# ACOUSTIC CHARACTERIZATION OF DYSARTHRIA IN CHILDREN WITH CEREBRAL PALSY: EXPLORING AGE-RELATED EFFECTS

Anja Kuschmann[1] and Frits van Brenk[2]

[1]University of Strathclyde, Glasgow, UK; [2]University at Buffalo, USA
anja.kuschmann@strath.ac.uk; brenk@buffalo.edu

## ABSTRACT

The speech of children with dysarthria and cerebral palsy (CP) is characterized by respiratory, phonatory and articulatory difficulties. Whilst, traditionally, speech deviations were described perceptually, the focus has recently shifted to acoustic measures to quantify the children's speech changes more objectively and systematically. This study investigated the role of age in acoustically characterizing dysarthria in children with CP. Speech samples of eight children were analyzed using various acoustic measures and compared to those of typically-developing peers. Results showed overall group differences for several acoustic measures. Additionally, the degree to which acoustic measures may differentiate children with CP and their peers is influenced by age, with various measures found to be more suitable in differentiating older affected and unaffected children (13-18 years) compared to younger ones (7-8 years). This finding suggests that age is important when selecting acoustic markers of dysarthria, with some markers constituting more sensitive measures than others.

**Keywords**: speech, acoustics, cerebral palsy, dysarthria, age-related effects

## 1. INTRODUCTION

Cerebral palsy (CP) is a motor disorder caused by damage to the developing brain that affects movement, balance and posture [14]. The motor deficits are frequently accompanied by difficulties with cognition and sensorimotor function [4]. In about 50% of children with CP the brain damage also leads to communication difficulties, with dysarthria representing the most frequent form of communication impairment [12]. Speech characteristics associated with dysarthria include shallow, irregular breathing, harsh and/or breathy voice, hypernasality and imprecise articulation [3, 7, 11, 18]. Although the presentation of dysarthria in children with CP can vary considerably, in most cases all speech subsystems, i.e. respiration, phonation, resonance and articulation, are affected by the motor control issues.

Current treatment approaches for children with dysarthria secondary to CP focus on improving intelligibility, and considerable research efforts have been made to determine those features that impact most on intelligibility. Perceptual evaluations of speech produced by children with dysarthria and CP have identified difficulties with articulation, voice quality, hypernasality and speech rate as the primary features contributing to reduced speech intelligibility [6, 11, 18]. However, the studies also showed that perceptual evaluations do not lend themselves very well to differentiating between types of dysarthria as perceptual features are often similar across the different types of CP-related dysarthria. In order to quantify and classify the perceived changes in a more objective and systematic way, researchers have begun exploring the usefulness of acoustic measures to capture the children's speech changes. Measuring acoustic correlates offers the advantage of objectively capturing those changes to the acoustic signal that lead to the perception of impaired speech in children with dysarthria and CP [2]. Furthermore, acoustic measures allow the quantification of differences in speech features produced by children with CP and their typically-developing peers. Based on this, studies using acoustic data have identified changes in articulation rate and F2 range, among other characteristics, as primary features in children with CP that differ from those of typically-developing children [e.g. 2, 10].

It is important to note that studies on adult dysarthria have long been using acoustic analyses to objectively quantify speech features [1, 8, 16, 19], whereas research into childhood dysarthria has only recently started exploring the usefulness of acoustic analyses in characterizing speech. This does not come as a surprise, given the challenges in collecting speech data from children with disabilities and the complexities associated with evaluating atypical speech characteristics at an age where the motor system is yet to fully develop and mature. Unlike in adult dysarthria, age is therefore likely to have an influence on the acoustic features of speech in childhood dysarthria.

The current study aims to investigate to what extent age-related effects can be observed with regard to acoustic markers of dysarthria in children with CP. This will help establish whether and to what extent age should be considered when designing speech tasks and collecting and interpreting speech data of children with dysarthria and CP for clinical research and practice.

