Oromotor dysfunction in non-verbal children with cerebral palsy: Characteristics and associated factors

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Abstract

Aim To explore the characteristics and associated factors of oromotor dysfunction in minimally verbal children with cerebral palsy (CP) aged five to six years, recruited from a population-based registry.

Methods Twenty children with CP who were minimally verbal completed a standardised, observational oromotor assessment. Linear regression analyses examined the relationship between oromotor dysfunction and potential associated factors (e.g., fine and gross motor function, communication, feeding).

Results Oromotor dysfunction affected every participant and was identified in all structures examined (i.e., face, jaw, lips, tongue). Oromotor movements showed little dissociation between jaw, lip and tongue movements. Oromotor dysfunction was univariately associated with the Manual Ability Classification System levels IV-V (p=0.001), reduced communication skills (p=0.002), and a prolonged eating duration (>45 minutes) (p=0.006), even when non-verbal cognition served as a covariate.

Interpretation Oromotor dysfunction was highly prevalent in our sample of minimally verbal children with CP, having significant functional impacts on feeding and communication. Findings suggest that fine motor function (i.e., Manual Ability Classification System levels IV-V) is a stronger predictor than gross motor function for identifying children with CP who are minimally verbal and at risk of oromotor dysfunction.

Key words: Cerebral palsy, children, minimally verbal, oral motor, motor speech

Introduction

Oromotor dysfunction is commonly experienced by children with cerebral palsy (CP), affecting up to 92% [1]. Oromotor dysfunction for this group reflects deficits in the timing, dissociation, coordination, range and strength of oral movements [1-6]. Consequently, impaired oromotor function associated with CP is closely related to dysarthria, dysphagia and drooling. Its impacts are broader however, and can detrimentally effect quality of life (where associated with drooling or speech impairment) [7], peer interactions and self-esteem as a result of drooling [8], and caregiver strain due to prolonged mealtimes [9].

Numerous studies examining oromotor function in children with CP have utilised convenience recruitment methods [3,4,10-13] rather than population-based methods [1,6,14-16]. Studies have typically examined oromotor outcomes across the range of CP presentations. This has resulted in an underrepresentation of studies examining the oromotor outcomes of solely children with CP who are non-speaking or minimally verbal (i.e., children unable to verbally produce meaningful/comprehensible speech). A considerable portion of children with CP are non-speaking, with prevalence figures ranging from 19-32% [16-20]. Yet at a population level, features of oromotor dysfunction specific to this subgroup have not been comprehensively described, impacting our understanding of their clinical presentation.

A potential limiting factor is the absence of a psychometrically robust and universally adopted oromotor assessment for minimally verbal children with CP. This has led to different measures being used across studies, including informal or non-standardised approaches. Swallowing-related oromotor dysfunction assessments have dominated the field and provide an appropriate approach to use with minimally verbal children given that they do not rely on speech-related oromotor tasks. However, this predominance has resulted in a gap in the evidence-base describing the motor speech-related oromotor outcomes of minimally verbal children with CP. These data can provide an understanding of oromotor development for this subgroup and reveal features of oromotor dysfunction impacting on communication.

Specific factors contributing to the absence of speech in children with CP may include the nature of the brain pathology (cortical/subcortical and basal ganglia lesions).

Some types of CP presentation are associated with a greater likelihood of impaired speech including non-spastic motor types, greater motor impairment, and more limb involvement [18,21,22]. These factors as well as the presence of intellectual disability and sensory impairments (hearing, vision) can impact a child's communication and oromotor development. A number of factors associated with oromotor dysfunction have been identified to enhance the identification of cases at risk of the condition. In particular, oromotor dysfunction has been associated with greater limb involvement and non-spastic motor types [1,9,16]. Whilst oromotor dysfunction can occur across all levels of severity, it is more prevalent in children with more severe gross and fine motor limitations [6,14-17]. Further associated factors include intellectual disability and epilepsy [16]. Although a range of factors, which often co-occur, have been identified, those specific to oromotor dysfunction in children with CP who are minimally verbally remain unexplored, limiting the ability to identify cases at greater risk for oromotor dysfunction.

Here we focus exclusively on children with CP who are minimally verbal given the lack of studies that have comprehensively described their oromotor outcomes to inform clinical management. We specifically aimed to provide an initial exploration on the characteristics and factors associated with oromotor dysfunction in minimally verbal children with CP aged 5 and 6 years drawn from a representative community-based sample.

Methods

Participants

Participants were recruited from the Victorian Cerebral Palsy Register using previously described methods in a study documenting the language outcomes of this cohort [23]. In summary, children aged 5 to 6 years (born between 25 August 2005 and 24 August 2007) were eligible for study inclusion. Of those eligible (n=176), 84 were recruited. The recruited sample was representative for gender, CP motor type and distribution, gross motor function, epilepsy, cognition, hearing and vision [23]. Of the 84 participants recruited, 20 were minimally verbal (i.e., unable to verbally produce meaningful/comprehensible speech) and were included here. Characteristics of the minimally verbal participants are detailed in table 1. Ethics approval was

obtained from the Human Research Ethics Committees at the Royal Children's Hospital (#30048) and Southern Health (#11380).

