How to Cite:
Mohamed, S. S., Ghany, W. A. A., & Abdelazeim, F. H. (2022). Upper limb physical therapy interventions to improve functions in cerebral palsy children: A review article. *International Journal of Health Sciences*, *6*(S5), 6545–6560. https://doi.org/10.53730/ijhs.v6nS5.10380

Upper limb physical therapy interventions to improve functions in cerebral palsy children: A review article

Sara Samir Mohamed
Department of Physical Therapy for Paediatrics, Faculty of Physical Therapy, Cairo University, Giza, Egypt.

Walid A. Abdel Ghany
Department of Neurosurgery, Faculty of Medicine, Ain Shams University, Cairo, Egypt.

Faten Hassan Abdelazeim
Professor, Department of Physical Therapy for Paediatrics, Faculty of Physical Therapy, Cairo University, Giza, Egypt.

***Abstract*---**Introduction: upper limb function is considered challenging barrier for children with cerebral palsy hindering their activity levels and participation in play activities at home, school or other contexts. The aim of this critical review is to gain a deeper understanding of how the different physical therapy interventions could be beneficial in terms of functional outcomes either when used separately or combined with each other's and provide summary of dosing reported for each. Method: A literature search was conducted using electronic databases for health research; Embase, Cochrane, Pedro, Science Direct and Clinical Key. 16 papers where selected meeting the aim of the review and the criteria of work (randomized control trials. systematic reviews, meta-analysis) and critically reviewed. Findings: recommended dosing in literature was: for CIMT dosing 60 hours over 10 days and 6 hours per day for 15 days, for HABIT 6 hours per day for 15 days and 6 hours per day for 3 weeks, for Strength Training is 6-10 per set, and the intensity (load) is increased to 85% 1RM. While, goal directed training dosing to be effective should exceed 30-40 hours per week and Virtual reality to be more than 1080 minutes over 4 weeks. Conclusion: hand functions improvement needs a multidimensional structured program based on each child assessment and needs. A high dose recommended implicates the necessity of family contribution through home programs. Further researches are needed to validate some reported dosing and compare and/or combined more modalities to guide clinical practice.

International Journal of Health Sciences ISSN 2550-6978 E-ISSN 2550-696X © 2022.
Manuscript submitted: 9 April 2022, Manuscript revised: 18 June 2022, Accepted for publication: 27 July 2022

***Keywords*---**Physical therapy, unilateral cerebral palsy, upper limb, functional outcomes, children, motor control.

Introduction

Cerebral palsy (CP) is a non-progressive neurodevelopmental disorder which begins in the early stage of life. The motor disorders are often accompanied by a disturbance of sensation, perception, cognition, communication, behaviour, epilepsy, and by secondary musculoskeletal problems. **(1)** Children with CP usually have difficulties reaching and grasping with the involved upper extremity characterized by: decreased speed, decreased timing and coordination of reaching movements, weak grasp, and immature coordination of precision grasp forces **(2)**

Muscle tightness and subsequently joint deformities contribute to the limited use of the extremities for functional activities such as writing and the manipulation of toys. Children with CP may develop long-term structural and functional difficulties such as development of thumb-in-hand deformity, metacarpophalangeal joint dislocation, reduced limb growth, or upper limb muscle weakness. This hinders opposition and grasp movements which result in reduced bilateral dexterity function, a neglecting of the involved limb and possibly a reliance on others to complete functional activities. **(3)** Currently, functional training regimen and strengthening programs are used considering that muscle weakness is one of the important reasons influencing motor function and thus enhancing muscular strength is a major treatment for motor performance. There is increasing evidence that muscle weakness of the upper limb also decreases the ability of children with CP to perform daily activities**. (4)**

While children with unilateral cerebral palsy have demonstrated changes in movement performance of the upper limb as a result of functional interventions, there have been few studies that have evaluated intervention effects on kinematics and/or muscle activation patterns of the upper limbs**.** Recommendations of a systematic review that there is a need to perform randomized control trials in the field of strength training of the upper limb in children with CP, using specific guidelines for strength training as a start to standardize the training principles. The same review also reported that there is no clear method of training could be advised. Both stand-alone and embedded strength training showed equal effects. Combining electrical stimulation and task-oriented therapy did not hamper the effect of training. **(5)**

Das and Ganesh 2019 concluded that physiotherapy interventions should improve both the quantity and quality of motor control. Despite having analysed the evidence of various techniques, it is not yet known the types of activities and/or approaches that should be encouraged and whether or not there is a need for external equipment to augment motor acquisition. Based on the results, it may be concluded that CIMT and task-oriented functional training to be effective in this population. Other interventions have very low-quality evidence. Contrary to popular beliefs, interventions such as NDT are not backed sufficiently by evidences. Considering the importance of the role played by physiotherapy profession in the management of CP, it is of foremost importance that all

clinicians involved in treating these children need to base their therapy based on the recent evidences. More research using rigorous designs is urgently needed. **(6)**
The question of this review is to establish structured guidelines of interventions that were recommended in literature to improve participation of CP children via improvement of upper limb functional outcomes. Also, to highlight other interventions that need further researches to prove its efficacy and benefits.

