SCIENTIFIC ARTICLE

Affected and Contralateral Hand Strength and Dexterity Measures in Children With Hemiplegic Cerebral Palsy

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Purpose To determine how the affected hemiplegic hand and contralateral dominant hand in children with hemiplegic cerebral palsy compare with age-matched norms for grip strength, pinch strength, and dexterity.

Methods We enrolled 37 children with hemiplegic cerebral palsy (26 boys; average age, 9.8 y). Grip and pinch strength and Box and Blocks Test for dexterity were measured in both hands. Affected and contralateral hands results were analyzed and compared with each other and with norms for age and sex.

Results Affected hands had significantly less grip and pinch strength than the contralateral hands. Subjects transported significantly fewer blocks in one minute with the Box and Blocks Test (mean, 10.8 blocks) with the affected hand than the contralateral hand. Compared with normative values, affected-side grip and pinch strengths were significantly less, whereas contralateral hand grip and pinch strengths were similar. Dexterity in both affected and contralateral hands was significantly less than normative values. Decreased dexterity in the contralateral hand was correlated with decreased nonverbal intelligence quotient.

Conclusions Dexterity of the contralateral hand is diminished in children with hemiplegia. Assessment of the contralateral hand may reveal opportunities for therapeutic intervention that improve fine motor function. *(J Hand Surg Am. 2015;■(■):■−■. Copyright © 2015 by the American Society for Surgery of the Hand. All rights reserved.)*

Type of study/level of evidence Therapeutic IV.

Key words Cerebral palsy, dexterity, hemiplegia.

HAND IMPAIRMENT IN CEREBRAL palsy is due to a nonprogressive disturbance of the developing fetal or infant central nervous system that affects movement and posture causing activity limitations.[1] In hemiplegia, the central nervous system disturbance causes impairment on one side of the body. The degree of impairment of the contralateral limb is unclear because strength and dexterity have not been established. In spastic hemiplegia due to cerebral palsy, some have considered the affected hemiplegic hand to be an "assisting hand" and the contralateral hand a "good" and "unimpaired" hand.[2–4]

The affected assisting hand can present with a combination of spasticity, weakness, and dystonia.[5,6] The extent of limb involvement and the degree of abnormal tone patterns vary among individuals. Most commonly in spastic hemiplegia, the resting posture includes elbow flexion, forearm pronation, wrist ulnar deviation and flexion, and thumb adduction and flexion and is caused by muscle imbalance and

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Received for publication June 11, 2014; accepted in revised form December 29, 2014.

No benefits in any form have been received or will be received related directly or indirectly to the subject of this article.

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0363-5023/15/■ ■-0001$36.00/0
http://dx.doi.org/10.1016/j.jhsa.2014.12.039

weakness, resulting in deficits in precision grasp, pinch, and dexterity. The severity of motor impairment has been shown to correlate with sensory deficits[7]; the greater the sensory deficit, the more likely there will be some neglect and disuse,[8] putting additional demands on the contralateral hand in activity.

However, it is unclear whether the central nervous system insult that causes hemiplegic cerebral palsy can impair both hands. Is the contralateral hand a "good,"[9] "unimpaired"[2,4] hand" or does it have "subtle deficits"[3–6,9,10]? Some authors have reported delays in the development of anticipatory control of grasp formation,[11] speed in movements,[12] fine finger dexterity,[13] and mild sensory impairments in the contralateral hand.[2,8]

Children with hemiplegic cerebral palsy may present with substantial deficits in hand function, because bimanual activities involve the ability to use the affected and contralateral hands together for grasp and stabilization. Several authors have evaluated bimanual involvement in cerebral palsy,[2,9,12,14–16] but these studies have not compared the contralateral hand with normative values, which have been established for grip strength, pinch strength, dexterity, and stereognosis.[7,8,17–20]

The aim of this study was to determine how the affected hemiplegic hand and contralateral hand in children with hemiplegic cerebral palsy compare with age- and sex-matched norms for grip strength, pinch strength, dexterity, and sensibility.