Table 1

Measures and Procedures

Oromotor Function

Oromotor function was measured using the Early Motor Control Scales [24], a standardised assessment evaluating oral, vocal, arm and hand motor control pertinent to speech and gesture. The assessment utilises the sampling procedures of the Communication and Symbolic Behaviour Scales-Developmental Profile Behaviour Sample [25], whereby participants are offered a range of toys to entice communication. The Early Motor Control Scales was designed and standardised for typically developing children aged 8 to 24 months, however, it may be used with children up to 6 years if they are developmentally functioning within this age bracket. The Early Motor Control Scales does not require the child to perform an oral motor action following a verbal command as per commonly used oral motor assessments. Instead, during the child's performance on the Communication and Symbolic Behaviour Scales, in which a range of activities are presented to the child (e.g., food in a container, bubbles), their oral structures are observed for a variety of features (e.g., abnormal jaw posture and movement, facial asymmetry). This makes it appropriate to use with minimally verbal children who may have severely impaired receptive language and cognitive abilities.

The Early Motor Control Scales consists of three composites: (1) Abnormal Structure and Function, (2) Motor Speech Control and (3) Arm and Hand Control. The latter two are combined to obtain an overall total score. In the Abnormal Structure and Function composite, children are observed for the presence or absence of abnormal features such as facial asymmetry, excessive drooling and jaw sliding (e.g., the jaw moving left or right). The Motor Speech Control composite requires the examiner to rate the complexity, range and movement of five motor speech components (i.e., voicing, jaw, face, lips, tongue) (see table 4 in the results section for examples of each component). The Arm and Hand Control composite evaluates actions such as grasping objects and pointing.

Given that participants were aged 5 to 6 years and were outside of the norming age range of the Early Motor Control Scales, raw scores (not standardised scores) are reported here. Table 3 (see results section) details the highest score possible for each composite. Methods previously described to interpret Communication and Symbolic Behaviour Scales raw scores [23] were used to identify a participant's strengths and weaknesses in oromotor function relative to other participants. A strength in oromotor function was identified when a participant's raw score was greater than or equal to the raw score at the 75th percentile of the 21-24-month norms. If there was no raw score at the 75th percentile, the 50th percentile of the 21-24-month norms was used. Age equivalent scores were determined using the Early Motor Control Scales age band where the normative mean corresponded to the participant's raw score.

Associated Factors

To identify factors associated with oromotor function, a number of additional measures were completed. This included the Gross Motor Function Classification System (GMFCS) [26], the Manual Ability Classification System (MACS) [27], and the Columbia Mental Maturity Scale, a measure of non-verbal intellectual functioning [28]. Two measures of communication were completed; the Communication Function Classification System [29] and the Communication and Symbolic Behaviour Scales Behaviour Sample. As the Eating and Drinking Ability Classification System [30] was not published at the time of testing, parent report was used to determine mealtime duration (<15min, 15–30min, 30–45min, >45min) and the frequency of feeding problems on a scale of (almost) never, sometimes, often, and (almost) always [31]. Other potential associated variables examined were gender, CP motor type and distribution, gestation, birth weight, plurality, socioeconomic status, and the presence of vision impairment and epilepsy. All assessments were administered by a speech pathologist.

Inter-rater reliability

The Early Motor Control Scales was administered by CM, with video recordings of the assessment later scored by MH. A second rater (BF) independently scored 15% (n=3) of the sample (selected at random) for inter-rater reliability using pairwise correlation. Agreement between raters was excellent, indicated by a Pearson's

correlation of 0.99 for the Motor Speech Control composite, 1.00 for the Arm and Hand Composite, and 0.99 for Early Motor Control Scales Total scores.

Statistical analysis

Descriptive analyses were used to examine the features of oromotor dysfunction. Linear regression was used to explore the association between Early Motor Control Scales raw scores (outcome variable) and the associated factors described above (explanatory variables). All explanatory variables, with the exception of Communication and Symbolic Behaviour Scales score, were entered as categorical variables. The association between each explanatory variable was examined univariately and adjusted for non-verbal IQ for each Early Motor Control Scales composite. *P*-values <0.05 were considered statistically significant.

Results

Performance on the Early Motor Control Scales

Abnormal Structure and Function

Features of oromotor dysfunction identified in the Abnormal Structure and Function composite are shown in table 2. The most common feature was abnormal posturing (i.e., head held at an angle, irregular upper limb posturing), followed by abnormal tone in the trunk and/or face (i.e., mouth open or clenched). Drooling and tongue protrusion were also common, respectively experienced by 14 and 8 participants. The majority of participants did not exhibit the following: asymmetrical facial structure, uninhibited oral reflexes, excessive mouthing, overextension of the jaw, and asymmetrical facial contraction. None of the participants presented with abnormal relationship of the mandible/maxilla, jaw sliding, and over contraction of facial muscles.