Upper Limb Neural, Motor and Functional Challenges facing Cerebral Palsy Children

Neural Challenges: Challenges arise since early infancy or at insult time on many aspects: Neural plasticity, structural and functional changes, barriers facing participation in activities at home and school and secondary psychological challenges too.
Progressive maladaptive central nervous system processes due to brain injury are not limited to the corticospinal tract it affects also the development of spinal cord segmental circuitry which in turn affects motor map development due to motor cortex inhibition in early infancy. **(7)**

Motor Challenges: The infant developing HCP will often have a closed hand posture and flexed and adducted thumb persisting beyond the first few months. The development of asymmetrical hand functions how significant variation in infants with HCP; however, pronation of the forearm and thumb abnormalities is most frequently seen. As the infant develops reaching and grasping abilities on the unaffected side, parents start to notice a strong hand preference, with lack of use of the affected hand. The fingers are flexed, and the thumb is often adducted and flexed, resulting in the thumb-in-palm deformity. Dislocation may occur at the metacarpophalangeal joint, with hypermobility at the proximal interphalangeal joints causing swan-neck deformity, which impacts negatively on opposition and grasp. The thumb adduction also impacts on grasp, especially pincer and whole hand grasp. **(3)**

Functional challenges: The child has to battle with a number of hindrances in order to use the affected hand, and may make an active choice to use the less-affected hand alone. Note that subtle deficits in function are present on the side contralateral to the hemiplegia–hence the term less-affected hand. **(7)**
Recent studies indicate an increased cognitive load for movement preparation with the affected hand during a bimanual task. This could contribute to a preference for uni-manual task performance. Compensatory strategies commonly observed include use of the teeth or stabilizing objects between the knees or against the body instead of using the affected hand. While children may be able to perform some bimanual tasks largely one-handed using such strategies, task completion time often remains prolonged. This can lead children to seek the assistance of others, or to avoid certain activities. **(9)**

Children with fine motor deficiencies exhibit impairments in the execution of highly practiced and skilled motor actions such as drawing and handwriting. It have been recognized that children's dynamic drawing features as indicators of handwriting ability. **(10)**

Upper limb Interventions in Modern literature (table 1)
CIMT, HABIT, Resistive training, Splinting, Electrical Stimulation, TENS, virtual reality, are among the most commonly used upper limb interventions for upper limb in cerebral palsy children management.

HABIT and CIMT

Sakzewski et al Conducted an RCT where 64 unilateral CP children were randomly allocated to CIMT or Bimanual training group. Therapy was delivered over 60 hours on 10 days using circus theme and goal directed training. Change between baseline, 3, and 26 weeks on the Melbourne Assessment of Unilateral Upper Limb Function (MUUL 7.4%), Assisting Hand Assessment, and Canadian Occupational Performance Measure defined best responders. It was then concluded that Secondary analysis of a single-blind randomized trial comparing CIMT and bimanual training suggests therapists should target children with poorer hand function for an intensive block of UL training to achieve immediate gains in the ability to use the impaired limb, but longer-term retention of effects is more likely with CIMT. Gains in bimanual performance were associated with improved movement efficiency of the impaired UL. Regardless of the type of intervention, the achievement of individualized goals is more favourable for older children with left-sided hemiplegia. **(11)**

Hung et al evaluated the effects of Constraint Induced Movement Therapy (CIMT) and Hand Arm Bimanual Intensive Therapy (HABIT) on bimanual coordination and gait control during a complex whole-body task. 16 children with congenital hemiplegia (age 6–12 years; GMFCS: I-II, MACS: I-II) were randomly assigned to either CIMT or HABIT for 6 hours per day training for 15 days. Children were asked to perform two whole body tasks (walking with and without a tray carrying) while 3-D kinematic analysis was performed before and after training. The HABIT group improved their bimanual coordination (decreased differences in heights of the two hands, better tray levelness) and decreased the lateral tray excursion after training. However, the CIMT group only decreased the lateral tray. Findings supported the principles of practice specificity in that HABIT improved bimanual coordination during the current whole-body task for children with USCP. **(12)**

