MEASURING SPEECH MOTOR SKILLS IN NORMALLY DEVELOPING AND PHONOLOGICALLY DISORDERED PRE-SCHOOL CHILDREN

Wendy M M Cohen and Daphne Waters
Queen Margaret University College, Edinburgh, UK

ABSTRACT

Normally developing and phonologically disordered 3 and 4-year-old children (groups N and P) were compared on measures of articulation rate in imitated and spontaneous connected speech and in diadochokinetic (DDK) tasks. The P group exhibited significantly slower mean articulation rates than the N group in the connected speech samples. There was no significant difference between the group means for DDK rates. However, the P subjects, when required to articulate at maximum speed in the DDK task, were more likely than the N subjects to make pronunciation errors additional to those observed in their spontaneous and imitated speech. Implications of the findings for the clinical evaluation of speech motor abilities in young children are discussed.

1. INTRODUCTION

Children who present with disordered speech development in the absence of known pathology, usually labeled phonologically disordered, may have a variety of deficits underlying their surface speech errors. Their difficulties may be primarily perceptual, linguistic or motoric. In order to provide appropriate therapy it is necessary to identify individual children's underlying deficits. The investigation reported in this paper focused on speech motor skill in a group of 3 and 4-year-old children with phonological disorder.

A number of instrumental techniques can be used to investigate speech motor skills, including imaging techniques [1] and movement transduction and point tracking techniques [2]. However, these methodologies are not easily applied to young child subjects. Much previous research with children has used acoustic analysis of temporal features in recorded speech data to make inferences about the status of speech motor ability. The rationale for using such measures is based on the widely held expectation that as any new motor skill is acquired, gradual maturation of that skill is reflected in increased speed and in increasing consistency of performance. In the case of speech motor skill, there is much evidence to suggest that adult-like rate of production and temporal consistency (in multiple token speech data) are not achieved by normally developing children until around 8 - 11 years of age [3]. Cross-sectional studies indicate a gradual progression throughout childhood towards increased rate of speech production (that is, shorter segment and phrase durations) and towards decreased variability of temporal and other acoustic features [4]. Some previous investigations [5,6] have found that young phonologically disordered children as a group tend to exhibit slower articulation rates and longer segment durations compared with their normally developing peers suggesting that immaturity of speech motor development may underlie at least some phonologically disordered children's speech acquisition difficulties.

1.1. Measuring rate of speech production

Investigations of rate of speech production use diverse methodologies. Some have measured speech rate in spontaneous connected speech which includes pauses [7] while others have calculated articulation rate by first subtracting the duration of pauses from the total utterance duration [6]. Rate measures have been made in syllables/s. (syll/s) and/or segments/s. (seg/s) and have been based on spontaneous connected speech data and/or imitated speech where length of target utterance is controlled. Findings are likely to be affected by the choice of methodology, since speed of connected speech production is influenced by a number of variables, including linguistic and cognitive factors as well as utterance length and speaking context [8, 9,10].

Maximum rate of syllable production in non-linguistic, DDK tasks is widely used in both research and clinical contexts as a means of gaining insight into an individual's speech motor ability free from many of these complicating factors. Normative data on DDK rates is available for a variety of monosyllabic, bisyllabic and polysyllabic syllable sequences [11, 12, 13]. Cross-sectional studies indicate a gradual increase in DDK rates with age in typically developing children. Some previous research has found that speech disordered children, including those with diagnoses of developmental dyspraxia and dysarthria, tend to exhibit slower DDK rates than their non-speech disordered peers [14, 15, 16, 17].

2. AIMS OF THE INVESTIGATION

The principle aim was to compare a group of phonologically disordered (P) children with a group of same aged normally developing (N) children on measures of articulation rate in three types of speech data: spontaneous connected speech, imitated connected speech and DDK data. No previous studies had made rate measures in all three of these data types in the same group of subjects. These measures would be used to make inferences about speech motor abilities in the N and P subject Groups.

The study also aimed to address a number of issues surrounding the collection and analysis of DDK data from very young subjects. The first concerned the design of an appropriate data collection procedure. The second issue, neglected in previous research and clinical protocols, concerned the problem of whether the calculation of DDK rates should exclude data in which mispronunciations of the target syllables occur. Third, the investigation examined the value of analysing children's pronunciation error patterns in DDK tasks rather than focusing solely on rate measures.