Table 2

Motor Speech Control

Oromotor dysfunction was observed in all oromotor structures (i.e., jaw, face, lips and tongue). The jaw (M=1.7, SD=1.5) and tongue (M=1.1, SD=1.8) were areas of greatest difficulty (table 3). Minimal or reduced range of jaw (n=13) and lip movements (n=9) were common, as was the absence of speech-related tongue

movements (n=12) (table 4). Social forms of oromotor function such as smiling (with symmetry and sufficient rounding) were frequently noted (n=18). Most participants (n=13) obtained a Motor Speech Control composite score that was suggestive of motor speech abilities equivalent to children younger than 8 months (figure 1).

Tables 3 and 4, Figure 1

Arm and Hand Control

Overall, performance on this composite was less affected than the Motor Speech Control composite (table 3). Age equivalency for Arm and Hand Control was <8 months for 13 participants and >24 months for 3 (figure 1). One participant scored above the 75th percentile of the 21-24-month norms in the Arm and Hand Control composite, indicating a strength in this area relative to other participants. This participant presented with left spastic hemiplegia and was one of two participants who demonstrated superior oromotor skills compared to the other participants.

Associated factors of oromotor dysfunction

The univariate linear regression model depicting the relationship between oromotor dysfunction and potential associated factors is shown in table 5.

Tables 5 and 6

Motor Speech Control Composite

Lower scores (indicating greater impairment) on the Motor Speech Control composite were univariately associated with eating duration (>45 minutes, p=0.006), a lower Communication and Symbolic Behaviour Scales Total score (i.e., greater communication impairment; p=0.002), and MACS levels IV-V (p=0.001) (table 5). These factors accounted for 43%, 40% and 47% of the variance in the Motor Speech Control composite, respectively. Non-verbal cognition was not a predictor of participants' performance (p=0.541). All factors associated with the Motor Speech Control composite remained significant when non-verbal cognition was included as a covariate (see table 6). All other factors included in the analysis remained non-significant when controlled for non-verbal cognition, except for an eating duration of 30-45 mins (table 6).

Arm and Hand Control Composite

CP distribution (p=0.049), GMFCS levels IV-V (p=0.019), MACS levels IV-V (p=0.002), vision impairment (p=0.021), and Communication and Symbolic Behaviour Scales Total score (p=<0.001) were univariately associated with the Arm and Hand Control composite (table 5). Communication and Symbolic Behaviour Scales Total score accounted for 71% of variance in the Arm and Hand Control score. This was followed by MACS (accounting for 61% of the variance), GMFCS (21%), vision impairment (22%), and CP distribution (16%). In the model controlled for non-verbal cognition, GMFCS levels IV-V, MACS levels IV-V, Communication and Symbolic Behaviour Scales-Developmental Profile score, and eating duration (>45 minutes) were significant (table 6).

Early Motor Control Scales Total score

In the unadjusted model, CP distribution (p=0.035), MACS levels IV-V (p=<0.001), vision impairment (p=0.028), Communication and Symbolic Behaviour Scales Total score (<0.001), and eating duration (>45 minutes, p=0.026) were all associated with Early Motor Control Scales Total scores (table 5). The Communication and Symbolic Behaviour Scales Total score and MACS levels respectively accounted for 72% and 64% of the variation in Early Motor Control Scales Total scores. Findings from the univariate model adjusted for non-verbal cognition showed an association between Early Motor Control Scales Total scores and bilateral distribution, MACS levels IV-V, eating duration (>45 minutes), and Communication and Symbolic Behaviour Scales-Developmental Profile score (table 6).

Discussion

To date, no study has solely addressed the oromotor outcomes of children with CP who are minimally verbal, with most studies describing these outcomes within a broader cohort that includes both verbal and minimally verbal children. Here we focused exclusively on children with CP who are minimally verbal to provide an initial exploration on the characteristics and associated factors of motor speech-related oromotor dysfunction pertinent to this subgroup. This is important given that previous research has focused on feeding-related oromotor dysfunction. As anticipated, our findings highlight that oromotor dysfunction is highly prevalent for

this subgroup and has broader impacts on children's communication and feeding. Of note, and as expected, fine motor functioning (rather than gross motor functioning) was univariately associated with oromotor dysfunction.

Given that the included sample demonstrated more severe CP presentations, it is not unexpected that the frequency of oromotor dysfunction described here (100%) was considerably higher than previous reports that have included children with milder forms of CP and a range of verbal abilities [14,15]. Whereas previous research involving children with severe CP presentations has focused on swallowing-related oromotor dysfunction, here we systematically assessed motor speech-related oromotor dysfunction. Oromotor dysfunction was apparent across all oromotor domains, specifically the jaw, lips, tongue, and face, which may assist in explaining the high incidence of drooling (70%). Speech-related jaw movements (where present) were minimal, with very few participants demonstrating a full range of stable movements. This likely contributes to participants' overall absence of independent lip and tongue movements, which are dependent on established jaw movements and stability [32]. Lip and tongue movements were predominately propelled by the jaw and did not reflect actions that are independent of the mandible. This aligns with participants' age equivalency of <8 months for the Motor Speech Control composite. As expected, the high degree of abnormal truncal tone most likely underlies participant's oral motor difficulties given that it provides the foundations for head stabilization and precise oral motor movements [33].

