Kuschmann, Anja and Miller, Nick and Lowit, Anja and Pennington, Lindsay (2016) Intonation patterns in older children with cerebral palsy before and after speech intervention. International Journal of Speech-Language Pathology, 19 (4). pp. 370-380. ISSN 1754-9507 , http://dx.doi.org/10.1080/17549507.2016.1216601

Intonation patterns in older children with cerebral palsy before and after speech intervention

Anja Kuschmann[1], Nick Miller[2], Anja Lowit[1], and Lindsay Pennington[3]

[1]University of Strathclyde Speech and Language Therapy
[2]Newcastle University School of Education Communication and Language Sciences
[3]Newcastle University Institute of Health and Society

This is an author accepted manuscript accepted for publication on 4 July 2016 by Taylor & Francis Group in International Journal of Speech-Language Pathology.

Abstract

Purpose: This paper examined the production of intonation patterns in children with developmental dysarthria associated with cerebral palsy (CP) prior to and after speech intervention focussing on respiration and phonation. The study further sought to establish whether intonation performance might be related to changes in speech intelligibility.

Method: Intonation patterns were examined using connected speech samples of 15 older children with moderate to severe developmental dysarthria due to CP (9 females; age range: 11-18). Recordings were made prior to and after speech intervention based on a systems approach. Analyses focused on use of intonation patterns, pitch accentuation and phrasing.

Result: Group analyses showed a significant increase in the use of rising intonation patterns after intervention. There were also some indications that this increase might have been related to gains in speech intelligibility for some of the children. No changes were observed regarding pitch accentuation and phrasing following intervention.

Conclusion: The findings highlight that changes can occur in the use of intonation patterns in children with dysarthria and CP following speech systems intervention. It is hypothesised that the emergence of the rising pattern in some of the children's intonational inventories possibly reflected improved breath support and control of laryngeal muscles.

Intonation patterns in older children with cerebral palsy before and after speech intervention

Intonation refers to the variation of pitch in spoken utterances. It represents an integral part of communication which both speakers and listeners rely on to successfully convey and interpret information. Intonation serves a variety of linguistic functions such as the marking of sentence modality, demarcation of phrase boundaries and structuring of discourse by highlighting relevant information in an utterance (e.g. Baltaxe, 1984; Eady & Cooper, 1986).

Pitch is the perceptual equivalent of fundamental frequency (F0), which corresponds to the rate of vibration of the vocal folds. The latter is primarily determined by the activities of the intrinsic laryngeal muscles, which regulate vocal fold tension, as well as by subglottal air pressure (e.g. Hirano, Ohala, & Vennard, 1969). As waning breath support leads to declining sub-glottal pressure during speech production, falling patterns are easier to produce than rising patterns (Lieberman, 1967). This is thought to explain why falling intonation patterns appear earlier developmentally than rising ones (Cruttenden, 1981; Crystal, 1979; Menn, 1976). Rising patterns require a more effortful and purposeful physiological manipulation to bring about an increase in tension of the vocal folds by changing the level of activation of the intrinsic laryngeal muscles, and/or a rise in subglottal pressure through increase in glottal airflow (e.g. Ladefoged, 1963; Lieberman, 1967). Successful manipulation of these processes goes hand in hand with improved motor control, and as a result stabilises at a later age (Cruttenden, 1981; Li & Thompson, 1977). A range of experimental studies on the production of falling and rising intonation patterns in typically-developing children confirm this (Allen & Hawkins, 1980; Snow, 1998, 2001, 2006; Snow & Balog, 2002). The acquisition of intonation is a continuous process that evolves throughout childhood, and successful acquisition is closely entwined with cognitive, emotional and physical development (Baltaxe & Simmons, 1985; Samuelsson, 2004; Snow, 2006). Fine tuning continues well into adolescence (Atkinson-King, 1973; Stathopoulos & Sapienza, 1997; Tingley & Allan, 1975; Wells, Peppé, & Goulandris, 2004).

