Journal of Communication Disorders 48 (2014) 27–37

Contents lists available at ScienceDirect

Journal of Communication Disorders

Oral-diadochokinesis rates across languages: English and Hebrew norms

Michal Icht [a], Boaz M. Ben-David [b,c,d,*]

[a] Department of Communication Disorders, Ariel University, Israel
[b] Communication Aging and Neuropsychology Lab (CANlab), School of Psychology, Interdisciplinary Center (IDC) Herzliya, Israel
[c] Department of Speech-Language Pathology and Graduate Department of Rehabilitation Sciences, University of Toronto, Canada
[d] Toronto Rehabilitation Institute, Canada

ARTICLE INFO

Article history:
Received 11 June 2013
Received in revised form 29 January 2014
Accepted 15 February 2014
Available online 23 February 2014

Keywords:
Oral-diadochokinesis
Speech-motor control
Speech diagnosis
Language differences
Literature analysis
Hebrew

ABSTRACT

Oro-facial and speech motor control disorders represent a variety of speech and language pathologies. Early identification of such problems is important and carries clinical implications. A common and simple tool for gauging the presence and severity of speech motor control impairments is oral-diadochokinesis (oral-DDK). Surprisingly, norms for adult performance are missing from the literature. The goals of this study were: (1) to establish a norm for oral-DDK rate for (young to middle-age) adult English speakers, by collecting data from the literature (five studies, $N = 141$); (2) to investigate the possible effect of language (and culture) on oral-DDK performance, by analyzing studies conducted in other languages (five studies, $N = 140$), alongside the English norm; and (3) to find a new norm for adult Hebrew speakers, by testing 115 speakers. We first offer an English norm with a mean of 6.2 syllables/s ($SD = .8$), and a lower boundary of 5.4 syllables/s that can be used to indicate possible abnormality. Next, we found significant differences between four tested languages (English, Portuguese, Farsi and Greek) in oral-DDK rates. Results suggest the need to set language and culture sensitive norms for the application of the oral-DDK task world-wide. Finally, we found the oral-DDK performance for adult Hebrew speakers to be 6.4 syllables/s ($SD = .8$), not significantly different than the English norms. This implies possible phonological similarities between English and Hebrew. We further note that no gender effects were found in our study. We recommend using oral-DDK as an important tool in the speech language pathologist's arsenal. Yet, application of this task should be done carefully, comparing individual performance to a set norm within the specific language.

Learning outcomes: Readers will be able to: (1) identify the Speech-Language Pathologist assessment process using the oral-DDK task, by comparing an individual performance to the present English norm, (2) describe the impact of language on oral-DDK performance, and (3) accurately detect Hebrew speakers' patients using this tool.

* Corresponding author at: Communication, Aging and Neuropsychology Lab (CANlab), School of Psychology, Interdisciplinary Center Herzliya, P.O. Box 167, Herzliya 4610101, Israel. Tel.: +972 9 9602429; fax: +972 9 9602845.
E-mail addresses: boaz.ben.david@idc.ac.il, boaz.ben.david@utoronto.ca (B.M. Ben-David).

http://dx.doi.org/10.1016/j.jcomdis.2014.02.002
0021-9924/

1. Introduction

Speech is a very complex motor skill that requires high neuromuscular control and coordination of several systems – respiration, phonation and articulation. Changes in speech production (e.g., rate, fluency and accuracy) can be an early sign for the existence of diseases of the nervous system and motor-speech disorders (Duffy, 1995). Consequently, valid assessment of speech production carries high clinical importance. One of the most common tools for the detection of such changes is the oral-diadochokinesis performance task (oral-DDK). DDK is the ability to perform rapid repetitions of relatively simple patterns of opposite muscular contractions (Baken & Orlikoff, 2000). Oral-DDK is a phonoarticulatory speech task that involves the repetition of syllables composed of a consonant and a vowel (a single syllable, /pa/, /ta/ and /ka/) or of a syllabic sequence (/pataka/) as quickly as possible in a clear manner (Kent, Kent, & Rosenbek, 1987; McClean, 2000; Ziegler, 2002). It is used in order to assess the function of the articulators (tongue and lips). Although it involves actual speech sounds (syllables), it is considered as a nonspeech oral motor task (Ziegler, 2002). Indeed, the orofacial motor function can be evaluated by a non-verbal oral-DDK tasks as well, such as rounding and spreading the lips, and moving the tongue from side to side (Hartelius & Lillvik, 2003). Yet, as the set of syllables in the verbal version of the oral-DDK reflects different places of articulation (bilabial, alveolar and velar), fast and accurate repetitions indicate better control of consonant articulation and speech performance.

