Developmental Neurorehabilitation

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/ipdr20

Speech-Language Profile Groups in School Aged Children with Cerebral Palsy: Nonverbal Cognition, Receptive Language, Speech Intelligibility, and Motor Function

Jennifer U. Soriano & Katherine C. Hustad

To cite this article: Jennifer U. Soriano & Katherine C. Hustad (2020): Speech-Language Profile Groups in School Aged Children with Cerebral Palsy: Nonverbal Cognition, Receptive Language, Speech Intelligibility, and Motor Function, Developmental Neurorehabilitation, DOI: 10.1080/17518423.2020.1858360

To link to this article: https://doi.org/10.1080/17518423.2020.1858360

Published online: 27 Dec 2020.

DEVELOPMENTAL NEUROREHABILITATION
https://doi.org/10.1080/17518423.2020.1858360

Taylor & Francis
Taylor & Francis Group

Speech-Language Profile Groups in School Aged Children with Cerebral Palsy: Nonverbal Cognition, Receptive Language, Speech Intelligibility, and Motor Function

Jennifer U. Soriano and Katherine C. Hustad

University of Wisconsin, Madison, WI, USA

ABSTRACT

Purpose: To explore the relationship of intelligibility, receptive language, executive functioning, and motor skills to nonverbal cognitive skills among children with cerebral palsy (CP) in different speech-language profile groups.

Method: Twenty-seven children with CP aged 10–12 years old participated in the study. They completed a battery of standard clinical assessments. The relationship of various skillsets with nonverbal cognitive ability was explored using correlational procedures. Additionally, we examined pairwise differences in nonverbal cognitive skills among profile groups. Cohen's Kappa and Chi-square tests were used to study the consistency of receptive language and nonverbal cognitive performance.

Results: Children who showed better nonverbal cognitive abilities demonstrated better motor, receptive language, and intelligibility skills. Nonverbal cognition was generally consistent with receptive language.

Conclusion: Nonverbal cognitive impairment often co-occurs with language and speech motor impairment among children with CP. Speech-language profile groups are a useful framework for describing both communication and cognitive abilities.

ARTICLE HISTORY
Received May 01, 2020
Revised October 19, 2020
Accepted November 28, 2020

KEYWORDS
Cerebral palsy; nonverbal cognition; intelligibility; receptive language; functional motor abilities; speech-language profile groups

Introduction

Cerebral palsy (CP) is a neuro-motor condition that occurs secondary to damage sustained by a premature brain.[1] Children with CP may present impairments related to behavior, cognition, sensory-perceptual, and/or communication domains.[2,3] Studies suggest that children with CP who have more complex brain damage tend to have severe motor involvement and more co-occurring impairments,[4–7] subsequently leading to greater functional limitations.[8] Communication challenges are common and may be associated with deficits in cognitive, language, and/or speech motor domains.[6,9] Türkoğlu and colleagues[10] reported that 63.8% of children with CP in their study had intellectual disability. Several studies have noted the challenges of measuring the cognitive abilities of children with motor involvement.[11–14] Nonverbal cognitive measures typically involve interacting with manipulables. Thus, children must rely on their manual abilities to demonstrate knowledge and complete test items (i.e. complete puzzles, move cards, place objects, etc.). Moreover, most tests of cognitive functions are lengthy and fatiguing.[15] Several studies have identified a correlation between the development of receptive language and cognition,[16–19] which suggests that language performance may be a potential marker for cognitive abilities.[20–22] For children with CP, language comprehension testing offers advantages over nonverbal cognitive measures in that motor requirements for some tests are considerably reduced (e.g. requiring pointing or alternative selection methods to indicate a choice among discrete pictures). Consequently, the question of whether language comprehension abilities are consistent with nonverbal cognitive abilities in children with CP is of interest because if one measure can stand in for or approximate the other, it may be possible to use this information to support educational and therapeutic programming.

Because of the wide range of potential co-occurring deficits, children with CP are heterogeneous. Classification systems can help reduce heterogeneity by creating smaller subgroups with common features, thereby paving the way for a common language among professionals, family members, and individuals with CP within clinical and research settings.[3,23] Classification of ability profiles within and between domains can lead to an in-depth analysis of the nature and severity of CP,[3] better interpretation and generalization of CP intervention studies,[23] and generating more tailored intervention approaches.[24] Of particular interest for the present study is the Speech-Language Profile Group paradigm,[25] which classifies children based on nature and severity of both speech and language impairments. Three levels of differentiation are used to determine speech-language profile group membership (Figure 1). In the first level, children with CP are grouped based on the presence or absence of speech motor involvement as determined by clinical assessment. Children without clinically identified speech motor involvement comprise their own group and are referred to as children with no clinical speech motor involvement. The second level of differentiation separates children with speech motor impairment according to whether they are able to produce speech. Children who are unable to produce more than five differentiable words or word approximations comprise their own group and are referred to as having anarthria. In the third level of differentiation, children with speech motor impairment who are able to produce more than five words are further divided into two groups based

CONTACT Jennifer U. Soriano jusoriano@wisc.edu Waisman Center, University of Wisconsin, Madison, WI 53706, USA.

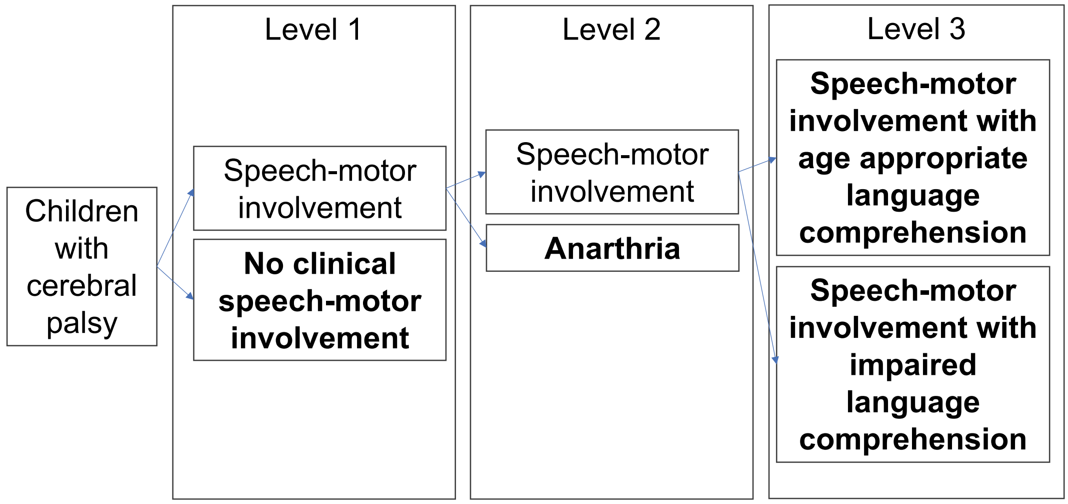

Figure 1. Speech-language profile group levels of differentiation.

on the presence or absence of language comprehension impairment (per standardized assessment results).