Ouyang et al 2020, supported the evidence of using HABIT in a recent systematic review and found that nearly half of the 15 included studies used HABIT for 6 h a day for three consecutive weeks (totalling 90 h), and some studies used different doses/schedules or added training components to HABIT. Synthesis of the results demonstrated a significantly small effect for improving upper limb function immediately after the interventions, and the improvements were maintained at follow-up. Similarly, significantly moderate or large effect sizes were found for self-care function and goal improvements. It was concluded that HABIT in the form of 6 h a day for three consecutive weeks led to the improvement of bimanual ability, unilateral dexterity, self-care function, and functional goals after the intervention and that the improvements were mostly maintained during the follow-up period. In addition, other forms of HABIT with different dosages or added training components have been investigated for effectiveness in children with CP. While these modified forms of HABIT showed evidence for improving self-care function and functional goals, there was little impact on upper extremity function. **(13)**

Basu et al, described the Infant CIMT application as Baby-CIMT which is considered a modified CIMT protocol, the restraint being a mitt or glove. The intervention will be for 30 min daily for 6 weeks in infants aged 3–8 months and will focus on grasping and exploring objects in an enriched environment with close attention to carers' and therapists' behaviour toward the infant, toy selection and position of the infant. With respect to the need for development of movement control of the unaffected hand and for bimanual motor integration in infancy, caution is needed when considering CIMT in infants; however, this protocol represents a much reduced intensity of intervention compared with classical CIMT, which would typically involve 60 or 90 h of therapy within a few weeks. **(3)**

Alahmari et al, conducted a meta-analysis aiming to compare effect of HABIT to other interventions in improving hand function and found that the efficacy of HABIT versus CIMT or structured and unstructured bimanual therapy, HABIT showed a trivial effect compared to the other interventions in improving hand function, with an effect size of 0.06. More RCTs are needed to substantiate their evidence **(14)**

Resistive Training

Moreau et al concluded in his review that Links exist among muscle performance and functional skill ability, as well as health and happiness. These links are an avenue for treatment for children with CP. Paediatric physical and occupational therapists can optimize muscle performance in youth with CP through resistance training programs. Muscle performance consists of not only strength but also muscle power and rate of force development. Muscle power and rate of force development are often more impaired than strength and muscular endurance in children and adolescents with CP and should be addressed when designing a resistance training protocol. Improving muscle performance through resistance training requires adherence to the dosing parameters of duration, frequency, volume, intensity, and velocity of movement depending on the goal of the exercise. Too often resistance programs for children with CP are inadequately dosed for the intended purpose. Optimizing dosing parameters for resistance training will ensure maximal results that promote changes at the structural and functional level. The recommended dosing for Strength Training was number of reps is decreased to 6-10 per set, and the intensity (load) is increased to 85% 1RM. Power training exercises should be modified such that volume is increased to 6 sets of 3-6 repetitions, with an intensity target of 30-80% 1RM or greater so that no more than 6 reps can be performed in any single set at a fast velocity before fatigue occurs. **(15)**

Rameckers et al, concluded from their review that there is no clear method of training can be advised. Both stand-alone and embedded strength training showed equal effects. Combining electrical stimulation and task- oriented therapy did not hamper the effect of training. The introduction of BoNT-A does hamper the effect of strength training. A frequency of minimal 3 times a week was performed in all studies and duration of minimal 8 weeks seemed to be effective for strength training. The variation related to dose and intensity is too large to come to conclusions. It can, therefore, be concluded that there is a need to perform RCTs in the field of strength training of the upper limb in children with CP, using specific guidelines for strength training as a start to standardize the training principles. Dosing preference to the PRE training is at least 12 weeks of training, 3 times per week, with a resistance of 8–15 RM. **(16)**

Vaz et al study was conducted on nine children with spastic hemiplegic cerebral palsy who underwent 24 sessions of wrist muscles strengthening in the extended wrist range aided by electrostimulation. Isometric strength of flexors and extensors was registered in three wrist positions (30◦ of flexion, neutral, and 30◦ of extension) to infer on angle–torque curves. Passive stiffness of wrist flexors and wrist flexion angle during manual tasks and hand function were also documented. Significant strength gains were observed at 30◦ of wrist extension for flexors and extensors. No gains were observed at 30◦ of flexion. The difference in extensor strength between the three test positions changed after intervention, suggesting a shift in the angle–torque curve. No changes were observed in passive stiffness, wrist angle, or hand function. Strength training in specific joint ranges may alter angle–torque relationships. For functional gains to be observed, however, a more aggressive intervention and contextualized task training would probably be needed. **(17)**

Splinting

Barosso et al, examined the hand movements of children with cerebral palsy during functional tests and compares the children's performance with and without the aid of an orthosis that provides wrist extension and thumb abduction. The range of motion of the trapezio-metacarpal joint was assessed for 32 participants via a reflexive markers image system. Observed motions included flexion–extension and abduction–adduction motions performed in the course of four tests for manual ability; the rest position, lateral and tripod pinches and cylindrical grasp. Muscle strength and manual ability were evaluated using dynamometry and the Jebsen–Taylor test. It was concluded that the orthosis improved the range of motion of the trapeziometacarpal joint, muscle strength and manual ability. The combination of the three techniques may provide the basis for a quantitative assessment of hand dysfunction/improvement in cerebral palsy that will ultimately guide health professionals in their clinical interventions. **(18)**

