Early Speech Production in Infants and Toddlers Later Diagnosed with Cerebral Palsy: A Retrospective Study

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Abstract

In this retrospective study, we compared the early speech development between infants with cerebral palsy (CP) and typically developing (TD) infants. The recordings of utterances were collected from two CP infants and two typically-developing (TD) infants at approximately 8 and 24 months old. The data was analyzed by volubility, consonant emergence, canonical babbling ratio (CBR), mean babbling level (MBL). The major findings show that comparing with TD group, CP group has the characteristics of: 1) lower volubility 2) CBR^{utter} below 0.15 at 2 years old 3) MBL score below 2 at the age of 2 with a feature of above 95% in level 1 4) using consonants mainly at two oral places (bilabials and velars) and three manners of articulation (nasal, fricative, and stop) at 2 years old.

Keywords: volubility, consonant emergence, canonical babbling ratio (CBR), mean babbling level (MBL)

1 Introduction

Cerebral palsy (CP) is a non-progressive and permanent motor disorder, caused by the impairment of neurodevelopment in the fetal or infant brain (Rosenbaum et al., 2007). More than 60% of children with CP has communication problems stemming from the language or/and speech impairments, including delayed language development, voice disorders, and speech disorder (Sadowska et al., 2020).These abnormality in speech may adversely affect the following ability in terms of communication, intelligibility, phonological awareness and literacy (Peeters et al., 2009). For children with CP, these difficulties may eventually result in the poor performance in academy, problems in relationship, and also less career opportunities. As a result, many researches have suggested early intervention not only aim to diminish the negative impact of the limited motor functions but also provide mental health support for the caregivers(Novak et al., 2017).

Previous studies have widely documented similar transition in developing stages for infants' vocalization in the first and second year of life and showed the strong relation to the future language ability(D'Odorico et al., 2011). However, rare speech development related studies included data with CP infants under 2 years old.

Studying early infants' vocalization has helped enriched our knowledge about disorders, such as hearing impairment, down syndrome, fragile X syndrome (Belardi et al., 2017), autism (Patten et al., 2014), and CAS (M. Overby & Caspari, 2015; M. S. Overby et al., 2019), reducing the severity and providing evident-based support for clinical decision. Volubility, consonant inventory, and the development of canonical babbling are three widely studied domain in early infant speech production, and many has shown to be a precursor to later language ability (Smith & Stoel-Gammon, 1996).

Hustad et al. (2014) measured the speech and language development of 27 children at the age between 24 and 30 months, finding that three groups of children with CP with different level of language ability (i.e., not talking, emerging talking, and established talking) can be identified at the age of 2. Speech and/or language delay was found in two groups of children (nearly 85% of the children in this study) and also suggested speech and language assessment and intervention before 2 years old.

Since obvious differences appeared at the age of 2, more data is required to clarify the details of the progression in speech development. Therefore, the goal of this study is to investigate the speech development of 2 CP and 2 TD infants and try to answer the following questions:

- What are the differences in the volubility, the diversity of consonant emergence, CBR and MBL of CP group and TD group at 1 and 2 years old?
- What are the changes in speech development of CP group and TD group at 1 and 2 years old?

2 Method

2.1 Participants and equipment

Speech data of two TD infants and two CP at approximately 8 and 24 months were collected (Table 1).

participants	TD1	TD2	CP1	CP2
Gender	F	F	F	F
Type	-	-	Spastic hemiplegia	Unidentified
GMFCS	-	-	IV	-
Recording Age 1 (month, day)	12,09	12,18	10,19	08,22
Length (minute: second)	53:48	54:02	35:16	41:27
Recording Age 2 (month, day)	24,00	24,11	21,19	23,16
Length (minute: second)	43:41	53:05	44:10	44:38
Total utterances	369	646	137	234

Table1. Data recordings

All recordings were taken at either hospital or home under the natural interaction with caregivers and/or an experimenter. For each infant, one recording is included by the age around 1 year and 2 years old. Each recording session lasted for around 35 to 60 minutes. A SHURE wireless mini microphone was clipped to the cloth near infants' mouth and connected to a TASCAM recorder.