## 2. METHOD

### 2.1. Participants

Speech recordings from eight children with dysarthria due to CP were analysed with regard to various acoustic measures and subsequently compared to the performances of eight age-, gender- and dialect-matched TD children (cf. Table 1; six boys and two girls; CP: mean age = 12.0 years, range = 7-18 years; TD: mean age = 11.8 years, range = 7-20 years). The data were collected as part of a project on prosodic abilities in children with CP [9]. Three children had been diagnosed with dyskinetic CP, two with spastic CP, and two with ataxic CP. The children's motor speech difficulties ranged from mild to severe as established by the Children's Speech Intelligibility Measure (CSIM) [17]. All children were native speakers of Scottish English (West of Scotland variety). Hearing and vision was normal or adjusted-to-normal with cognitive skills appropriate to follow task instructions.

| Speaker | Gender | Age | CP type | Severity | Control speaker | Age |
|---|---|---|---|---|---|---|
| CP1 | M | 7 | Dys | Mild | TD1 | 7 |
| CP2 | M | 7 | Sp | Mild | TD2 | 8 |
| CP3 | M | 16 | Sp | Mod | TD3 | 16 |
| CP4 | M | 18 | At | Mod | TD4 | 20 |
| CP5 | M | 13 | At | Sev | TD5 | 14 |
| CP6 | F | 8 | Dys | Mod | TD6 | 7 |
| CP7 | F | 15 | Dys | Mild | TD7 | 16 |
| CP8 | M | 7 | Sp | Sev | TD8 | 6 |

**Table 1**: Participants characteristics (CP=cerebral palsy, TD=typically-developing, Dys=dyskinetic, Sp=spastic, At=Ataxic, Mod=moderate, Sev=severe (CSIM score (mild: ≥ 80%, moderate: 50 – 80%, severe: < 50%))

### 2.2. Materials

Acoustic measures were obtained from four structured and unstructured speech tasks ranging from single words to connected speech. The tasks were carefully selected or designed to elicit speech data for the investigation of prosodic abilities in children with CP [9]. The speech tasks also lent themselves for further detailed acoustic analysis, and therefore subsequently formed the basis of the acoustic analyses reported in the current study. For each speaker acoustic analyses were conducted on a set of 50 single words from the CSIM [17], 20 short sentences (SENT) [9], the retelling of the Renfrew Bus Story (RETELL) [13], and a monologue task (MONO) where children spoke either about their last birthday or their hobbies. The latter two speech tasks were geared towards obtaining connected speech samples, as this is generally considered the most ecologically valid material in assessing disordered speech. It is deemed more natural and captures a wider range of speech characteristics under investigation. In addition, the increased motor control demands of longer utterances may lead to speech deviations emerging that might not be apparent in single words or short utterances, motivating the need to look beyond analyses of single words [2].

### 2.3. Measures

Across the speech tasks, suitable voiced fragments for acoustic analyses were identified, marked and extracted using Praat [5]. Non-lexical fillers (e.g., uh or um) were excluded. As a next step, acoustic measures were quasi-automatically obtained by means of custom Praat scripts. Acoustic measures were selected taking account of the fact that multiple speech dimensions can be affected in the speech of children with dysarthria, and included voice quality, vocal intensity, prosody and articulatory working space. Specifically, the following measures were taken:

- Sound Pressure Level (SPL; Mean, SD, 90th-10th percentile range)
- Fundamental Frequency (F0; Mean, SD, 90th-10th percentile range)
- Second Formant Interquartile Range (F2 IQR, 3rd quartile – 1st quartile).
- Cepstral Peak Prominence (CPP) and Smoothed Cepstral Peak Prominence (CPPS)

### 2.4. Statistical analyses

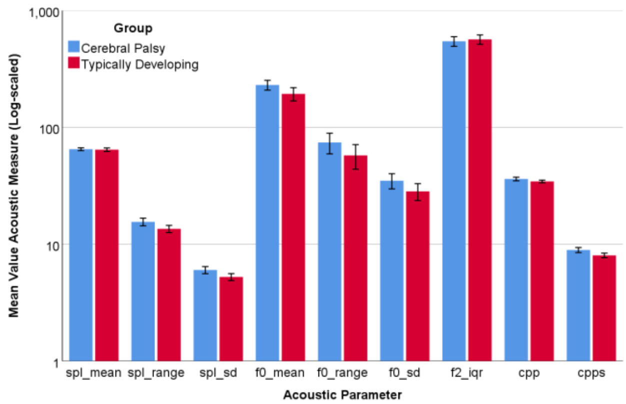
A series of 2-way ANOVAS were performed to compare Group performances (CP, TD) for each acoustic measure and speech tasks (CSIM, SENT, RETELL, MONO). In a first step, groups and tasks were compared by pooling the acoustic outcome measures over the different speech tasks to establish potential group differences. The next step involved subgroup analyses to determine the role of Age as a factor that may affect Group performance. Subgroups were formed of younger children (7 to 8 years, i.e. CP1, CP2, CP6, CP8) and older children (13 to 18 years, i.e. CP3, CP4, CP5, CP7).