Hustad and colleagues[25] validated the speech-language profile group paradigm, which included the following four communication profile groups: 1) those with no clinically observable speech motor involvement; 2) those with speech motor involvement who were unable to produce speech; 3) those with clinical speech motor involvement who had concurrent language comprehension impairment; and 4) those with clinical speech motor involvement who had language comprehension in the typical range. Several studies have examined this classification paradigm, providing support for the validity of these profile groups.[25–28]

Other studies using the speech-language profile group paradigm have revealed several important findings regarding the development of communication abilities in children with CP. For example, Hustad, Sakash, Broman, and Rathouz[29] described receptive language development trajectories of children with CP aged 18 to 54 months by profile group. One of the key findings was that early language comprehension performance (i.e. abilities at 24 and 30 months) was highly predictive of later communication abilities. The authors observed that children with speech motor impairment demonstrated receptive language delay, which was constant across the time span of the study relative to children with no clinical speech motor involvement. In another study, Sakash, Broman, Rathouz, and Hustad[30] examined the executive functioning skills of children with CP. Results showed that regardless of speech-language profile group membership, children with CP had significantly elevated scores on the Behavior Rating Inventory of Executive Function (BRIEF),[31] indicating deficits in executive function skills. These results suggest that executive function deficits did not appear to be directly linked to speech and language abilities, and support the argument that language and cognition are separate and different constructs.[32] However, the domain of cognition is multifaceted. A deeper understanding of how cognitive abilities co-vary with speech and language abilities is needed to further characterize the constellation of deficits in children with CP, and may contribute to development of more effective intervention programs.[33]

One important limitation of the speech-language profile group paradigm employed by Hustad and colleagues is that cognitive abilities were not measured directly. As a result, the extent to which cognitive abilities and the presence of intellectual disability may relate to profile group membership is unknown. Other studies examining cognition have provided useful information to advance our understanding of the nature of cognitive challenges experienced by children with CP. Some authors describe specific cognitive impairments, such as attention, visual-perceptual, and executive functioning deficits among individuals with CP.[4,5,30,34] Studies have documented that children with CP had lower performance (i.e. nonverbal cognitive abilities) intelligence quotient (IQ) than verbal IQ.[9,34,35] Lower scores have been attributed to presence of visual perceptual problems and severe motor involvement. Moreover, Peeters, Verhoeven, van Balkom, and de Moor[36] reported that children with CP obtained lower scores on nonverbal cognitive abilities as compared to age-matched typically developing peers. Inter-relations between different facets of cognitive, speech motor, and language abilities in children with CP are not well understood but clearly have important implications for intervention.

In research among children with CP, speech impairments have been correlated with intellectual disability and poor gross and manual motor abilities.[7,37–39] Recent studies have identified cognition and manual motor function as risk factors for speech impairments.[10,40] In these studies, the authors collected standardized cognitive measures and looked at the relationship of these measures with the presence of speech impairment. Choi and colleagues[40] reported that an experienced clinician determined the speech abilities of their participants; while Türkoğlu's team[10] noted the presence of speech impairment as part of their demographic data, providing no further information regarding the nature or severity of speech deficits. Measures and procedures for diagnosing speech impairment were not reported in either of the studies. Although these studies contribute to a general understanding of the associated impairments of children with CP and the interrelationship of speech and cognition, research that looks more specifically at quantitative measures of speech and the relationship of these measures to cognition is needed.

In the present study, we had two aims. First, we sought to examine the inter-relations among nonverbal cognition, language comprehension, speech intelligibility, executive function, fine motor abilities, and gross motor abilities among children with CP. Guided by the findings of previous studies on the relationship of receptive language and cognition,[16–22] we anticipated a strong correlation between these two domains. We hypothesized, following the findings of Sakash, Broman, Rathouz, and Hustad[30], that the relationship of nonverbal cognitive skills with executive functioning and with intelligibility would be modest or weak. We predicted significant association between nonverbal cognitive and motor skills (i.e. Gross Motor Classification System [GMFCS][41] and Manual Ability Classification System ratings [MACS][42]) for children with the most and least severe involvement following previous studies.[4,5]

Our second aim was to examine whether there were differences in nonverbal cognitive ability among the three speech-language profile groups of children who were able to produce speech (those with no speech motor involvement; those with speech motor involvement and typical language comprehension; and those with speech motor involvement and language comprehension impairment). We also sought to examine the extent to which binary judgments of language comprehension abilities (impaired vs. typically developing) would be consistent with binary judgments of nonverbal cognitive abilities (impaired vs. typically developing) for children in the three speech-language profile groups, thus exploring the potential utility of using receptive language performance as a marker for cognitive abilities within the speech-language profile group paradigm. The present study is the first to quantify the extent to which speech-language profile groups based, in part, on language comprehension abilities, were also reflective of nonverbal cognitive abilities in children with CP. We anticipated that nonverbal cognitive skills of children with no speech motor involvement and those with speech motor impairment and typical language comprehension would be higher as compared to those with speech motor involvement and language comprehension impairment. We expected that binary performance judgments on language comprehension and nonverbal cognitive abilities would be highly consistent within groups. Such findings would support the use of receptive language as a potential indicator for cognition in children with CP who are able to speak. However, other studies have documented lower scores for nonverbal reasoning IQ than verbal IQ in children with CP.[9,34,35] Considering overlapping skills between verbal IQ and receptive language measures, we anticipated that a significant difference between performance in the two domains may be possible.

Method

Participants

Children with Cerebral Palsy

Participants of the present study were part of a larger longitudinal study on the communication development of children with CP. Ethical approval was granted by the University of Wisconsin-Madison Health Sciences Institutional Review Boards for the larger longitudinal study (ID number: 2013–1258). The participants were recruited through medical clinics in the Upper Midwest region of the USA. Eligibility criteria for the larger study required that children 1) have a medical diagnosis of CP, 2) have hearing within normal limits according to a distortion product otoacoustic emission screening, and 3) have no co-occurring diagnosis of autism spectrum disorder. In the present study, additional inclusion criteria required that the children 4) be 10–12 years of age.

Twenty-seven children met the inclusion criteria. All children were born in the USA between the year 2004 and 2007. Mean age was 11.45 years (SD = 0.77). The sample comprised 12 girls and 15 boys.

Children were separated into individual speech-language profile groups by two certified speech-language pathologists with expertise in assessment and treatment of children with CP. To classify children, each child was first differentiated based on the presence or absence of speech motor impairment. This was determined through clinical evaluation of each child's speech during data collection sessions. Sources of information included audio samples and video clips of children in both structured and spontaneous speech tasks. Clinicians looked for evidence of drooling, facial asymmetry at rest and during movement, and increased tone of the orofacial muscles during parent–child and clinician–child interactions. They also made perceptual assessments of speech samples with a focus on identifying perceptual features of speech that were consistent with dysarthria for each speech-subsystem. Examples of subsystem-specific perceptual features include, but are not limited to hoarse, harsh, or breathy vocal quality, low vocal volume, short breath groups, hypernasality, imprecise articulation, presence of articulatory distortions that were not developmentally appropriate. Classification agreement for clinical presentation of speech motor involvement between the speech-language pathologists was 100% and Cohen's Kappa, $\kappa = 1$. Of the children in this study, eight were determined to have no clinical speech motor involvement; 19 had speech motor impairment.

The 19 children who had clinical evidence of speech motor impairment were subdivided into those with clinical evidence of language comprehension impairment, and those with language comprehension that was typically developing. Determination of language comprehension impairment was based on standard scores that were 1.5 standard deviations below age expectations as described in Test of Auditory Comprehension of Language, Fourth Edition (TACL-4) technical manual.[43] Of the 19 children with speech motor involvement, nine demonstrated language comprehension that was typically developing, while 10 were determined to have language comprehension impairment. Demographic characteristics of the participants are presented in Table 1.

Adult Listeners

Fifty-four adult listeners (two per child) participated in this study to provide speech intelligibility ratings of children with CP. Listeners made orthographic transcription of the lexical content of children's recorded speech which were scored as correct or incorrect. Listeners were predominately undergraduate students from the University of Wisconsin-Madison community. They were recruited via public postings and were compensated either monetarily or with extra credit in a Communication Sciences &

Table 1. Demographic characteristics of children with cerebral palsy by speech-language profile group.

	NMSI, $n = 8$	SMI-LCT, $n = 9$	SMI-LCI, $n = 10$	All children, $n = 27$
Mean age (Std. Deviation)	11.56 (0.56)	11.92 (0.60)	10.95 (0.80)	11.45 (0.77)
Sex				
Male	5	5	5	15
Female	3	4	5	12
GMFCS				
I	7	4	0	11
II	1	1	6	8
III	0	2	1	3
IV	0	1	2	3
V	0	1	1	2
MACS				
I	3	3	0	6
II	5	3	6	14
III	0	2	2	4
IV	0	1	2	3
V	0	0	0	0
CP type				
Spastic				
Diplegia	2	2	1	5
Hemiplegia (left)	3	0	2	5
Hemiplegia (right)	2	1	5	8
Quadriplegia	0	3	1	4
Unknown	1	1	0	2
Ataxic	0	2	0	2
Unknown	0	0	1	1
Vision				
Within normal limits	6	6	2	14
Corrected	1	3	7	11
Uncorrected	1	0	1	2

Note: NSMI = No speech motor involvement; SMI-LCT = Speech motor involvement with typical language; SMI-LCI = Speech motor involvement with impaired language; GMFCS = Gross Motor Function Classification System; MACS = Manual Ability Classification System.

