



ORIGINAL RESEARCH ARTICLE

Open Access



# Pinch grip strength and fine manual control in children with diplegic cerebral palsy: a cross-sectional study

Asmaa Ahmed Abd El-samad<sup>1\*</sup> , Gehan Hassan El-Meniawy<sup>2,3</sup>, Sahar Mohamed Nour El-Din<sup>4</sup> and Nanees Essam Mohamed<sup>3\*</sup> 

## Abstract

**Background:** In children with spastic diplegia, efficient use of the upper extremity especially the hands play an important role in participation in daily living. Hands can perform heavy activities and also enable to perform extremely gentle, skillful, and precise activities. Inadequate hand strength and fine motor skills may lead to functional limitations. This study was planned to investigate the pinch grip strength and fine manual control in children with spastic diplegic cerebral palsy and to determine if there is a relation between them. Thirty children with diplegic cerebral palsy and 30 normal developed children from both sexes between 5 and 10 years old were included in this study as diplegic and control groups. For all children, pinch grip strength measured by Baseline Mechanical Pinch Gauge and Bruininks-Oseretsky Test of Motor Proficiency, Second Edition used to evaluate fine manual control.

**Results:** Children with diplegic cerebral palsy have significant impairment in the pinch grip strength (tip, tripod, and key) and the fine manual control (fine motor precision and integration) compared to their healthy peers of the same age. There was large positive significant correlation ( $r > 0.5, p < 0.05$ ) between tip and tripod pinch strength, and fine motor precision and medium positive significant correlation ( $r = 0.47, p < 0.05$ ) between key pinch and fine motor precision in children with spastic diplegia. Also, there was large positive significant correlation between tip pinch and fine motor integration ( $r = 0.54, p < 0.05$ ). The correlations are small and medium positive between tripod and key pinch strength, and fine motor integration respectively but they are not statistically significant.

**Conclusions:** Pinch grip strength and fine manual skills are affected in children with spastic diplegia. Also, there is a significant correlation between the pinch strength and activities require precise control of the hand.

**Keywords:** Baseline Pinch Gauge, BOT-2, Cerebral palsy, Children, Diplegia, Fine skills, Fine precision, Fine integration, Pinch strength

## Background

Cerebral palsy (CP) is a neurodevelopmental disorder that affects muscle tone, posture and motor skills. It is the most common cause of motor disability in infants

and children. It describes a group of permanent disorders resulting from non-progressive injury to the fetal or infant developing brain. Although the disorder itself is non-progressive, the clinical manifestations change over time as the brain matures. About 2–3 per 1000 children worldwide have CP [1, 2].

Thirty-five percent of children with CP have spastic diplegia; it is considered to be the most common clinical phenotype of CP. This type of CP is mainly associated with premature birth and can be detected with a brain

\* Correspondence: [asmaasima20@gmail.com](mailto:asmaasima20@gmail.com); [nanessam2015@gmail.com](mailto:nanessam2015@gmail.com)

<sup>1</sup>Physical Therapist, Abo-El Reesh Hospital, Cairo University Hospitals, Giza, Egypt

<sup>3</sup>Department of Physical Therapy for Pediatrics, Faculty of Physical Therapy, Cairo University, 7 Ahmed Elzayat St. Been Elsarayat, PO 12624, Dokki, Giza, Egypt

Full list of author information is available at the end of the article

magnetic resonance imaging, which shows severe periventricular leukomalacia and multicystic cortical encephalomalacia [3–5]. Children with spastic diplegia show more impairment in the lower extremities than upper extremities. Spasticity is frequently asymmetrical in the lower limb and it is less severe in the arms and hands [6, 7].

Fine motor skills start in utero and progress through first years of child's life and continuing its progress through adolescence. Fine motor skills mean using the smaller muscles of the hands to grasp and manipulate objects. These skills are important for all children in everyday activities. By using fine motor skills, children provide their manual abilities and later on these manual abilities connect to various cognitive skills such as writing, drawing, and playing [8]. A large number of scales are available to evaluate fine motor skills and one of these scales is Bruininks-Oseretsky Test of Motor Proficiency 2 (BOT-2). Previous study suggested that the BOT-2 is a valid, reproducible tool to evaluate upper-limb fine and gross motor function in children with CP with a gross motor function classification system (GMFCS) level 1–3 and a manual ability classification system (MACS) level 1–4 so BOT-2 can be used in clinical practice and in research for the evaluation and the follow-up of children with CP [9].