Disordered intonation development can occur in various paediatric populations such as children with autism (e.g. Hubbard & Trauner, 2007) and Specific Language Impairment (e.g. Wells & Peppé, 2003). Motoric impairments associated with developmental dysarthria are also likely to impact on intonation development given the effect of limited motor control on the speech production system. The most common cause of motor disorders in childhood is cerebral palsy, which has an estimated prevalence of 2-3 per thousand live births (Cans, De-la-Cruz, & Mermet, 2008; Yeargin-Allsopp et al., 2002). Developmental dysarthria is associated with all types of motor disorders in cerebral palsy (spastic, dyskinetic and ataxic) and affects approximately one third of children with the diagnosis (Nordberg, Miniscalco, Lohmander, & Himmelmann, 2013; Parkes, Hill, Platt, & Donnelly, 2010). All speech subsystems are usually affected and speech characteristics include speaking on residual air, difficulty maintaining adequate loudness, harsh and/or breathy voice quality, voicing errors, hypernasality, slow speech rate, reduced articulatory precision and phonemic repertoire (Ansel & Kent, 1992; Hodge & Wellman, 1999; Workinger & Kent, 1991) .

Despite the frequent occurrence of vocal tract involvement in children with dysarthria, few studies have examined intonation patterns, i.e. the rising and falling of pitch levels across utterances, in developmental dysarthria. Patel and Salata (2006) studied vocal control of vowel productions in five children with severe dysarthria by asking caregivers to identify distinctions realised through pitch and length. The study found that some children were able to manipulate pitch to signal intention despite limited levels of speech intelligibility. A subsequent study by Whitehill, Patel and Lai (2008) on four Cantonese children with severe dysarthria associated with CP confirmed these findings, indicating that children with moderate to severe dysarthria have at least some ability to use pitch reliably to communicate with their caregivers.

Whilst effective pitch control can contribute considerably to functional communication and intelligibility in motor speech disorders (De Bodt, Hernandez-Diaz, &Van De Heyning, 2002; Klopfenstein, 2009), clinicians rarely focus specifically on intonation during intervention. Having said that, pitch control is the result of complex interaction of laryngeal muscle adjustments, subglottal air pressure and aerodynamic forces. It is therefore likely that intervention approaches targeting breathing and phonation could potentially effect changes in pitch, and therefore intonation, without directly focusing on this aspect. Taking this perspective, one of the approaches that could potentially have an impact on intonation patterns is the 'speech systems' approach (Pennington, Miller, Robson, & Steen, 2010). This approach focuses on breathing and phonation in connected speech to create and maintain sufficient breath support for speech with the aim to improve speech intelligibility. Given the intrinsic relationship between the regulation of pitch and volume in speech - in most cases, an increase in pitch goes hand in hand with an increase in volume (e.g. Gramming, Sundberg, Ternstöm, Leanderson, & Perkins, 1988) - one might further expect changes in pitch control with intervention targeting loudness. LSVT LOUD (Lee Silverman Voice Treatment) is an intervention approach that focuses on vocal loudness. Fox and Boliek (2012), for example, used this approach to investigate the effect of intensive voice intervention in five children with developmental dysarthria and spastic type CP. The results showed gains on specific aspects of vocal functioning with listeners preferring post-treatment samples in terms of pitch variability, amongst other factors.

Whilst these observations appear promising, to date no research has been undertaken that systematically and comprehensively explored the use of intonation patterns before and after speech intervention. The present study aims to fill this gap by investigating intonation patterns in children with developmental dysarthria and CP prior to and after intervention based on a speech systems approach targeted at improving speech intelligibility. Specifically, we aimed to

1) characterise and compare the use of intonation patterns in connected speech pre- and post-intervention using a phonological approach, and

2) explore whether potential post-intervention differences in intelligibility could be associated with observed intonational changes.