In view of participants' impaired jaw, lip and tongue movement function, it is perhaps not unexpected that greater oromotor impairment was univariately associated with a prolonged eating duration (>45 minutes) and reduced communication abilities. This demonstrates the potential functional consequences and clinical implications of oromotor dysfunction for this population. Further, it also indicates potential outcome measures to consider for oral motor therapies. Feeding duration for children with CP who are minimally verbal is a critical area to consider during management given the potential concerns associated with lengthy feeding times such as inadequate nutrition intake, weight loss, and caregiver strain [1,9]. Contrary to our findings, Reilly and colleagues (1996) observed that children with more severe oromotor dysfunction had shorter feeding times than reported by parents. It is possible that parents of the current

sample may have overestimated their child's mealtime length or this difference in findings across studies may reflect our small sample size.

With regard to communication, the strong univariate association between the Early Motor Control Scales (i.e., oromotor) and the Communication and Symbolic Behaviour Scales (i.e., communication) echoes findings by Parkes et al. (2010), who found impairments in communication and oromotor function commonly co-occur. In contrast, the Communication Function Classification System was not significantly associated with oromotor dysfunction here. This may reflect differences between the Communication Function Classification System and Communication and Symbolic Behaviour Scales, that is, the former is more focused on children's ability to send and receive messages (i.e., arguably tapping more into language functioning) whereas the latter includes speech items that rely on children's articulation and oromotor abilities.

Fine motor function (i.e., MACS levels IV-V) was a further factor strongly associated with greater oromotor impairment. Our finding supports previous reports of an association between oromotor dysfunction and MACS levels [14,19]. As expected, MACS and Arm and Hand Control were strongly associated. Unlike previous studies [16], GMFCS was not significantly related to oromotor dysfunction in our cohort. Thus, our findings indicate that severe fine motor impairment (and not gross motor impairment) is a risk factor of oromotor dysfunction for children with CP who are minimally verbal. This result was not unexpected given that the brain regions for speech within the primary motor cortex (i.e., the mouth, tongue, jaw, face and lips) are in closer proximity to the hand regions than the lower extremities [34]. While the association between the Early Motor Control Scales Total score and vision impairment most likely reflects the latter's association with the Arm and Hand Control subscale (rather than Motor Speech Control), it highlights the importance of vision for motor function.

Interestingly, CP distribution was not associated with oromotor function. A bilateral distribution was associated with Early Motor Control Scales Total scores, however, this likely reflects the association between CP distribution and the Arm and Hand Composite. This finding was somewhat unexpected given the known association between greater limb involvement and oromotor dysfunction [1,11,15,16,35-37]. Only

one child with unilateral CP was recruited, which likely impacted on this finding. Additionally, non-verbal cognition was not statistically associated with oromotor dysfunction as previously reported [16]. Similarly, this may be attributed to the current sample size, missing non-verbal cognitive data (n=5), and the low number of participants with age appropriate non-verbal cognition (n=4).

Strengths and Limitations

A strength of the study was that participants were drawn from a representative cohort of verbal and minimally verbal children who were recruited from a population-based registry, allowing for greater confidence in the present results. Whilst our sample size might be considered small, participants represented 24% (20/84) of the larger community-based cohort they were drawn from [23], which is in line with prevalence figures for non-verbal CP (e.g., 22% [38]). Findings here provide a range of characteristics and associated factors that can be explored in future research but should be interpreted with consideration of their limitations. For instance, the small sample size and relatively low degree of variability in participant characteristics may have impacted on the power needed to identify significant associations in the regression analyses. Further, the ability to detect significant factors may have been impacted by the lack of variation in Motor Speech Control scores. This potentially could have reduced the likelihood of detecting differences across participants. Future research studies that contain a larger sample size and are suitably powered to perform multivariable analyses may be able to elucidate the strongest predictor of oromotor dysfunction in minimally verbal children with CP as well as further examine the association between cognition and oromotor dysfunction. Although we performed multiple comparisons, formal correction for multiple testing was not conducted as it can be overly conservative and, in small sample sizes, can lead to false negatives [39].

Consideration should also be given to the measures used in this study and its potential impact on study findings. First, while the Early Motor Control Scales proved to be a feasible measure to administer to this population, it was not designed for children with CP and may not capture some of the features of oromotor dysfunction relevant to this population. The Early Motor Control Scales, in addition to our sample's characteristics, could have potentially impacted on the lack of variation in observed oromotor skills. Second, although parent report is a common method for assessing

feeding behaviours and mealtime duration [40], it can be impacted by a range of factors (e.g., the parent's mood, recall) and reported durations may be overestimated by parents [1].