The full hand grip and pinch are the main functions of the hand. The grip function of the hand is of great importance in professional and daily life activities [10]. According to American Society of Hand Therapists (ASHT) hand strength is one of the components measured during the evaluation of hand function that reflect the overall strength of the upper limb. Hand strength can be obtained by measuring grip and pinch strength; there are three different types of pinch strength such as tip, key, and tripod pinch strength [11, 12]. Although the link between grip strength and subjective measures of hand function based on assessment questionnaires has been established, the relationship between objective measures of disability and impairment is not clear [10, 13].

Several studies have provided comprehensive normative data on the grip strength of healthy children [12, 14, 15]. Studies on diplegic children focused mainly on hand grip strength and dexterities [16, 17] with little attention on pinch strength, and fine motor precision and integration. There is no literature that specifies the relation between the three types of pinch grip strength and fine motor precision and integration. So, this study was planned to investigate the pinch grip strength (tip, tripod, and key) and fine manual control (fine motor precision and integration) in children with spastic diplegic CP and to determine if there is a relation between them.

## Methods

### Study design

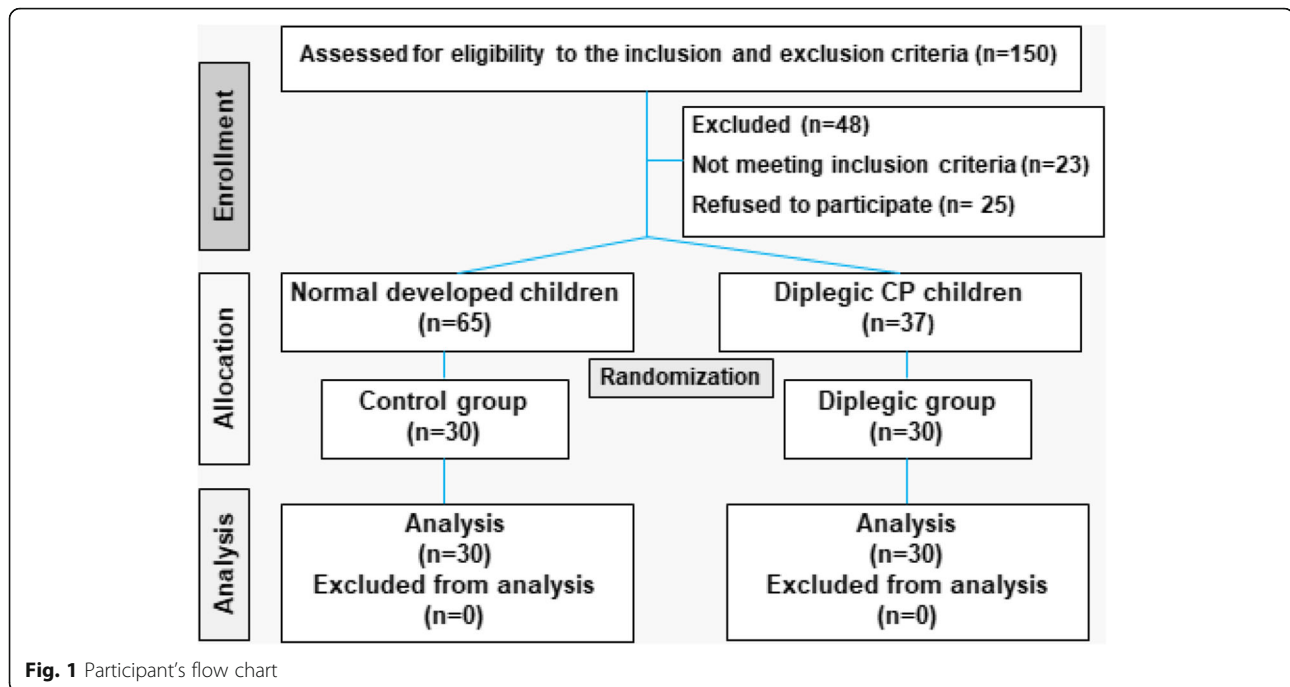
This cross-sectional study was carried out from September 2019 to March 2020 at the outpatient clinics of the

Abo El-Reesh hospital, Cairo university in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki). Ethical committee approval of the Faculty of Physical Therapy, Cairo University, Egypt (No:P.T.REC/012/002189) obtained before the study beginning.