Burtner et al, The effect of wrist/hand orthoses on force production, dexterity, and upper extremity muscle recruitment was investigated in children with and without cerebral palsy (CP) to determine if splint design affects 1) hand function and 2) muscle activation. Ten children with hemiplegic CP used hands with spasticity and five age-matched control children used dominant and non-dominant hands in three splint conditions (no, dynamic, static) during grip, pinch, and peg-board tests while electromyography (EMG) recorded muscle activation. It was found that all children had significantly less wrist EMG activity during grip with static splints; only children with CP had greater compensatory shoulder activation. Preliminary findings suggest that dynamic splints increased function of children with CP while static splints decreased muscle activation at wrist and increased compensatory shoulder muscle recruitment **(19)**

Electrical stimulation and TENS

Yıldızgören et al, studied the effects of neuromuscular electrical stimulation on wrist range of motion, wrist and finger flexor spasticity, and hand functions in patients with unilateral cerebral palsy. Twenty-four children with unilateral spastic cerebral palsy (14 boys and 10 girls) between the ages of 5 and 14 years were randomized into neuromuscular electrical stimulation and control groups. Conventional exercises were applied, and static volar wrist-hand orthosis was administered to all patients 5 days a week for 6 weeks. Additionally, 30-minute neuromuscular electrical stimulation sessions were applied to the wrist extensor muscles in the neuromuscular electrical stimulation group. Patients were evaluated by Zancolli Classification System, Manual Ability Classification System, and Abilhand-Kids Test. It was found that NMES treatment in addition to splinting and conventional exercises seems to be effective in improving active ROM, spasticity, and hand functions. **(20)**

Vaz et al, studied the effect of NMES combined with strength training on isometric strength and passive stiffness but didn't address the functional outcomes that could be related to improvement gained in the previously mentioned aspects**. (17)**

Alhusseiny et al, studied the effect of TENS combined with therapeutic exercises on hand function by spasticity in children with hemiplegic cerebral palsy (CP). Twenty-nine children with hemiplegic CP were randomly assigned to the TENS group or the control group. The TENS group received traditional physical therapy with the adjunct application of conventional TENS for 30 minutes on the wrist extensors, once daily, 3 days a week, for 8weeks, while the control group received traditional physical therapy. The results showed a significant intergroup difference in handgrip strength over the 8-week period. The time to accomplish the Jebsen Taylor Hand Function Test (JTHFT) task decreased by 48% and the ABILHAND-Kids questionnaire scores improved by 23% in the TENS group. It was concluded then that the use of TENS in combination with therapeutic exercise may improve strength and hand function. **(21)**

Virtual Reality

Rathinam et al., conducted a systematic review on virtual reality interventions impact on hand function in cerebral palsy. The study purpose was to determine the effectiveness of VR as an intervention to improve hand function in children with CP compared to either conventional physiotherapy or other therapeutic interventions. The secondary purpose was to classify the outcomes evaluated according to the International Classification of Functioning, Disability and Health dimensions. It was concluded that the role of VR to improve hand function in children with CP is unclear due to limited evidence; use as an adjunct has some support. But the dosing reported which resulted in hand function improvement in the included trials was reported to be as follows: 4 weeks of intervention (3 sessions/week.) resulted in improved hand function, another study stated that at least 6 weeks of intervention is required to find a measurable effect on hand function, another study found 8 weeks of intervention (1 session/week) may not be sufficient to produce any meaningful changes, another compared total duration of intensive intervention for VR group was 1080 minutes in 4 weeks with 720 minutes in 8 weeks. This suggests that an intensive VR intervention may be more likely to result in improvement**. (1)**