## 3. RESULTS

### 3.1. Comparisons of groups

The results of the group comparisons conducted across all speech tasks revealed that the children with CP had a significantly higher *SPL Range* ($F$ (1, 56) = 6.800, $p$ = .0012) and *SPL SD* ($F$ (1, 56) = 7.551, $p$ = .008) than their TD peers. Significant differences were also found for *F0 Mean* ($F$ (1, 56) = 4.612, $p$ = .036) and *F0 SD* ($F$ (1, 56) = 4.078, $p$ = .048), which were higher in the CP group, with *F0 Range* showing a trend in this direction ($F$ (1, 56) = 3.194, $p$ = .079). *CPP* and *CPPS* measures also differed significantly between groups, with children with CP showing higher mean CPPS ($F$ (1, 56) = 11.410, $p$ = .001) and CPP values ($F$ (1, 56) = 4.854, $p$ = .032). The remaining acoustic measures (F2 IQR and SPL mean) did not differ significantly between groups. An overview of the results of the group comparisons of the different acoustic measures pooled over speech tasks is displayed in Figure 1.

**Figure 1**: Overview of group comparisons per acoustic measure, pooled over speech tasks (logarithmic-scaled)




When comparing the two speaker groups for each of the four speech tasks separately, the results on group differences were largely similar to those found when pooling all speech tasks. In addition, few significant differences were found when comparing speech tasks in their ability to differentiate speaker groups. The acoustic outcome measures were therefore summed across the four speech tasks in further reporting.

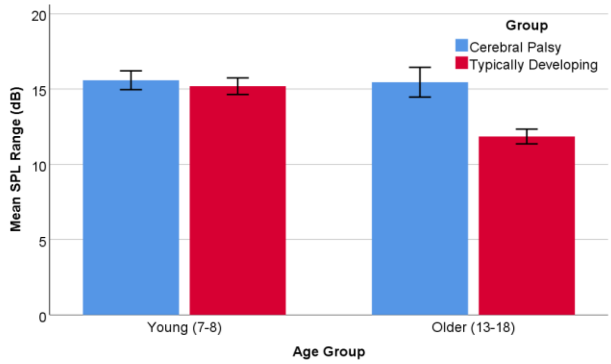
### 3.2. Subgroup analyses for Age

Subgroup analyses were conducted to determine the role of Age as a factor that may affect Group performance. We focus on presenting results from three of the acoustic measures that showed promise for indicating group differences, namely *SPL Range*, *CPP*, and *F0 SD*. These were also selected as they represent measures associated with different speech subsystems.

*SPL Range*

Figure 2 displays group comparisons of the speech parameter *SPL Range* divided into age groups. Comparisons across both groups in terms of Age showed a significant main effect for Group (CP vs. TD; $F$ (1, 60) = 8.389, $p$ = .005), with the CP group showing a larger SPL Range compared to the TD group. The main effect for Age was also significant (Younger vs Older; $F$ (1, 60) = 6.318, $p$ = .015), with the younger children showing a larger SPL Range compared to the older children. The interaction effect was also significant: $F$ (1, 60) = 5.403, $p$ = .023. Post-hoc analysis showed a group difference in SPL range for the Older children ($p$ < .001) but not the Younger ones ($p$ = .687), indicating a higher differentiating sensitivity for the former group.

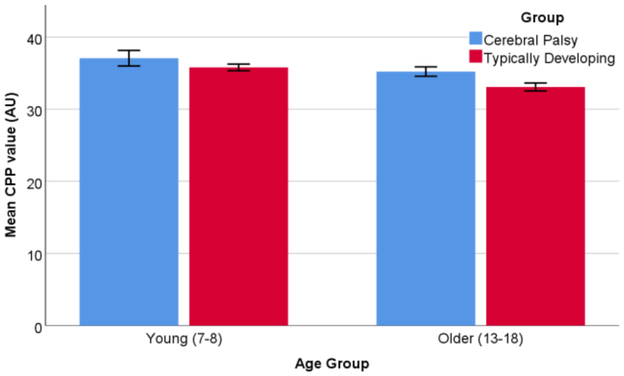
**Figure 2**: Group comparisons of acoustic measure SPL Range with Age as factor, pooled over speech tasks