Disorders class. Eligibility criteria for participation were 1) aged 18 and 45 years, 2) be a native speaker of American English, 3) have no identified language, learning, or cognitive disabilities per self-report, and 4) pass a standard pure tone hearing screening. Among the 54 listeners, nine were male and 45 were female. The mean age of listeners was 21.91 years (SD = 5.70).

Materials and Procedures

Children participated in standard data collection sessions that were up to three hours in duration. A research speech-language pathologist collected all data from the children following a research protocol. All sessions occurred in a sound attenuating suite. The following specific measures were of interest for the present study.

Receptive Language Skills

The Test of Auditory Comprehension of Language, Fourth Edition (TACL-4)[43] was administered. All three subtests of the TACL-4 were included in the testing: Vocabulary, Grammatical Morphemes, and Elaborated Phrases and Sentences, yielding a comprehensive receptive language score. The TACL-4 composite scores were converted to standard scores following the test manual. Standard scores were based on a mean of 100 and a standard deviation of 15. Presence of language comprehension impairment was operationally defined as having a standard score that was 1.5 standard deviations below age expectations. Per the technical manual, the cutoff point was a standard score of 77. Participants who obtained a score of 77 and below were considered to have language comprehension impairment. Note that 1.5 standard deviations below age expectation are described as being in the borderline impaired or delayed range in the technical manual. We used a conservative operational definition of language comprehension impairment to be consistent with clinical and research practice in child language delays/disorders. The use of 1.5 standard deviations from the mean as a cutoff score for language impairment has been reported in previous studies of children with language impairment.[44]

Nonverbal Cognitive Skills Measure

The Leiter International Performance Scale – Revised (Leiter-R)[45] was used as a measure of nonverbal cognitive ability. Specifically, we used the Brief Intelligence Quotient (IQ) composite score from the Leiter-R primarily because of its shorter administration requirements (using fewer subtests than the full-scale IQ). The four subtests that were administered measured fluid reasoning and visuospatial processing, namely, Figure Ground, Form Completion, Sequential Order, and Repeated Patterns. Composite scores were based on a mean of 100 and a standard deviation of 15. Children were determined to have nonverbal cognitive impairment based on standard scores that were 2.0 standard deviations below age expectations as described in Leiter-R technical manual. Thus, children with Brief IQ composite scores of 69 or lower were considered to have nonverbal cognitive impairment. IQ scores below 2.0 standard deviations from the mean are widely used in psychology testing as a criterion for cognitive impairment or intellectual disability.[46,47]

Note that modifications were necessary to accommodate for motor impairment for several children for three subtests which required children to place cards into slots. Eight of the participants (29.63%, $n = 27$) encountered difficulty with this task; thus, accommodations were given to support their dexterity level. Specifically, participants who had difficulty picking up and placing the cards in the slots used pointing to select a picture and indicate the intended slot; then, the examiner placed the picture as directed.

Parent Completed Measures

At the time of each visit, parents completed the GMFCS, MACS, and the BRIEF rating scales. We used the Global Executive Composite T-Score from the BRIEF as a measure for executive functioning skills. Per the technical manual, T-scores equal to 60 and above are considered to be within the elevated range. Elevated scores indicate the presence of executive dysfunction. The BRIEF was not completed for three participants.

Speech Production Skills Measure

Each child produced stimuli from the Test of Children's Speech Plus (TOCS+),[48] which involved repetition of individual words and sets of utterance ranging from two to seven words in length. All utterances were developmentally appropriate in terms of lexical, phonetic, syntactic, and morphological features. Professional-quality digital audio and video equipment were used to record the productions.

Research assistants trained in acoustic analysis segmented the collected speech samples into individual utterances and peak amplitude normalized wav files of each utterance produced by each child using Audacity® version 2.2.2. All parsed utterances were compiled into a control file to be played for adult listeners.

Adult participants listened to a child through a computer with a 19-inch flat-screen monitor, a keyboard, and an external speaker in a sound-attenuated booth. Listeners were informed that the aim of the study was to determine how understandable children's speech is to unfamiliar adult listeners. They were asked to orthographically transcribe what they thought the child produced. To control for possible learning effects associated with hearing the same speaker over time and/or repeated speech stimuli, two unique listeners made orthographic transcriptions for each speech sample. Each transcribed word was scored as correct or incorrect relative to the target utterance from the TOCS+ produced by the child. Homonyms and misspellings were accepted as correct if the orthographic transcription matched the phonemes from the spoken version of the utterance. Intelligibility scores were determined by computing for the percent of words identified correctly by each listener, averaged across the two listener per child.

As there are no widely accepted cutoff scores, the presence of significant functional speech deficits was operationally defined as intelligibility scores equal to 79 and below. Intelligibility scores equal to 80 and above were considered to reflect functional speech intelligibility following our earlier work.[49]

Experimental Design and Statistical Procedures

To address the first aim of examining relationships between nonverbal cognitive skills and other child variables of interest, we used descriptive statistics and correlational analyses. Using the Shapiro-Wilk test (Table 2), we determined that the GMFCS, MACS, and intelligibility rating data were not normally distributed. In addition, GMFCS and MACS levels are ordinal ratings; thus, Spearman correlation coefficients were used. Pearson correlation coefficients were used for receptive language and executive function measures.

To address the second aim of examining differences in nonverbal cognitive skills among children in different speech-language profile groups, we used descriptive statistics and the nonparametric Mann-Whitney U test to examine pairwise group differences. Given that hypothesis testing involved directionality, all comparisons were one-tailed with an alpha level of .05. To examine the binary consistency of children's performance based on receptive language vs. nonverbal cognitive measures, the children were identified to either have typical or impaired abilities for both domains. For receptive language, children were identified to have language comprehension impairment when their standard scores were 1.5 standard deviations below age expectations per the TACL-4 manual. The cutoff point was a standard score of 77. For the nonverbal cognitive domain, children who scored 2.0 standard deviation below age expectation per the Leiter-R manual were identified to have nonverbal cognitive impairment. The cutoff point was a standard score of 69 on the Leiter-R. Performance based on language comprehension and cognitive measures were cross tabulated to determine the percentage of match and mismatch via Cohen's Kappa coefficient. We used the McNemar's Chi-square to test for the significance of marginal probabilities. Given the small sample size, continuity correction was used.

Table 2. Results of Shapiro-Wilk test for normality.

	W-value	*p*-value
GMFCS	0.82	<.001*
MACS	0.84	<.001*
TACL-4 standard score	0.95	.337
Leiter-R Brief IQ score	0.96	.371
Intelligibility rating	0.76	<.001*
BRIEF *T*-score	0.96	.371

Note: GMFCS = Gross Motor Function Classification System; MACS = Manual Ability Classification System; TACL-4 = Test of Auditory Comprehension of Language, Fourth Edition; BRIEF = Behavior Rating Inventory of Executive Function; Test for normality was used to determine the appropriate statistical correlation test.

* Statistical significance at $p < .05$.

Results

Relationship of Nonverbal Cognitive Abilities with Motor, Receptive Language, Intelligibility, and Executive Function Skills

Table 3 shows distributions of child data according to impaired and typical nonverbal cognitive abilities in relation to motor, receptive language, intelligibility, and executive function skills. Scatterplots of nonverbal cognitive abilities with motor, receptive language, and intelligibility are presented in Figures 2 and 3. Table 4 shows the correlational analysis of all variables included in the study, which indicated that motor, nonverbal cognitive, receptive language, and speech were moderately to strongly correlated with each other. Executive function skills had weak correlations with all the other variables. Guided by Dancey and Reidy[50] descriptive categories for the strength of correlation, results indicated that better nonverbal abilities were strongly correlated with better receptive language ($r(27) = .75$, $p = <.001$) and gross motor skills ($r(27) = .72$, $p = <.001$). Fine motor skills ($r(27) = .50$, $p = .007$) and intelligibility ($r(27) = .65$, $p = <.001$) were moderately positively correlated. Executive function skills ($r(27) = .23$, $p = .280$) demonstrated a weak correlation.