### Subjects

Sixty children from both sexes with ages ranged from 5 to 10 years participated in this study. Thirty normally developed children from kindergarten and primary schools in Giza Governorate were allocated in the control group. And 30 diplegic cerebral palsy children from the outpatient clinic of Abo El-Reesh hospital and the outpatient clinic at Faculty of Physical Therapy, Cairo University, Egypt were allocated in the diplegic group. Potential participants were screened by one investigator. All normally developed children were physically normal and performed activities of daily living of their ages independently. Inclusion criteria of the study group include the ability to sit without support, upper limbs' spasticity graded 1 or 1+ according to Modified Ashworth's Scale [18]. The spasticity of the upper limbs was in flexion pattern. They had levels II and III at GMFCS [19]. Children in all groups were able to follow instructions and understand commands given during test procedures and all children followed normal average of weight and height (according to the scale for normal boys and girls). Children were excluded from the study if they practice any regular sport activities involving the upper extremities, had restricted joint motion in the upper limbs because of skin lesions or contracture, and congenital or acquired deformity in the upper extremities or unhealed fracture. Also, if they had Botox injection in the upper limbs in the last 6 months, recent neurological/orthopedic surgeries of upper extremities in the last 12 months, significant visual or auditory problems, and significant perceptual deficits or epilepsy.

Sample size estimation was conducted using G\*Power software 3.1.9.2 (Neu-Isenburg, Germany) with  $\alpha$  error = 0.05, actual power  $(1-\beta) = 0.82$ , and an effect size  $(f) = 0.51$  indicated a total sample size of at least 42 children. We recruited up to 60 children to account for the possible dropout rates. The participant's flowchart is shown in Fig. 1. Out of 150 children who were assessed for eligibility, 102 (65 normally developed and 37 diplegic) met the inclusion criteria. Sixty children (thirty from each) were randomly selected using sealed envelopes where a specific identification number firstly determined for all enrolled normally developed and diplegic children. Then cards with their identification numbers were hidden in sealed opaque envelopes. After that, two volunteers who did not participate in this study



randomly select 30 envelopes for each normally developed and diplegic group. The randomization process was accomplished by a researcher who did not participate in sample recruitment.

### Procedures

The purposes and protocols of this work were explained to each child's parents of both groups before conducting the study. Children's participation was authorized by a signed written consent form with parent's/legal guardian's acceptance for participation before starting the study procedures. All measurements were obtained by the same assessor, who trained all procedures previously. To confirm that all children have normal averages of weight (kg) and height (cm), weight and height scale (RGZ-120 Health Scale, SMIC, Shanghai, China) was used.

### Anthropometric measurements

*Forearm length* was measured in centimeter as the distance from the head of radius to the tip of the styloid process of the radius at elbow flexed 90° and supinated position. *Hand length* was measured in centimeter as the distance from the tip of the middle finger to the midline of the distal wrist crease. These measures were done with a tape measurement from supinated forearm and outstretched hand [20, 21].

### Dominancy detection

Each child's preferred hand to pick up a pencil from the table and draw either circle or line in a white paper placed on the table in front of him/her was recorded [21].

### Measuring pinch strength

Baseline mechanical Pinch gauge (0–60 lb.) (Fabrication Enterprises, Inc. White Plains, NY 10602 USA) used to measure tip, tripod, and key pinch strength of dominance and non-dominance hands for all participated children. It provides a more accurate measure of pinch strength compared to similar devices [22] and has excellent intra- and inter-rater reliability for assessing pinch grip strength in children with cerebral palsy [23]. This study followed the American Society of Hand Therapist (ASHT) protocol for evaluating pinch strength [21, 24].

The researcher demonstrated how to hold and use the gauge to each child. Child's shoes, watches, and/or bracelets were removed. Each child sat in comfortable chair with a back support and fixed arm rests, with rest his/her forearms on the arms of the chair keeping feet flat on the floor. Shoulder adducted and neutral rotate, elbow flexed at 90°, forearm in neutral position, wrist in neutral position between 0–30° extension and 0–15° of ulnar deviation [20, 21]. Additionally, the ulnar fingers and the interphalangeal joint of the thumb flexed during the pinch measurement for greater pinch force [24]. To ensure safety of the pinch gauge, researcher held the pinch gauge and wrapped the strap around her wrist as the child applied force. The researcher encouraged the child to squeeze as hard as possible during each trial using consistent instruction by saying "go, go, go, stop" for standardization of the test; this contraction time is 3 s. The mean of three trails calculated and used for analysis; a rest of 10 s occurred between trails [20, 21].

### **Bruininks-Oseretsky Test of Motor Proficiency, Second Edition (BOT-2)**

We assessed the subtests of fine manual control composite of dominance hand for all participated children. This motor area composite measures control and coordination of the distal musculature of the hands and fingers, especially for grasping, drawing, and cutting. It composites of two subtests: *fine motor precision* which includes test items that require precise control of finger and hand movement. Emphasis is placed on precision; therefore, the items are not timed. And *fine motor integration* which requires the child to reproduce drawings of various geometric shapes that range in complexity from a simple circle to overlapping pencils. It also requires precise control of finger and hand movement therefore, the items are not timed. It measures the ability to integrate visual stimuli with motor control [25].