	Title	Author/ Year	Study Design	Interventions	Measurements/ purpose	Results/ Recommendations	Level of evidence
1	**Best Responders After Intensive Upper-Limb Training for Children With Unilateral Cerebral Palsy**	**Sakzewski et al 2011**	randomized comparison trial	constraint-induced movement therapy (CIMT) / bimanual training	• Melbourne Assessment of Unilateral Upper Limb Function • Assisting Hand Assessment • Canadian Occupational Performance Measure	Children with poor hand function have benefited the most. Favourable outcomes for bimanual performance were associated with gains in movement efficiency and older children with left-sided hemiplegia achieved more favourable gains in perceived occupational performance.	1-
2	**Improvement of hand function in children with cerebral palsy via an orthosis that provides wrist extension and thumb abduction**	**Barroso et al 2011**	Longitudinal study	orthosis that Provides wrist extension and thumb abduction.	• dynamometry • The Jebsen–Taylor test.	The range of motion tests for the rest position, lateral and tripod pinches and cylindrical grasp demonstrated improvements from 17% to 42% for flexion/extension and from 36% to 54% for abduction/adduction with the use of the orthosis. Dynamometry measurements showed that the improvement in muscle strength obtained through use of the orthosis was 50%. Improvements in the time required to perform the movements varied from 13% to 24% for the four considered tests of manual ability.	**1-**
3	**Effects of Neuromuscular Electrical Stimulation on the Wrist and Finger Flexor Spasticity and Hand Functions in Cerebral Palsy**	**Yıldızgören et al 2014**	RCT	NMES Splinting	• Zancolli Classification System • Manual Ability Classification System, • Abilhand-Kids Test	Neuromuscular electrical stimulation application in addition to conventional treatments is effective in improving active wrist range of motion, spasticity, and hand functions in cerebral palsy.	1-
4	**Addressing muscle performance impairments in cerebral palsy: Implications for upper extremity resistance training**	**Moreau et al 2015**	Case study and literature review.	resistance training	It described how resistance training principles can be applied to the upper extremity in CP through a case study.	For Strength Training was number of reps to be decreased to 6-10 per set, and the intensity (load) is increased to 85% 1RM. For Power training exercises; the volume is increased to 6 sets of 3-6 repetitions, with an intensity target of 30-80% 1RM or greater.	2-
5	**Effectiveness of virtual reality in the treatment of hand function in**	**Rathinam et al 2019**	A systematic review	Virtual Reality	The purpose of this study was to determine the effectiveness of VR as an intervention to improve	The role of VR to improve hand function in children with CP is unclear due to limited evidence; Use as an adjunct has some support. A dose of 1080 minutes in 4 weeks duration	1+

	children with cerebral palsy:				hand function in children with CP compared to either conventional physiotherapy or other therapeutic interventions.	showed remarkable functional outcomes.	
6	**Evidence-based Approach to Physical Therapy in Cerebral Palsy**	**Ganesh et al 2019**	A systematic review		The objective of this review was to summarize and evaluate the effectiveness of physiotherapy interventions in children with CP	Moderate evidence of effectiveness was found for Constraint induced movement therapy for upper limb recovery, goal-directed/functional training, and gait training to improve gait speed. Conflicting evidence was found for the role of exercises on strength training and cardiorespiratory training. Intervention such as neurodevelopmental therapy (NDT) was found ineffective. future research is required to determine the best ways to improve functional outcomes in children with CP.	1+
7	**Intensive upper extremity training improved whole body movement control for children with unilateral spastic cerebral palsy**	**Hung et al 2020**	Not mentioned	HABIT versus CIMT	• 3-D kinematic analysis	Two types of intensive upper extremity training have provided significant improvements to whole body movement control for children with USCP. Adhering to the specificity of practice concept, HABIT improved bimanual coordination after training during the whole body tray carrying tasks. Given extensive interactions between the upper and lower extremities in real-world activities, future studies should focus on the effects of such combined training.	2-
8	**Effectiveness of hand-arm bimanual intensive training on upper extremity function in children with cerebral palsy**	**Ouyang et al 2020**	A systematic review	HABIT		Recommended dose is 6 h a day for three consecutive weeks (total 90 h) led to the improvement of bimanual ability, unilateral dexterity, self-care function, and functional goals.	1+
9	**What is the threshold dose of upper limb training for children with cerebral palsy to**	**Jackman et al 2020**	A systematic review		The main objective of this systematic review was to determine any threshold dose of upper limb training needed for children with	To improve individual goals, children need to practice goals for more than 14–25 hr, combining face-to-face therapy with home practice. To improve general upper limb function children need to practice for more	1+

	improve function?				CP to achieve clinically significant functional improvements.	than 30–40 hr.	
10	**Effectiveness of Hand-Arm Bimanual Intensive Therapy on Hand Function among Children with Unilateral Spastic Cerebral Palsy:**	**Alahmari et al 2020**	A Meta-Analysis		Testing HABIT versus CIMT efficacy	HABIT showed a trivial effect compared to the other interventions in improving hand function, with an effect size of 0.06. More RCTs are needed to substantiate our evidence.	1+
11	**Efficacy of transcutaneous electrical nerve stimulation combined with therapeutic exercise on hand function in children with hemiplegic cerebral palsy**	**Alhusseiny Et al 2019**	RCT	TENS combined with therapeutic exercises	• Hand grip strength • Jenden taylor HFT • Abilhand-kids	The time to accomplish the Jebsen Taylor Hand Function Test (JTHFT) task decreased by 48% and the ABILHAND-Kids questionnaire scores improved by 23% in the TENS group. Recommended dose: traditional physical therapy with the adjunct application of conventional TENS for 30 minutes (pulse duration, 250 ms; pulse rate, 100 Hz) on the wrist extensors, once daily, 3 days a week, for 8weeks	1-
12	**The Effect of Comprehensive Hand Repetitive Intensive Strength Training (CHRIST) Using Motion Analysis in Children with Cerebral Palsy**	**Kim Et al 2012**	RCT	CHRIST and general rehab	• movement time (MT), • mean velocity (MV), • normalized jerk score (NJS), • mean angular velocity (MAV) • normalized jerk score are tested for the shoulder, elbow and wrist joint with comfortable and fast speed	CHRIST proved to be an effective intervention for improving upper limb extremity function of reaching movement in children with cerebral palsy.	1-
13	**Efficacy of Upper Limb Therapies for Unilateral Cerebral Palsy:**	**Sakzewski et al 2014**	Meta-analysis			There is modest evidence that intensive activity-based, goal-directed interventions (eg, constraint-induced movement therapy, bimanual training) are more effective than	1+