Method

This study is based on secondary data from a speech intervention study by Pennington et al. (2010). The extended use of these data was approved by London – Camden and Islington Local Research Ethics Committee. Speech samples of children with cerebral palsy (CP) and developmental dysarthria collected by Pennington et al. (2010) served as a basis for examining intonation patterns in the current investigation. The authors employed a group interrupted time-series study design, in which children acted as their own controls. The present study builds on this design adopting a within-participant control design, which uses changes to intonation patterns measured at a time point before and after invention as the main outcome measure.

Participants

Fifteen of the sixteen children with CP and developmental dysarthria (9 females; age range: 11-18 years; mean: 14 years; SD: 2) recruited by Pennington et al. (2010) were included in this study. The speech data of child 12 was excluded as the pre-intervention sample was clipped resulting in a distorted output signal waveform. All children grew up in

Tyneside in the north of England[1].The children had a confirmed diagnosis of CP. Nine children had spastic type CP, two had dyskinetic CP, four had mixed type CP (spastic and dyskinetic) and one child had Worster-Drought syndrome (Clark, Harris, Jolleff, Price, & Neville, 2009). Gross Motor Function Classification System (Palisano et al., 1997) ranged from levels I to V (median IV, meaning that their self-mobility was limited and many used powered wheelchairs). The children had normal or corrected to normal vision, no significant hearing loss and were able to follow instructions. The level of dysarthria ranged from moderate to severe as diagnosed by their treating speech-language pathologist using a range of clinical assessments. Children were included in the study if they experienced any speech production problems outlined by Duffy (2005) that affected their activity or participation. An overview of the participants' characteristics is provided in Table I.

-- Insert Table I about here --

Speech samples

As part of Pennington et al.'s (2010) study all children had received six weeks of intensive speech intervention focusing on controlling breath support and phonation, with three 35 to 40 minutes individual sessions per week. Single word and connected speech data had been collected for intelligibility scoring at four time points: six weeks and one week prior to intervention and one week and six weeks after intervention. Recordings had been made using an EDIROL R1 digital recorder and a head-mounted microphone (AKG WMS 40 pro).

For the present study, the connected speech samples recorded one week before and after intervention were used to investigate potential changes in intonation patterns. The

[1] Tyneside English is the regional dialect spoken in the area, particularly in Newcastle upon Tyne and in the conurbation. An estimated 800.000 people speak this variety of British English (Watt & Allen, 2003). It can be considered one of the more distinctive accents in the United Kingdom with phonological, phonetic and lexical features specific to this accent. In terms of intonation, Tyneside English can be characterised by a rise at the end of statements, which is typical of northern varieties of British and Irish English.

speech samples were up to one minute long, and consisted of the children describing a series of three cartoon pictures. Four sets of picture sequences were used across time points.

All data considered in the current study were derived from the same cartoon picture description. Intelligibility ratings were taken directly from Pennington et al.'s (2010) data set, whereas intonational analyses were performed as part of this study, as follows.

Speech intelligibility measures

Pennington et al., 2010 asked one hundred and twenty adults who had no experience of conversing with children with speech disorders to listen to the recordings. The listeners were professionals from the Newcastle/Tyne and Wear Area working for local companies whose staff volunteered as part of the company's charity work. They were thus familiar with the children's accent. Three recordings were allocated to each listener on a random basis, with the constraint that each listener heard three different children. As a result, each recording was judged by three listeners. Recordings were played at the sound pressure level at which they were recorded and were played only once. Listeners heard a phrase once and were asked to transcribe the words they had heard or thought they had heard verbatim. Listeners were blind to the time points they judged. Words transcribed by listeners were checked against a transcript agreed by the child at the point of recording. The number of words transcribed correctly was calculated for each recording for each listener. The agreement between listeners in intelligibility ratings was calculated using intraclass correlation coefficient (ICC) in the study by Pennington et al (2010). The ICC of 0.67 (95% CI: 0.59, 0.75) for connected speech was judged to be moderate (Streiner & Norman, 2003). The mean percentage intelligibility scores across all three listeners for each participant are shown in Table I.