For both subtests, the child seated on supported chair and suitable table length with feet rested on the floor. Before each item, the researcher teared out its page from the examinee booklet before placing it in front of the child. The examiner sharpened the pencil before testing begins and re-sharpened it as needed during testing. Erasing was not allowed on any item using the pencil. Each child used his/her preferred drawing hand for all items in these subtests. For each test item, the researcher taught the task to the child using verbal and non-verbal directions to ensure the child's understanding of the task and then observed the child's performance to determine a raw score. For each test item in both subtests, each child performed one trail only. Scoring can be completed through hand scoring. The child's raw scores that recorded during the administration of the test are converted first to point scores, then to total point score for each subtest. Finally, by using specific tables total point scores converted to scale score [25].

### **Statistical analysis**

Descriptive statistics and *t* test were conducted for comparison of the mean age, weight, height, and forearm and hand length between children with diplegia and control group. Chi-squared test was conducted for comparison of sex distribution between groups. One-way multivariate analysis of variance (MANOVA) test was used to analyze the difference between groups with respect to the pinch grip strength and BOT-2. Person Product Moment Correlation Coefficient was conducted to investigate the correlation between BOT-2 and pinch grip strength in diplegic group. The level of significance for all statistical tests was set at  $p < 0.05$ . All statistical measures were performed through the statistical package for social sciences (SPSS) version 24 (IBM SPSS, Inc., Chicago, IL, USA).

### **Results**

Participant's baseline details are presented in Table 1. There were no statistically significant differences between children with diplegia and normal developed peers with respect to the demographic and anthropometric characteristics. Five children with diplegia have grade 1, and 25 have grade 1+ according to Modified Ashworth Scale. According to GMFCS, 7 children with diplegia have level II, and 23 were at level III.

The multivariate analysis of variance revealed a statistically significant overall group difference in the dependent variables [pinch grip strength (tip, tripod, and key) and BOT-2 scores (fine motor precision, and fine motor integration)] where  $F(8, 51) = 19.189$ ;  $p < 0.05$ ; Wilk's  $\lambda = 0.249$ ; partial  $\eta^2 = 0.751$ .

Test of between subjects' effects revealed a statistically significant difference between diplegic and control groups in all dependent variables ( $p < 0.05$ ). There is a decrease in both dominant and non-dominant hands pinch grip strength in children with diplegia compared with that of the control group. Also, there is a decrease in the BOT-2 scores (fine motor precision, and fine motor integration) of children with diplegia compared with their peers at the control group. The effect size is large (Partial  $\eta^2 > 0.14$ ) (Table 2).

As demonstrated in Table 3, there were large positive significant correlation between tip pinch of the dominant hand with fine motor precision, and fine motor integration ( $r > 0.5$ ,  $p < 0.05$ ) in diplegic group, while tripod pinch had large positive significant correlation with fine motor precision ( $r = 0.53$ ,  $p < 0.05$ ), and small positive non-significant correlation with fine motor integration ( $r = 0.29$ ,  $p > 0.05$ ). Key pinch had medium positive significant correlation with fine motor precision ( $r = 0.47$ ,  $p < 0.05$ ), but it had medium positive non-significant correlation with fine motor integration ( $r = 0.35$ ,  $p > 0.05$ ).

### **Discussion**

Hand is a dynamic sensory motor organ which carries out a variety of complex tasks that require a combination of complex movements and controlled force production, also quality of the activities of daily living and independent functioning requires effective fine motor skills [26]. A loss in grip strength is associated with neurological and musculoskeletal conditions; so, an assessment of hand grip strength is included in hand evaluations as a test of gross motor power. So, the present study investigated the impairment in pinch grip strength and fine manual control in children with spastic diplegic CP and studied if there is a relation between them.

This study showed significant decrease in tip, tripod, and key pinch strength in children with diplegia that is supported by the results of Elbasan et al. [17] who evaluated hand grip strength with Jamar Hand Dynamometer

**Table 1** Participants' baseline characteristics

	Diplegic group, <i>n</i> = 30	Control group, <i>n</i> = 30	<i>t</i> value	<i>P</i> value
Age (years)	7.55 ± 1.67	7.74 ± 1.46	- 0.486	0.183
Weight (kg)	21.73 ± 5.43	22.00 ± 4.96	- 0.198	0.226
Height (cm)	121.10 ± 10.06	121.76 ± 9.40	- 0.265	0.447
Forearm length (cm)	17.01 ± 1.65	17.43 ± 1.59	- 0.995	0.827
Hand length (cm)	14.06 ± 1.52	14.36 ± 1.37	- 0.798	0.562
Girls/boys	13/17	17/13	$\chi^2 = 1.067$	0.302