MATERIALS AND METHODS

Five baseline assessments were administered prospectively as part of a multicenter randomized trial that compared tendon transfer surgery in upper extremity (UE) cerebral palsy with botulinum toxin injections and regular ongoing therapy. The participants were recruited from 7 Shriners Hospitals for Children (see Acknowledgments). Each hospital obtained approval from their local institutional review board, and written consent was obtained from each participant's parent or guardian.

Inclusion criteria for the study were children, aged 4 to 17 years with spastic hemiplegic cerebral palsy who were surgical candidates for pronator teres release, flexor carpi ulnaris to extensor carpi radialis brevis tendon transfer, and adductor pollicis release with extensor pollicis longus based on standard indications as determined by a hand surgeon who participated in the study. Exclusion criteria were House score of 0; previous UE surgery; or UE botulinum injections within 12 months.

Between 2006 and 2013, we enrolled 37 children (26 boys and 11 girls) with an average age of 9.8 years (range, 4–15 y). Four were 4 to 5 years old, 7 were 6 to 7 years old, 12 were 8 to 9 years old, 4 were 10 to 11 years old, 5 were 12 to 13 years old, and 5 were 14 to 15 years old.

The left side was affected in 19 children. Occupational therapists from each site of the study, who were trained with the same protocol, administered assessments to each subject, including grip strength, lateral pinch strength, Box and Blocks Test of manual dexterity, stereognosis, and the Comprehensive Test of Nonverbal Intelligence (CTONI).[17,21] Scenarios from each testing session describing cooperation with the test protocol were made and reviewed to verify patient understanding of the tests.

Grip strength was measured for each hand using a calibrated Jamar hydraulic hand dynamometer (Patterson Medical, Warrenville, IL) following administration guidelines from the American Society of Hand Therapists Clinical Assessment Recommendations, Second edition.[22,23] For the affected hand, attempts to maintain the dynamometer in an upright alignment per testing guidelines were made to correct posturing from spasticity of forearm pronation and wrist flexion. The average of 3 separate maximum voluntary contractions was recorded in kilograms. Available normative data for pediatric grip strength were reviewed. The Ferreira norms were selected which includes ages 6 to 15 years for boys and girls by hand dominance.[20]

Lateral pinch strength was measured using a calibrated Preston pinch gauge (Patterson Medical, Warrenville, IL) following the Mathiowetz 1985 administration guidelines by applying force to the gauge using the pulp of the thumb and the radial lateral side of the middle phalange of the index finger.[17] Three separate maximum voluntary contractions for each hand were exerted and the average was recorded in kilograms. Available normative data for pediatric pinch strength were reviewed. The Ferreira norms were selected, which includes ages 6 to 15 years for boys and girls by hand dominance.

The Box and Blocks Test of unilateral manual dexterity was measured using a standardized test kit with administration guidelines by Mathiowetz et al.[17] The kit includes a large wooden box with a center partition, with 200 2-inch (2.54-cm) wood blocks positioned on one side. The child is asked to quickly move one block at a time from one side of the box over the center partition to the other side. The total number of blocks transported in one minute was recorded for each hand. Normative data have been established for

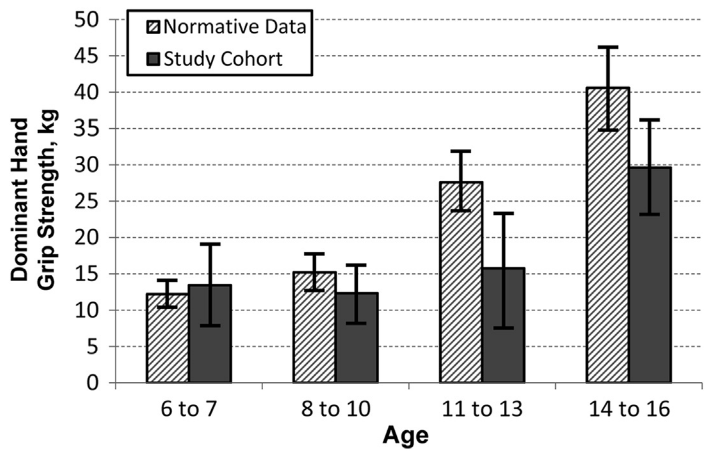

FIGURE 1: Grip strength comparing dominant hand normative data[23] and contralateral dominant hand in this study cohort. Error bars are one SD around the mean. There are no significant differences between the 2 groups.