3 METHOD

3.1. Subjects

Two groups of children were recruited to the investigation. Group N consisted of fourteen children aged between 3;10 and 4;11 (mean = 4;04) who had no speech, language or hearing difficulties (on the basis of standardised assessments and parental questionnaire). Group P consisted of fourteen children aged between 3;08 and 5;03 (mean = 4;03) who presented with specific phonological delay/disorder in the context of normal hearing and normal receptive and expressive language skills.

3.2. Data, data collection and analysis

Four types of speech data were elicited from each subject: single word data; imitated and spontaneous connected speech data; rapid repetitions of the following syllables and syllable sequences /pə/, /tə/, /kə/, /pətə/ and /pətəkə/ (DDK data). All data were recorded on to a Sony Digital Audio Tape Recorder (DTC 60ES) in a sound proofed recording studio over two sessions lasting between 30-45 minutes for each child. All the data were transcribed phonetically and analysed for the occurrence of error patterns (simplifying phonological processes).

3.2.1. Single word data. 44 single words were collected from each child from picture/object naming using a published screening procedure for phonological impairment [18]. Spontaneous naming responses were elicited wherever possible but delayed imitation was used when necessary.

3.2.2. Imitated connected speech data. Eight tokens of the imitated utterance '*two naughty boys are picking*', in three different carrier sentences, were collected using an innovative procedure involving pictorial and auditory stimuli presented via a PC. Each sentence was illustrated as a picture on the computer screen. An audio attachment of the target utterance accompanied each picture as a model for imitation. Articulation rate in each token was measured from waveform and spectrographic displays using Kay Computerised Speech Laboratory (CSL) software. Total utterance duration, number of syllables and number of segments were determined for each token. Durations of all pauses >250ms were summed and subtracted from the total utterance duration giving a total articulating time. Articulation rate was calculated in seg/s and in syll/s. Mean values for each child were derived and group means calculated for the P and N subject groups. An independent t-test was used to determine whether the two subject groups were significantly different on this measure.

3.2.3. Spontaneous connected speech data. A sample of spontaneous connected speech was collected from each subject using a story re-telling task. First, a short video cartoon with sound track was played to the child. Then, during a second playing of the videotape, the sound was turned off and the child was encouraged to tell the story. The first eight utterances between 6 and 9 syllables in length were selected for analysis. (This criterion was adopted to ensure comparability with the target phrase in the imitated data.) Individual and group mean articulation rates were calculated as for the imitated speech data and group mean values were compared using an independent t-test.

3.2.4. DDK data. Rapid repetitions of three monosyllables /pə/, /tə/ and /kə/, the bisyllabic sequence /pətə/ and the polysyllabic sequence /pətəkə/ were collected from each child using a newly devised game format, described in a previous publication by the present authors [19]. Five attempts at each of the five target sequences were recorded from each child.

The total duration of each token was calculated from the end of the first syllable to the end of the penultimate syllable using waveform and spectrogram displays, from those trials which were free of pauses >250ms. DDK rate in syll/s was derived for each of the target sequences. Individual and group mean rates for each target sequence were calculated and group mean values compared using independent t-tests. These calculations and comparisons were carried out a) using all tokens and b) using only accurately produced tokens.

3.2.5. Further analysis. Analysis of the perceptually based phonetic transcriptions of all the data was carried out to compare the occurrence of errors made by individual subjects in the various types of speech data. First, for each subject, any segmental errors in the imitated speech data were noted which did not occur in that child's spontaneous single-word and connected speech data. Second, errors in the DDK data from individual subjects were noted that had not occurred in any of the other speech samples from that child. Finally, the bisyllabic and polysyllabic sequences were examined to determine whether the required two or three places of articulation had been achieved in the correct order.

4. RESULTS

4.1. Articulation rates in spontaneous and imitated speech data.

Table 1 shows the group results of the articulation rate measures in the spontaneous and imitated speech data. The number of children in each group (*n*), group means and group ranges are shown for each variable. One of the P children presented with lax articulation, which made the identification of segment and syllable boundaries difficult. This child's data were therefore excluded from statistical analysis.

In both connected speech contexts the P Group exhibited significantly slower mean articulation rates than the N Group. However the ranges of individual means overlap.