Data are represented as mean ± SD

kg kilogram, cm centimeter, *n* number, *p* value probability value,  $\chi^2$  chi-square  
*P* > 0.05 not significant

for 18 children with spastic diplegia, aged between 5 and 12 years and compared their results with 15 typically developing peers. They found decrease in the hand strength of the dominant and non-dominant hands in children with spastic diplegia compared to healthy children of the same age. Also, Arnould et al. [16] measured hand grip strength with Jamar Dynamometer and suggested that more than half of children with diplegia showing bilateral impairments in grip strength. The impairment in strength in children with CP can be due to both the disturbed neural mechanisms and the muscle tissue changes. In children with CP, the central input that stimulates the motor neurons of the muscles is decreased due to pyramidal tract damage, also the child is unable to activate the high-threshold motor unit groups necessary for maximum voluntary contraction [27]. Modlesky and Zhang [28] suggested that CP have smaller muscles that contain less contractile tissue and more fat, which interfere with force generation and contribute to significant muscle weakness.

Evaluation of fine manual control (fine motor precision and fine motor integration) using BOT-2, the

results found significant impairment in the fine motor precision in children with spastic diplegia compared with normal developed children at the same age. The results of this study supported by Kara et al. [7] who evaluated the gross and fine motor skills of 73 children with diplegic CP aged between 6 and 12 years by Bruininks-Oseretsky Test 2-Short Form and reported that the mean and standard deviation with (minimum and maximum values) of girls and boys for fine motor precision were  $1.76 \pm 1.04$  (0–3) and  $1.25 \pm 0.96$  (0–4), and for fine motor integration were  $5.32 \pm 1.90$  (3–9) and  $4.58 \pm 1.44$  (2–8) respectively. Our results confirming findings reported by study done by Elbasan et al. [17] which assessed finger dexterity by Nine-hole Peg Test and assessed fine and gross motor hand function using simulated activities of daily living with Jebsen-Taylor test and observed that children with diplegic CP were inadequate in their fine motor skills compared to the healthy peers and suggested that beside the main cause of corticospinal pathways affection, the over protective attitudes of the family members on these children restrict the use of their hands that affect the development of their fine motor skills.

**Table 2** Comparison of pinch strength and BOT-2 scores between diplegia and control groups

			Diplegic group ( <i>n</i> = 30)	Control group ( <i>n</i> = 30)	<i>F</i> value	<i>P</i> value	Partial $\eta^2$ (95%CI)
Pinch grip strength (lb.)	Dominant hand	Tip pinch	5.50 ± 1.46	7.25 ± 1.33	23.395	0.0001*	0.287
		Tripod pinch	6.70 ± 1.88	8.96 ± 2.37	16.611	0.0001*	0.223
		Key pinch	7.27 ± 1.97	9.17 ± 2.34	11.476	0.001*	0.165
	Non-dominant hand	Tip pinch	4.48 ± 1.24	5.99 ± 1.35	19.709	0.0001*	0.254
		Tripod pinch	5.56 ± 1.49	7.61 ± 2.06	19.396	0.0001*	0.251
		Key pinch	6.18 ± 1.67	7.98 ± 2.09	13.541	0.001*	0.189
BOT-2 scores	Dominant hand	Fine motor precision	3.10 ± 1.15	13.73 ± 5.23	118.151	0.0001*	0.671
		Fine motor integration	6.86 ± 1.96	13.43 ± 2.63	119.921	0.0001*	0.674

Data are expressed as mean ± SD

*p* value probability value, Partial  $\eta^2$  partial eta squared, CI confidence interval

\*Significant at alpha level 0.05

**Table 3** Correlation between pinch grip strength and BOT-2 of the dominant hand in children with diplegia

		BOT-2 scores			
		Fine motor precision		Fine motor integration	
		<i>r</i> value	<i>p</i> value	<i>r</i> value	<i>p</i> value
Pinch grip strength (lb.)	Tip pinch	0.62	0.0001*	0.54	0.002*
	Tripod pinch	0.53	0.002*	0.29	0.11
	Key pinch	0.47	0.008*	0.35	0.053

*r* value Pearson correlation coefficient, *p* value probability value

\*Correlation is significant at alpha level 0.05

The fine motor integration was significantly impaired in children with diplegia compared with the control group. In children with diplegia, visual–perceptual impairment occurs more frequently as the periventricular leukomalacia which is the commonest cause of spastic diplegia; its location of along the posterior part of the lateral ventricles may cause interruption in the optic radiations which responsible for visual perception impairment in those children [29]. A study by Fang et al. [30] found significant correlation between the visual perception and the development of fine motor integration. That can explain why children with diplegia have deficit in the fine motor integration skills.

