Assessment of Rate and Consistency in Performance of Diadochokinetic Task in Children and Adults Using an Automated Assessment Protocol: A Preliminary Study

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Abstract
In spite of various methodological controversies, Diadochokinetic (DDK) task is a widely used measure that differentiates persons with and without speech disorders by assessing the rate of movement of articulators for production of syllabic utterances. Normative data reported for this measure for children and adults differ in the methodology used and lack consistency across studies. This study was a preliminary attempt to establish normative rate consistency and accuracy data of DDK measures specific to Indian population across age, and gender using an efficient and automated assessment protocol (Motor Speech Profile 5141, Kay Pentax) for comparison of clinical samples but such data is not published in literature.

A total of 38 participants (19 children of 6;0 – 11;11 years and 19 adults of 18;0 – 24;11 years) performed three trials of monosyllabic bilabial token of DDK task for 8 seconds recorded on the Motor Speech Profile 5141. The best trial was subjected to DDK analysis protocol for obtaining rate and accuracy measures. The data was analyzed descriptively for mean DDK scores in each age group. Multivariate analysis showed no gender but age effect on rate measures with longer DDK period and reduced DDK rate in children compared to adults (p < 0.01). Contrary to existing literature, the accuracy measures showed no age or gender effects. This study compliments the previous reports that DDK rates are age related and the findings affirm the need to establish normative specific to the population tested on DDK measures.

Key words: Diadochokinetic, motor speech, automated assessment.

Introduction
The number of syllables produced in one second is usually taken as measure of DDK rate. Two tasks are used to calculate DDK: repetition of monosyllabic strings (Alternate motion rate, AMR) and repetition of bi/tri-syllabic sequences (Sequential motion rate, SMR). Normative data for these tasks has been reported for children (Blomquist, 1950; Canning & Rose, 1974; Oliver, Jones, Smith & Newcombe, 1985; Robins & Klee, 1987) and adults (Fletcher, 1972; Irwin & Becklund, 1953) but these reports vary widely in their methodology.

Rate is the most widely used measure of DDK (Fletcher, 1978) but other measures such as consistency and accuracy are also probed in few studies (Bradford & Dodd, 1996; Connery, 1992; Crary & Anderson, 1990; Williams & Stackhouse, 2000; Yaruss & Logan, 2002). Generally, the reports indicate an increase in DDK rate as the motor system matures (Henry, 1990). The DDK rate reaches adult like performance by the age of 9–10 years (Canning & Rose, 1974) or 15;0 years (Fletcher, 1972). Good correlation of DDK rate in mono-, bi-, and tri-syllabic utterances were reported by Hale, Kellum, Richardson, Messer, Gross, and Sisakun (1992) and Wolk, Edward and Conture (1993). Studies on correlation of DDK rate with the actual speaking rate showed poor correlation (Haselager, Slis & Rietveld, 1991) making the sensitivity of DDK rate questionable. However, DDK rate was found sensitive in distinguishing children with and without speech and language disorders (Dworkin, 1978; Henry; 1990; Maasen, Thoonen & Wit, 1991; McNutt, 1977; Riley & Riley, 1979; Wit, Maasen, Gabréëls & Thoonen, 1993; Wolk, Edwards & Conture, 1993) and within the group of children with communication disorders (Malek, Amiri, Hekmati, Pirzadeh & Gholizadeh, 2013; Rupela & Manjula, 2010; Thoonen, Maasen, Gabréels & Schreuder, 1999). Attempts to sensitize measures other than DDK rate was also carried out by few researchers (Riley & Riley, 1985; Yaruss & Logan, 2002).

Methodology for calculation of DDK measures also vary across studies. In a study by Juste, Rondon, Sassi, Ritto, Colalto and de Andrade (2012), acoustic measures were derived for obtaining the rate and accuracy of DDK task. Most of the studies used a manual phonetic transcription method to calculate the DDK rate (Yaruss & Logan, 2002) or used subjective rating scales of measurement of accuracy (Riley & Riley, 1985) making the assessment time consuming and highly subjective. These limitations led the automated assessment protocols to gain attention among the practicing speech-language pathologists. The DDK protocol of Motor Speech Profile (MSP, Kay Elemetrics, USA) can be easily run on recorded or live inputs of DDK tasks. The measures obtained from this protocol can be used to document the DDK performance of clients with communication disorders. The use of MSP module is convenient as it is automatic and provides a detailed evaluation of rate and consistency of DDK performance. The normative for this module was established by Deliyski and Gress (1997). But, variations in DDK measures across culture are reported by Prarthanee,
Thanaviratananich and Pongjanyakul (2013). They studied the DDK rates in Thai children and their findings in DDK rates were different compared to English children. This called for a need to establish separate normative for each population, including the Indian population. However, very few studies have been reported in Indian literature on automated DDK assessment protocol of MSP. One such report by Deepa and Jayashree (2012) reported differences in DDK rate for tri-syllabic token across adults and geriatrics using this protocol.