Conclusion

While it is commonly anticipated that children with more severe CP presentations experience oromotor dysfunction, here we add to the evidence base by systematically describing the motor speech oromotor outcomes of minimally verbal children with CP recruited from a representative population-based cohort. Similar to clinic-based studies, we identified functional limitations in all oromotor structures examined (i.e., lips, tongue, face, jaw). These deficits were associated with significant functional consequences, impacting on communication and feeding duration. With regard to potential factors associated with oromotor dysfunction, univariate findings indicate that severe fine motor impairment may be a greater indicator of oromotor dysfunction compared to gross motor function, as expected; however, this finding should be confirmed in a larger study. Our findings highlight key characteristics of oromotor dysfunction for minimally verbal children with CP that can be used to help guide assessment, targeted treatment and identification of at risk cases.

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Figure 1 Caption. Early Motor Control Scales age equivalents (in months) for Motor Speech Control and Arm and Hand Control composites.

Table 1. Participant characteristics (n=20)

Variable	n (%)
Mean age (years) / SD (range)	5;6 / 5;7 (5;0-6;3)
Female	10 (50)
Motor type	
Spastic	9 (45)
Dyskinetic	1 (5)
Hypotonia	3 (15)
Mixed*	7 (35)
Bilateral distribution	19 (95)
Unilateral distribution (left)	1 (5)
GMFCS level	
II	2 (10)
III	1 (5)
IV	10 (50)
V	7 (35)
MACS level	
I	1 (5)
II	3 (15)
III	5 (25)
IV	5 (25)
V	6 (30)
CFCS level	
III	9 (45)
IV	7 (35)
V	4 (20)
Epilepsy	11(55)
Non-verbal cognitive impairment	11 (55)
Unknown	5 (25)
Vision impairment	9 (45)
Hearing impairment	3 (15)
Mealtime Duration	
Less than 15 mins	3 (15)
15 – 30 mins	2 (10)
30 – 45 mins	3 (15)
Greater than 45 mins	8 (40)
Unknown	4 (20)
Presence of feeding problems	
(Almost) always	1 (5)
Often	9 (45)
Sometimes	3 (15)
(Almost) never	7 (35)
Gestation (>38 weeks' gestation)	12 (60)
Birth Weight	
Normal (≥2500g)	14 (70)
Low (<2500g)	1 (5)
Very low (<1500g)	2 (10)
Extremely low (<1000g)	3 (15)
Twin birth	3 (15)

Socioeconomic status	
High	8 (40)
Medium	11 (55)
Low	1 (5)
Parent education	
Degree/postgraduate	8 (40)
13 years	6 (30)
Less than 13 years	4 (20)
Unknown	2 (10)

Notes: Data obtained from the Victorian Cerebral Palsy Register, Australian Bureau of Statistics, parent questionnaire and examiner completed measures (GMFCS, MACS, CFCS); SD = standard deviation; GMFCS = Gross Motor Function Classification System; MACS = Manual Ability Classification System; CFCS Communication Function Classification System; Non-verbal cognitive functioning was determined by the Columbia Mental Maturity Scale using a cut off of 1SD below the mean. In instances where the Columbia Mental Maturity Scale could not be completed, cognitive data were obtained from the Victorian Cerebral Palsy Registry. Vision impairment defined as blindness (vision <6/60) or requiring corrective lenses. Hearing impairment defined as a >40dB hearing loss in the better ear or bilateral deafness; * = dominant motor types spastic (6/7) and ataxic (1/7). The Socio-Economic Index for Areas (SEIFA) Index of Relative Socio-Economic Disadvantage was used as an indicator of socio-economic status [41].

Table 2. Abnormal Structure and Function results (n=20)

	n (%)
Abnormal posturing	17 (85)
Excessive drooling	14 (70)
Tongue protrusion	8 (40)
Abnormal tone	
Trunk	17 (85)
Face	8 (40)
Both	8 (40)
Neither	3 (15)
Excessive mouthing	3 (15)
Overextension of jaw	2 (10)
Asymmetrical facial structure	1 (5)
Upper medial border lifted	1 (5)
Uninhibited oral reflexes	1 (5)
Asymmetrical facial contraction	1 (5)
Abnormal relationship of mandible/maxilla	0 (0)
Jaw sliding	0 (0)
Over contraction of facial muscles	0 (0)

Table 3. Early Motor Control Scales Composite Scores

Composite Results	EMCS Maximum Score	Mean	SD	Range	Median	IQR
Motor Speech Control	72	15.4	10.7	0-35	13	6.5-22.5
Voicing	18	6.4	4.6	0-15	6	2.5-10.5
Jaw	12	1.7	1.5	0-6	1	0.5-3.0
Face	15	4.4	3.2	0-12	4	2.0-6.0
Lips	12	1.9	1.7	0-5	2	0.0-2.5
Tongue	15	1.1	1.8	0-7	0	0.0-1.5
Arm & Hand Control	72	23.4	21.4	0-64	24	2-38
Total	144	38.8	29.5	2-98	36	12.5-54.5

Notes: EMCS = Early Motor Control Scales; SD = standard deviation; IQR = interquartile range. Maximum score = maximum score achievable on scale (i.e., this score does not reflect the maximum score achieved by participants but rather reflects the highest score that is possible on the Early Motor Control Scales).

