Diadochokinetic rate in Saudi and Bahraini Arabic speakers: Dialect and the influence of syllable type

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A B S T R A C T

Arabic is spoken by more than 420 million people worldwide and still there are a limited number of studies on dialects of the Gulf Arabic regions where most selected respondents are male speakers. This study aimed to explore and establish normative data for the Diadochokinetic Rate (DDK) for two dialects (Saudi Arabia's *Najdi* and Bahrain's *Bahraini*) speakers. Furthermore, it aimed to investigate whether there are differences between the two dialects and whether sex differences are evident. In addition, it investigated syllable type differences. The study used the monosyllables /ba, da, ga/ and the multisyllabic sequence /badaga/ to analyse the DDK rates. Acoustic analysis was carried out to obtain DDK rates for the syllables. A mixed model ANOVA was performed to investigate dialect and sex differences, in addition, to syllable type. The study included 40 males and 40 female speakers from each of the two dialects. Results showed that for DDK, Saudi speakers had faster DDK rates for the monosyllables /ba/, /da/, /ga/, than Bahrainis, while, no significant differences were observed for the multisyllabic sequences. However, there were no differences between male and female speakers with regard to the DDK rates. The syllable /ga/ showed the slowest DDK rate among the monosyllables while the multisyllabic sequences displayed the slowest DDK rates. In brief, normative data for DDK rates for clinic were determined for the Arabic *Nadji* and Bahrain's *Bahraini* dialects. DDK rate was shown to be more sensitive to dialect differences for the monosyllable tasks. However, no sex differences were observed for the Arabic dialects in this study across all DDK tasks.

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1. Introduction

Speech is produced by the combination of neuromuscular control and the coordination between respiratory, phonatory and articulatory systems. The breakdown of such a complex system when examining speech output might be indicative of disorders of the nervous and/or motor speech systems. Therefore, a careful assessment of speech production must be performed in order to identify the underlying causes of any motor speech disorders. Amongst the battery of tests used by health professionals are

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diadochokinetic rates (DDK) which can be defined as a phonoarticulatory speech task where a monosyllable /pa/ or multisyllabic sequence /pataka/ is repeated quickly as possible in a clear manner (McClean, 2000; Ziegler, 2002). DDK rates have been employed in motor speech assessment to examine the integrity of systems involved in speech (Blomquist, 1950; Lundeen, 1950; St Louis and Ruscello, 1981; Kent et al., 1987; Modolo et al., 2011), and they assess the ability of coordination of respiratory, articulatory, and laryngeal behaviours (Portnoy and Aronson, 1982; Padovani et al., 2009; Skodda et al., 2010). DDK rate is often used in the assessment of motor speech disorders and voice (Maassen et al., 1990; Williams and Stackhouse, 2000: Rosen et al., 2005; Gadesmann and Miller, 2008). Moreover, it is used as simple neurological test in determining the presence and the degree of severity of motor speech disorders such as apraxia and dysarthria (Mason et al., 1977; Platt et al., 1980; Teichgraeber et al., 1985; Kent et al., 1991; Ackermann et al., 1995; Ziegler and Wessel, 1996; Padovani et al., 2009).

DDK rates that are not within a set of validated normative DDK rates might be indicative of disorders as described above. There-

fore, a set of normative DDK rates for languages have been established for English (Lundeen, 1950; Ptacek et al., 1966; Amerman and Parnell, 1982; Kreul, 1972; Deliyski and DeLassus Gress, 1996; Neel and Palmer, 2012; Topbaş et al., 2012), Chinese (Hongzhi et al., 2010), Portuguese (Padovani et al., 2009; Louzada et al., 2011) and Hebrew (Icht and Ben-David, 2014).

DDK rates are used to assess neurological integrity and coordination between respiratory, phonatory and articulatory systems as described earlier. Children display lower DDK rates than adults (Netsell, 1986; Cohen et al., 1998), and the deceleration in articulatory movements and lower accuracy of speech gestures will lower DDK rates in older adult (Shanks, 1970; Cheng et al., 2007). Young adults in contrast displays more accurate and consistent DDK production than either children or older adults. Furthermore, some investigations into DDK rates have shown no sex differences.

Two methods of analysis of DDK rate are often used, the "time-by-count method" (Fletcher, 1972; 1978) and the "traditional approach". The traditional approach can be described as the number of syllables produced over a specified time (Prins, 1962); variations for the specified time are often seen across different studies (Alshahwan, 2015). In contrast, the "time-by-count method" (Fletcher, 1972; 1978) can be described as the time measured for a predetermined number of syllables to be spoken in seconds.