						standard care in improving UL and individualized outcomes. There is little evidence to support block therapy alone as the dose of intervention is unlikely to be sufficient to lead to sustained changes in UL outcomes. There is strong evidence that goal-directed OT home programs are effective and could supplement hands-on direct therapy to achieve increased dose of intervention.	
14	**Early intervention to improve hand function in hemiplegic cerebral palsy**	**Basu et al 2015**	**Review article**			Therapy approaches including CIMT and action observation therapy are now being actively explored in the youngest children and infants. Functional elastic taping has some potential merits in this age group but requires further investigation with properly controlled studies.	
15	**Efficacy of upper limb strengthening in children with Cerebral Palsy**	**Rameckers et al 2015**	A critical review		This review focuses on the effects of strengthening interventions of the upper limb in children with Cerebral Palsy (CP).	All of the reported upper limb strength training studies found an increase in muscle strength. In addition, the quality of these studies was not high. More RCTs on strength training according to the official strength training guidelines are necessary to assess the impact and potential of strength training of the upper limb to improve the daily activities and participation in children with CP	
16	**Effects of Strength Training Aided by Electrical Stimulation on Wrist Muscle Characteristics and Hand Function of Children with Hemiplegic Cerebral Palsy**	**Vaz et al 2008**	RCT	• Electric stimulation • Resisted training	Strength measurements	Increases in strength with the wrist in extended position for both extensors and flexors. Recommended dose: 24 sessions of wrist muscles strengthening in the extended wrist range aided by electrostimulation.	1-

Table 1: Summary of reviewed articles and levels of evidence

Areas for Improvement and Further Research work
To further define characteristics of children who achieve better outcomes after intensive UL training and for each type of intervention, pooling of multiple studies for meta-analysis, and investigation of neural correlates is required. **(11)**
Hung et al recommended future studies to evaluate the influence of gait and posture training on bimanual coordination and the effectiveness of whole body intensive training. **(12)**
Ouyang et al stated in their systematic review that more studies of good methodological quality are warranted to investigate the effect of these HABIT-related interventions on upper extremity function in children with CP.
Further research to study and recommend the optimum dosing of resisted training for specific age groups are highly needed **(13)**
Rameckers et al recommended that in future the outcome at the activity and participation domains should also be assessed in strength training studies, in relation to functional goals the children want to achieve. From a clinical point of view it is very important to know if the increase in strength due to training is associated with meaningful change in children's independence/abilities**. (15)**
Vaz et al, recommended more aggressive strength intervention with or without electrical stimulation for functional gains to be observed, and contextualized task training would probably be needed. **(17)**
Further studies was recommended on NMES topic which should utilize a larger sample size including a crossover design and the effects of NMES along with other treatment modalities such as botulinum toxin **(20)**
Rathinam et al,; recommended to conduct higher quality RCT to study the effect of VR on upper extremity function on different age groups to suggest clear dosing**. (1)**
Conclusion and Recommendations for Clinical Practice
CIMT and bimanual training could be more beneficial for children with poorer hand function and dosing reported to be effective was between 60 hours over 10 days and 6 hours per day for 15 days. While CIMT dosing for infants between 3-8 months is 30 minutes per day over 6 weeks.
HABIT was recommended to be part of therapy protocol not a stand-alone treatment and reported effective dosing is 6 hours per day for 15 days and 6 hours per day for 3 weeks.
The recommended dosing for Strength Training was number of reps is decreased to 6-10 per set, and the intensity (load) is increased to 85% 1RM. Power training exercises should be modified such that volume is increased to 6 sets of 3-6 repetitions, with an intensity target of 30-80% 1RM or greater so that no more than 6 reps can be performed in any single set at a fast velocity before fatigue occurs.
According to **Jackman et al.**; Goal directed training dosing to improve individual goals, children need to practice goals for more than 14–25 hr, combining face-to-face therapy with home practice. To improve general upper limb function children need to practice for more than 30–40 hr per week. **(22)**
Splinting dosing wasn't clear in reviewed papers as its impact was measured directly after the fitting not on the long term.
Neuromuscular Electrical stimulation effective dosing reported is: 5 days per week for 6 weeks and 24 sessions over 8 weeks. However, TENS combined with therapeutic exercises dosing is 30 min, 3 days per week for 8 weeks.
Finally VR dosing which was highly variable but intensive intervention that could reach 1080 minutes in 4 weeks duration showed a positive effect on hand functions.
From dosing reported in all interventions we can conclude that hand functions improvement needs a multidimensional structured program based on each child assessment and needs that could include many of the mentioned interventions and others not mentioned in this review to achieve the functional outcomes needed.
Additionally, the high dosing reported could not be achievable without a good follow up and home programs which could be encouraged by education materials and telehealth technologies.