Differences in Nonverbal Cognitive Skills among Children in Different Speech-language Profile Groups

Descriptive data showing group means, medians, and ranges on the Leiter-R Brief IQ scores by profile groups are presented in Figure 4. The majority of the participants with no speech motor involvement and with speech motor involvement and typical language comprehension (76.47%, $n = 13$ of 17) scored above the cutoff score (i.e. 69) for cognitive impairment, while the majority of the participants with speech motor involvement and language comprehension impairment (80%, $n = 8$ of 10) scored below the cutoff score for cognitive impairment. Mann-Whitney U test results (Table 5) indicated that participants with no speech motor involvement ($M = 92.00$, $SD = 19.65$, $n = 8$) and children with speech motor involvement and typical language comprehension ($M = 76.56$, $SD = 16.06$, $n = 9$) had significantly higher

Table 3. Distribution of child data on nonverbal cognitive abilities according to motor, receptive language, intelligibility, and executive function skills.

	NVT, *n* (%)	NVI, *n* (%)	All children, *n*
GMFCS			
I	10 (90.91)	1 (9.09)	11
II	3 (37.50)	5 (62.50)	8
III	1 (33.33)	2 (66.67)	3
IV	1 (33.33)	2 (66.67)	3
V	0 (0)	2 (100.00)	2
All children	15 (55.56)	12 (44.44)	27
MACS			
I	6 (100.00)	0 (0)	6
II	7 (50.00)	7 (50.00)	14
III	2 (50.00)	2 (50.00)	4
IV	0 (0)	3 (100.00)	3
V	0 (0)	0 (0)	0
All children	15 (55.56)	12 (44.44)	27
TACL-4 standard score			
Typical language (78–129)	12 (75.00)	4 (25.00)	16
Language impairment (0–77)	3 (27.27)	8 (72.73)	11
All children	15 (55.56)	12 (44.44)	27
Intelligibility rating			
Functional speech (80–100)	12 (70.59)	5 (29.41)	17
Significant functional speech deficit (0–79)	3 (30.00)	7 (70.00)	10
All children	15 (55.56)	12 (44.44)	27
BRIEF T-Score+			
Average executive function (0–59)	5 (62.50)	3 (37.50)	8
Elevated executive function (60–100)	9 (56.25)	7 (43.75)	16
All children	14 (58.33)	10 (41.67)	24
Speech-language profile groups			
NSMI	6 (75.00)	2 (25.00)	8
SMI-LCT	7 (77.78)	2 (22.22)	9
SMI-LCI	2 (20.00)	8 (80.00)	10
All children	15 (55.56)	12 (44.44)	27

Note: NVT = Typical nonverbal cognitive abilities; NVI = Impaired nonverbal cognitive abilities; GMFCS = Gross Motor Function Classification System; MACS = Manual Ability Classification System; TACL-4 = Test of Auditory Comprehension of Language, Fourth Edition; BRIEF = Behavior Rating Inventory of Executive Function; NSMI = No speech motor involvement; SMI-LCT = Speech motor involvement with typical language; SMI-LCI = Speech motor involvement with impaired language.
+ BRIEF missing data for three participants.

nonverbal cognitive scores than those with speech motor involvement and language comprehension impairment (M = 53.70, SD = 12.84, n = 10). Results showed that the difference between the groups of children with no speech motor involvement and those with speech motor involvement and typical language comprehension was not significant, although the participants with no speech motor involvement generally had higher scores as indicated by a moderate effect size.

Consistency of Performance according to Receptive Language vs. Nonverbal Cognition Abilities

Cross tabulation of performance based on language comprehension and nonverbal cognitive measures resulted in an overall match of 74%, indicating that the majority of children were consistently classified as impaired or not impaired in both language comprehension and cognitive development domains. Cohen's Kappa coefficient was obtained to assess the level of agreement between performance on the two measures. A moderate value of kappa, $K = .47$, was obtained. Table 6 shows the cross tabulation of performance based on language comprehension and nonverbal cognitive measures. Sensitivity results indicate that there was a 72.72% probability that nonverbal impairment will be present among those who have language impairment. Specificity results indicate that there was a 75% probability that nonverbal impairment will be absent among those who have typical language. The positive predictive value indicated that children who have language impairment have a 66.67% chance of having nonverbal cognitive impairment. The negative predictive value indicated that children who have typical language have an 80% chance of having typical nonverbal cognitive abilities. For this analysis, true positives were conditions when both domains identified the presence of an impairment, while, true negatives included identification of typical development for both domains. Results of McNemar Chi-square test indicated no significant changes in proportion between the two domains, χ^2 (1, n = 27) = 0, p = 1.

Discussion

This study was the first to examine inter-relations among speech, language, cognitive, gross motor, and fine motor abilities in children with CP using directly measured indices of speech intelligibility and language comprehension (as opposed to indirect ratings of these abilities by parents or professionals). It was also the first to examine the extent to which cognitive

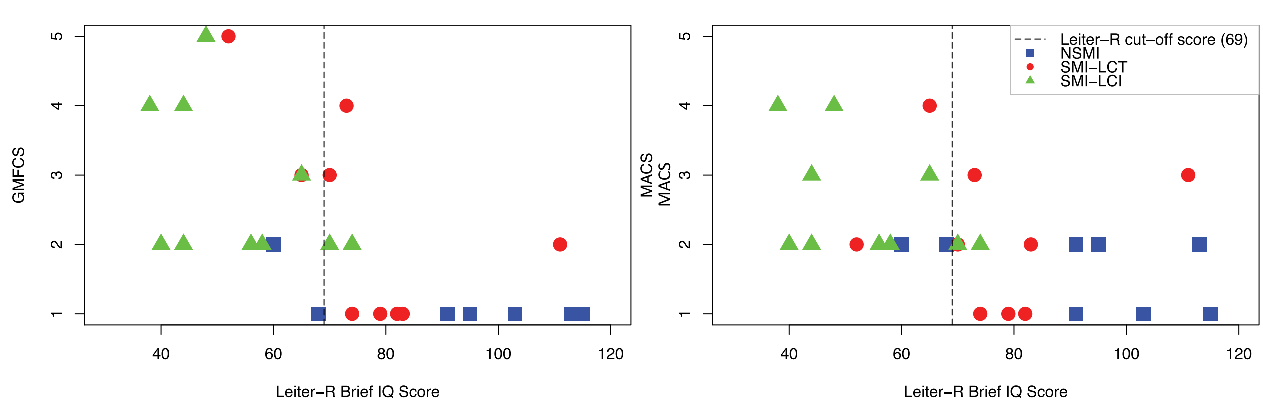

Figure 2. Scatterplots examining relationships between nonverbal cognitive skills and motor skills. Vertical lines mark the cutoff score for the Leiter-R (69). Scores on the left side of the vertical line indicate impaired nonverbal cognitive abilities, while, scores on the right side indicate typical nonverbal cognitive abilities. Data points are grouped according to speech-language profile groups: GMFCS = Gross Motor Function Classification System; MACS = Manual Ability Classification System; NSMI = No speech motor involvement; SMI-LCT = Speech motor involvement with typical language; SMI-LCI = Speech motor involvement with impaired language.