For both groups of subjects, the group mean articulation rate in the imitated connected speech data was faster than in the spontaneous speech data. This tendency for faster rate in the imitated data was found in 13 individual subjects in the N Group and 11 of the P Group subjects.

4.2. DDK rates.

Table 2 shows the group mean DDK rates for each of the target sequences. The left side of Table 2 shows results based on all tokens while the right side of the Table shows results based on accurately produced tokens only. The number of tokens (*n*), the group mean and group range is shown for each variable.

With the exception of the results for the accurate productions of /kə/, there were no significant differences between the group mean DDK rates for the two subject groups. Different rate values were obtained depending on whether all productions

or only accurate productions were included in the calculation.

	P (n = 13) mean and range	N (n = 14) mean and range	Sig. value of the difference between the group means
imitated seg/s	9.37 6.55-12.13	10.68 8.62-12.55	***p =0.011***
imitated syll/s	3.83 2.54-4.47	4.25 3.42-4.99	***p =0.025***
spontaneous seg/s	7.67 5.89=10.02	9.29 8.04-10.66	***p =0.002***
spontaneous syll/s	3.30 2.39-4.36	3.60 3.25-3.89	***p =0.059***

Table 1. Differences between group mean articulation rates in Groups N & P in imitated and connected speech data.

4.3. Error analysis of all the speech data.

In the imitated speech samples two of the N subjects and eleven P subjects exhibited phonological errors (simplification processes) that were not present in their spontaneous speech data. These were classified as 'non-predictable' errors. In the DDK data (monosyllables) there was a much higher occurrence in the P Group than in the N Group of errors that could not be predicted on the basis of subjects' error patterns in any of the other data types. Figure 1 displays the results of this analysis. The left bar shows the proportion of accurate DDK sequences produced by each subject group. The centre bar shows the occurrence of errors that were predictable on the basis of subjects' performance in the spontaneous and imitated speech data. The right bar shows the occurrence of non-predictable errors in the two subject groups. It is clear that P Group subjects were more likely than N Group subjects to make both predictable errors and errors that could not be accounted for by their habitual speech patterns.

Non-predictable errors mainly involved voiceless plosive targets in the syllable sequences that were perceived as voiced cognates. Acoustic analysis (measuring the time from release of stop closure to F1 onset in the following schwa vowel) was used to confirm that productions heard as voiced and voiceless were acoustically distinct.

Error analysis of the bisyllabic and polysyllabic sequences showed that P subjects as a group were less likely to produce sequences that included the required number of different places of consonant articulation and were less likely to maintain the correct order of syllables.

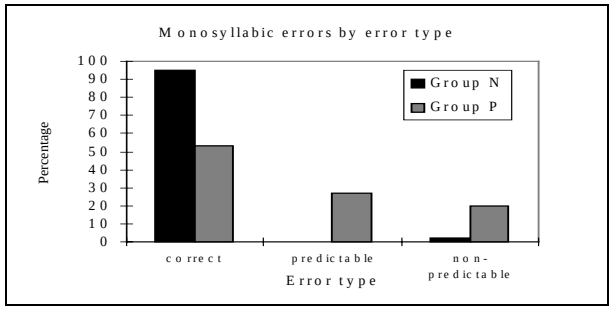

Figure 1. Error analysis of the monosyllabic DDK sequences in both subject groups

In Figures 2 & 3 the percentage of accurate sequences from each subject group is shown on the left. The next bars show percentages of errors of consonant order in each subject group. The remaining sections in each figure show the percentage occurrence, in each subject group, of tokens in which fewer places of consonant articulation occurred than in the target sequence.