Data annotation

The annotation of the speech data for the intonation analysis was conducted with Praat speech analysis software (version 5.3.39, Boersma & Weenink, 1992–2015). As a first step the pitch settings were optimised for each speaker using a designated Praat script. In a second step the fundamental frequency contour was checked for remaining halving and doubling errors of the pitch tracker.

The data were annotated within the autosegmental-metrical (AM) framework of intonational analysis (Pierrehumbert, 1980), which represents a phonological approach to analysing intonation. The usefulness of this approach for capturing intonation patterns in dysarthria has been highlighted by Kent and Kim (2003), and been validated by a range of studies on adult dysarthria (e.g. Kuschmann, Lowit, Miller, & Mennen, 2012; Kuschmann & Lowit, 2012; Lowit & Kuschmann, 2012). This study will thus be the first to implement a phonological approach to analysing intonation in children with CP.

Within the AM framework, intonation patterns are described in terms of sequences of high and low pitch targets which are then interpreted as distinct phonological categories. This allows assessment of the acoustic-phonetic properties of speech as well as their underlying phonological representations, thereby taking a dual approach to characterising intonation patterns. Intonation patterns are described in terms of sequences of H(igh) and L(ow) pitch targets, which are further organised into 'pitch accents' and 'boundary tones'. The former are associated with stressed syllables and marked with an asterisk '*'. They consist of a high or low pitch target or a combination of these. Pitch accents are combined with boundary tones, which describe pitch at the beginning and end of phrases. These are indicated with a percentage sign '%'. In English, the term *pitch accent* refers to a phonological feature that serves as a cue to prominence (Ladd, 2008). Word level phonemic differences which exist in Scandinavian languages, for instance, are not included in this definition.

The AM framework served as a basis for the development of a number of annotation systems including IViE (Intonational Variation in English; Grabe, 2001, 2004), the prevailing system for capturing intonation patterns of British dialects. In IViE, speech data are labelled on several levels to arrive at the phonological description of the intonation pattern (cf. Figure 1): (1) a syllable-by-syllable orthographic transcription, (2) a phrase-level transcription, (3) a transcription of phrase boundaries (%), pauses (#) and prominent syllables (P), (4) a phonetic transcription of pitch movements around the prominent syllables (stressed syllables are marked using capital letters H, M, L i.e. high, middle, low, unstressed syllables are indicated by small letters, i.e. h, m, l), (5) a phonological transcription of pitch accents and boundary tones, and (6) comments. For the phonological transcription of the data, the following labels were used: H* (high pitch accent), L* (low pitch accent), H*L (falling pitch accent), L*H (rising pitch accent), H*LH (fall-rise pitch accent) and L*HL (rise-fall pitch accent). Boundary tones were labelled as %L and L% (phrase-initial and phrase-final low boundary tone respectively), %H and H% (phrase-initial and phrase-final high boundary tone) and % (phrase-final level boundary tone). The latter label specifies that the pitch level between the boundary tone and its preceding pitch accent did not change. In addition to these traditional labels, the present study employed the labels X* and %X/X% to indicate labelling uncertainties (cf. Beckman & Ayers-Elam, 1997). Specifically, X* was used for pitch-accented syllables, where the specific type of pitch accent could not be established due to voice quality issues and associated pitch tracking difficulties; %X and X% were employed when the pitch height of the boundary tone could not be identified reliably.

-- Insert Figure 1 about here--

Data analysis

Intonational analysis

Based on the annotated data, the intonational inventory, i.e. range, prevalence and realisation of pitch accents and boundary tones were analysed. According to Ladd (2008), these aspects comprehensively describe the intonation patterns of a language or dialect, or group of individuals. The inventorial analysis determined which pitch accents and boundary tones were present in the children's speech samples. The prevalence analysis determined the frequency of use of these features. The realisational analysis established phrasing and pitch accentuation patterns by calculating the mean length of intonation phrases (IP) as well as the pitch accent-syllable ratio, which represents the overall frequency of pitch accentuation of a speaker. Mean IP length was measured in terms of the number of syllables produced per IP; the pitch accent-syllable ratio was established by dividing the overall number of syllables by the overall number of pitch accents, thus reflecting the distance between pitch accents expressed in syllables. A lower ratio is indicative of a high frequency of pitch accentuation.