The syllables that are often analysed are /pə/,/tə/,/kə/, or their voiced counterparts, /bə/,/də/,/gə/ for monosyllables (Sigurd,1973). While, /pətəkə/ can be considered the most common multisyllabic sequence used in DDK rates. Caution should be exercised when making comparisons between languages and dialects where articulatory behaviours might be different due to phonological or other linguistic-based differences (Cohen et al., 1998). Therefore, it is suggested that stimuli should be appropriate for the language and dialects being investigated in order for DDK rates to be reliable for the speakers being studied (Crary, 1993).

To the knowledge of the researchers, normative DDK rates have not been established for the Arabic language. Arabic is commonly spoken by more than 420 million speakers across North Africa, Middle East and other parts of world. Moreover, Gulf Arabic and more specifically the Saudi Arabian Najdi *Saudi* dialect spoken in the central area of the Kingdom of Saudi Arabia and the Bahraini *Bahraini* dialect in the Kingdom of Bahrain have not been explored. The current paper aims to determine normative DDK rates using the "time-by-count method" (Fletcher, 1972; 1978) for two Gulf Arabic dialects: the Najdi *Saudi* dialect spoken in Saudi Arabia and for the Bahraini *Bahraini* dialect in Bahrain. It also explores if there are differences between the two dialects and between young adult male and female speakers of Arabic. In addition, it explores differences between syllables.

2. Materials and methods

2.1. Ethics and method of recruitment

This study was approved by the University Research Ethics Committee at the University of Sheffield. The participants in this study were volunteers who responded to a bulletin letter that was circulated via e-mail to contacts in hospitals and universities in Riyadh, Saudi Arabia, and Manama, Bahrain. The volunteers were contacted by the researcher by either phone or e-mail and meetings were arranged to take place in clinics or university rooms. The participants were given an information sheet and were offered to ask question prior to signing the consent form to confirm their agreement to join the study and were informed of their right to withdrew from the study.

2.1.1. Participants

The initial group of volunteers was composed of 87 participants. However, only 80 participants remained which consisted of 40 males and 40 females. Reasons for exclusion were loss of data or not fulfilling the inclusion criteria. Twenty males and 20 females represented the two Arabic dialects with age ranges between 22 and 35 years old (Bahraini males m = 25.96 (SD = 3.75) and females 27.71 (3.51) and Saudi males 27.45 (3.98) and females 26.36 (3.66)). A one-way ANOVA revealed no significant differences between the four groups (F (3,76) = 1.008, p = .394).

2.1.2. Inclusion criteria

The inclusion criteria reflected the research design that was descriptive, exploratory and explanatory as would be illustrated in the details of health status and dialect inclusion criteria that follows.

2.1.2.1 Health status. The following inclusion criteria were adopted where participants: (a) Had no current or previous symptoms of voice, speech or fluency difficulties (b) Had not undertaken any professional speech or voice training, (3) were non-smokers, (4) had no self-reported hearing loss or ear infections, (5) had passed the whisper test and (6) displayed no evidence of voice-related problems such as allergic rhinitis, upper respiratory problems or a cold (Pirozzo et al., 2003).

2.1.2.2 Dialect. All participants identified themselves as a speaker of their respective dialects. Further monitoring and confirmation of the *Najdi* speaking participants was done by the researcher, whereas, the Bahraini speakers was confirmed by a Bahraini *Bahraini* Arabic speaker.

2.2. Stimuli

The speech samples selected for the DDK rate assessment were production data for the monosyllables /ba/, /da/, /ga/ as well as the multisyllabic sequence /badaga/ which is part of a stimuli list used from a larger study comparing the two dialects (Alshahwan, 2015). The choice of these stimuli was based on the lack of the voiceless plosive /p/ in Arabic as well as earlier studies that have employed the voiced plosive /b/ in their assessment of DDK (Sigurd, 1973). In addition, no differences have been reported for voiced and voiceless monosyllables (Lundeen, 1950). Moreover, the choice of the vowel /a/ was more appropriate for Arabic language speakers, and is shared with a range of Arabic dialects; it can therefore be used in future comparisons.

2.3. Data gathering procedure and preparations for analysis

The speech samples were gathered by audio-recordings in a room with a low ambient noise on a high quality digital audio recorder (Olympus DS-40) connected to a microphone (ME53S). The microphone was situated at a relatively constant 20 cm from each participant's mouth.

The sampling rate of the recordings was 44 KHz with a 32-bit resolution, and the recordings were stored internally on the digital audio recorder in WMA format. Participants were recorded sitting comfortably in a chair in a quiet room or residence in Saudi Arabia and Bahrain. Data were collected from speakers in their respective Arabic dialects. All participants in this study produced the stimuli for DDK which included the monosyllables (/ba/, /da, /ga/) and the multisyllabic sequence /badaga/. Participants were shown the monosyllables and the multisyllabic sequence in written Arabic and were then given a demonstration by the researcher. All participants were instructed to take a deep breath before initiation of

each syllable and were instructed to produce the syllables for more than 20 s and were cued when to stop.