2.2 Coding process

The coder was trained by another experienced coder first, and a completed coding recording is checked by the experienced coder before formally conducting the rest of the recordings. For inter-judge reliability, another coder randomly checked 10% of the coding results. Infant's utterance boundaries are roughly marked by Elan and the utterances was coded with Worldbet (Hieronymus et al., 1993) conducted in Praat (Lab & 2013, n.d.). Eventually, the data extracted from coded recording is analyzed by a script to obtain results including, volubility, consonant inventory, MBL, and CBR.

2.3 Deciding an utterance

One distinctive utterance is defined as the voluntary vocal sound made by the child, produced by the egressive airstream in a breath group. The boundaries of the utterance are required to be established by at least one second silence, others' voice, or any other sound which meet the exclusion standard.

2.4 Inclusion and exclusion standard of utterances for coding

The standard of the inclusion and exclusion of utterances are extracted from Stoel-Gammon (1989), and was added with several modifications. The included utterances are considered as speech-like by coder's subjective judgement, and must contain at least one vocal element featured with voicing. Other non-speech like sound (i.e., cry, laugh, scream, cough, and vegetative sound), singing, and sounds overlapped with other background sound or others' voice are excluded from coding. In addition, if the quality of the recording is poor and thus can't be transcribed by the coder under four trials, the utterance was not acceptable for coding. All the meaningful utterances identified as non-Mandarin were also excluded.

2.5 CBR

Three ways of counting CBR were widely used in different studies as an index for the onset of CB (Kimbrough & Eilers, 1988; Kimbrough Oller et al., 1994; Nyman & Lohmander, 2018). However, CBR^{utter} was reported to have strong correlation with the other two ways. Meanwhile, it was less time-consuming in calculation, and the categorization of the utterances can also be done

instantly (Nyman & Lohmander, 2018; Willadsen et al., 2022). Therefore, the result of CBR^{utter} was collected for analysis. The formula of CBR^{utter} is listed below:

$$CBR = \frac{\text{number of utterances with conanical syllables}}{\text{total number of utterances}}$$

2.6 Scoring of MBL

MBL level was created by Stoel-Gammon (1989) and sorted by Morris in 2010. Level 1includes the utterances with only one, sequencing or the combination of vowel and consonant of glide or glottal. Level 2 and level 3 includes the combination of true consonants, and respectively meet the definition of Oller's canonical babbling stage and variegated babbling stage. Total number of utterances in each level is multiple with different numbers: Level 1 multiple with 1, level 2 multiple with 2, and level 3 multiple with 3. The mean babbling level is calculated by dividing the sum of each weighted level with the total numbers of utterances. The formula of MBL is described below:

$$MBL = \frac{\text{level } 1 \times 1 + \text{level } 2 \times 2 + \text{level } 3 \times 3}{\text{total number of utterances}}$$

3 Result and discussion

In this study, we investigate volubility, consonant emergence, canonical babbling in order to enrich the knowledge about early speech production in CP infants. The results are also considered as several possible warning signs for CP infants who may have language and/or speech problems in the future.

3.1 Volubility

A total of 1386 utterances were collected and analyzed across all children. The volubility, calculated as utterances per minutes in each recording, was found higher in TD group than in CP group regardless of age (TD mean = 5.40, CP mean = 3.97 at around 1 year old; TD mean = 4.68, CP mean = 1.59 at around 2 years old). However, a reduction of volubility with age was found in both TD and CP group (Figure1).

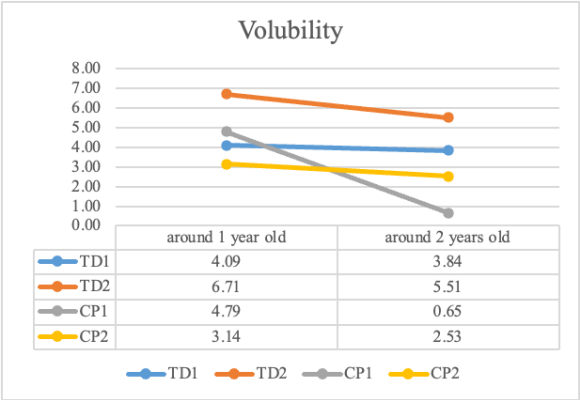

Figure 1. Volubility at 1 and 2 years old

Previous studies indicated that volubility in typically developing infants would increase with age (Stark et al., 1993). However, in recent studies, with a different criterion of annotating the boundaries of utterances, the volubility reduced with age (Iyer et al., 2016). In this study, the volubility in TD and CP also reduced with age, but either at around 1 year old or 2 years old, all CP children tended to vocalized fewer than TD children. The low volubility compared with the roughly same age of peers may be a warning sign for development in speech sound.