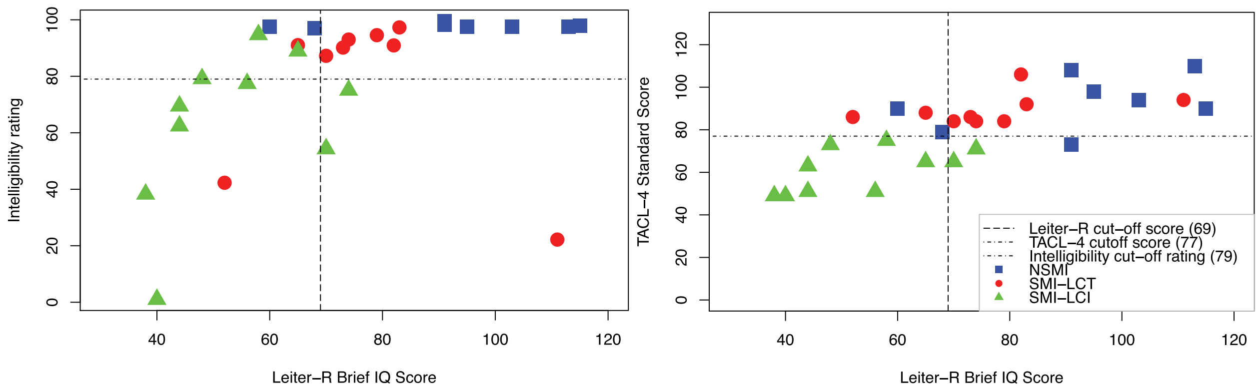

Figure 3. Scatterplots examining relationships between nonverbal cognitive skills, intelligibility, and receptive language abilities. Vertical lines mark the cutoff score for the Leiter-R (69). Scores on the left side of the vertical line indicate impaired nonverbal cognitive abilities, while, scores on the right side indicate typical nonverbal cognitive abilities. For the intelligibility rating plot, the horizontal line marks the cutoff score (79). Scores below the horizontal line indicate significant functional speech deficits, while, scores above the line indicate functional speech. For the TACL-4 plot, the horizontal line marks the cutoff score (77). Scores below the horizontal line indicate impaired receptive language, while, scores above the line indicate typical receptive language. Data points are grouped according to speech-language profile groups: NSMI = No speech motor involvement; SMI-LCT = Speech motor involvement with typical language; SMI-LCI = Speech motor involvement with impaired language.

Table 4. Correlation of all variables of interest.

	GMFCS	MACS	TACL-4 standard score	Intelligibility rating	BRIEF *T*-score	Leiter-R Brief IQ score
GMFCS⁺	1					
MACS⁺	.771$^{\rho *}$	1				
TACL-4 standard score	–.500$^{\rho *}$	–.387$^{\rho *}$	1			
Intelligibility rating	–.699$^{\rho *}$	–.490$^{\rho *}$	.613$^{\rho *}$	1		
BRIEF T-score⁺	<-.001$^{\rho}$	.209$^{\rho}$	–.102^{r}	.018$^{\rho}$	1	
Leiter-R Brief IQ score	–.724$^{\rho *}$	–.503$^{\rho *}$	.753$^{r *}$	.651$^{\rho *}$	–.228^{r}	1

Note: GMFCS = Gross Motor Function Classification System; MACS = Manual Ability Classification System; TACL-4 = Test of Auditory Comprehension of Language, Fourth Edition; BRIEF = Behavior Rating Inventory of Executive Function.
⁺Motor scales and BRIEF T-scores utilize an inverse scale.
$^{\rho}$Spearman Coefficient; ^{r} Pearson Coefficient.
* Statistical significance at *p* <.05.

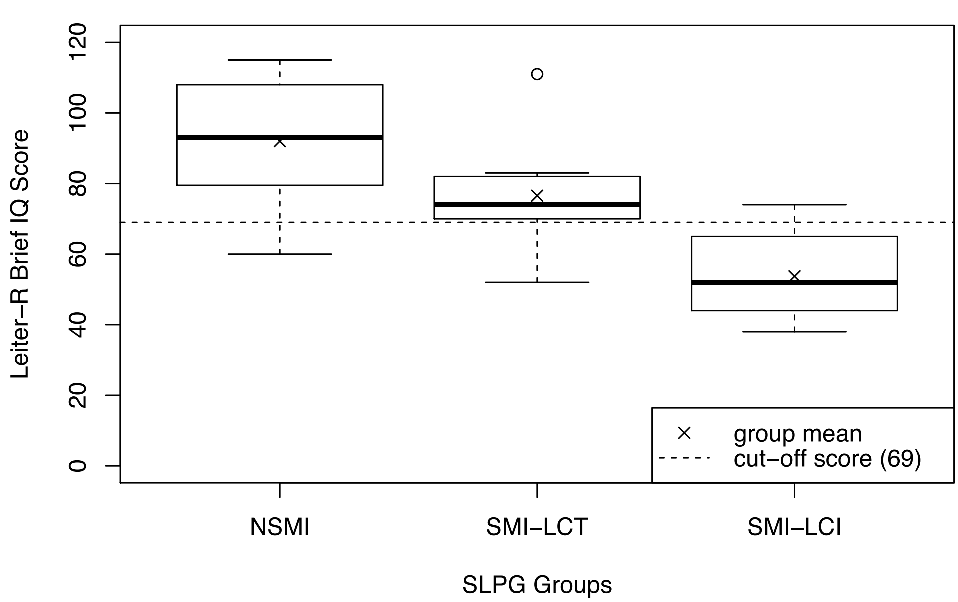

Figure 4. Differences between Leiter-R Brief IQ scores according to speech-language profile groups. Horizontal line marks the cutoff score for the Leiter-R (69). Scores below the line indicate impaired nonverbal cognitive abilities, while, scores above the line indicate typical nonverbal cognitive abilities. NSMI = No speech motor involvement; SMI-LCT = Speech motor involvement with typical language; SMI-LCI = Speech motor involvement with impaired language.

Table 5. Mann-Whitney test results for difference in nonverbal cognitive abilities according to speech-language profile groups.

	U-value	Absolute difference	*p*-value	*r*
NSMI vs. SMI-LCT	19	15.44	.056	.40
NSMI vs. SMI-LCI	5	38.30	.001*	.73
SMI-LCT vs. SMI-LCI	5	22.86	.003*	.65

Note: NSMI = No speech motor involvement; SMI-LCT = Speech motor involvement with typical language; SMI-LCI = Speech motor involvement with impaired language.
* Statistical significance at $p < .05$.

Table 6. Cross tabulation of performance based on language comprehension and nonverbal cognitive measures.

	Nonverbal cognition			
Language comprehension	NVT	NVI	Total	
LCT	12	4	16	*Specificity* = 75.0%
LCI	3	8	11	*Sensitivity* = 72.7%
Total	15	12	27	
	NPV = 80.0%	*PPV* = 66.7%		

Note: LCT = Typical receptive language abilities; LCI = Impaired receptive language abilities; NVT = Typical nonverbal cognitive abilities; NVI = Impaired nonverbal cognitive abilities; PPV = Positive predictive value; NPV = Negative predictive value.

ability profiles were consistent with language comprehension performance in children with CP in the context of speech and language classification. There were two main findings from this study. First, children who showed better nonverbal cognitive abilities generally demonstrated better motor, receptive language, and intelligibility skills. Second, nonverbal abilities were generally consistent with receptive language abilities. In particular, regardless of whether children had speech motor involvement, those with typical receptive language demonstrated significantly higher nonverbal cognitive abilities than children with language comprehension impairment. Further, the majority of the children were consistently classified as impaired or not impaired in both language comprehension and nonverbal cognitive domains. These findings are discussed subsequently.

Relationship of Nonverbal Cognitive Abilities and Other Variables of Interest

A key result of this study was that children who showed better nonverbal cognitive abilities generally demonstrated better motor abilities, receptive language scores, and higher speech intelligibility. At the same time, children with greater cognitive impairment were more likely to have more co-morbidities such as dysarthria. Our results are consistent with previous work showing that intellectual impairment was significantly related to having speech impairment,[7,38] and to Bimanual Fine Motor Function levels.[10] Moreover, Ballester-Plané and colleagues[4] determined that more cognitive functions were impaired as motor involvement increased. Previous studies also suggest that children with higher GMFCS level (indicating worse motor skills) had lower verbal IQ, performance IQ, and full-scale IQ scores.[35]

The weak association between nonverbal cognitive and executive function skills found in the present study is consistent with research on typically developing children[51,52] and research on children with autism spectrum disorder.[53] Various authors have highlighted the distinction between metacognitive or cool executive function, such as planning and verbal fluency, and emotional/motivational or hot executive function skills, such as attention control and emotional regulation.[54–57] Ardila[54] suggested that IQ measures were related to metacognitive executive function rather than to emotional/motivational executive function. The BRIEF Global Executive Composite T-Score includes the skillsets from both subdomains of executive function, which may explain the weak correlation between nonverbal cognitive skills and executive function. One direction for follow-up is to examine the relationship of these various sub-components of executive function in children with CP through the hot and cool executive function dichotomy.