*CPP*

Figure 3 shows group comparisons of the speech parameter *CPP* for the different age groups. Statistical analyses revealed significant main effects for Group (CP vs. TD; $F$ (1, 60) = 5.509, $p$ = .022), with higher CPP values for the CP group, as well as for Age (Younger vs Older; $F$ (1, 60) = 9.847, $p$ = .003), with higher CPP values for the Younger group. However, the interaction effect was not significant ($F$ (1, 60) = .350, $p$ = .557). This indicates that relative differences between groups were not influenced by Age, but remained fairly constant. Post-hoc analysis indicated a marginally significant group effect for the Older children ($p$ = .042) and a non-significant group effect for the Younger children ($p$ < .219), again indicating a higher differentiating sensitivity in the Older group.

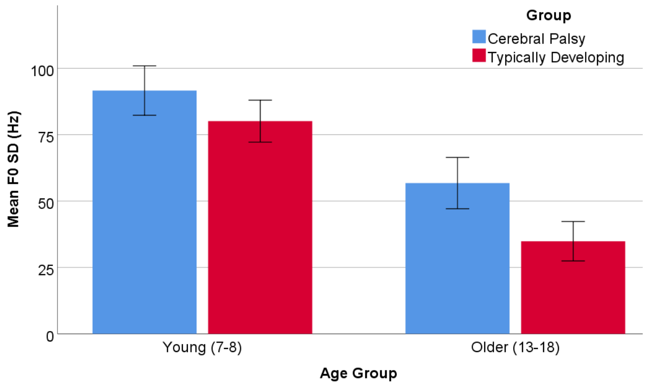
**Figure 3**: Group comparisons of acoustic measure CPP with Age as factor, pooled over speech tasks




*F0 SD*

Figure 4 displays group comparisons of the speech parameter *F0 SD*, separated by age groups. Statistical analysis showed a significant main effect for Group (CP vs. TD; $F$ (1, 60) = 4.709, $p$ = .034), with the CP group showing a larger F0 SD compared to the TD group. The main effect of Age was also significant (Younger vs Older; $F$ (1, 60) = 17.783, $p$ < .001), with the younger children showing a larger F0 SD compared to the older children. The interaction effect was non-significant: $F$ (1, 60) = .061, $p$ = .806. Post-hoc analysis confirmed the absence of differences for each age group, i.e. Older: $p$ = .093; Young: $p$ = .179. These results indicate that *F0 SD* behaved fairly similar across age groups when differentiating speech of children with CP speech and their TD peers.

**Figure 4**: Group comparisons of acoustic measure SPL Range with Age as factor, pooled over speech tasks




## 4. DISCUSSION

This study sought to explore the effect of age on the acoustic characterisation of dysarthria in children and adolescents with CP. Knowledge on this will be helpful for researchers and clinicians when designing speech tasks and selecting acoustic parameters for the analysis of speech at different ages in this population.

The group comparisons across speaking tasks revealed higher values for F0 and SPL measures in the speech of children with CP. This reflects greater variation of these features in this group, most likely due to reduced respiratory and phonatory control. Similarly, CPP and CPPS measures were higher in this group, suggesting that the voice of the children with CP had a hoarser quality to it. Overall, these findings indicate that the selected acoustic measures were suitable to quantify speech differences between children with CP and their TD peers.

The subsequent subgroup analyses of younger and older speakers established that age represents a variable that influences acoustic performance patterns, with younger children's speech consistently yielding higher values. This finding shows that children's speech changes as the system matures and indicates that, even though CP is a permanent condition, it is not a static one and speech difficulties and its manifestations are likely to change over time. However, the fact that for SPL Range systematic group differences were observed for the older children, but not the younger ones, whilst the CPP and F0 SD outcome measures remained relatively constant across both age groups suggests that some acoustic measures may be more suited than others to detect differences between groups in older children. That is, these measures might become more relevant and sensitive predictors of acoustic differences once the speech system has matured.

Whilst these results appear promising in terms of guiding researchers and clinicians in their selection of acoustic markers for quantifying differences in the speech of children with CP, it is important to highlight that the present group of children with CP varied considerably with regard to CP type and severity of dysarthria. This heterogeneity needs to be considered when interpreting the current findings.

## 5. CONCLUSION

Our study has shown that a range of acoustic measures are suited to capture speech features in children with CP and their TD peers. In addition, our subgroup analyses has shown the extent to which age is a variable that can influence speech performance in children with dysarthria and CP. The present study therefore highlights the complexities in acoustically characterizing dysarthria features in children with CP and points to age as a factor that should be considered when selecting acoustic parameters for assessment and comparison purposes.