3.2 Consonant emergence

Consonants of infants' vocalizations are analyzed based on the feature of place (bilabial, labiodental, alveolar, retroflex, palatal, and velar) and manner (stop, fricative, affricate, liquid and nasal). At around 1 year old, TD group used massively alveolars (mean = 37.92%), bilabials (mean = 25.15%), and velars (mean = 32.68%), which was similar in CP1 (alveolar = 31.24%, bilabial = 40.62, velars = 28.12%). However, CP2 developed almost exclusively bilabials (92%) with little velar /h/ (8%). TD group had developed consonants at almost all different oral places, but CP group developed consonants on limited oral places (mainly bilabial and velar). At around 2 years old, TD group still mainly used consonants at the places of alveolar and velar, but the proportion of other places, such as retroflex and palatal, increased. As to CP group, only consonants at bilabial (mean = 68.34%) and velar (mean = 31.66%) places were used in vocalizations. The diversity of the consonants with the feature of places were seemingly decreased with age in CP group.

In terms of the feature of manner, TD children used excessively stops (mean = 64.64%) and nasals

(mean = 16.93%) at 1 around 1 year old, and similar consonant division was also found in CP at the same age, but with a reverse proportion (stop = 22.06%, nasal = 59.88%). While at around 2 years old, TD children used most stops (45.85%) and affricates (22.98%) in utterances, but CP children used merely nasal /m/ (63.34%) and fricatives (31.66%) with little stops (5%) in speech. CP children vocalized with very limited manners in consonants compare with TD children.

In summary, CP group only developed consonants at two oral places (bilabials and velars) and three manners of articulation (nasal, fricative, and stop). The restricted consonants found in CP group could be another warning sign.

3.3 CBR and MBL

At around 1 year old, CBR of all children were > 0.15, showing a success on the onset of canonical babbling, though the figures were relatively higher in TD children (Table 2).

	TD1	TD2	CP1	CP2
Age (month, day)	12,09	12,18	10,19	08,22
CBR^{utter}	0.33	0.31	0.17	0.16
Age (month, day)	24,0	24,11	21,19	23,16
CBR^{utter}	0.93	0.91	0.04	0.04

Table 2. CBR

The differences were found in two groups around age 2. CBR^{utter} in CP children greatly declined and fell below the CB onset standard, while the TD children steadily increased.

CBR has been used widely for the purpose of understanding the speech development in typically-developing infants from 10 to 12 months old and also in neurodevelopmental disordered population (Lohmander et al., 2017; Nyman & Lohmander, 2018). Different formulas and standard for onset CB were studied recently. Nyman et al. (2021) pointed out the use of 0.14 may be more sensitive to detect the BC onset in 10-month-old infants, but further research is required to reach the agreement of the criterion. Similar results were found in this study and in (Levin, 1999). that some CP infants were able to enter CB stage, though using a different formula to obtain the result of CBR. However, with the trend of decreasing after 1 year old, none CP infants remained at the CB stage or move further to the next stage, showing that CP infants' development of speech sound did not improve with age. Therefore, the third possible warning sign may be the score of CBR^{utter} failing to reach above 0.15 at 2 years old.

Some researchers suggested that the sole judgment of CBR for describing the developmental status of speech was not enough (Lang et al., 2019). In this study, MBL score provides additional information for children's maturity of syllable structure. For example, a score of 1.4 may indicates infant's speech characterized with various vowels and some true consonants (Morris, 2010). Overall, the score of MBL in TD group is higher than the CP group at around 1 year old and 2 years old (TD mean = 1.36, CP mean = 1.18 at around 1 year old; TD mean = 2.60, CP mean = 1.04 at around 2 years old). Two groups had a seemingly start of the MBL score, but end differently with the TD continuously increasing and CP gradually going down around age 2 (Figure 2).