the Box and Blocks Test by Mathiowetz et al (1985)[17] for children ages 6 to 19 years with both sexes combined. However, Mathiowetz et al presented the normative data only as right and left hand. Thus, for this test, Mathiowetz et al's left hand normative data were compared with our affected hemiplegic side data, and right hand normative data of Mathiowetz et al were compared with our contralateral side data.

Stereognosis was measured as previously standardized to determine a child's tactile recognition of common objects with vision occluded.[7,8] The child was shown and asked to name 12 objects: a wooden block, key, pencil, penny, marble, string, button, safety pin, bead, glove, spoon, and paperclip. The child placed his or her hand inside a tabletop tent and the test administrator placed an object in the tent in random order without the child seeing it. The child was asked to manipulate and identify each object. A duplicate set of objects was available so the child could point to the object if he or she could not verbalize it. The total number of correct responses out of 12 was recorded for each hand.

The CTONI[21] was measured using a computerized format and standardized administration guidelines to assess intellectual ability. The 3 subtests of geometric designs employed a 2 × 2 matrix format without using words. The child was asked to understand that this was to this (the upper 2 boxes of the matrix) as that was to what (the lower 2 boxes of the matrix). The child pointed to one of the choices that went into the blank box. The computer automatically scored each response and moved onto the next subtest as soon as a ceiling was reached. The geometric nonverbal intelligence quotient was recorded and could range from 35 "very poor" to 165 "very superior."

Statistical analysis

Paired *t* tests were used to compare scores between the affected and the contralateral hands for grip strength, lateral pinch strength, the Box and Blocks Test, and stereognosis testing.

Unpaired *t* tests were used to compare scores between the affected and the contralateral hands and published norms.[20,23] For pinch and grip strength, normative data are presented by age from 6 to 15 years, divided by hand dominance and sex. Because the normative data start at age 6 years, the 4- to 5-year-old children tested in our study were not included in the analysis. Our study cohort was not large enough to allow separate analysis stratifying by both age and sex. Initial data analysis showed no differences in our group when separated by sex, but significant differences did exist when stratified by age. Because no significant differences existed between girls and boys, our female cohort (n = 11) was combined with our male group (n = 26), because the majority were male. For grip and pinch strength norms, Ferreira et al's published norms[20] for males dominant hand were compared with the contralateral hand, and males nondominant hand were compared with the affected hand of our cohort, stratified by age.

For Box and Blocks Test norms, Mathiowetz et al's published norms[20] include normative data for ages 6 to 17 years by sex for right or left hands. Our 4- to 5-year-old subjects were not included. Similar to grip and pinch, our males and females did not have significant differences. Because our study cohort was small when stratified by both age and sex, males (n = 26) and females (n = 11) were combined and compared with male normative data because that was

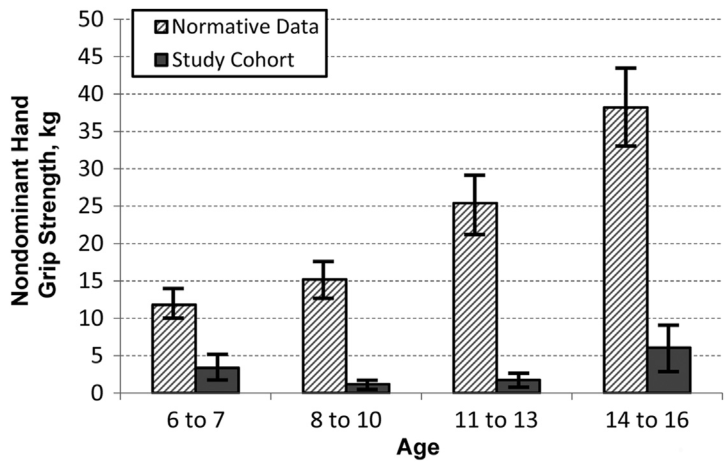

FIGURE 2: Grip strength comparing nondominant hand normative data[23] and affected hemiplegic hand in this study cohort. Error bars are one SD around the mean. The affected hemiplegic hand has significantly less grip strength than normative data ($P < .01$) for all age groups.