Pinch strength is one of the factors affecting the fine motor performance in children. The significant correlation between tip, tripod, and key pinch grip and fine motor precision supported by the results of Sai Gayathri and Prabhu [31] who studied the correlation between pinch strength and limitations of hand function in spastic diplegic CP children between 6 and 12 years and found that pinch strength showed a small positive correlation with hand function ( $r = 0.260$ ,  $p = 0.049$ ). In their study, they assessed only one type of pinch strength with a Pinchometer and correlate it with the results of Sollerman Hand Function test which shows the ability and quality of hand while performing activities of daily living. Kadaskar and Borkar [32] evaluated the correlation between palmer pinch grip strength and handwriting among 9 to 10 years old school-going children. They found a significant positive correlation between pinch grip strength and handwriting as the child needs to have strong muscles in their hands to grasp a pencil and manipulate it for functional use.

Studying the correlation between pinch grip and fine motor integration showed large positive significant correlation with tip pinch. Also, small and medium positive correlation with tripod and key pinch respectively that is not statistically significant were showed. Possibly, one of the reasons of this result is that fine motor integration not only depends on the finger movement but also on the visual

perception which is commonly affected in children with diplegia. Many studies suggest there is positive correlation between visual perception and visual motor integration in children with CP [33, 34]. Instead of key pinch is the strongest type of pinch as fingers resist the pressure of the thumb followed by tripod pinch. Tip pinch is used for more sophisticated processes requiring fine coordination. Although grip strength is one aspect of hand function which can be objectively and accurately measured; it may bear little relationship to the patient's actual fine motor integration.

There are some limitations of the current study; few children in the diplegic group required more time than their colleagues of the same age to learn, integrate, recall, and receive feedback which may be due to the impact of their lesions. The small number of the participants could be considered another limitation. In general, it was noted that the older children had better outcomes than younger children which indicate the significant effect of age. So, it is recommended to do future research with strata sample of small age intervals.

### Conclusions

As a conclusion, it was found that pinch grip strength (tip, tripod, and key) and fine manual skills (fine motor precision and integration) are affected in children with spastic diplegia. Also, there is a significant correlation between the pinch strength and activities require precise control of the hand. So, children with diplegia may be benefit from physical therapy interventions increasing the strength of the hand. In addition to the physical therapy, it is important to added occupational therapy programs for improving the fine skills of those children.

### Abbreviations

CP: Cerebral palsy; BOT-2: Bruininks-Oseretsky Test of Motor Proficiency 2; GMFCS: Gross motor function classification system; MACS: Manual ability classification system; ASHT: American Society of Hand Therapists

### Acknowledgements

The authors would like to express their appreciation to all the children and their parents for their co-operation and participation in this study.

**Authors' contributions**

AA, GH, and NE suggested the research idea, conception, and design of the work. AA collected the data and performed the assessment procedure. AA and NE shared in acquisition and analysis of the data, interpretation of the data, and contributors in the writing process. GH, SM, and NE revised the manuscript. All authors read and approved the final manuscript.

**Funding**

Not applicable

**Availability of data and materials**

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

**Declarations****Ethics approval and consent to participate**

The study was approved by the ethical committee of the Faculty of Physical Therapy, Cairo University (P.T.REC/012/002189). A written consent was obtained from the participants.

**Consent for publication**

All parents of the participating children in this study were informed about the nature and purpose of this study and signed a written consent form including their acceptance for participation of their children and publication of the study before starting the study procedure.

**Competing interests**

The authors declare that they have no competing interests.

**Author details**

<sup>1</sup>Physical Therapist, Abo-El Reesh Hospital, Cairo University Hospitals, Giza, Egypt. <sup>2</sup>Dean of Faculty of Physical Therapy, Cairo University, 7 Ahmed Elzayat St. Been Elsarayat, PO 12624, Dokki, Giza, Egypt. <sup>3</sup>Department of Physical Therapy for Pediatrics, Faculty of Physical Therapy, Cairo University, 7 Ahmed Elzayat St. Been Elsarayat, PO 12624, Dokki, Giza, Egypt. <sup>4</sup>Medical Genetics Center, Faculty of Medicine, Ain Shams University, Cairo, Egypt.