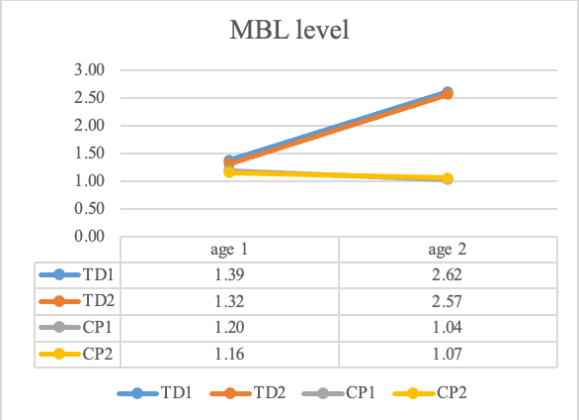

Figure 2. MBL at 1 and 2 years old

The frequency of occurrence in three MBL levels were similar in all children at 1 year old, presenting a ratio tendency: level 1, level 2, and level 3 (from high to low). However, the utterances of TD were twice more concentrated in Level 2, showing a sign of developing more consonants compared with CP at the same age. The situation was a lot different at age 2. The proportion of utterances in TD children were presented in a reverse order: level 3, level 2, level 1 (from high to low). Above 65% of the utterances were variegated

babbling. On comparison, the division of utterances in CP subjects at around age 2 remained approximately the same, but the division became even more concentrated on level 1. An obvious decline at level 2 and level 3 were observed (Figure 3).

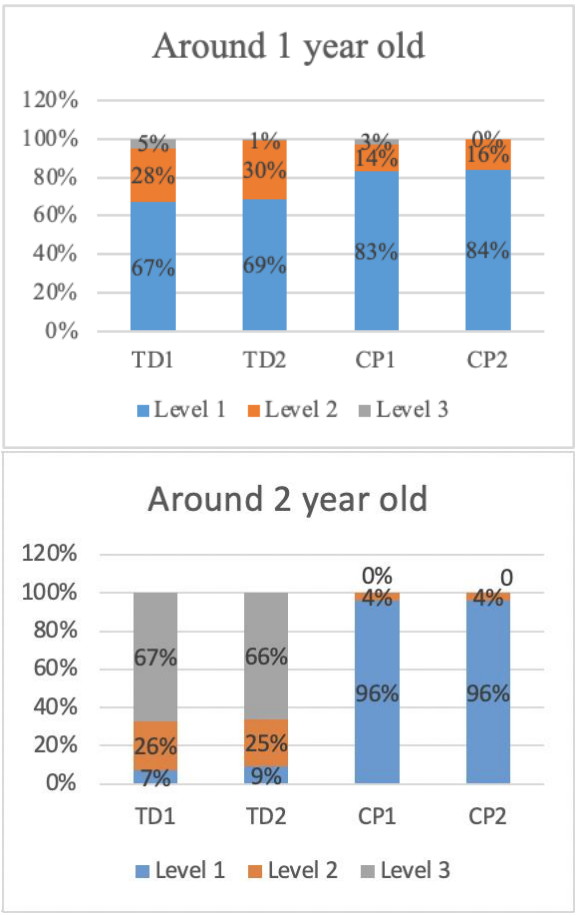

Figure 3. MBL in TD and CP

In summary, the division of the three levels were similar at 1 year old, but obvious differences between 2 groups were also showed at around 2 years old. Therefore, the last possible warning sign may be the MBL score below 2 at age 2 with a feature of above 95% in level 1.

4 Conclusion

Findings in this investigation imply the speech development differences between TD infants and CP infants at the age between 8 to 24 months old. Although it is a preliminary study, the below possible warning sign might be clinical warning sign that could help the identification of infants and toddlers at risk for later diagnosis of speech and language problem in children with CP: (1) low volubility (2) $CBR^{utter} < 0.15$ at 2 years old (3) MBL score < 2 at the age of 2 with a feature of above 95% in level 1 (4) use consonants only at two oral places (bilabials and velars) and three manners of articulation (nasal, fricative, and stop) at most at 2 years old. More data and studies are required for clarifying the changing course between 1 and 2 years old. More amounts of subjects are also suggested to be included in future studies.

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