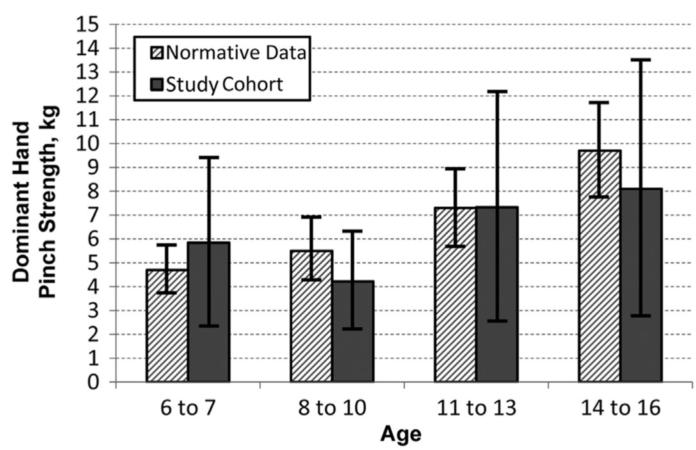

FIGURE 3: Lateral pinch strength comparing dominant hand normative data[20] and contralateral dominant hand in this study cohort. Error bars are one SD around the mean. There are no significant differences between the 2 groups, except for the 8- to 10-year-old age group, which was borderline less ($P = .05$) than normative values.

the larger group. Because Mathiowetz et al only presented their data for right and left (not dominant or nondominant), our normative left hand data were compared with the affected hand of our cohort, and normative right hand data were compared with the contralateral dominant hand of our cohort.

The Pearson correlation was used to analyze the correlation of the CTONI with contralateral hand stereognosis and Box and Blocks Test scores, with the level of statistical significance set at 5% ($P \leq .05$).

RESULTS

Grip strength

Affected hands had significantly ($P = .001$) less grip strength (mean, 2.7 kg; SD, 3.4) than contralateral hands (mean, 16.3 kg; SD, 12.3). As shown in Figure 1, grip strength in the contralateral hands in our study subjects was similar to age-normative values for dominant hands for all age groups. As shown in Figure 2, grip strength in the affected hand in our study subjects was significantly below normative values for nondominant hands for all age groups ($P < .01$).

Lateral key pinch strength

Affected hands had significantly ($P =.001$) less pinch strength (mean, 1.7 kg; SD, 1.1) than contralateral hands (mean, 5.6 kg; SD, 3.3). As shown in Figure 3, pinch strength in the contralateral dominant hand in our study subjects was similar to age-normative values except for the 8- to 10-year-old age group, which was borderline less ($P = .05$) than normative values. As shown in Figure 4, pinch strength in the

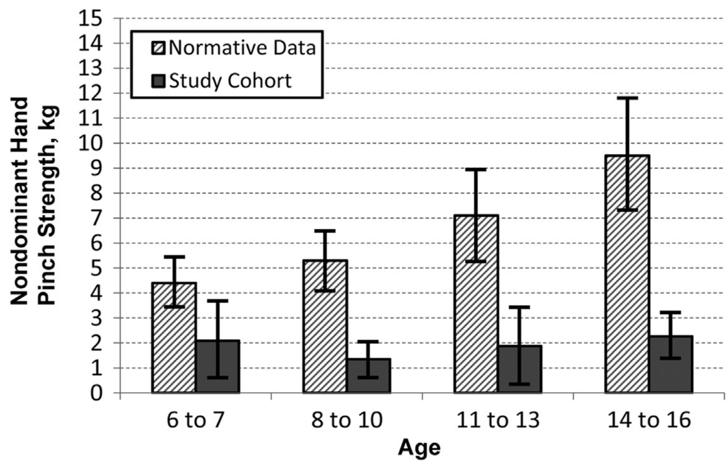

FIGURE 4: Lateral pinch strength comparing nondominant hand normative data[20] and affected hemiplegic hand in this study cohort. Error bars are one SD around the mean. The affected hemiplegic hand has significantly less pinch strength than normative data ($P < .01$) for all age groups.