As a preliminary attempt in facilitating use of this automated assessment protocol in Indian population, this study aimed at understanding the differences in rate and consistency measures obtained using MSP in a small population of Indian children and adults. Thus, this study was carried out with the following objectives:

1. To obtain mean scores of DDK rate and consistency measures in children and adults.
2. To compare the DDK rate and consistency measures obtained by DDK assessment protocol of MSP across children and adults.
3. To compare the DDK rate and consistency measures obtained by DDK assessment protocol of MSP across males and females.

Method

Participants

The participants of this study were nineteen typically developing children (n=19) of 6;0-11;11 years and nineteen typical adults (n=19) of 18;0-24;11 years (N=38). There were 10 males and 9 females in each group. None of the participants had any speech, language, hearing, cognitive and neurological defects.

Equipment used

The automated assessment protocol of Motor Speech Profile 5141 module of computerized speech lab (Model 4500, Kay Pentax) was used to obtain the DDK rate and consistency measurements. The module has a pre-loaded sample of the maximal repetition of the monosyllabic /pa/. This pre-loaded sample was used to train the participants in the DDK task before the sample was recorded for the study. Data was recorded using a one channel unidirectional dynamic microphone placed approximately 20cm from the participant’s mouth, at 11025Hz sampling frequency for a period of 8 seconds in a quiet room with minimal background noise.

Procedure

The participants were enrolled into the study after obtaining their consent. The participants were instructed to take a deep breath and produce continuous strings of the bilabial monosyllable /pa/ for a minimum of 8 seconds. The pre-loaded sample of the task was played for their training and reference. Trial attempts were given to ensure that the instruction was understood clearly and correctly. Once the participant could perform the task, the DDK task was recorded into the MSP module as live input. Three trials of the DDK task were recorded from each participant and the data was saved for further analysis.

Analysis

All the three recorded trials were carefully analyzed for quality of recording, length of recorded sample and breaks in DDK utterances. A trial was discarded if it had (a) background noise that interfered with execution of the protocol (b) less than 8 seconds of continuous repetition of the monosyllabic sequence (c) interruptions or pauses within the recorded sample. If more than one sample of a participant qualified the inclusion criteria, the best sample was selected based on perceptual evaluation of rate of utterance. The final selected sample was then subjected to automated analysis using the Diadochokinesis protocol of MSP. A sample of the DDK analysis window of MSP is shown in Figure 1. The DDK measures obtained were: Average DDK period (DDKavp), Average DDK rate (DDKavr), Coefficient of variation of DDK period (DDKcvp), Perturbation of DDK period (DDKjit) and Coefficient of variation of intensity of DDK (DDKcvi). The measures generated were then tabulated and subjected to statistical analysis.

![Figure 1. Sample of the Diadochokinesis analysis window of the Motor Speech Profile 5141.](image-url)
Assessment of Rate and Consistency in Performance of Diadochokinetic Task in Children and Adults Using an Automated Assessment Protocol: A Preliminary Study.

Results

This study aimed at comparing the rate and consistency measures of the DDK task performance across gender and age in clinically normal population. The participants were instructed to perform bilabial monosyllabic DDK for 8 seconds. The best trial was selected after three consecutive attempts. MSP protocol was run on this recorded sample and the rate and consistency measures were automatically derived from the protocol. The measures were tabulated and statistical analysis was run on the data. Table 1 shows the mean and standard deviation of DDK rate and consistency parameters obtained for male and female participants in the two age groups during monosyllabic bilabial DDK.