2.4. Acoustic analysis

2.4.1. Monosyllables and multisyllabic sequences

The "time-by-count method was employed where Praat was used in the analysis of all the parameters for all participants (Boersma and Weenink, 2013). Using visual inspection, the time marker was placed after the first production of /ba/, /da/, /ga/ and /badaga/. The first set of the monosyllables was excluded from the analysis because Ackermann et al. (1995) suggest that the first production of the first syllable is longer than the remaining syllables. The first time marker was placed at the end of the vowel formant and before the start of the release of the voiced stops /b/ of the next iteration, after the count of the 20 full repetitions of /ba/, /da/, /ga/, the second time marker was placed at the end of the vowel preceding the voicing of the next iteration which was not counted (see Fig. 1(a)). The same procedure was conducted for all monosyllables.

Similar to the monosyllables, the first time marker was placed after the first full iteration of /badaga/ at the end of the vowel preceding the next repetition. The second time marker was placed at the end of the number of full repetitions of the selected multisyllable; Fig. 1(b) shows 10 repetitions that were selected. The procedure was repeated for 20 repetitions for the monosyllables /ba/, /da/, /ga/ and for the multisyllabic sequences /badaga/, in addition to 10 repetitions for the multisyllabic sequence for all speakers (see Fig. 2).

A Praat script was modified to extract for each participant the duration in seconds from the marked iteration for all syllables from the sound files in WAV format and text grids (Crosswhite and Antoniuo, 2007). The output of the script was then transferred to an Excel (2010) spreadsheet. The results for all participants were then compiled into an Excel spreadsheet that was transferred into the Statistical Package for the Social Sciences (SPSS, Inc., Chicago, IL), version 23, for statistical analysis. In the present study, the statistical analysis used a mixed model ANOVA with dialect (Najdi and Bahraini) and sex (male and female) as the between subjects factors. The within subject factor was the five tasks for the DDK rates (20 repetitions for the monosyllables /ba/, /da/, /ga/ and the multisyllabic sequences /badaga/ for 20 and 10 repetitions).

2.5. Reliability

For reliability, a Pearson correlation was performed to establish correlation between two measurements, intra-rater reliability by the first author after a duration of at least 6 months and inter-rater reliability by an independent speech and language pathologist colleague after a demonstration from the researcher as well as a trial. A total of 8 participants were randomly selected, with 2 representing each group (2 Saudi and 2 Bahraini males, and 2 Saudi and 2 Bahraini females) from the total of 80 participants in the study. For each participant, DDK rate measures were obtained for the monosyllables /ba/,/da/,/ga/ for the 20 repetitions and for 20 and 10 repetitions for the multisyllabic sequences /badaga/ in the same method described above. A total of 5 measures for DDK syllables for each participant had been made. Therefore, the number of DDK rates analysed for these participants was 40, representing 10% of the total sample (n = 400). The intra-rater reliability levels were used to assess the reliability of the DDK measurements. There was a strong positive correlation for the intra-rater reliability between the two measurements that was performed by the researcher for the monosyllables (r = 1.00, n = 24, p < .001) as well as the multisyllabic for 20 repetitions (r = 1.00, n = 8, p < .001) and 10 repetitions (r = 0.998, n = 8, p < .001). In addition, the second measurement (inter-rater reliability), taken by an independent second rater, revealed a strong positive correlation for the monosyllables (r = 1.00, n = 24, p < .001) as well as the multisyllabic for 20 repetitions (r = 1.00, n = 8, p < .001) and 10 repetitions (r = 1.00, n = 8, p < .001). Overall, there was a strong positive correlation between the measurements revealing a high level of reliability for the acoustic analysis of DDK duration in seconds.
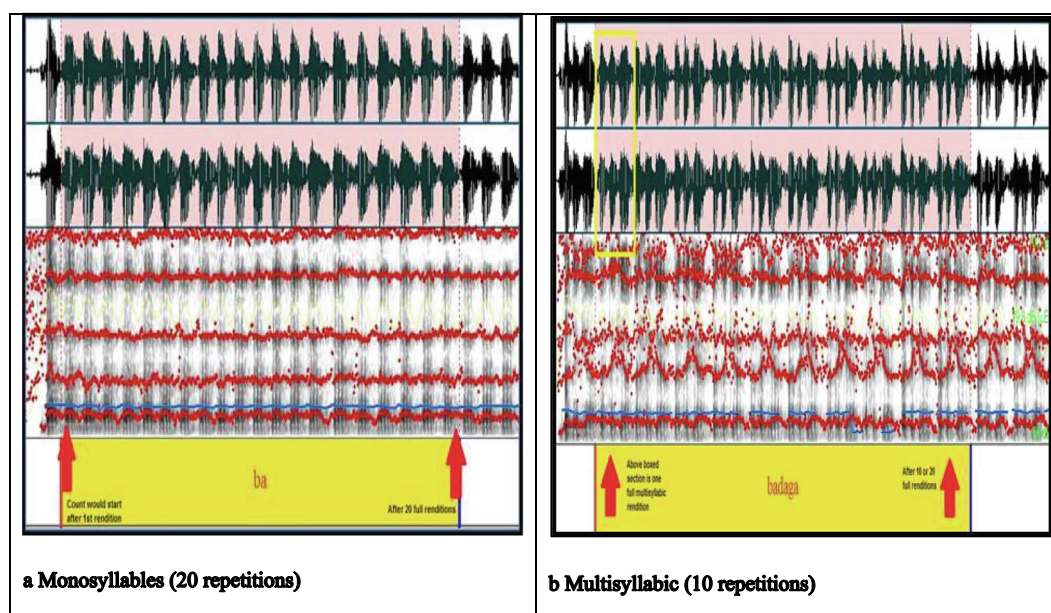