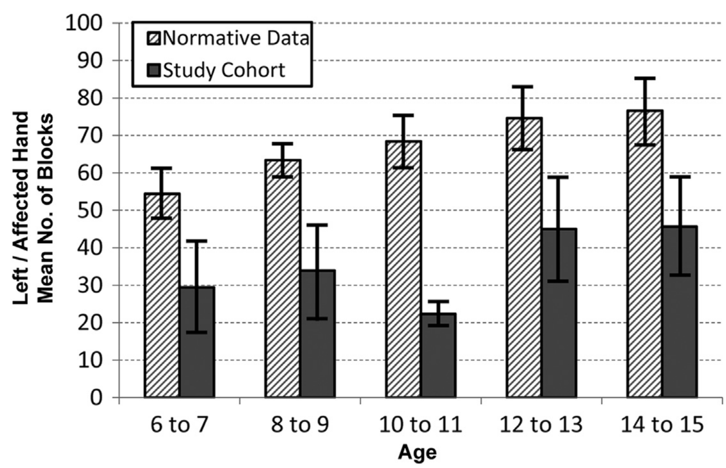

FIGURE 5: Box and Blocks Test scores comparing right hand normative data[17] and the contralateral-dominant hand in this study cohort. Error bars are one standard deviation around the mean. The contralateral hand scores are significantly lower ($P< 0.01$) than normative values for all age groups.

affected hand in our study subjects was significantly below normative values for nondominant hands for all age groups ($P < .01$).

Blocks and Box Test (dexterity)

Subjects transported significantly fewer blocks in one minute with the Box and Blocks Test (mean, 10.8 blocks, SD 7.2) with their affected hand than with their contralateral hands (mean, 35.6; SD, 13.6; $P = .001$). As shown in Figure 5, Box and Blocks Test scores for subjects' contralateral hands in our study subjects were significantly lower ($P < .01$) than normative values for all age groups. Similarly, as shown in Figure 6, Box and Blocks scores for subjects' affected hands in our study subjects were significantly lower ($P < .01$) than normative data for all age groups.

Box and Blocks Test impairment analysis

Although it would be expected that the affected hemiplegic hand would have dexterity impairment, it was not expected that the contralateral dominant hand would have dexterity impairment. Consideration as to whether this may be due to sensibility deficiency or intelligence impairment was further evaluated.

For sensibility, subjects identified a mean of 6.1 objects correctly in the affected hand (SD, 3.6), and a mean of 11.1 objects correctly in the contralateral hand (SD, 1.5). There was significant correlation (Pearson correlation, 0.403; $P = .014$) comparing the contralateral hand for stereognosis to the contralateral hand Box and Blocks Test. In other words, children with greater sensibility impairment in the contralateral dominant hand had greater dexterity impairment.

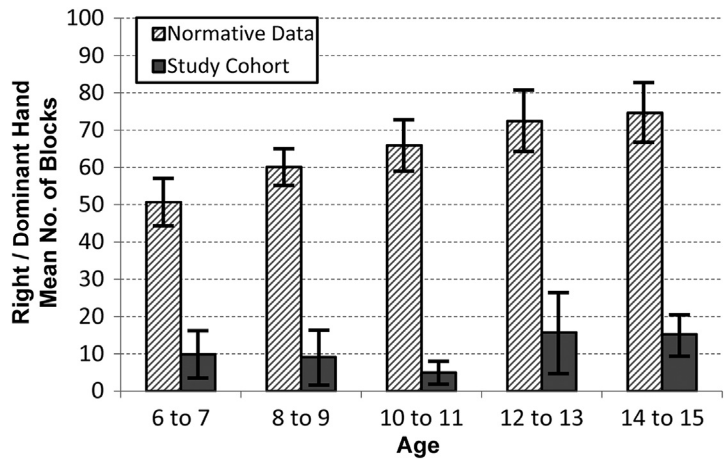

FIGURE 6: Box and Blocks Test scores comparing left hand normative data[17] and the affected hemiplegic hand in this study cohort. Error bars are one standard deviation around the mean. The affected hemiplegic hand scores are significantly lower ($P < 0.01$) than normative values for all age groups.