Collectively our findings contribute to the growing evidence that level of motor function is related to communication, speech, language, and intellectual abilities in children with CP. However, one issue that may impact the findings of the present study as well as previous work is that the relationship between motor and nonverbal cognitive skills may be confounded by severity as children depend on their motor skills to perform tasks during assessments. That is, children with greater motor limitations may perform more poorly simply because they have more difficulty with testing, which always requires some type of motor skill. There is a clear need for more research on alternative means of testing for children with CP such as the use of eye gaze or switch devices.

Nonverbal Cognitive Abilities and Receptive Language Abilities

A second major finding was that nonverbal cognitive abilities were generally commensurate with receptive language abilities in children with CP. Our results are consistent with those of van der Schuit and colleagues,[58] who explored the language development of children with intellectual disability (not including children with CP), and suggested that nonverbal cognitive abilities were a predictive factor for vocabulary and syntax. Moreover, Vos and colleagues[59] reported that the development of receptive language skills was strongly related with intellectual abilities among children with CP. Results of the present study support the idea that receptive language abilities may be a reasonable indicator of cognitive abilities for most, but not necessarily all children with CP who are able to speak. Consequently, inferences regarding cognitive impairment may be reasonable based on speech-language profile group membership if cognitive testing cannot be adapted sufficiently. For example, we would expect that children with speech motor impairment and typical language comprehension may have typical cognitive abilities. Similarly, we would expect that children with speech motor impairment and language comprehension impairment may have impaired cognitive skills. It should be noted that this generalization is of interest because language comprehension measures are more straightforward to obtain from children with CP than are nonverbal IQ measures. In particular, language comprehension abilities can be measured using simple picture pointing tasks which can be adapted for eye gaze or scanning, two techniques that are frequently used for children with limb involvement that makes pointing difficult.

With the majority of children with CP consistently classified as impaired or not impaired in both language comprehension and nonverbal cognitive domains, our findings suggest that the prevalence of language-specific deficits in this population may be low. We examined descriptive findings by speech-language profile group to obtain a deeper understanding of individual differences among children within each group.

Children with CP who had no speech motor involvement were qualitatively different from other profile groups. Language and cognitive abilities were not considered in the classification parameters for this group; however, results of the present study showed that all but one child had typical receptive language abilities. The child who presented receptive language impairment was considered to be within the borderline impaired or delayed range as described in TACL-4 manual. Of the eight children with no speech motor involvement, five children showed consistent performance between nonverbal cognitive and receptive language abilities. That is, their standard scores for both domains fell within the typical range. One child demonstrated language impairment with typical nonverbal cognitive abilities, indicating the presence of language-specific deficits. However, two children showed typical receptive language ability with nonverbal cognitive impairment. For one participant, the difference between receptive language and nonverbal cognitive performance appeared to be descriptively minimal. His receptive language standard score was 79, which was only two points above the cutoff score, while his nonverbal cognitive standard score was 68, which was only one point lower than the cutoff score, suggesting that he performed fairly consistently for both domains. The other participant who showed typical receptive language ability with nonverbal cognitive impairment earned a score of 90 on the TACL-4, which indicated average receptive language skills per the technical manual. Her score for the Leiter-R was 60, which fell within the mild to moderate range as described in the manual. Generally, we would not expect to see a child have stronger language comprehension skills than cognitive skills; however, this child had visual impairment and had moderate motor involvement, which may have affected her visual-perceptual skills and her ability to use her hands for testing, which may have had a disproportionally negative impact on her ability to complete the Leiter-R.

Seven of the nine children with speech motor involvement and typical language comprehension demonstrated typical nonverbal cognitive abilities, showing that their receptive language performance was consistent with their nonverbal cognitive abilities. Two children showed typical receptive language ability with nonverbal cognitive impairment; they earned scores of 88 and 86, respectively, on the TACL-4, indicating average receptive language skills. Their scores for the Leiter-R were 65 and 52, respectively, which fell within the mild to moderate delay range. Again, both children who demonstrated nonverbal cognitive impairment had visual impairment according to parent report and had severe motor involvement. The presence of visual and motor impairments may have affected their performance, perhaps resulting in misrepresentation of their true abilities[11] particularly in the cognitive domain. This finding highlights the need for alternative means of testing that do not rely on motor skills to demonstrate cognitive abilities.

Eight of the 10 children with speech motor involvement and language comprehension impairment demonstrated nonverbal cognitive impairment, indicating that their receptive language performance was consistent with their nonverbal cognitive abilities. The remaining two children showed receptive language impairment with typical nonverbal cognitive abilities, indicating the presence of language-specific deficits. This profile is not unexpected and, in fact, occurs frequently in children with developmental language disorders.[60] Children with this profile have a unique need for language intervention to help them acquire language abilities that are commensurate with their cognitive abilities.

Although there was a strong trend of nonverbal cognitive abilities being generally consistent with receptive language abilities, there were some exceptions. A total of three children in this study showed better language comprehension skills than nonverbal cognitive skills. These findings may be attributed to the presence of visual deficits and more severe motor deficits which have been associated with nonverbal cognitive impairment and with test taking difficulties due to motor limitations, respectively. Other studies have linked the presence of lower nonverbal cognitive scores to visual perceptual problems and severe motor involvement.[9,34,35] There were also three exceptions in the opposite direction, with children having typical cognitive abilities and impaired receptive language abilities, suggesting language-specific impairments independent of cognitive abilities. Overall, however, results of the present study suggest that language comprehension abilities likely are a gross indicator of cognitive abilities for most children with CP who are able to speak.[20,21]

Limitations and Future Directions

This study included a relatively small group of children with CP, which was not fully representative of the larger population of children with CP. Specifically, children in the anarthria profile group were not included in our sample as we focused on participants who had speech production ability and could reliably complete language and nonverbal IQ assessments. Children with anarthria are often more severely involved across developmental domains,[9] posing challenges to accurately measuring nonverbal cognitive abilities[11] and language comprehension skills.[25,61]

The majority of the participants scored from level II to IV on the MACS (77.78%, n = 27), indicating that they had reduced quality and/or speed of performing fine motor tasks. Since the expected responses for nonverbal cognitive and receptive language measures involved pointing to pictures, children relied on their manual abilities in completing tasks. For eight participants, allowable accommodations were given to support their dexterity level. Thus, fine motor challenges may have affected their performance, resulting in potential misrepresentation of their true abilities. Alternative means of testing, potentially the use of eye gaze methods, should be explored by future studies. Moreover, assessment tools used were standardized with children without motor disabilities, further supporting the need for studies exploring the psychometrics for children with CP.[11]

We used different standard deviation levels to determine the cutoff scores for receptive language and nonverbal cognitive domains following respective disciplinary practices.[44,46,47] Had we used different cut points for identifying the presence or absence of impairment in either language or cognitive domains, results would have been slightly different. For instance, using 1.5 standard deviations from the mean for both domains would have resulted in more children being identified as having nonverbal cognitive impairment. On the other hand, using 2.0 standard deviations from the mean for language comprehension scores would have resulted in fewer children being identified with receptive language impairment. Reanalysis of our data using different cutoff points for determination of language comprehension and cognitive impairment is beyond the scope of this paper but would be an interesting avenue for exploration in future.

Clinical Implications

Despite the identified limitations, there are several clinical implications of this work. First, moderate to strong correlations between motor severity and nonverbal cognitive abilities imply the need for assessment tools that cater to the specific motor limitations of children with CP. Second, receptive language abilities are a gross indicator of nonverbal cognitive abilities for most children with CP who are able to speak. Third, moderate to strong correlations between intelligibility and motor severity further support the interrelationship of speech and overall motor abilities. Lastly, nonverbal cognitive impairment can co-occur with speech motor, language, and visual impairments among children with CP, highlighting the complex needs of this population. Speech-language profile groups are a useful framework for describing the communication skills of children with CP, and may prove useful in guiding the development of interventions that address the unique needs of different groups of children with CP.

Acknowledgements

The authors thank the children and families who participated in this research as well as the staff, graduate and undergraduate students in the Wisconsin Intelligibility, Speech, and Communication Lab of the University of Wisconsin–Madison who assisted in data collection and data reduction. In particular, we thank Susan Ellis Weismer and Kimberly Mueller for sharing their insights and expertise on the topic.