- **Abbreviations**

BoNT-A Botulinum toxin A
CIMT Constrained induced movement therapy

CP Cerebral palsy
HABIT hand arm bimanual training
JTHFT Jebsen Taylor Hand Function Test
NDT Neurodevelopmental therapy
NMES Neuromuscular electrical stimulation
RM Repetition maximum
ROM Range of Motion
TENS Transcutaneous electrical nerve stimulation
UL Upper limb
USCP Unilateral spastic cerebral palsy
VR Virtual Reality
Wk. week

- **Author's contributions**

All authors have read and approved the final manuscript.

- **Funding**

Not applicable

- **Availability of data and materials**

Not applicable

- **Ethics approval and consent to participate**

Not applicable

- **Consent for publication**

Not applicable

- **Competing interests**

The author declares no competing interest.

Reference

1. Rathinam C. , Vikram Mohan , Janet Peirson , Jane Skinner , Kalidass Subash Nethaji, Isla Kuhn, Effectiveness of virtual reality in the treatment of hand function in children with cerebral palsy: A systematic review. Journal of Hand Therapy (2019), 32; 426-434. DOI: 10.1016/j.jht.2018.01.006
2. Charles J. Upper extremity muscle activation in children with unilateral cerebral palsy during an auditory cued repetitive task: Effects on bimanual coordination. Journal of Pediatric Rehabilitation Medicine: An Interdisciplinary Approach (2017) 10; 19–26. DOI: 10.3233/PRM-170407
3. Basu A. P., Janice Pearse, Susan Kelly, Vicki Wisher and Jill Kisler. Early intervention to improve hand function in hemiplegic cerebral palsy. Frontiers in Neurology, Neuro-pediatrics January 2015, Volume5, Article 281. DOI: 10.3389/fneur.2014.00281
4. Kim D.A., Jung-Ah Lee , Pil-Woo Hwang , Min-Jin Lee , Hyun-Kyung Kim, Jeong-Joon Park , Joshua H. You, Dong-Ryul Lee, Nam-Gi Lee. The Effect of Comprehensive Hand Repetitive Intensive Strength Training (CHRIST) Using Motion Analysis in Children with Cerebral Palsy. Ann Rehabil Med (2012); 36: 39-46. doi: 10.5535/arm.2012.36.1.39
5. Rameckers E.A.A., Y.J.M.Janssen-Potten, I.M.M.Essers, R.J.E.M. Smeets. Efficacy of upper limb strengthening in children with Cerebral Palsy: Acritical review. Research in Developmental Disabilities 36 (2015) 87–101. https://doi.org/10.1016/j.ridd.2014.09.024
6. Das S. P., G Shankar Ganesh. Evidence-based Approach to Physical Therapy in Cerebral Palsy. Indian Journal of Orthopaedics | Volume 53 | Issue 1 | January-February 2019. doi: 10.4103/ortho.IJOrtho_241_17
7. Friel K., Samit Chakrabarty, Hsing-Ching Kuo and John Martin. Using Motor Behaviour during an Early Critical Period to Restore Skilled Limb Movement after Damage to the Corticospinal System during Development. Journal of Neuroscience 4 July 2012, 32 (27) 9265-9276. doi: 10.1523/JNEUROSCI.1198-12.2012
8. Basu A, Eyre J. A plea for consideration of the less affected hand in therapeutic approaches to hemiplegia. Developmental Medicine Child Neurology (2012) 54:380. DOI:10.1111/j.1469-8749.2012.04242.x
9. Skold A, Josephsson S, Eliasson AC. Performing bimanual activities: the experiences of young persons with hemiplegic cerebral palsy. American Journal of Occupational Therapy (2004) 58:416–25. DOI: 10.5014/ajot.58.4.416
10. Lin J, Lumsden DE, Gimeno H, et al. The impact and prognosis for dystonia in childhood including dystonic cerebral palsy: a clinical and demographic tertiary cohort study. Journal of Neurology, Neurosurgery & Psychiatry 2014; 85:1239-1244. DOI: 10.1136/jnnp-2013-307041
11. Sakzewski L., Jenny Ziviani, Roslyn N. Boyd. Best Responders after Intensive Upper-Limb Training for Children with Unilateral Cerebral Palsy. Archives of Physical Medicine and Rehabilitation (2011). Vol 92. DOI: 10.1016/j.apmr.2010.12.003
12. Hung Y.C., Fawzia Shirzada, Maria Saleema, Andrew M. Gordonb. Intensive upper extremity training improved whole body movement control for children with unilateral spastic cerebral palsy. Gait & Posture (2020) 81, 67–72. DOI: 10.1016/j.gaitpost.2020.07.009
13. Ouyang R., Chieh-Ning Yang, Ya-Lan Qu, Manohar Prasad Koduri, Chi-Wen Chien. Effectiveness of hand-arm bimanual intensive training on upper extremity function in children with cerebral palsy: A systematic review. European Journal of Paediatric Neurology (2020) 25; 17-28. DOI: 10.1016/j.ejpn.2019.12.017
14. Alahmari K., Jaya Shanker Tedla, Devika Rani Sangadala, Debjani Mukherjee, Ravi Shankar Reddy, Kalyana Chakravarthy Bairapareddy, Praveen Kumar Kandakurti. Effectiveness of Hand-Arm Bimanual Intensive Therapy on Hand Function among Children with Unilateral Spastic Cerebral Palsy: A Meta-Analysis. European Neurology (2020), 7 DOI: 10.1159/000507325
15. Moreau N. G., Mary E. Gannotti. Addressing muscle performance impairments in cerebral palsy: Implications for upper extremity resistance training. Journal of Hand Therapy (2015) 28, 91-100. DOI: 10.1016/j.jht.2014.08.003
16. Rameckers E.A.A., Y.J.M.Janssen-Potten , I.M.M.Essers, R.J.E.M. Smeets. Efficacy of upper limb strengthening in children with Cerebral Palsy: Acritical review. Research in