**Acknowledgements:** The data analysed in this study was collected as part of a British Academy Postdoctoral Fellowship awarded to the first author.

## 6. REFERENCES


[1] Ackermann, H., Ziegler, W. 1991. Articulatory deficits in parkinsonian dysarthria: an acoustic analysis. *J Neurol Neurosurg Psychiatry.* 54, 1093-1098.

[2] Allison, K. M., Hustad, K. C. 2018. Acoustic Predictors of Pediatric Dysarthria in Cerebral Palsy. *J Speech Lang Hear Res*. 61, 462–478.

[3] Ansel, B.M., Kent, R.D. 1992. Acoustic-phonetic contrasts and intelligibility in the dysarthria associated with mixed cerebral palsy. *J Speech Hear Res*. 35, 296–308.

[4] Bax, M., Goldstein, M., Rosenbaum, P., Leviton, A., Paneth, N., Dan, B., Jacobsson, B., Damiano, D. 2005. Proposed definition and classification of cerebral palsy. *Dev Med Child Neurol*. 47, 571–576.

[5] Boersma, P., Weenink, D. 2018. *Praat: doing phonetics by computer.* http://www.fon.hum.uva.nl/praat/.

[6] DuHadway, C. M., Hustad, K. C. 2012. Contributors to intelligibility in preschool-aged children with cerebral palsy. *J Med Speech Lang Pathol*. 20, 1-5.

[7] Hodge, M.M., Wellman, L. 1999. Management of children with dysarthria. In: Caruso, A. J., Strand, E. (eds), *Clinical management of motor speech disorders in children*. New York: Thieme, 209-280.

[8] Kent, R. D., Netsell, R., Abbs, J. H. 1979. Acoustic characteristics of dysarthria associated with cerebellar disease. *J Speech Lang Hear Res*. 22, 627-648.

[9] Kuschmann, A., Lowit, A. 2018. Sentence stress in children with dysarthria and cerebral palsy. *Int J Speech Lang Pathol*. Early Online.

[10] Lee, J., Hustad, K. C., Weismer, G. 2014. Predicting Speech Intelligibility With a Multiple Speech Subsystems Approach in Children With Cerebral Palsy. *J Speech Lang Hear Res.* 57, 1666-1678.

[11] Nordberg, A., Miniscalco, C., Lohmander, A. 2014. Consonant production and overall speech characteristics in school-aged children with cerebral palsy and speech impairment. *Int J Speech Lang Pathol.* 16, 386-395.

[12] Parkes, J., Hill, N., Platt, M.J., Donnelly, C. 2010. Oromotor dysfunction and communication impairments in children with cerebral palsy: A register study. *Dev Med Child Neurol.* 52, 1113–1119.

[13] Renfrew, C. (1997). *Bus story test: a test of narrative speech*. Bicester, England: Winslow.

[14] Rosenbaum, P., Paneth, N., Leviton, A., Goldstein, M., Bax, M. 2006. A report: the definition and classification of cerebral palsy April 2006. *Dev Med Child Neurol*. 49, 8–14.

[15] Rusz, J., Cmejla, R., Tykalova, T., Ruzickova, H., Klempir, J., Majerova, V., … Ruzicka, E. 2013. Imprecise vowel articulation as a potential early marker of Parkinson's disease: Effect of speaking task. *J Acoust Soc Am.* 134, 2171-2181.

[16] Tjaden, K., Sussman, J., Liu, G. 2010. Long-term average spectral measures (LTAS) of dysarthria and their relationship to perceived severity. *J Med Speech Lang Pathol*. 18, 125–132.

[17] Wilcox, K., Morris, S. 1999. *Children's Speech Intelligibility Measure.* Pearson.

[18] Workinger, M. S., Kent, R. D. 1991. Perceptual analysis of the dysarthrias in children with athetoid and spastic cerebral palsy. In: Moore, C. A., Yorkston, K. M., Beukelman, D. R. (eds), *Dysarthria and Apraxia of Speech: Perspectives on Management*. Baltimore, MD: Paul Brookes, 109-126.

[19] Ziegler, W., von Cramon, D. 1986. Spastic dysarthria after acquired brain injury: An acoustic study. *Int J Lang Commun Disord*. 21, 173-187.