Table 4. Features of Motor Speech Control (n=20)

Motor Speech Control Feature	n (%)
Voicing	
Squeals	7 (35)
Vocalizes with object in mouth	3 (15)
Open or nasalized vowels	12 (60)
Prosodic vowel contours	2 (10)
Syllables with voiced consonants (e.g., /b, d, g/)	10 (50)
Syllables with unvoiced consonants (e.g., /p, t, k/)	1 (5)
None of the above demonstrated	4 (20)
Jaw	
Minimal jaw movement	13 (65)
Full range of jaw movement	3 (15)
Stabilizing jaw posture	0 (0)
Integrated vertical and horizontal planes	0 (0)
None of the above demonstrated	5 (25)
Face	
Facial rounding without accompanying vocalization	5 (25)
Smiles	18 (90)
Lip retraction (e.g., /i/)	1 (5)
Lip rounding (e.g., /o/)	3 (15)
Lip protrusion (e.g., /u/)	1 (5)
None of the above demonstrated	2 (10)
Lips	
Minimal lip movement	9 (45)
Closure for bilabials with jaw	8 (40)
Lip movement independent of jaw	1 (5)
Individual lip control	0 (0)
None of the above demonstrated	7 (35)
Tongue	
Mid-tongue contacts palate	6 (30)
Tongue blade flattens	0 (0)
Back of tongue contacts palate	3 (15)
Tongue movement with blade and back	1 (5)
Independent tongue movement	0 (0)
None of the above demonstrated	12 (60)

Table 5. Univariate linear regression of the Early Motor Control Scales (EMCS) composite scores

	Motor Speech Control			Arm and Hand Control			EMCS Total		
	Coefficient (95% CI)	Adj. R^2	*p*	Coefficient (95% CI)	Adj. R^2	*p*	Coefficient (95% CI)	Adj. R^2	*p*
Gender (male)	0.6 (-9.7, 10.9)	-5.5	0.904	3.6 (-16.9, 24.2)	-4.8	0.718	4.2 (-24.2, 32.6)	-5.0	0.759
CP motor type									
Spastic	ref			ref			ref		
Dyskinetic	-1.4 (-27.1, 24.2)	-14.7	0.906	-24.4 (-74.2, 25.4)	-8.4	0.314	-25.9 (-95.2, 43.5)	-10.8	0.440
Hypotonic	3.8 (-20.1, 12.4)		0.628	-3.11 (-34.6, 28.4)		0.837	-6.9 (-50.7, 37.0)		0.743
Mixed	-4.0 (-16.3, 8.2)		0.497	-9.6 (-33.4, 14.2)		0.406	-13.6 (-46.8, 19.5)		0.397
Bilateral distribution	-19.6 (-41.2, 2.1)	12.1	0.073	-42.7 (-85.2, -0.3)	15.5	**0.049***	-62.3 (-119.8, -4.8)	18.0	**0.035***
GMFCS II	ref			ref			ref		
III	1.5 (-27.0, 30.0)	-6.0	0.913	-24.0 (-73.3, 25.3)	20.6	0.319	-22.5 (-93.8, 48.8)	12.3	0.515
IV-V	-6.1 (-23.5, 11.3)		0.470	-36.9 (-67.0, -6.8)		**0.019***	-43.0 (-86.6, 0.5)		0.052
MACS I-II	ref			ref			ref		
III	-8.2 (-19.2, 2.9)	47.2	0.137	6.8 (-12.3, 25.9)	60.5	0.462	-1.4 (-26.3, 23.6)	64.3	0.910
IV-V	-18.8 (-28.3, -9.2)		**0.001***	-29.6 (-46.2, -13.0)		**0.002***	-48.4 (-70.1, -26.7)		**<0.001***
CFCS III	ref			ref			ref		
IV	-3.2 (-14.8, 8.5)	-4.8	0.573	4.1 (-17.4, 25.6)	10.8	0.695	-0.9 (-29.5-31.3)	5.8	0.952
V	-6.9 (-20.8, 7.0)		0.310	-21.2 (-46.9, 4.4)		0.099	-28.1 (-64.4-8.2)		0.120
Epilepsy	-5.9 (-15.9, 4.0)	2.9	0.226	-15.6 (-34.9, 3.6)	9.1	0.106	-21.6 (-48.1-4.9)	9.2	0.105
Non-verbal cognitive impairment	4.5 (-10.9, 19.9)	-4.5	0.541	2.5 (-27.4, -32.5)	-7.4	0.857	-1.9 (-44.3, 40.4)	-7.6	0.923
Vision impairment	-6.8 (16.6, 3.0)	5.5	0.164	-21.5 (-39.4, -3.7)	22.3	**0.021***	-28.3 (-53.3, -3.4)	19.8	**0.028***
CSBS-DP Total	2.6 (1.1, 4.1)	39.7	**0.002***	1.7 (-9.4, 23.2)	70.9	**<0.001***	1.2 (0.9, 1.6)	71.8	**<0.001***
Eating duration									
<15 mins	ref			ref			ref		
15-30 mins	-1.8 (-18.5, 14.8)	43.4	0.814	-7.3 (-50.7, 36.1)	8.3	0.719	-9.2 (-62.4-44.1)	25.5	0.714
30-45 mins	-12.0 (-26.9, 2.9)		0.104	-9.3 (-48.2, 29.5)		0.610	-21.3 (-68.9-26.3)		0.349
>45 mins	-18.8 (-31.2, -6.5)		**0.006***	-27.3 (-59.5, 4.86)		0.089	-46.2 (-85.7, -6.7)		**0.026***