TABLE 1. Stereognosis and CTONI Scores for the Contralateral Dominant Hand With Correlation to Box and Blocks Dexterity Testing

	n	Mean Score	Range	Pearson Correlation With Box and Blocks	*P* Value
Stereognosis score	37	11	5−12	.403	.014*
CTONI score	37	83	44−115	.430	.008†

*Patients with greater stereognosis impairment had greater Box and Blocks dexterity impairment with a Pearson correlation significant at the 0.01 level (2-tailed).

†Patients with greater CTONI impairment had greater Box and Blocks dexterity impairment with Pearson correlation significant at the 0.05 level (2-tailed).

The relationship of Box and Blocks Test impairment in the contralateral hand with intelligence impairment was further evaluated. Intelligence was measured by the CTONI. In our subjects, the mean CTONI geometric nonverbal intelligence quotient was 82 (range, 44−115), which was considered "below average" for intellectual ability. A CTONI score of 35 to 69 is described as "very poor," 70 to 79 as "poor," 80 to 89 as "below average," 90 to 110 as "average," and 111 to 120 as "above average." The CTONI had a significant correlation with the Box and Blocks Test (Pearson correlation, 0.430; $P = .008$) for contralateral hands. In other words, children with greater intelligence impairment had greater dexterity impairment in the contralateral hand (Table 1).

DISCUSSION

Most published studies of UE function in hemiplegic cerebral palsy emphasize assessment of the affected hand. People with hemiplegic cerebral palsy rely on their contralateral and dominant hand for most functional tasks. We do not know the effect of hemiplegia on the contralateral hand or how that hand is affected by diminished control of the opposite hand. The dominant hand in children with hemiplegic cerebral palsy has not been systematically investigated, although "subtle deficits" have been reported.[24] Subtle signs of coordination disorders have been shown with anticipatory control of grasp formation[14] when the dominant hand is preparing for reach and grasp. Slower speed of movements[15] has been shown with both hands during keyboarding that requires finger aiming and repetition.[13] When the hemiplegic hand is being challenged, mirror movements can occur at the same time in the dominant hand.[14] Subtle deficits in fingertip forces have been observed in the sequencing of the grip-lift movement[5] and fine-finger dexterity.[2]

The subjects of this study were surgical candidates for tendon transfer and muscle release surgery in their affected hand. As part of their participation in a study examining the results of the surgical intervention, both the affected and the contralateral hands were assessed for strength and dexterity and were compared with published norms for typically developing children.

This study had several expected findings. The affected side in hemiplegic cerebral palsy had less strength, less dexterity, and worse stereognosis function than the contralateral side. The contralateral hand of a child with hemiplegic cerebral palsy was without exception the dominant hand, so it was not surprising that grip strength and pinch strength of the contralateral hands were similar to normative values. Comparing the contralateral with the affected hands, the contralateral hands had 60% stronger grip strength and 32% stronger pinch strength and scored 33% higher on the dexterity test used in the study. This information may offer guidelines for clinicians when discussing hand strength and dexterity differences with families.

It was, however, an unexpected finding that that dexterity in the contralateral hands of children with hemiplegic cerebral palsy as measured by Box and Blocks Test was statistically significantly less than published norms for typically developing children's dominant hands. Upon further analysis, impairment of dexterity as measured by Box and Blocks Test was correlated with both impairment of stereognosis function and with lower intelligence scores as measured by CTONI. The results of stereognosis testing of the unaffected hand (mean, 11.1 objects) were similar to those of Van Heest et al[8] (11.8 objects), with both studies indicating "intact" stereognosis on the unaffected side. However, on further analysis of our study cohort, the unaffected hand did have a range of impairment of stereognosis from 5 to 12 objects correctly identified. Furthermore, those children with greater impairment of stereognosis also had greater impairment of dexterity in the contralateral hand.