Funding

This work was supported by the National Institute of Child Health and Human Development [U54HD090256]; National Institute on Deafness and Other Communication Disorders [R01DC009411].

Declaration of Interest

This study was funded by grant R01DC009411 from the National Institute on Deafness and Other Communication Disorders, National Institutes of Health. Support was also provided by a core grant to the Waisman Center, U54HD090256, from the National Institute of Child Health and Human Development, National Institutes of Health. The content is solely the responsibility of the authors and does not necessarily represent the official views of the NIH. The authors have no financial relationships relevant to this article to disclose. The authors have no conflicts of interest to disclose.

References

1. Bax M, Tydeman C, Flodmark O. Clinical and MRI correlates of cerebral palsy: the European cerebral palsy study. JAMA. 2006;296(13):1602–08. doi:10.1001/jama.296.13.1602.
2. Novak I, Hines M, Goldsmith S, Barclay R. Clinical prognostic messages from a systematic review on cerebral palsy. Pediatrics. 2012;130(5):e1285–e1312. doi:10.1542/peds.2012-0924.
3. Rosenbaum P, Paneth N, Leviton A, Goldstein M, Bax M, Damiano D, Dan B, Jacobsson B. A report: the definition and classification of cerebral palsy April 2006. Dev Med Child Neurol Suppl. 2007;109:8–14.
4. Ballester-Plané J, Laporta-Hoyos O, Macaya A, Póo P, Meléndez-Plumed M, Toro-Tamargo E, Gimeno F, Narberhaus A, Segarra D, Pueyo R. Cognitive functioning in dyskinetic cerebral palsy: its relation to motor function, communication and epilepsy. Eur J Paediat Neurol. 2018;22(1):102–12. doi:10.1016/j.ejpn.2017.10.006.
5. Bottcher L. Children with spastic cerebral palsy, their cognitive functioning, and social participation: a review. Child Neuropsychol. 2010;16(3):209–28. doi:10.1080/09297040903559630.
6. Himmelmann K, Lindh K, Hidecker MJC. Communication ability in cerebral palsy: a study from the CP register of western Sweden. Eur J Paediat Neurol. 2013;17(6):568–74. doi:10.1016/j.ejpn.2013.04.005.
7. Nordberg A, Miniscalco C, Lohmander A, Himmelmann K. Speech problems affect more than one in two children with cerebral palsy: Swedish population-based study. Acta Paediatr. 2012;102(2):161–66. doi:10.1111/apa.12076.
8. Straub K, Obrzut JE. Effects of cerebral palsy on neuropsychological function. J Dev Phys Disabil. 2009;21(2):153. doi:10.1007/s10882-009-9130-3.
9. Sigurdardottir S, Vik T. Speech, expressive language, and verbal cognition of preschool children with cerebral palsy in Iceland. Dev Med Child Neurol. 2010;53(1):74–80. doi:10.1111/j.1469-8749.2010.03790.x.
10. Türkoğlu G, Türkoğlu S, Çelik C, Uçan H. Intelligence, functioning, and related factors in children with cerebral palsy. Arch Neuropsychiat. 2017;54(1):33–37. doi:10.5152/npa.2015.12676.
11. Foo RY, Guppy M, Johnston LM. Intelligence assessments for children with cerebral palsy: a systematic review. Dev Med Child Neurol. 2013;55(10):911–18. doi:10.1111/dmcn.12157.
12. Sherwell S, Reid SM, Reddihough DS, Wrennall J, Ong B, Stargatt R. Measuring intellectual ability in children with cerebral palsy: can we do better? Res Dev Disabil. 2014;35(10):2558–67. doi:10.1016/j.ridd.2014.06.019.
13. Losch H, Dammann O. Impact of motor skills on cognitive test results in very-low-birthweight children. J Child Neurol. 2004;19(5):318–22. doi:10.1177/088307380401900502.
14. Stadskleiv K. Cognitive functioning in children with cerebral palsy. Dev Med Child Neurol. 2020;62(3):283–89. doi:10.1111/dmcn.14463.
15. Castellino SM, Tooze JA, Flowers L, Parsons SK. The Peabody Picture Vocabulary Test as a pre-screening tool for global cognitive functioning in childhood brain tumor survivors. J Neurooncol. 2011;104(2):559–63. doi:10.1007/s11060-010-0521-1.