Multivariate analysis was run on the data to explore age and gender effects on the DDK rate and consistency measures. The results revealed no significant difference across gender in any of the rate and consistency measures of DDK at \( p < 0.001 \) (DDKavp: \( F_{(1,18)} = 0.37 \); DDKavr: \( F_{(1,18)} = 0.07 \); DDKcvp: \( F_{(1,18)} = 1.01 \); DDKjit: \( F_{(1,18)} = 0.43 \); DDKcvi: \( F_{(1,18)} = 0.60 \)). Interestingly, age showed a significant effect only on DDKavp (\( F_{(1,18)} = 15.94, p < 0.001 \)) and DDKavr (\( F_{(1,18)} = 22.70, p < 0.001 \)) but there was no interaction between these independent variables. The mean DDK rate and consistency measures obtained in each age group is represented in figure 2.

Table 1.

Mean (Standard Deviation) scores of rate and consistency measures of bilabial monosyllabic DDK sequence obtained by male and female participants across age group.

<table>
<thead>
<tr>
<th>Age (in years)</th>
<th>DDKavp</th>
<th>DDKavr</th>
<th>DDKcvp</th>
<th>DDKjit</th>
<th>DDKcvi</th>
</tr>
</thead>
<tbody>
<tr>
<td>6;0-11;11</td>
<td>211.75</td>
<td>243.30</td>
<td>4.80</td>
<td>22.28</td>
<td>4.55</td>
</tr>
<tr>
<td>11:11</td>
<td>(32.50)</td>
<td>(77.59)</td>
<td>(0.60)</td>
<td>(22.30)</td>
<td>(22.30)</td>
</tr>
<tr>
<td>18;0-24;11</td>
<td>178.86</td>
<td>164.36</td>
<td>5.65</td>
<td>8.65</td>
<td>1.39</td>
</tr>
<tr>
<td>24;11</td>
<td>(18.90)</td>
<td>(17.06)</td>
<td>(0.60)</td>
<td>(6.47)</td>
<td>(7.93)</td>
</tr>
</tbody>
</table>

Table 2. Mean DDK rate and consistency measures obtained for 6;0-11;11 years and 18;0-24;11 years.

Figure 2. Mean DDK rate and consistency measures obtained for 6;0-11;11 years and 18;0-24;11 years.

However, to confirm the findings of MANOVA, non parametric Mann-Whitney U-test was run on DDKcvp, DDKjit and DDKcvi parameters to explore differences within groups and found no significant differences across gender in children (DDKcvp: \( U = 39, p = 0.624, r=0.11 \); DDKjit: \( U = 38, p = 0.568, r=0.13 \); DDKcvi: \( U = 41, p = 0.744, r=0.17 \)) and adults (DDKcvp: \( U = 31, p = 0.253, r=0.26 \); DDKjit: \( U = 42, p = 0.806, r=0.06 \); DDKcvi: \( U = 41, p = 0.744, r=0.08 \)). Similarly no differences across age was found in males (DDKcvp: \( U = 21, p = 0.028, r=0.50 \); DDKjit: \( U = 22, p = 0.034, r=0.49 \); DDKcvi: \( U = 33, p = 0.199, r=0.29 \)) and females (DDKcvp: \( U = 20, p = 0.070, r=0.41 \); DDKjit: \( U = 18, p = 0.047, r=0.46 \); DDKcvi: \( U = 23, p = 0.122, r=0.35 \)) at \( p < 0.001 \).

The statistical comparisons of DDK measures obtained using the automated assessment protocol of MSP revealed age effects on DDKavp and DDKavr. The other DDK parameters that measured consistency of DDK performance (DDKcvp, DDKjit and DDKcvi) were not influenced by age or gender.
Discussion

As reported by Kent, Kent and Rosenbeck (1987) and Henry (1990), the DDK rates increase as the motor system matures (and the DDK period decreases). Adult like performance in DDK rates in children was found to be at 9:0-10:0 years by Canning and Rose (1974) but was as old as 15:0 years in a report by Fletcher (1972). The exact age of adult like performance in Indian children could not be established with this study due to the small corpus but research in this track is under progress. In contrary to the findings in English speaking children (DeLassus Gress & Deliyski, 1995), there were no differences in performance across gender in DDK measures affirming the need for normative data of DDK measures specific to various world populations.

In a study by Nip and Green (2013) that provided a development pattern in rate and displacement of articulators using a three dimensional motion capture system, the DDK task was associated with decreased displacement of articulators in the 4 to 13 year old children. Older children had significant increases in movement speed and decreases in pauses. However, there was an influence of linguistic demand on peak speed and displacement of articulators in all age groups with less demanding tasks such as DDK produced with lesser peak speed, lesser displacement of articulators and shorter duration. The results of the present study support these findings of Nip and Green (2013) and further emphasize that the rate of DDK increases and the period of DDK decrease with increase in age from 8:0 to 11:11 years. Many studies have reported similar findings in speaking rates of younger and older age groups (Stern & Seery, 2007; Walker, Archibald, Cherniak & Fish, 1992).