Statistical analysis

A Wilcoxon signed rank test was conducted to establish group differences pertaining to prevalence and realisation of pitch accents and boundary tones between the speech samples recorded prior to and after intervention. Relationships between measures as well as their association with speech intelligibility were determined through a Spearman rank order correlation coefficient. The level of significance was set at $p < .05$.

Reliability analysis

Intra-rater reliability measures for annotation were carried out by the first author on 20% of the data three months after completing the initial annotation. The samples were randomly selected, with numbers of pre- and post-intervention samples being balanced. Reliability scores were sought for intonation phrase (IP) boundaries, prominent syllables (P) and classification of pitch accents and boundary tones. Given the categorical nature of the data point-to-point agreement was calculated and expressed in percentages. Overall reliability for intra-rater analysis was consistently over 88%, which matches or exceeds previously reported reliability scores for intonational annotation (e.g. Pitrelli, Beckman, & Hirschberg, 1994). Specifically, agreement concerning the identification of IP boundaries was 98.6%;

agreement on prominent syllables was 92.6%. The relabeling of pitch accents and boundary tones showed 88.1% of agreement for intra-rater analysis.

Inter-rater reliability was conducted by the third author on 10% of the data. Agreement on the placement of IP boundaries was 100%; agreement pertaining to prominent syllables was 94.3%. The labelling of tones yielded 80% agreement, reflecting very good agreement levels for intonational data. Both raters were blinded to the pre- and post-intervention status of the recordings.

Result

Inventory and prevalence of pitch accents

Figure 2 displays the types of pitch accents that were used by the speakers with CP prior to and after speech systems intervention. Pitch accents H*, H*L and L* were observed at both time points, as were pitch accents that could not unequivocally be identified (X*). The only inventorial difference between the pre- and post-intervention speech samples related to the rising pitch accent L*H, which only featured in the post-intervention data.

-- Insert Figure 2 about here --

In terms of prevalence, Figure 2 shows that the high pitch accent H* was the most common accent used pre- and post-intervention, followed by the falling pitch accent H*L. The prevalence of both pitch accents prior to and after intervention was similar. The low pitch accent L* was rarely used at either time point. More notable differences between the pre- and post- intervention samples were observed with regard to the pitch accents L*H and X*. As indicated above the rising pitch accent did not feature in the pre-intervention samples, but constituted 8.5% of all pitch accents in the post-intervention samples. At the same time, the mean occurrence of X* changed from 13.7% to 5.1%. Statistical evaluation of the data revealed that the difference in pre- versus post-intervention use was significant for L*H ($Z = -2.52$, $p = .012$) but not for the other pitch accents (including X*). A detailed analysis of L*H showed that eight of the 15 speakers used this pitch accent following intervention (1, 2, 4, 6, 7, 10, 14 and 16). Variability was high: for five of these speakers (1, 2, 4, 6 and 10) L*H represented less than 10% of the pitch accent inventory; for the remaining three speakers a more considerable occurrence of 23% (16), 33% (14) and 45% (7) was noted. A post-hoc examination of the relation between the use of L*H and various other speaker characteristics including gender and type of CP using Fisher's Exact Test did not reveal any significant link between the variables.

Inventory and prevalence of boundary tones

The inventorial analysis of the boundary tones before and after intervention revealed the use of low and high tones in phrase-initial position and that of low, high and level tones in phrase-final position (cf. Figure 3). In both positions and at both time points the labels %X/X% were required to mark unidentifiable tones.