Received: 31 March 2021 Accepted: 10 August 2021

Published online: 15 September 2021

**References**

- Gulati S, Sondhi V. Cerebral palsy: an overview. *Indian J Pediatr.* 2018;85(11):1006–16. <https://doi.org/10.1007/s12098-017-2475-1>.
- Patel DR, Neelakantan M, Pandher K, Merrick J. Cerebral palsy in children: a clinical overview. *Transl Pediatr.* 2020;9(Suppl 1):S125–35. <https://doi.org/10.21037/tp.2020.01.01>.
- Korzeniewski SJ, Slaughter J, Lenski M, Haak P, Paneth N. The complex aetiology of cerebral palsy. *Nat Rev Neurol.* 2018;14(9):528–43. <https://doi.org/10.1038/s41582-018-0043-6>.
- Michael-Asalu A, Taylor G, Campbell H, Lelea LL, Kirby RS. Cerebral palsy: diagnosis, epidemiology, genetics, and clinical update. *Adv Pediatr Infect Dis.* 2019;66:189–208. <https://doi.org/10.1016/j.yapd.2019.04.002>.
- te Velde A, Morgan C, Novak I, Tantsis E, Badawi N. Early diagnosis and classification of cerebral palsy: an historical perspective and barriers to an early diagnosis. *J Clin Med.* 2019;8(10):1599. <https://doi.org/10.3390/jcm8101599>.
- Bean SC. Cerebral palsy prognosis based on the physical and neurologic examination. In: Miller F, Bachrach S, Lennon N, O'Neil ME, editors. *Cerebral palsy*. Cham: Springer; 2020. [https://doi.org/10.1007/978-3-319-74558-9\\_17](https://doi.org/10.1007/978-3-319-74558-9_17).
- Kara ÖK, Şahin S, Köse B, Tonak HA, Kara K. Investigation of motor abilities according to gender in children with diplegic cerebral palsy. *Bezmi'alem Sci.* 2020;8(3):258–63. <https://doi.org/10.14235/bas.galenos.2019.3569>.
- Tóth R. Improvement of fine motor skills in cerebral paretic patients. *Különleges Bánásmód.* 2017;11(szám):79–85. <https://doi.org/10.18458/KB.2017.1.79>.
- Selves C, Stoquart G, Renders A, Detrembleur C, Lejeune T, et al. Reliability and concurrent validity of the Bruininks-Oseretsky Test in children with cerebral palsy. *Biomed J Sci Tech Res.* 2019;18(5):13961–7 BJSTR. MS.ID. 003226.
- Duruöz MT. Assessment of hand function. In: Duruöz MT, editor. *Hand function: a practical guide to assessment*. 2nd ed. Switzerland AG: Springer Nature; 2019. p. 45–7.
- Martins JC, Teixeira-Salmela LF, Castro e Souza LA, Aguiar LT, Lara EM, Moura JB, et al. Reliability and validity of the modified sphygmomanometer test for the assessment of strength of upper limb muscles after stroke. *J Rehabil Med.* 2015;47(8):697–705. <https://doi.org/10.2340/16501977-1978>.
- Shetty M, Balasundaran S, Mullerpatan R. Grip and pinch strength: reference values for children and adolescents from India. *J Pediatr Rehabil Med.* 2019;12(3):255–62. <https://doi.org/10.3233/PRM-180580>.
- Cantero-Téllez R, Martín-Valero R, Cuesta-Vargas A. Effect of muscle strength and pain on hand function in patients with trapeziometacarpal osteoarthritis. A cross-sectional study. *Reumatol Clin.* 2015;11(6):340–4. <https://doi.org/10.1016/j.reuma.2014.12.002>.
- Ebrahim AHM, Salah eldeen M. Normal handgrip strength for egyptian children in prepubertal developmental stage. *Bull Fac Ph Th Cairo Univ.* 2008;13(11):177–85.
- Gómez-Campos R, Andruske CL, de Arruda M, Sulla-Torres J, Pacheco-Carrillo J, Urrea-Albornoz C, et al. Normative data for handgrip strength in children and adolescents in the Maule Region, Chile: Evaluation based on chronological and biological age. *PLoS One.* 2018;13(8):e0201033. <https://doi.org/10.1371/journal.pone.0201033>.
- Amould C, Bleyenheuft Y, Thonnard JL. Hand functioning in children with cerebral palsy. *Front Neurol.* 2014;5(48):1–10. <https://doi.org/10.3389/fneur.2014.00048>.
- Elbasan B, Bozkurt E, Oskay D, Oksuz C. Upper extremity impairments and activities in children with bilateral cerebral palsy. *Iran J Pediatr.* 2017;27(6):e7711. <https://doi.org/10.5812/ijp.7711>.
- Meseguer-Henarejos AB, Sánchez-Meca J, López-Pina JA, Carles-Hernández R. Inter- and intra-rater reliability of the Modified Ashworth Scale: a systematic review and meta-analysis. *Eur J Phys Rehabil Med.* 2018;54(4):576–90. <https://doi.org/10.23736/S1973-9087.17.04796-7>.
- Park EY. Stability of the gross motor function classification system in children with cerebral palsy for two years. *BMC Neurol.* 2020;20(172). <https://doi.org/10.1186/s12883-020-01721-4>.
- Alahmari KA, Kakarparthi VN, Reddy RS, Silvian PS, Ahmad I, Rengaramanujam K. Percentage difference of hand dimensions and their correlation with hand grip and pinch strength among school children in Saudi Arabia. *Niger J Clin Pract.* 2019;22(10):1356–64. [https://doi.org/10.4103/njcp.njcp\\_121\\_19](https://doi.org/10.4103/njcp.njcp_121_19).
- Mahmoud AG, Elhadidy EI, Hamza MS, Mohamed NE. Determining correlations between hand grip strength and anthropometric measurements in preschool children. *J Taibah Univ Med Sc.* 2020;15(1):75e81.
- Mathiowetz V, Vizenor L, Melander D. Comparison of baseline instruments to the Jamar dynamometer and the B&L Engineering Pinch Gauge. *Occupational Therapy J Res.* 2000;20(3):147–62. <https://doi.org/10.1177/153944920002000301>.
- Mandanka N, Diwan S. Intra rater and inter rater reliability of hand dynamometer and pinch gauge in children with spastic cerebral palsy. *Indian J Physiother Occupational Therapy.* 2020;14(2). <https://doi.org/10.37506/ijpot.v14i2.2619>.
- McCoy W, Dekerlegand J. Effect of the position of ulnar three digits on thumb to index tip to tip pinch strength. *J Hand Therapy.* 2011;24(4):379. <https://doi.org/10.1016/j.jht.2011.07.008>.
- Bruininks R, Bruininks B. Bruininks-Oseretsky test of motor proficiency (BOT-2). 2nd ed. Minneapolis: NCS Pearson; 2005. p. 1–20.
- Schreuders TAR, Wim Brandsma J, Stam HJ. Functional anatomy and biomechanics of the hand. In: Duruöz MT, editor. *Hand function: a practical guide to assessment*. 2nd ed: Springer Nature Switzerland AG; 2019. p. 3.
- Ozal C, Türker D, Korkem D. Strength training in people with cerebral palsy. *Cereb Palsy Curr Steps.* 2016;103. Intech Open. <https://doi.org/10.5772/64638>.
- Modlesky CM, Zhang C. Muscle size, composition, and architecture in cerebral palsy. In: Miller F, Bachrach S, Lennon N, O'Neil M, editors. *Cerebral palsy*. 2nd ed. Springer, Cham; 2020. DOI: [https://doi.org/10.1007/978-3-319-50592-3\\_14-1](https://doi.org/10.1007/978-3-319-50592-3_14-1)
- Ego A, Lidzba K, Bovedani P, Belmonti V, Gonzalez-Monge S, Boudia B, et al. Visual-perceptual impairment in children with cerebral palsy: a systematic review. *Dev Med Child Neurol.* 2015;57(2):46–51. <https://doi.org/10.1111/dmnc.12687>.
- Fang Y, Wang J, Zhang Y, Qin J. The relationship of motor coordination, visual perception, and executive function to the development of 4-6-year-old Chinese preschoolers' visual motor integration skills. *Biomed Res Int.* 2017;1:1–8. <https://doi.org/10.1155/2017/6264254>.