Associated factor	Motor Speech Control			Arm and Hand Control			EMCS Total		
	Coefficient (95% CI)	Adj. R^2	*p*	Coefficient (95% CI)	Adj. R^2	*p*	Coefficient (95% CI)	Adj. R^2	*p*
Feeding problem									
(Almost) never	ref			ref			ref		
Sometimes	-1.4 (-16.4, 13.5)	0.0	0.842	15.1 (-17.5, 47.6)	-0.0	0.342	13.6 (-30.5, 57.7)	-4.5	0.522
Often	-8.7 (-19.6, 2.2)		0.112	-1.4 (-25.2, 22.4)		0.902	-10.0 (-42.2, 22.1)		0.518
(Almost) always	-18.4 (-41.6, 4.7)		0.110	-10.3 (-60.8, 40.2)		0.671	-28.7 (-97.0-39.6)		0.386
Gestation (preterm)	-5.8 (-15.9, 4.4)	2.2	0.246	13.5 (-6.5, 33.5)	5.0	0.173	19.3 (-8.1, 46.7)	5.9	0.157
Birth weight									
Normal	ref			ref			ref		
Low	-2.5 (-25.5, 20.5)	4.1	0.821	-24.3 (-70.9, 22.4)	1.4	0.286	-26.8 (-90.4, 36.8)	3.3	0.385
Very low	6.5 (-10.3, 23.3)		0.424	17.7 (-16.3, 51.8)		0.287	24.2 (-22.2, 70.7)		0.285
Extremely low	-10.8 (-24.9, 3.3)		0.124	-9.6 (-38.3, 19.1)		0.487	-20.5 (-59.6, 18.6)		0.284
Twin birth	11.7 (-1.6, 24.9)	11.3	0.081	10.1 (-18.4, 38.6)	-2.4	0.466	21.8 (-16.5, 60.2)	2.2	0.248
Socioeconomic status									
High	ref			ref			ref		
Medium	9.6 (-0.3, 19.5)	10.9	0.056	2.0 (-20.1, 24.1)	-11.2	0.851	11.6 (-18.3, 41.6)	-7.5	0.424
Low	2.0 (-20.6, 24.6)		0.854	6.0 (-44.5, 56.5)		0.805	8.0 (-60.4, 76.4)		0.808

Notes: ref: reference category; * significant *p*=<0.05 level; CI confidence interval; CSBS-DP Communication and Symbolic Behaviour Scale Developmental Profile; GMFCS Gross Motor Function Classification System; MACS Manual Ability Classification System; CFCS Communication Function Classification System.

Negative adjusted R^2 (adj. R^2) values indicate that the variability explained is negligible.

Table 6. Univariate linear regression (controlled for non-verbal cognition) of the Early Motor Control Scales (EMCS) composite scores