Increase in speaking rate with age is attributed to various biological, cognitive and speech-motor control factors. Peripheral and central nerve conduction velocities are found to increase with age (Barlow, Finan, Bradford & Andreatta, 1993; Müller & Hömberg, 1992; Müller, Hömberg & Lenard, 1991). With increased nerve conduction velocities, adults may be able to perform tasks faster than the younger population. Also, with increased speaking experience over the years, access to the phonological repertoire, identification and retrieval of phonemes and its execution to produce accurate speech sounds may become more or less an automated process in adults. This might decrease the processing and execution time for production of speech sounds thus increasing the rate of speech in adults. Evidences that speech-motor control in children is less accurate than adults are widely reported (Green & Nip, 2010; Green & Wilson, 2006; Reily & Smith, 2003; Smith & Zelaznik, 2004; Walsh & Smith, 2002). Cognitive linguistic factors such as linguistic complexity of the production and attention demands are also reported to influence the rate of speech (Dromey & Benson, 2003; Green & Nip, 2010; Walker & Archibald, 2006).

Other measures of DDK such as consistency in amplitude and durational measures achieved adult like performance earlier than the DDK rate. This strengthens the assumptions in literature that DDK rate as a standard measure of DDK task sensitive to age. Also, consistent rate and period of DDK iterations in children of 6:0 to 11:11 years suggest the finer speech motor control that is achieved for non-sense monosyllable bilabial repetitions. This implies that while the motor control for rate of movement is still in the development process, consistency of movement is achieved in children of 6:0 to 11:11 years.

Consistency of DDK production is reported to be sensitive to differentiate between categories of speech motor disorders (Williams & Stackhouse, 2000). Consistency in production of DDK did not show age or gender related changes in the present study. This result is supported by the normative study of Williams and Stackhouse (2000) on 30 typically developing children. They reported progressive increase in consistency measures in typically developing children above 3:0 years. From the results of the present study, consistency in DDK period and intensity measures are achieved before the age of 8:0 years. Probably, a longitudinal study can provide more detailed information on the age of acquisition of adult like performance in DDK task. Other finer measures of consistency in DDK production such as acoustic parameters were also studied by other researchers. Comparable acoustic measures of DDK production such as peak intensity and inter-syllable pauses were reported by Juste, Rondon, Sassi, Ritto, Colalto and de Andrade (2012) in typically developing children and in children with stuttering of 4:0 to 7:11 years and 8:0 to 11:11 years. Children with stuttering had greater variability in these parameters. Variability in performance in acoustic measures of DDK indicates that consistency measures of DDK are sensitive in differentiating group of children with communication disorders from the typically developing group. However, this study could not find a difference in consistency across age or gender in children and adults in the parameters studied. Studies in speech motor control indicate plateau in performance measures at 8 years (Green & Nip, 2010). However, there is a need to study these variables on a larger data for inferring any conclusion.

With a number of studies reporting the sensitivity of DDK in differentiating various groups of children with communication disorders, a faster and easier method for calculation of DDK such as the automatic analysis of DDK might be of interest. Attempts to use electropalatography (EPG) in calculation of accuracy and rate of DDK.
Conclusion

The present study was carried out to compare the rate and consistency measures of bilabial monosyllabic DDK productions across age and gender in children of 6:0 to 11:11 years and adults of 18:0 to 24:11 years. Participants were initially trained on the DDK task and the best performance was selected for further analysis using the motor speech profile. The statistical analysis of DDKavp, DDKavr, DDKcvp, DDKjit and DDKcvi indicated no gender effects on any of these measures. Age had a significant effect of DDKavp and DDKavr with higher DDK rate (DDKavr) and lower DDK period (DDKavp) for adults compared to children. Consistency in DDK production is achieved before 6:0 years in the measures studied. The observations made in this study is supported by few studies in the literature indicating that the general trend followed in DDK production across age is similar in the Indian population. However, conclusive evidence needs to be derived by conducting similar studies on a large population. Also, normative data needs to be established for Indian population. This data, if incorporated into the Motor Speech Profile, will be more useful in assessment of clients with various speech and language disorders.

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