Fig. 1. Methods used to measure DDK rate for the monosyllables /ba/, /da/, /ga/ and the multisyllabic /badaga/. The time marker was placed after the first iteration as in Fletcher's (1972, 1978) time-by-count procedure, where the duration for 20 full repetitions was measured for the monosyllables (shown for /ba/ in a – left hand panel) and 10 full repetitions for the multisyllabic sequences/badaga/ (shown in b – right hand panel).
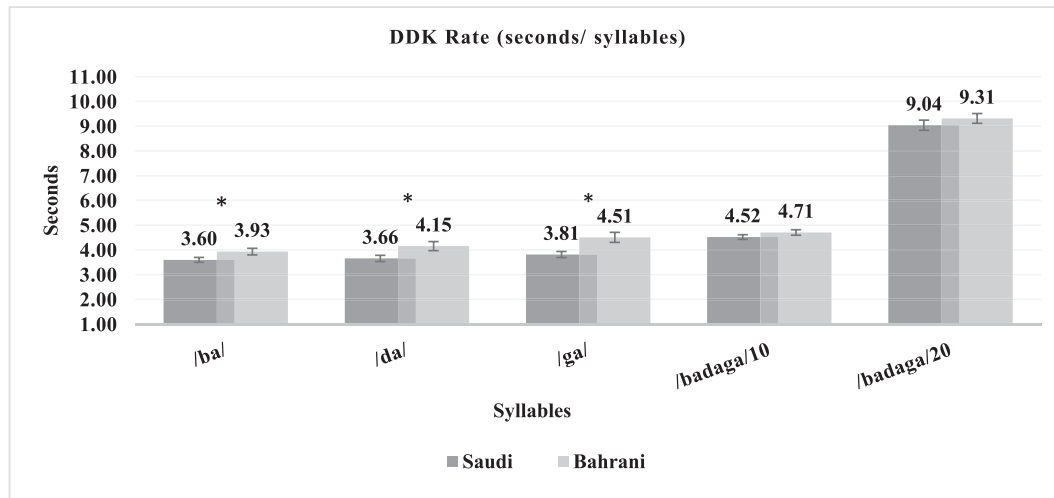
Fig. 2. Mean ± standard errors bars (Seconds) for 20 repetitions for monosyllables /ba/, /da/, /ga/ and the multisyllabic sequence /badaga/ in addition to 10 repetitions for Saudi and Bahraini speakers, * Indicates significant difference between the dialects.

3. Results

3.1. DDK rates

Normative DDK rates (mean, standard deviation, minimum and maximum) in seconds for 20 repetitions for monosyllables /ba/, /da/,/ga/ and the multisyllabic sequence /badaga/, according to the Fletcher method (1972, 1978) can be observed in Table 1 for 80 speakers (20 male and 20 female Saudi speakers and 20 male and female Bahraini speakers). In addition, the final column indicates the number of seconds required for the production of 10 repetitions for the multisyllabic sequence /badaga/.

3.2. Sex and dialect

As a first step, the results showed that sex had no effect on DDK rates among the Saudi Najdi and the Bahraini Bahraini speakers (F (1,76) = 0.637, p > .05) (5.08 and 5.16 in seconds collectively for all syllables produced for males and females respectively). Nor was there any interaction between sex and dialect (F (1,76) = 0.477,

p > .05). However, dialect had a significant impact (F (1,76) = 6.22, p < .05) where Saudi speakers had a faster rate and produced the syllables in shorter period (4.93 s) than the Bahraini group (5.32 s). Further analysis was conducted using a one-way ANOVA to compare the effects of dialect on the monosyllables and both multisyllabic sequence. The results showed a significant effect of dialect as observed in the monosyllables sequences where /ba/ (F (1,78) = 4.00, p < .05), /da/ (F (1,78) = 4.96, p < .05) and /ga/ (F (1,78) = 8.63, p < .05), while no differences were observed for the multisyllabic /badaga/ for 10 repetitions (F (1,78) = 1.06, p = .209) and 20 repetitions (F (1,78) = 0.941, p = .335).