	Motor Speech Control			Arm and Hand Control			Total EMCS		
	Coefficient (95% CI)	Adj. R^2	*p*	Coefficient (95% CI)	Adj. R^2	*p*	Coefficient (95% CI)	Adj. R^2	*p*
Gender (male)	4.7 (-9.7, 19.1)	-8.7	0.493	8.5 (-19.6, 36.6)	-12.3	0.522	13.2 (-26.4, 52.8)	-11.7	0.482
CP motor type									
Spastic	ref			ref			ref		
Dyskinetic	-15.3 (-51.3, 20.8)	-5.4	0.368	-42.3 (-112.4, 27.7)	-7.8	0.208	-57.6 (-115.1, 40.0)	-5.0	0.217
Hypotonic	-8.5 (-28.6, 11.7)		0.371	-9.5 (-48.6, 29.5)		0.598	-18.0 (-72.4, 36.4)		0.478
Mixed	-15.2 (-35.3, 5.0)		0.124	-26.7 (-65.8, 12.3)		0.158	-41.9 (-96.3, 12.5)		0.117
Bilateral distribution	-22.8 (-48.1, 2.5)	14.3	0.073	-45.6 (-94.2, 3.1)	13.6	0.064	-68.4 (-135.7, -1.1)	17.3	**0.047***
GMFCS II	ref			ref			ref		
III	-3.2 (-42.3, 36.0)	-13.8	0.862	-24.9 (-86.3, 36.6)	23.7	0.392	-28.1 (-121.8, 65.7)	11.0	0.523
IV-V	-8.8 -30.8, 13.1)		0.394	-40.9 (-75.3, -6.4)		**0.024***	-49.7 (-102.3, 2.8)		0.061
MACS I-II	ref			ref			ref		
III	-8.7 (-22.9, 5.6)	55.9	0.208	5.3 (-16.5, 27.2)	71.9	0.601	-3.3 (-31.8, 25.1.7)	76.1	0.801
IV-V	-22.2 (-33.9, -10.5)		**0.002***	-37.3 (-55.2, -19.43)		**0.001***	-59.6 (-82.9, -36.2)		**0.000***
CFCS III	ref			ref			ref		
IV	-2.5 (-22.3, 17.53)	-13.4	0.786	9.0 (-26.6, 44.6)	0.4	0.589	6.5 (-45.1, 58.1)	-5.0	0.787
V	-9.4 (-30.8, 12.0)		0.353	-21.0 (-59.5, 17.4)		0.255	-30.4 (-86.2, 25.3)		0.255
Epilepsy	-8.1 (-22.5, 6.3)	-0.6	0.244	-17.5 (-45.1, 10.0)	-0.3	0.190	-25.6 (-64.4, 13.1)	0.7	0.175
Non-verbal cognitive impairment	-	-	-	-	-	-	-	-	-
Vision impairment	-10.5 (-23.8, 2.9)	9.0	0.113	-23.9 (-48.6, 0.7)	15.3	0.056	-34.4 (-69.0, 0.2)	16.2	0.051
CSBS-DP Total	0.2 (0.1, 0.3)	55.0	**0.001***	0.5 (0.4, 0.6)	85.2	**0.000***	0.7 (0.6, 0.9)	87.2	**0.000***
Eating duration									
<15 mins	ref			ref			ref		
15-30 mins	11.2 (-9.0, 31.3)	71.2	0.230	24.5 (-33.7, 82.7)	37.1	0.353	35.7 (-31.0, 102.3)	58.0	0.246
30-45 mins	-28.6 (-47.3, -9.9)		**0.009***	-20.3 (-74.4, 33.9)		0.406	-48.8 (-110.9, 13.2)		0.105
>45 mins	-21.6 **(**-32.8, -10.5**)**		**0.003***	-35.0 (-67.3, -2.6)		**0.037***	-56.6 (-93.6, -19.7)		**0.008***

	Motor Speech Control			Arm and Hand Control			Total EMCS		
	Coefficient (95% CI)	Adj. R^2	*p*	Coefficient (95% CI)	Adj. R^2	*p*	Coefficient (95% CI)	Adj. R^2	*p*
Feeding problem									
(Almost) never	ref			ref			ref		
Sometimes	5.7 -24.6, 35.9)	3.2	0.685	16.0 (-51.8, 83.8)	-32.1	0.610	21.7 (-70.9, 114.2)	-23.5	0.613
Often	-13.7 (-31.8, 4.3)		0.122	-6.3 (-46.8, 34.2)		0.737	-20.0 (-75.3, 35.3)		0.439
(Almost) always	-22.0 (-52.2, 8.2)		0.136	-16.0 (-83.7, 51.8)		0.610	-38.0 (-130.5, 54.5)		0.382
Gestation (preterm)	6.3 (-8.0, 20.6)	-5.2	0.357	11.3 (-16.7, 39.3)	-9.3	0.397	17.6 (-21.7, 56.8)	-8.0	0.349
Birth weight									
Normal	ref			ref			ref		
Low	-1.3 (-32.2, 29.5)	-15.2	0.925	-29.3 (-90.0, 31.2)	-20.6	0.306	-30.7 (-116.6, 55.3)	-21.9	0.445
Very low	7.7 (-23.2, 38.5)		0.592	-1.3 (-62.0, 59.2)		0.962	6.3 (-79.6, 92.3)		0.873
Extremely low	-9.7 (-29.9, 10.5)		0.312	-14.7 (-54.3, 25.0)		0.429	-24.3 (-80.6, 31.9)		0.358
Twin birth	13.8 (-5.8, 33.5)	5.4	0.151	17.8 (-22.6, 58.1)	-8.1	0.356	31.6 (-24.1, 87.3)	-3.4	0.240
Socioeconomic status									
High	ref			ref			ref		
Medium	12.3 (-0.2, 24.8)	18.1	0.053	9.6 (-18.3, 37.6)	-11.1	0.467	21.9 (-16.0, 59.9)	-3.0	0.232
Low	-			-			-		

Notes: ref: reference category; * significant *p*=<0.05 level; B coefficient; CI confidence interval; CSBS-DP Communication and Symbolic Behaviour Scale Developmental Profile; GMFCS Gross Motor Function Classification System; MACS Manual Ability Classification System; CFCS Communication Function Classification System.