-- Insert Figure 3 about here --

In terms of prevalence, %H was the most common boundary tone in *phrase-initial position* at both time points, followed by %L. The statistical evaluation of the occurrences of each type of boundary tone prior to and after intervention revealed no significant change (%L: $Z = -1.783$, $p = .075$; %H: $Z = -1.161$, $p = .245$; %X: $Z = -1.735$, $p = .083$). In *phrase-final position*, level tones were the most frequently used boundary tones at both time points, followed by H% and L%. The statistical analysis suggested no changes from pre- to post-intervention performance in this position either (%: $Z = -.345$, $p = .730$; L%: $Z = -.414$, $p = .678$; H%: $Z = -.489$, $p = .625$; X%: $Z = -.447$, $p = .655$).

In summary, the results indicate a largely comparable use of pitch accents and boundary tones pre- and post-intervention for the participant group. The only significant difference to this pattern relates to the use of the rising pitch accent L*H, which was present in the post-intervention samples - but not in the pre-intervention data - of more than half of the speakers.

Realisation in terms of phrasing and pitch accentuation

In terms of phrasing, no significant change of mean and maximum IP length could be observed between the two time points (mean IP length: $Z = -.795$, $p = .427$; maximum IP length: $Z = -.598$, $p = .550$). Prior to intervention the mean length of phrases produced by the participants was just over three syllables (M = 3.09; SD = 1.12), following intervention the mean length was 2.94 syllables per IP (SD = 1.3). Maximum IP length was 5.67 syllables per phrase (SD = 2.16) pre-intervention and 5.93 syllables per phrase (SD = 2.02) post-intervention. With regard to frequency of pitch accentuation, the statistical analysis of the pitch accent-syllable-ratio showed no change of the distance between pitch accents following intervention ($Z = 1.420$, $p = .156$; pre-intervention: M = 2.33, SD = 0.57; post-intervention: M = 2.1, SD = 0.5). In summary, the analysis of phrasing and pitch accentuation revealed similar performance patterns prior to and after intervention.

Relationship of intonational changes to speech intelligibility

A Spearman rank-order correlation coefficient was computed to assess the relationship between the observed intonational changes. The correlation focused on significant changes to the children's intonational inventories, phrasing and accentuation patterns. As a result, L*H was the only element to be correlated with changes in connected speech intelligibility between the two time points as measured by Pennington et al. (2010).

The results revealed a significant positive correlation between the two variables (r_s = .0575, $p = .025$, n = 15), suggesting that the majority of children who used L*H post-intervention tended to show a larger improvement in intelligibility after intervention. Figure 4 summarises the results. However, given that only 8 of the 15 children showed L*H in their patterns post-intervention (cf. results section on inventory and prevalence of pitch accents), and of these children, two (7 and 14) showed considerable gains using L*H the results of the correlation analyses should be interpreted with caution.

-- Insert Figure 4 about here --

Discussion

The aim of this study was to characterise intonation patterns in children with developmental dysarthria associated with CP prior to and after speech intervention using a systems approach. This was achieved by exploring the differences in intonation patterns between these two time points regarding intonation inventory and use, phrasing and pitch accentuation. We also sought to establish whether intonational changes may be associated with changes in speech intelligibility.

Inventory and prevalence of pitch accents and boundary tones

The inventorial analysis showed that some of the children with CP and dysarthria who participated in the study were able to use the rising pitch accent L*H following intervention, thus extending the range of intonation patterns they could use. The emergence of the L*H in the children's intonational inventories could thus be related to the breathing and phonation intervention they received. It may be difficult to determine the exact sequence of change. However, given that intonation was not targeted directly, two scenarios, or a combination of both, seem likely to have resulted in the increase in laryngeal tension required for producing rising intonation patterns. Firstly, improved breath support and control may have led to an increase in subglottal air pressure increasing airflow through the glottis. Secondly, a more effective control of laryngeal muscles may have led to an increased ability to control vocal fold movement.