3.3. Syllable type

The results showed a significant effect regarding syllable type (F (1,82, 138.08) = 740.52, p < .001). A post hoc test using Bonferroni correction for multiple comparisons revealed that the 20 and 10 repetitions for /badaga/ (9.18 and 4.61 s respectively) took longer to complete than all the monosyllables (p < .001). Furthermore, /ga/ for the 20 repetitions was completed at a lower DDK rate

Table 1
Mean DDK rate (SD, Min and Max) in seconds for male and female Saudi and Bahraini speakers for 20 repetitions for monosyllables /ba/,/da/,/ga/ and the multisyllabic sequence /badaga/, and the final column shows seconds required for 10 repetitions for the multisyllabic sequence /badaga/.

| Sex	Dialect	/ba/ (20) Mean (S.D) Min-Max	/da/ (20) Mean (S.D) Min-Max	/ga/(20) Mean (S.D) Min-Max	/badaga/ (20) Mean (S.D) Min-Max	/badaga/ (10) Mean (S.D) Min-Max
Male	**Saudi**	3.53 (0.59)	3.57 (0.82)	3.73 (0.70)	8.89 (1.19)	4.45 (0.58)
	(20)	2.92–5.23	2.72–6.20	2.75–5.57	7.46–12.19	3.73–6.03
	Bharani	3.92 (0.90)	4.18 (1.33)	4.68 (1.57)	9.20 (1.42)	4.73 (0.82)
	(20)	2.84–6.54	2.66–7.15	2.67–8.17	6.74–12.71	3.70–6.74
	Mean	3.73 (0.78)	3.87 (1.14)	4.20 (1.29)	9.05 (1.30)	4.59 (0.71)
	(40)	2.84–6.54	2.66–7.15	2.67–8.17	6.74–12.71	3.70–6.74
Female	**Saudi**	3.67 (0.68)	3.75 (0.77)	3.90 (0.86)	9.19 (1.42)	4.60 (0.63)
	(20)	2.78–5.27	2.27–4.97	2.83–6.26	6.82–11.92	3.33–5.81
	Bharani	3.94 (0.83)	4.13 (1.02)	4.34 (0.91)	9.43 (1.08)	4.68 (0.55)
	(20)	2.98–5.95	2.91–5.79	3.17–6.39	8.19–12.43	4.12–6.39
	Mean	3.81 (0.76)	3.94 (0.91)	4.12 (0.90)	9.31 (1.25)	4.64 (0.59)
	(40)	2.78–5.95	2.27–5.79	2.83–6.39	6.82–12.43	3.33–6.39
Total	**Saudi**	3.60 (0.63)	3.66 (0.79)	3.81 (0.78)	9.04 (1.30)	4.52 (0.60)
	(20)	2.78–5.27	2.27–6.20	2.75–6.26	6.82–12.19	3.33–6.03
	Bharani	3.93 (0.85)	4.15 (1.17)	4.51 (1.28)	9.32 (1.25)	4.71 (0.69)
	(20)	2.84–6.54	2.66–7.15	2.67–8.17	6.74–12.71	3.70–6.74
	Mean	3.77 (0.76)	3.91 (1.02)	4.16 (1.11)	9.18 (1.28)	4.61 (0.65)
	(40)	2.78–6.54	2.27–7.15	2.67–8.17	6.74–12.71	3.33–6.74
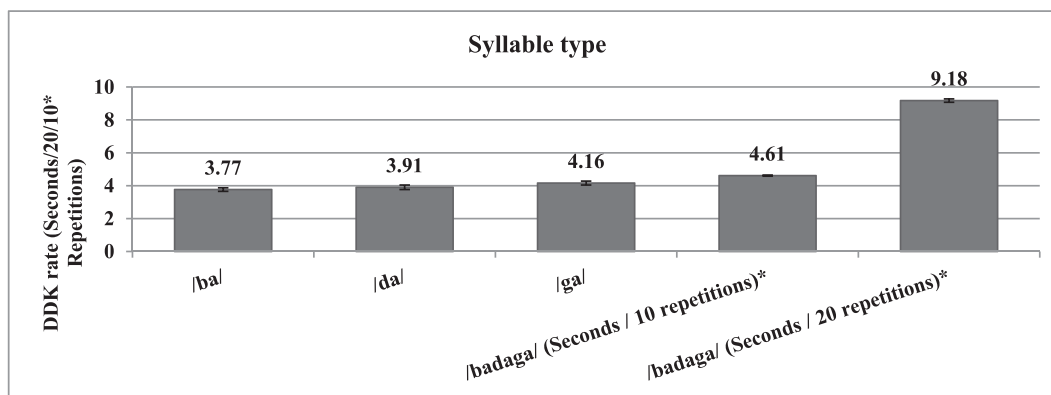
Fig. 3. Mean ± standard error bars (Seconds) for 20 repetitions for monosyllables /ba/, /da/, /ga/ and the multisyllabic sequence /badaga/ in addition to 10 repetitions.