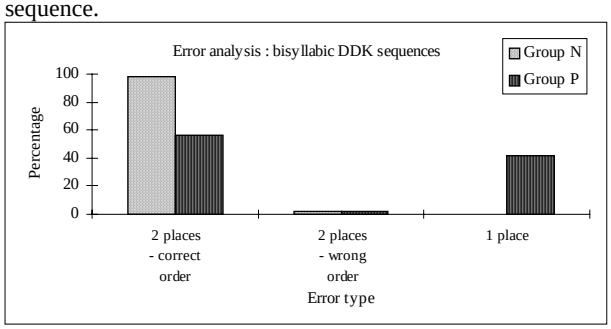

Figure 2. Error analysis of bisyllabic sequences in both subject groups

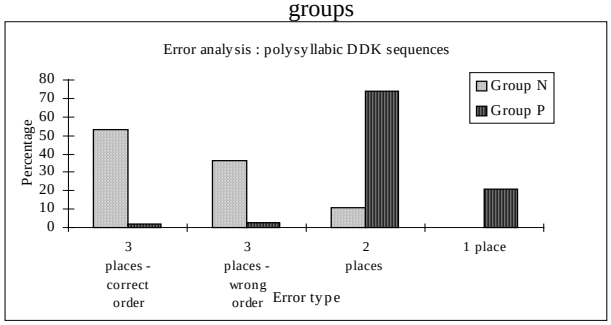

Figure 3 Error analysis of polysyllabic sequences in both subject groups

	all productions			accurate productions only		
	Group P mean	Group N mean	significance	Group P mean	Group N mean	significance
/pə/	3.93 syll/s (n =70)	4.03 syll/s (n =70)	p = 0.59	3.78 syll/s (n =50)	3.98 syll/s (n =68)	p = 0.24
/tə/	3.93 syll/s (n =68)	4.00 syll/s (n =70)	p = 0.99	3.91 syll/s (n =36)	3.99 syll/s (n =69)	p = 0.74
/kə/	3.68 syll/s (n =70)	3.74 syll/s (n =70)	p = 0.75	3.01 syll/s (n =20)	3.72 syll/s (n =69)	**p = 0.002**
/pətə/	4.18 syll/s (n =67)	4.58 syll/s (n =70)	p = 0.16	4.35 syll/s (n =29)	4.56 syll/s (n =69)	p = 0.39
/pətəkə/	3.98 syll/s (n =70)	3.55 syll/s (n =70)	p = 0.22	3.01 syll/s (n =1)	3.57 syll/s (n =37)	-

Table 2. Results comparing DDK rate in the N and P Groups

5. DISCUSSION

The main aim of the investigation was to compare speech motor ability in the P and N subject groups by measuring articulation rate in several types of speech data. Group mean articulation rates in both the imitated and spontaneous connected speech data, were significantly slower in the P group than in the N group suggesting that the P subjects, as a group, had less mature speech motor abilities than their normally developing peers. This supports previous findings [6]. However the DDK rate measures showed no significant differences between the two subject groups. This tends to contradict previous findings [14, 15]. The error analyses (especially of the DDK data), on the other hand, provided strong evidence of differences between the two subject groups that could be interpreted as indicative of poorer speech motor skills in the P Group. First, when P subjects increased rate of production in the imitated speech task (presumably in an effort to mimic the rate of production of the adult model) they tended, as a group, to be less accurate than in their spontaneous speech. Second, P subjects as a group had more difficulty than N subjects in achieving rapid alternation of even two places of articulatory closure in DDK tasks. Furthermore, the demand on speech motor capacity when producing rapid repetitions of monosyllables in DDK tasks, resulted in errors from the P subejcts that had not been found in their spontaneous speech (non-predictable errors). The N Group subjects exhibited some, but many fewer, non-predictable errors in the imitated and DDK data. It seems that N subjects, as a group, were better able to maintain accuracy of speech production at increased speeds, implying that their speech motor resources were greater. These findings support the view that speech DDK data should be analysed in terms of accuracy as well as rate and that normative data reporting both aspects of performance are required for clinical and research purposes.

The problem of dealing with inaccurate productions when making DDK rate measures is a particularly important issue when dealing with data from very young children and / or children with disordered phonology. The results displayed in Table 2 show that different rates were obtained depending on whether or not inaccurate productions of the target sequences were excluded from the calculations. It is not unexpected to find that where children substitute consonants in target sequences there is an effect on production rate, since different consonant phonemes have distinct durational characteristics.

This small investigation has provided some evidence for speech motor skill immaturity in 3 and 4-year-old children with phonological delay / disorder. Further, larger-scale, and preferably longitudinal studies are needed. The study has emphasised the value of analysing error patterns in the syllable repetitions produced in DDK tasks rather than focusing only on rate measures. The need to be explicit about the inclusion or exclusion of inaccurate productions of target syllable sequences in all research and clinical applications of DDK rate measures has been highlighted.

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