Our subjects also had a wide range of intellectual impairment. The average CTONI score of our study cohort was "below average intelligence," with a wide range from 44 to 115. Using CTONI standards, the range was from "very poor" to just "above average." "While the central feature of cerebral palsy is a disorder with movement, difficulties with thinking and learning often occur."[25] With cognitive testing of nonverbal intelligence, which includes solving problems and reasoning, 65% of our subjects scored "below average" or less. The results of the nonverbal intelligence (CTONI) were positively correlated with the performance on the Box and Blocks Test of manual dexterity. In our study, below average nonverbal intelligence correlated with impaired hand dexterity of the contralateral hand.

A strength of this study was the thorough and standardized application of validated testing of children with cerebral palsy hemiplegia who were candidates for surgery based on standard indications. Limitations of this study include normative data that were difficult to match directly to our study cohort. Pinch and grip strengths and dexterity norms were stratified by age and sex. Age norms in these data sets did not include 4- to 5-year-olds, so those subjects were not analyzed. Our study had an insufficient number of subjects simultaneously to analyze for both age and sex. Furthermore, normative data for Box and Blocks Test were based on right and left hands,[23] not dominant or nondominant. In order to compare our data, right hand normative data were compared with contralateral dominant hands and left hand normative data were compared with affected hemiplegic hands.

Our study has several implications. First, data were provided regarding significant impairment of the affected hand for strength, dexterity, and stereognosis. Second, data were provided showing normal pinch and grip strength in the contralateral dominant hand. Most importantly, this study had the unexpected finding of impairment of dexterity in the contralateral dominant hand, which was correlated to both impaired stereognosis and lower nonverbal intelligence. Assessment of the dexterity of the contralateral dominant hands of children with hemiplegic cerebral palsy may reveal opportunities for therapeutic intervention that improve fine motor function.

ACKNOWLEDGMENT

Institutional support for this project was received from the Shriners Hospitals for Children Multi-center Research Grant #9196: Comparison of functional outcomes of tendon transfer surgery, botulinum toxin injections, and regular ongoing treatment in hemiplegic cerebral palsy.

List of investigators, therapists (T), coordinators (C), other contributors (OC) (in order of number of subjects consented, given in parentheses): Jon Davids, MD, Shriners Hospitals for Children, Greenville, SC (8), and Lisa Wagner and Laura Peace (T); Philip Gates, MD, Shriners Hospitals for Children, Shreveport, LA (7), Ann Boyd, Laura Burford, (T), Susan Campbell (C), and Virginia Scales (OC); Alfred Hess, MD and Cara Novick, MD, Shriners Hospitals for Children, Tampa, FL (7), Adrienne Karol, Lynn White, Carmen Longnecker (T), and Nancy Pisciotto, Jennifer Jenkins, Ed Quigley (OC); Douglas Hutchinson, MD, Shriners Hospitals for Children, Intermountain, Salt Lake City, UT (5), Chris Pratt (T), and Bruce MacWilliamson, Barbara Johnson (OC); Michelle James, MD and Anita Bagley, PhD, Shriners Hospitals for Children, Northern California, Sacramento, CA (4), Trang Bui, Denise Caldwell, Cheryl Hanley (T), Sherry Middleton, Susan Anderson (C), and Grace McNelis (OC); Ann Van Heest, MD, Shriners Hospitals for Children, Twin Cities, MN (4), Wendy A. Tomhave (T), and Gabriela Ferski (C); Randip Bindra, MD, Shriners Hospitals for Children, Chicago (4), and Jasmine Gilliam (T).

The authors would also like to acknowledge the contributions of Fred Molitor, PhD, Andrew Koman, MD, Beth Patterson Smith, PhD, Roslyn Boyd, PhD, Paul Manske, MD, Chantal Janelle, MD, Jennifer Ty, MD, Carolien de Roode-Wentz, MD, Emily Hattwick, MD, Chris Church, Andrea Melanson, Julia Leamon, Randi Simenson, and Cathy Fox.

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