(4.16 s) than both /ba/ (3.77 s) (p < . 001), and /da/ (3.91 s) (p < .05). However, no significant differences were observed between /ba/ (3.77 s) and /da/ (3.90 s) (p > .05), (see Fig. 3).

The results showed no significant interaction between syllable type and sex (F(1.82, 138.08) = 0.54 , p > .05), syllable type and dialect (F(1.82, 138.08) = 0.1.44 ,p > .05) or between sex, dialect and syllables (F(1.82, 138.08) = 0.256 , p > .05).

4. Discussion

4.1. Sex and dialect

As mentioned earlier, sex did not show an effect which agrees with a number of studies on English (Ptacek et al., 1966; Kreul, 1972; Amerman and Parnell, 1982; Deliyski and DeLassus Gress, 1996; Topbaş et al., 2012; Neel and Palmer, 2012) and Hebrew (Icht and Ben-David, 2014). However, for dialect, Saudis had faster rates than Bahraini speakers for the 20 repetitions of the monosyllables (/ba, /da, /ga/). In contrast, the multisyllabic sequence /badaga/, showed no significant differences between the dialects for both measures (10 and 20 repetitions of /badaga/). The results from this study suggest that dialects might exhibit some differences in DDK rates. These differences were limited to the monosyllables between the Saudi and Bahraini dialects. Lower standard deviation values for DDK rates have been shown to be an indication of higher levels of coarticulation where articulatory movements are more rapid and flexible (Hongzhi et al., 2010). Bahrainis tended to show higher standard deviations than Saudis, which might indicate higher levels of coarticulation for the Saudi speakers. The results might also be reflective of differences between the two dialects considering that Najdi has been described as the closest to classical Arabic (Ingham, 1994) while Bahraini Bahraini might be influenced by the Bahrani Bahraini dialect which is largely influenced by Persian (Holes, 2001). In addition, the number of foreigners living in Bahrain makes up half the population (Government of the Kingdom of Bahrain. Bahrain Census, 2010); over time the heterogeneity of languages spoken may have had an effect on the dialects of Bahrain.

4.2. Syllable type

The results from this study showed that /ga/ had a lower DDK rate than /ba/ and /da/ in Najdi and Bahraini Arabic speakers for both sexes. The results are in agreement with the majority of studies on English (Ptacek et al., 1966; Kreul, 1972; Amerman and Parnell, 1982; Deliyski and DeLassus Gress, 1996; Topbaş et al., 2012; Neel and Palmer, 2012), Brazilian Portuguese (Louzada et al., 2011) reporting that monosyllables with velar consonants

have lower DDK rates than those with other consonants. This might be due to the involvement of more complex articulatory process in producing /g/ (Padovani et al., 2009). Furthermore, the more frequent the phoneme, the more accurate and rapid the movement of articulators (Icht and Ben-David, 2014). In Modern Standard Arabic (MSA), the /b/ phoneme has been shown to have a higher frequency than /d/ (Wehr, 1979; Newman, 2005). A study of Tunisian Arabic also showed that the frequency of /b/ was higher than /d/ which was in turn higher than /g/ (Krichi and Adnan, 2014). This in turn could have caused the differences in DDK number of repetition between the monosyllables where the voiced bilabial stop /b/ was observed to have a higher rate than the voiced alveolar stop /d/, which was higher than the voiced velar stop /g/. In addition, this might have been the cause of differences between DDK rates between the two dialects in this study. However, further studies are required on the frequency of phonemes in Arabic dialects, which might help to explain the results of this study.

In clinical settings, speech and language pathologists frequently employ minimum and maximum, in addition to mean DDK rates to ascertain if speech difficulties are present and are not within the range produced by healthy speakers. Therefore, this study provides normative DDK rates following the Fletcher (1972 & 1978) methods (means, standard deviation, minimum and maximum rates) for Saudi and Bahraini male and female young adult speakers. It is recommended for Arabic clinicians to assess the full range of DDK tasks within this study. One of the limitations of the study is that only mean values were used for comparison between dialect and sex. Additional analysis of ranges and standard deviation is recommended.