The emergence of L*H in children's intonation patterns is likely to be beneficial for a number of reasons. Firstly, the use of a greater variety of intonation patterns can lead to a redistribution of the functional weight of patterns (Local, 1982). Moving from a simple tonal system to a more complex one will allow the children to express communicative intent more appropriately in terms of e.g. asking or requesting something as well as signalling turn in a dialogue situation, which is commonly achieved by raising pitch at the end of the turn. Secondly, L*H is a common feature in declarative utterances in Newcastle and Tyneside English (Grabe, 2004; Watt & Allen, 2003), reflecting the sociolinguistic importance of the rising intonation pattern in this part of the UK. This, in turn, could have a positive effect on the acceptability of the children's speech as it features more characteristics typical of their regional variety of English.

Correlational analysis further established a relationship between the use of L*H and changes in speech intelligibility. This finding suggests that for those children who used the rising intonation pattern more frequently after intervention a larger improvement in speech intelligibility could be observed. Our data thus provide measurable support for Miller et al.'s (2013) speculation that the perceived improvement in intelligibility in their participant group could at least partly be explained through intonational changes. However, this result has to be interpreted with caution. First, only a small number of children in the current group showed this association between intonation use and intelligibility. Second, it is worthwhile acknowledging the wide variation in intelligibility gains across the children investigated. Pennington et al. (2010) speculated that intelligibility levels might have been affected by number of words spoken across data collection points. In addition, they considered that a minimum number of intervention sessions might be needed to effect any change as the children who changed little were also the ones to receive the fewest sessions. Further investigations are needed to establish to what extent these factors might influence intervention outcomes. This is also important in view of the fact that only eight of the 15 children used L*H post-intervention, of which two employed the pitch accent to a much larger extent than the others. That is, whilst gains in intelligibility could be associated with changes in intonation patterns, it is likely that a combination of factors accounted for the increased intelligibility levels.

The comparison of the inventory of pitch accents prior to and after speech intervention further revealed that those participants who used L*H following intervention added them to their inventory instead of trading it for e.g. falling or level pitch accents. This pattern suggests that the intonation patterns of the children with CP and dysarthria investigated in this study followed the trajectory of intonational development seen in typically-developing children (Cruttenden, 1981; Crystal, 1979; Menn, 1976). At the same time, the results show that no tritonal, i.e. complex, pitch accents were produced by the children in the speech samples analysed. Whilst this could be due to the picture description task not lending itself to eliciting the full range of pitch accents, findings by Local (1982) suggest that this absence could also point to these pitch accents not being established in the children's inventory yet. In his study, Local (1982) explored intonation development of six Tyneside school-age children using naturalistic speech contexts, and found that complex pitch accents represented a considerable proportion of inventory. It is therefore possible that the limited set of pitch accents available to the children is a reflection of the physiological limitations imposed by the dysarthric features of their speech, although the current results are unable to suggest the exact reasons for this behaviour. For example, as already alluded to above, the limited motor control abilities might impede the use of more complex pitch patterns. On the other hand, short utterances - frequently a sign of limited breath support - may limit the segmental material available to speakers over which to superimpose more complex intonation patterns. It would be interesting to see whether further treatment might result in even greater expansion of the intonational inventories of the children to include complex pitch patterns.

Realisation in terms of phrasing and pitch accentuation

The analysis of phrasing and pitch accentuation patterns showed no significant changes between the performances observed prior to and after intervention indicating that the speech subsystems approach did not impact on utterance length or the number of pitch accents used by the children.

While changes in e.g. utterance length might have been an expected treatment outcome, there are several reasons why no performance differences between the pre- and post-intervention speech samples could have been observed. One option is that the sample size might have been too small to detect differences as considerable variation in utterance length could have masked potential performance changes. Also, only one type of text style was used to elicit the data based on which phrasing and pitch accentuation were examined. Future investigations should thus ensure to use a variety of speech samples to control for possible influences of task nature on the speech output (e.g. Kuschmann & Lowit, 2015). Finally, the fact that the intervention protocols were tailored to children's individual needs and may have targeted different aspects of speech is likely to be a significant contributor to the observed performance variability. For some children speech intervention thus focused on increasing phrase length, whereas for others maintaining loudness across a phrase was the primary speech intervention goal. Such differences in focus might go some way towards explaining the absence of change for phrasing and pitch accentuation for all children.

