrotherapy to the rehabilitation of children with cerebral palsy can contribute positively to their motor development. Further studies with larger samples and rigorous control of confounding variables are recommended to confirm the effectiveness of hydrotherapy in pediatric rehabilitation.

Clinical Implications for Hydrotherapy in CP Rehabilitation:

Hydrotherapy, particularly using the Halliwick concept, is highly effective for children with CP across various GMFCS levels. It is especially beneficial for children with:

- Limited balance and coordination.
 - Reduced independence in land-based activities.
 - Difficulties with movement speed or transitions.
1. For optimal outcomes, Halliwick-based hydrotherapy should:
 - Be conducted in a warm, supportive aquatic environment with trained hydrotherapists.
 - Include structured sessions focusing on balance, speed, adaptability, and motor control.
 - Integrate play-based and task-oriented exercises to maintain engagement and improve functional skills.
 - Combining hydrotherapy with land-based interventions, such as the Bobath concept, may yield synergistic benefits, addressing motor impairments holistically.

Future directions

Although the results of this study underscore the effectiveness of hydrotherapy, further research is required to validate these findings. Larger, more homogeneous samples and extended intervention durations are needed to explore the full potential of this approach. Moreover, future studies should investigate individualised protocols tailored to specific motor impairments and functional goals.

Hydrotherapy using the Halliwick concept provides a safe and effective therapy for enhancing motor function, balance, and independence in children with CP. Clinicians are encouraged to incorporate this method into their therapeutic programs, particularly for children facing challenges in traditional land-based physiotherapy.

Availability of data

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Funding

This research did not receive any funding.

CRediT authorship contribution statement

Konstantinos Chandolias: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Eleni Argyroula Tsounia:** Writing – review & editing, Writing – original draft, Validation. **Nikolaos Strimpakos:** Writing – review & editing, Supervision. **Efthalia Zogka:** Writing – review & editing, Data curation. **Thomas Besios:** Writing – review & editing, Validation. **Georgios Marios Kyriakatis:** Writing – original draft, Data curation. **Panagiotis Tsimeas:** Writing – review & editing, Methodology. **Athanasios Tsiokanos:** Supervision, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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