5. Conclusion

Saudis showed higher DDK rates for monosyllables tasks than Bahrainis, while no differences between the dialects were observed for the multisyllabic sequences. Furthermore, no sex differences were found in DDK rates for both Arabic dialects. In addition, /ga/ showed lower rates among the monosyllables, while, the multisyllable showed the slower rates among DDK task for both dialects. It is recommended that clinics in Saudi Arabia and Bahrain utilize the normative data from this study for adults in the age range of 22–35 years. Further studies are recommended to determine normative DDK rates for children and older adults.

References

Ackermann, H., Hertrich, I., Hehr, T., 1995. Oral diadochokinesis in neurological dysarthrias. Folia Phoniatrica et Logopaedica 47, 15–23. https://doi.org/10.1159/000266338.

Alshahwan, M., 2015. Speech Characteristics of Arabic Speakers: Dialect Variations. (Unpublished Ph.D Thesis). University of Sheffield.

Amerman, J.D., Parnell, M.M., 1982. Oral motor precision in older adults. J. Natl. Stud. Speech Lang. Hear. Assoc. 100, 55–66.

Blomquist, B.L., 1950. Diadochokinetic movements of nine-, ten-, and eleven-year old children. J. Speech Disorders 15, 159–164.

Boersma, P., Weenink, D., 2013. Praat: doing phonetics by computer.

Cheng, H.Y., Murdoch, B.E., Goozee, J.V., Scott, D., 2007. Physiologic development of tongue-jaw coordination from childhood to adulthood. J. Speech, Lang., Hear. Res. 50, 352–360.

Cohen, W., Waters, D., Hewlett, N., 1998. DDK rates in the paediatric clinic: a methodological minefield. Int. J. Lang. Commun. Disorders 33, 428–433.

Crary, M.A., 1993. Developmental Motor Speech Disorders. Singular Publishing Group San Diego, CA.

Crosswhite, K., Antoniuo, M., 2007. Duration-Logger - Praat Script.

Deliyski, D.D., DeLassus Gress, C., 1996. Characteristics of Motor Speech Performance: Normative Data, Instructional Manual Visi-Pitch III/Sona-Speech Model 3900/3600. Lincoln Park.

Fletcher, S.G., 1978. Time-by-Count Test Measurement of Diadochokinetic Syllable Rate. PRO-ED, Austin, TX.

Fletcher, S.G., 1972. Time-by-count measurement of diadochokinetic syllable rate. J. Speech, Lang. Hear. Res. 15, 763–770.

Gadesmann, M., Miller, N., 2008. Reliability of speech diadochokinetic test measurement. Int. J. Lang. Commun. Disorders 43, 41–54. https://doi.org/10.1080/13682820701234444.

Government of the Kingdom of Bahrain, 2010. Bahrain Census.

Holes, C., 2001. Dialect, Culture, and Society in Eastern Arabia: Glossary. Brill Academic Publishers.

Hongzhi, Y., Huimin, J., Yansha, L., Yonghong, L., 2010. Analysis of reference normal values of diadochokinetic rate and U.S. China comparison. In: 2010 International Conference On Computer Design and Applications. Presented at the 2010 International Conference On Computer Design and Applications, pp. V4-399–V4-402. https://doi.org/10.1109/ICCDA.2010.5541023

Icht, M., Ben-David, B.M., 2014. Oral-diadochokinesis rates across languages: English and Hebrew norms. J. Commun. Disord. 48, 27–37.

Ingham, B., 1994. Najdi Arabic: Central Arabian. John Benjamins.

Kent, R.D., Kent, J.F., Rosenbek, J.C., 1987. Maximum performance tests of speech production. J. Speech Hear. Disorders 52, 367.

Kent, R.D., Sufit, R.L., Rosenbek, J.C., Kent, J.F., Weismer, G., Martin, R.E., Brooks, B.R., 1991. Speech deterioration in amyotrophic lateral sclerosis: a case study. J. Speech Hear. Res. 34, 1269–1275.

Kreul, E.J., 1972. Neuromuscular Control Examination (NMC) for Parkinsonism: vowel prolongations and diadochokinetic and reading rates. J. Speech Hear. Res. 15, 72–83.

Krichi, M.K., Adnan, C., 2014. The Arabic Speech Database: PADAS. Signal Process.: An Int. J. (SPIJ) 8, 10.

Louzada, T., Beraldinelle, R., Berretin-Felix, G., Brasolotto, A.G., 2011. Oral and vocal fold diadochokinesis in dysphonic women. J. Appl. Oral Sci. 19, 567–572.

Lundeen, D.J., 1950. The relationship of diadochokinesis to various speech sounds. J. Speech Hear. Disorders 15, 54.

Maassen, B., Thoonen, G., Wit, J., 1990. Toward assessment of articulo-motoric processing capacities in children. In: Speech Motor Control and Stuttering. Presented at the 2nd International Conference on Speech Motor Control and Stuttering, Nijmegen, the Netherlands, pp. 461–469.