Developmental Disabilities 36 (2015) 87–101. http://dx.doi.org/10.1016/j.ridd.2014.09.024

17. Vaz D.V., Marisa Cotta Mancini, S´ergio Teixeira da Fonseca, Nayara Flamini Arantes, Tatiana Pessoa da Silva Pinto, Priscila Albuquerque de Ara´ujo. Effects of Strength Training Aided by Electrical Stimulation on Wrist Muscle Characteristics and Hand Function of Children with Hemiplegic Cerebral Palsy. Physical & Occupational Therapy in Pediatrics (2008) Vol. 28(4). DOI: 10.1080/01942630802307069
18. Barroso P.N., S.D. Vecchio, Y.R. Xavier, M. Sesselmann, P.A. Araújo, M. Pinotti. Improvement of hand function in children with cerebral palsy via an orthosis that provides wrist extension and thumb abduction. Clinical Biomechanics 26 (2011) 937–943. https://doi.org/10.1016/j.clinbiomech.2011.05.006
19. Diniari, N. K. S., & Aryani, L. N. A. (2022). Characteristics and pharmacological treatment options of delirium patients treated at Sanglah Central General Hospital . International Journal of Health & Medical Sciences, 5(1), 37-43. https://doi.org/10.21744/ijhms.v5n1.1835
20. Burtner P.A., Janet L. Poole, Theresa Torres, Amanda Manhke Medora, Rose Abeyta, Joanne Keene, Clifford Qualls. Effect of Wrist Hand Splints on Grip, Pinch, Manual Dexterity, and Muscle Activation in Children with Spastic Hemiplegia: A Preliminary Study. JOURNAL OF HAND THERAPY (2008), 36-43. DOI: 10.1197/j.jht.2007.08.018
21. Yıldızgören M.T., Güldal Funda Nakipglu Yüzer, Timur Ekiz, Özgirgin N. Effects of Neuromuscular Electrical Stimulation on the Wrist and Finger Flexor Spasticity and Hand Functions in Cerebral Palsy. Pediatric Neurology 51 (2014) 360-364. DOI: 10.1016/j.pediatrneurol.2014.05.009
22. Alhusaini A., Saber Fallatah, Ganeswara Rao Melam & Syamala Buragadda. Efficacy of transcutaneous electrical nerve stimulation combined with therapeutic exercise on hand function in children with hemiplegic cerebral palsy. Somatosensory & Motor Research (2019), DOI: 10.1080/08990220.2019.1584555.
23. Suryasa, I. W., Rodríguez-Gámez, M., & Koldoris, T. (2022). Post-pandemic health and its sustainability: Educational situation. *International Journal of Health Sciences*, *6*(1), i-v. https://doi.org/10.53730/ijhs.v6n1.5949
24. Jackman M., Natasha Lannin, Claire Galea, Leanne Sakzewski, Laura Miller, Iona Novak. What is the threshold dose of upper limb training for children with cerebral palsy to improve function? A systematic review. Australian Occupational Therapy Journal (2020) ;00:1. DOI: 10.1111/1440-1630.12666