31. Sai Gayathri M, Prabhu C. To find out the relation between hand impairments and activity limitations of spastic diplegic grasp patterns. *Sch J App Med Sci*. 2016;4(8B):2834–9. <https://doi.org/10.21276/sjams.2016.4.8.22>.
32. Kadaskar V, Borkar T. A Study to evaluate the correlation between pinch grip and handwriting among school going children in rural areas. *Int J Res Rev*. 2020;7(2):412–6.
33. Ng M, Chui M, Lin L, Fong A, Chan D. Performance of the visual-motor integration of preschool children in Hong Kong. *Hong Kong J Occup Ther*. 2015;25(1):7–14. <https://doi.org/10.1016/j.hkjot.2015.06.002>.
34. Cho M, Kim D, Yang Y. Effects of visual perceptual intervention on visual-motor integration and activities of daily living performance of children with cerebral palsy. *J Phys Ther Sci*. 2015;27(2):411–3. <https://doi.org/10.1589/jpts.27.411>.

### Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

**Submit your manuscript to a SpringerOpen<sup>®</sup> journal and benefit from:**

- ▶ Convenient online submission
- ▶ Rigorous peer review
- ▶ Open access: articles freely available online
- ▶ High visibility within the field
- ▶ Retaining the copyright to your article

---

Submit your next manuscript at ▶ [springeropen.com](https://www.springeropen.com)

---