Conclusion

The current study used secondary data to explore potential changes to intonation patterns before and after intervention based on a speech systems approach that focused on breathing and phonation. Intonational changes in the speech of children with dysarthria and CP were observed with regard to inventory of intonation patterns and their prevalence, with analyses suggesting that this change might be related to gains in speech intelligibility for some of the children. Whilst the study established that changes in intonation patterns can occur after speech intervention, insights into the mechanisms of change will require further investigation to pinpoint the exact reasons for the observed intonational changes. Despite the evident need for further investigations, the current study is the first to provide a detailed phonological account of intonation patterns in children with CP and dysarthria prior to and after speech intervention. It demonstrates that intonational changes can be observed following speech intervention, as well as the potential that such changes could contribute to improving speech intelligibility in children with developmental dysarthria. It thus highlights the importance of systematically capturing the intonation abilities of this speaker group, not only for the purpose of characterising the nature of the speech disorder, but also to help our understanding of how these children's communication effectiveness can be improved through speech intervention.

Acknowledgments

This research was supported by a British Academy Postdoctoral Fellowship awarded to the first author (PF120045). The speech data was collected as part of an intervention study funded by Cerebra, UK.

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Table I

Participant information with mean percent intelligibility scores for connected speech samples, recorded one week before and after speech intervention and rated by unfamiliar listeners.

Child	Age	Sex	Type of CP	GMFCS	Mean % intelligibility pre-intervention	Mean % intelligibility post-intervention
1	15	F	SD	IV	24.4	21.6
2	15	M	D	II	32.1	48.4
3	14	F	SD	V	55.1	46.8
4	15	M	S	IV	67.6	81
5	12	M	S	IV	35.5	34.4
6	12	M	S	II	10.5	27.8
7	13	F	SD	III	11.7	63.5
8	17	M	S	III	6.6	5.2
9	18	F	D	II	18.8	52.5
10	11	M	S	IV	18.8	23.4
11	17	F	S	V	4.4	29.8
13	18	F	SD	V	12.3	12.5
14	14	M	S	IV	1.4	80
15	13	F	S	II	33.3	68.5
16	16	F	WD	I	36.6	25

Note: F – female, M – male; CP – cerebral palsy, SD – mixed spastic-dyskinetic, D – dyskinetic, S – spastic, WD – Worster-Drought syndrome; GMFCS – Gross Motor Function Classification System (I - walks without limitations, II - walks with limitations, III - walks using a hand-held mobility device, IV - self-mobility with limitations, V - transported in a manual wheelchair)

Figure captions

Figure 1: Intonational Variation in English (IViE) transcription showing the annotation levels for an utterance of a speaker with cerebral palsy (CP). Above the annotation levels the oscillogram (representation of sound wave) and the spectrogram (representation of frequency distribution) are displayed along with the pitch contour.

Figure 2: Mean percentage of pitch accents employed pre- and post-intervention; L* = low pitch accent, L*H = rising pitch accent, H* = high pitch accent, H*L = falling pitch accent, X* = labelling uncertainty (Numbers denote performances of individual speakers).

Figure 3: Mean percentage of boundary tones pre- and post-intervention in phrase-initial (left) and phrase final position (right); %L/L% = phrase-initial/ -final low tone, %H/H% = phrase-initial/ -final high tone, % = phrase-final level tone, %X/X% = phrase-initial/ -final labelling uncertainty. The numbers in the figure denote the participants whose performances were outside the expected range (Numbers denote performances of individual speakers).

Figure 4: Scatterplot showing change in percent intelligibility and change in percent use of L*H post intervention.