Mason, R.M., Helmick, J.W., Unger, J.W., Gattozzi, J.G., Murphy, M.W., 1977. Speech screening of children in the dental office. J. Am. Dent. Assoc. 1939 (94), 708–712.

McClean, M.D., 2000. Patterns of orofacial movement velocity across variations in speech rate. J. Speech, Lang., Hear. Res. 43, 205–216.

Modolo, D.J., Berretin-Felix, G., Genaro, K.F., Brasolotto, A.G., 2011. Oral and Vocal Fold Diadochokinesis in Children. Folia Phoniatrica et Logopaedica 63, 1–8.

Neel, A.T., Palmer, P.M., 2012. Is tongue strength an important influence on rate of articulation in diadochokinetic and reading tasks? J. Speech, Lang., Hear. Res. 55, 235–246. https://doi.org/10.1044/1092-4388(2011/10-0258).

Netsell, R., 1986. A Neurobiological View of Speech Production and the Dysarthrias. College-Hill Press, San Diego, CA.

Newman, D., 2005. Contrastive analysis of the segments of French and Arabic. In: Elgibali, A. (Ed.), Investigating Arabic: Current Parameters in Analysis and Learning. Brill Academic Publishers, Leiden, pp. 185–220.

Padovani, M., Gielow, I., Behlau, M., 2009. Phonarticulatory diadochokinesis in young and elderly individuals. Arq. Neuropsiquiatr. 67, 58–61.

Pirozzo, S., Papinczak, T., Glasziou, P., 2003. Whispered voice test for screening for hearing impairment in adults and children: systematic review. Brit. Med. J. (Clin. Res. ed.) 327, 967. https://doi.org/10.1136/bmj.327.7421.967.

Platt, L.J., Andrews, G., Young, M., Quinn, P.T., 1980. Dysarthria of Adult Cerebral Palsy: I. Intelligibility and articulatory impairment. J. Speech Hear. Res. 23, 28–40.

Portnoy, R.A., Aronson, A.E., 1982. Diadochokinetic syllable rate and regularity in normal and in spastic and ataxic dysarthric subjects. J. Speech Hear. Disorders 47, 324–328.

Prins, T.D., 1962. Motor and auditory abilities in different groups of children with articulatory deviations. J. Speech Hear. Res. 5, 161–168.

Ptacek, P.H., Sander, E.K., Maloney, W.H., Jackson, C.R., 1966. Phonatory and related changes with advanced age. J. Speech, Lang., Hear. Res. 9, 353–360.

Rosen, K.M., Kent, R.D., Duffy, J.R., 2005. Task-Based profile of vocal intensity decline in parkinson disease. Folia Phoniatrica et Logopaedica 57, 28–37. https://doi.org/10.1159/000081959.

Shanks, S.J., 1970. Effect of aging upon rapid syllable repetition. Percept. Mot. Skills 30, 687–690.

Sigurd, B., 1973. Maximum rate and minimal duration of repeated syllables. Lang. Speech 16, 373–395. https://doi.org/10.1177/002383097301600408.

Skodda, S., Flasskamp, A., Schlegel, U., 2010. Instability of syllable repetition as a model for impaired motor processing: is Parkinson's disease a "rhythm disorder"? J. Neural Transm. 117, 605–612. https://doi.org/10.1007/s00702-010-0390-y.

St Louis, K.O., Ruscello, D.M., 1981. The Oral Speech Mechanism Screening Examination (OSMSE). University Park Press, Baltimore, MD.

Teichgraeber, J., Bowman, J., Goepfert, H., 1985. New test series for the functional evaluation of oral cavity cancer. Head Neck Surg. 8, 9–20. https://doi.org/10.1002/hed.2890080104.

Topbaş, O., Orlikoff, R.F., St. Louis, K.O., 2012. The effect of syllable repetition rate on vocal characteristics. J. Commun. Disorders, vol. 45, pp. 173–180. https://doi.org/10.1016/j.jcomdis.2012.02.001.

Wehr, H., 1979. A Dictionary of Modern Written Arabic. Otto Harrassowitz Verlag.

Williams, P., Stackhouse, J., 2000. Rate, accuracy and consistency: diadochokinetic performance of young, normally developing children. Clin. Linguist. Phonet. 14, 267–293. https://doi.org/10.1080/02699200050023985.

Ziegler, W., 2002. Task-related factors in oral motor control: Speech and oral diadochokinesis in dysarthria and apraxia of speech. Brain Lang. 80, 556–575.

Ziegler, W., Wessel, K., 1996. Speech timing in ataxic disorders: Sentence production and rapid repetitive articulation. Neurology 47, 208–214.