16. Fluss J, Lidzba K. Cognitive and academic profiles in children with cerebral palsy: a narrative review. Ann Phys Rehabil Med. 2020 Feb 19;63(5):447–56 [accessed 2020 Mar 10]. http://www.sciencedirect.com/science/article/pii/S1877065720300361
17. Pueyo R, Ariza M, Narberhaus A, Ballester-Plané J, Laporta-Hoyos O, Junqué C, Vendrell P. Does verbal and gestural expression ability predict comprehension ability in cerebral palsy? Percept Mot Skills. 2013;116(2):512–27. doi:10.2466/15.10.PMS.116.2.512-527.
18. Smith BL, Smith TD, Taylor L, Hobby M. Relationship between intelligence and vocabulary. Percept Mot Skills. 2005;100 (1):101–08. doi:10.2466/pms.100.1.101-108.
19. Choi JY, Choi YS, Park ES. Language development and brain magnetic resonance imaging characteristics in preschool children with cerebral palsy. J Speech, Language, Hear Res. 2017;60 (5):1330–38. doi:10.1044/2016_JSLHR-L-16-0281.
20. Marston L, Peacock JL, Calvert SA, Greenough A, Marlow N. Factors affecting vocabulary acquisition at age 2 in children born between 23 and 28 weeks' gestation. Dev Med Child Neurol. 2007;49(8):591–96. doi:10.1111/j.1469-8749.2007.00591.x.
21. da Costa Ribeiro C, Abramides DVM, Fuertes MG, Lopes Dos Santos PN, Lamônica DAC. Receptive language and intellectual abilities in preterm children. Early Hum Dev. 2016;99:57–60. doi:10.1016/j.earlhumdev.2016.03.011.
22. Goharpey N, Crewther DP, Crewther SG. Problem solving ability in children with intellectual disability as measured by the Raven's Colored Progressive Matrices. Res Dev Disabil. 2013;34(12):4366–74. doi:10.1016/j.ridd.2013.09.013.
23. Hidecker MJC, Paneth N, Rosenbaum PL, Kent RD, Lillie J, Eulenberg JB, Jr KC, Johnson B, Michalsen L, Evatt M, et al. Developing and validating the Communication Function Classification System for individuals with cerebral palsy. Dev Med Child Neurol. 2011;53(8):704–10. doi:10.1111/j.1469-8749.2011.03996.x.
24. Barty E, Caynes K, Johnston LM. Development and reliability of the Functional Communication Classification System for children with cerebral palsy. Dev Med Child Neurol. 2016;58(10):1036–41. doi:10.1111/dmcn.13124.
25. Hustad KC, Gorton K, Lee J. Classification of speech and language profiles in 4-year old children with cerebral palsy: a prospective preliminary study. J Speech, Language, Hear Res. 2010;53 (6):1496–513. doi:10.1044/1092-4388(2010/09-0176).
26. Hustad KC, Allison K, McFadd E, Riehle K. Speech and language development in 2 year old children with cerebral palsy. Dev Neurorehabil. 2014;17(3):167–75. doi:10.3109/17518423.2012.747009.
27. Hustad KC, Schueler B, Schultz L, DuHadway C. Intelligibility of 4-year-old children with and without cerebral palsy. J Speech, Language, Hear Res. 2012;55(4):1177–89. doi:10.1044/1092-4388 (2011/11-0083).
28. Lee J, Hustad KC, Weismer G. Predicting speech intelligibility with a multiple speech subsystems approach in children with cerebral palsy. J Speech, Language, Hear Res. 2014;57(5):1666–78. doi:10.1044/2014_JSLHR-S-13-0292.
29. Hustad KC, Sakash A, Broman AT, Rathouz PJ. Longitudinal growth of receptive language in children with cerebral palsy between 18 months and 54 months of age. Dev Med Child Neurol. 2018 May 22;60(11):1156–64. doi:10.1111/dmcn.13904.
30. Sakash A, Broman AT, Rathouz PJ, Hustad KC. Executive function in school-aged children with cerebral palsy: relationship with speech and language. Res Dev Disabil. 2018;78:136–44. doi:10.1016/j.ridd.2018.05.015.
31. Gioia GA, Isquith PK, Guy SC, Kenworthy L. Behavior rating inventory of executive function. Child Neuropsychol. 2000;6 (3):235–38. doi:10.1076/chin.6.3.235.3152.
32. Perlovsky L, Sakai KL. Language and cognition. Front Behav Neurosci. 2014 [accessed 2018 Oct 10];8. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4267264/
33. Nip ISB, Green JR, Marx DB. The co-emergence of cognition, language, and speech motor control in early development: a longitudinal correlation study. J Commun Disord. 2011;44 (2):149–60. doi:10.1016/j.jcomdis.2010.08.002.
34. Fedrizzi E, Inverno M, Botteon G, Anderloni A, Filippini G, Farinotti M. The cognitive development of children born preterm and affected by spastic diplegia. Brain Dev. 1993;15(6):428–32. doi:10.1016/0387-7604(93)90082-J.
35. Sigurdardottir S, Eiriksdottir A, Gunnarsdottir E, Meintema M, Arnadottir U, Vik T. Cognitive profile in young Icelandic children with cerebral palsy. Dev Med Child Neurol. 2008;50(5):357–62. doi:10.1111/j.1469-8749.2008.02046.x.
36. Peeters M, Verhoeven L, van Balkom H, de Moor J. Foundations of phonological awareness in pre-school children with cerebral palsy: the impact of intellectual disability. J Intell Disability Res: JIDR. 2008;52(Pt 1):68–78. doi:10.1111/j.1365-2788.2007.00986.x.
37. Cockerill H, Elbourne D, Allen E, Scrutton D, Will E, McNee A, Fairhurst C, Baird G. Speech, communication and use of augmentative communication in young people with cerebral palsy: the SH&PE population study. Child Care Health Dev. 2014;40 (2):149–57. doi:10.1111/cch.12066.
38. Parkes J, Hill N, Platt MJ, Donnelly C. Oromotor dysfunction and communication impairments in children with cerebral palsy: a register study. Dev Med Child Neurol. 2010;52(12):1113–19. doi:10.1111/j.1469-8749.2010.03765.x.
39. Pirila S, van der Meere J, Pentikainen T, Ruusu-Niemi P, Korpela R, Kilpinen J, Nieminen P. Language and motor speech skills in children with cerebral palsy. J Commun Disord. 2007;40 (2):116–28. doi:10.1016/j.jcomdis.2006.06.002.
40. Choi JY, Park J, Choi YS, Goh Y, Park ES. Functional communication profiles in children with cerebral palsy in relation to gross motor function and manual and intellectual ability. Yonsei Med J. 2018;59(5):677–85. doi:10.3349/ymj.2018.59.5.677.
41. Palisano R, Rosenbaum P, Walter S, Russell D, Wood E, Galuppi B. Development and reliability of a system to classify gross motor function in children with cerebral palsy. Dev Med Child Neurol. 1997;39(4):214–23. doi:10.1111/j.1469-8749.1997.tb07414.x.
42. Eliasson A-C, Krumlinde-Sundholm L, Rösblad B, Beckung E, Arner M, Öhrvall A-M, Rosenbaum P. The Manual Ability Classification System (MACS) for children with cerebral palsy: scale development and evidence of validity and reliability. Dev Med Child Neurol. 2006;48(7):549–54. doi:10.1111/j.1469-8749.2006.tb01313.x.
43. Carrow-Woolfolk E. Test for auditory comprehension of language. Fourth. Texas (USA): Pro-Ed; 2014
44. Spaulding TJ, Plante E, Farinella KA. Eligibility criteria for language impairment. Lang Speech Hear Serv Sch. 2006;37(1):61–72. doi:10.1044/0161-1461(2006/007).
45. Roid G, Miller L. Leiter International Performance Scale-Revised. Illinois (USA): Stoelting Co.; 1997 doi:10.1037/t05120-000
46. American Psychiatric Association. Diagnostic and statistical manual of mental disorders. 5th ed. Washington (D.C): American Psychiatric Publishing; 2013.
47. Committee to Evaluate the Supplemental Security Income Disability Program for Children with Mental Disorders, Board on the Health of Select Populations, Board on Children, Youth,, and Families, Institute of Medicine, Division of Behavioral, and Social Sciences, and Education, The National Academies of Sciences, Engineering, and Medicine. Clinical characteristics of intellectual disabilities. In: Boat TF, Wu JT editors, Mental disorders and disabilities among low-income children. Massachusetts (USA): National Academies Press; 2015. p. 169–178. http://www.ncbi.nlm.nih.gov/books/NBK332877/
48. Hodge M, Gotzke CL. Criterion-related validity of the Test of Children's Speech sentence intelligibility measure for children with cerebral palsy and dysarthria. Int J Speech Lang Pathol. 2014;16(4):417–26. doi:10.3109/17549507.2014.930174.
49. Braza MD, Sakash A, Natzke P, Hustad KC. Longitudinal change in speech rate and intelligibility between 5 and 7 years in children

with cerebral palsy. Am J Speech-Language Pathol. 2019;28 (3):1139–51. doi:10.1044/2019_AJSLP-18-0233.
50. Dancey CP, Reidy J. Statistics without maths for psychology. 7th. New York (USA): Pearson; 2017.
51. Ardila A, Pineda D, Rosselli M. Correlation between intelligence test scores and executive function measures. Archi Clin Neuropsychol. 2000;15(1):31–36. doi:10.1016/S0887-6177(98)00159-0.
52. Welsh MC, Pennington BF, Groisser DB. A normative-developmental study of executive function: a window on prefrontal function in children. Dev Neuropsychol. 1991;7(2):131–49. doi:10.1080/87565649109540483.
53. Ellis Weismer S, Kaushanskaya M, Larson C, Mathée J, Bolt D. Executive function skills in school-age children with autism spectrum disorder: association with language abilities. J Speech, Language, Hear Res. 2018;61(11):2641–58. doi:10.1044/2018_JSLHR-L-RSAUT-18-0026.
54. Ardila A. Is intelligence equivalent to executive functions? Psicothema. 2018;30(2):159–64. doi:10.7334/psicothema2017.329.
55. Lensing N, Elsner B. Development of hot and cool executive functions in middle childhood: three-year growth curves of decision making and working memory updating. J Exp Child Psychol. 2018;173:187–204. doi:10.1016/j.jecp.2018.04.002.
56. Poon K. Hot and cool executive functions in adolescence: development and contributions to important developmental outcomes. Front Psychol. 2018 [accessed 2019 Aug 25];8. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5767838/
57. Zelazo PD, Carlson SM. Hot and cool executive function in childhood and adolescence: development and plasticity. Child Dev Perspect. 2012;6(4):354–60. doi:10.1111/j.1750-8606.2012.00246.x.
58. van der Schuit M, Segers E, van Balkom H, Verhoeven L. How cognitive factors affect language development in children with intellectual disabilities. Res Dev Disabil. 2011;32(5):1884–94. doi:10.1016/j.ridd.2011.03.015.
59. Vos RC, Dallmeijer AJ, Verhoef M, Schie PEMV, Voorman JM, Wiegerink DJHG, Geytenbeek JJM, Roebroeck ME, Becher JG. Developmental trajectories of receptive and expressive communication in children and young adults with cerebral palsy. Dev Med Child Neurol. 2014;56(10):951–59. doi:10.1111/dmcn.12473.
60. Botting N. Non-verbal cognitive development and language impairment. J Child Psychol Psychiat. 2005;46(3):317–26. doi:10.1111/j.1469-7610.2004.00355.x.
61. Geytenbeek J, Harlaar L, Stam M, Ket H, Becher JG, Oostrom K, Vermeulen J. Utility of language comprehension tests for unintelligible or non-speaking children with cerebral palsy: a systematic review. Dev Med Child Neurol. 2010;52(12):1098–1098. doi:10.1111/j.1469-8749.2010.03833.x.