The evaluation of speech-motor coordination using the oral-DDK is neither exact nor consistent without a comparison of individual performance to a validated set of norms. Nevertheless, it appears that such norms are missing from the pertinent literature. The current paper aims to rectify this by providing an analysis of existing findings, culled from the literature on English speakers, offering a norm for adult oral-DDK rates (Experiment 1). Moreover, as language and culture might impact articulation rates (see, Jacewicz, Fox, O'Neill, & Salmons, 2009) it is not clear whether an English-based norm suffices, or is there a need to generate norms specific for each different language. For that end, the current study (Experiment 2) also examines the possible impact of language (and culture) differences on the oral-DDK performance, as found in pertinent studies. Finally, we test native-Hebrew speakers (Experiment 3) and present a norm for adults, comparing it to the English one. This will serve to add a missing standard to the literature.[1] Moreover, oral-DDK performance in Hebrew can be taken as a test-case, because of its unique set of similarities and differences from the English language (see Section 1.4).

1.1. Oral-DDK – background

Oral-DDK is also known as Alternate Motion Rates (referring to rapid repetitions of a single syllable, /pa/, /ta/ or /ka/) or Sequential Motor Rates (rapid repetitions of a syllable sequence, such as /pataka/; Darley, Aronson, & Brown, 1975; Duffy, 1995). The rate of oral-DDK, defined as the rate of maximally rapid syllable repetition, is the most common measure of DDK performance and is a standard component of motor speech assessment (Bernthal, Bankson, & Flipsen, 2008). Typically, oral-DDK rate is either gauged by counting the number of repetitions produced in 10 s (or 5 s, 'count-by-time') or by measuring the time taken for producing ten repetitions (or any other number, 'time-by-count'; see, Fletcher, 1972; Kent et al., 1987). Each measure has its shortcomings and advantages (see Ben-David, van Lieshout, & Leszcz, 2011, for a discussion on averaging performance time in a selective attention task), and both are fairly used. Yet, one may note that the 'count-by-time' method presents a time constraint, which induces stress (see an example in emotional Stroop task, Ben-David, Chajut, & Algom, 2012). Some evidence suggests that this may improve the performance of people with speech disorders. For example, people who stutter had less events of disfluency under high time-stress as compared to low time-stress conditions (Peters, Hulstijn, & Starkweather, 1989).

1.1.1. Stimuli

Oral-DDK paradigms vary also in the choice of stimuli. Several different sound sequences were used in the oral-DDK task. The scope of this study does not permit us to review all of them. We focus on one sequence, /pataka/. The ability to accurately sequence these sounds is an important index in different linguistic systems, as they can be found in many langauges. These target sounds, all voiceless plosives, represent varying levels of physiological complexity, indicated by differences in the acquisition age and places of articulation (lips, tongue tip and tongue dorsum, see a detailed description by Ladefoged, 1993). This task assesses a vital ability – to program a sequence of speech movements rapidly and successively. In terms of cost-effectiveness within a therapy session, this task is quick and easy to perform and monitor. Importantly, it does not require any special equipment.

1.1.2. Oral-DDK as an index of speech/articulation rates

The simple nature of the oral-DDK task renders it an efficient first estimate for speech rates in the clinic (as well as a measure of oral-motor abilities). Speech (or speaking) rate is an index of articulatory functions, measured by counting the number of spoken units (words or syllables) over a given time (minutes or seconds), incorporating all forms of pauses, disfluencies and interruptions (Howell, Au-Yeung, & Pilgrim, 1999). Yet the relation between speech and Oral-DDK rates is

[1] The first author, who has been working as an SLP clinician in Israel for the past 15 years, can indicate from personal experience on the necessity of Hebrew (the main spoken language in Israel) norm for Oral-DDK performance.

somewhat debated in the literature. In an early study, Lass and Sandusky (1971) failed to demonstrate a strong association between Oral-DDK and speech rates, whereas later studies (Ackermann, Hertrich, & Hehr, 1995; Ziegler, 2002) found that DDK rates were highly correlated with speaking rate, as well as with other measures of speech impairment. Alternatively, one may relate oral-DDK performance specifically to articulation (rather than speaking) rate, a measure for fluent speech excluding disfluencies, long pauses or speech breaks (Hall, Amir, & Yairi, 1999). Indeed, the literature suggests that the factors influencing motor control for connected speech (e.g., kinematic properties) are fairly independent from the factors influencing oral-DDK rate (Flanagan & Dembowski, 2002; Ziegler, 2002).

1.1.3. Clinical use for the oral-DDK

Notably, the oral-DDK reflects neuromotor maturation and integration of the orofacial structures involved in speech, for instance tongue and lips (Baken & Orlikoff, 2000; Mason, Helmick, Unger, Gattozzi, & Murphy, 1977; Wang, Kent, Duffy, & Thomas, 2009). As such, it has been used to evaluate the presence and severity of neurological impairments. Inaccurate, inconsistent or an abnormal oral-DDK performance might indicate disorders of the central nervous system or peripheral sensory motor functions. Indeed, neurotrauma has been shown to impact DDK scores. For example, Wang, Kent, Duffy, Thomas, and Weismer (2004) found slower oral-DDK rates for persons with traumatic brain injury (TBI). They concluded that TBI can influence speech rate, and as a consequence impair communication (see a discussion on communication skills after TBI in Ben-David, van Lieshout, et al., 2011). Similarly, spinocerebellar ataxia (Schalling, Hammarberg, & Hartelius, 2007), Parkinson's disease and Friedreich's ataxia (both presenting orofacial motor impairments; Ackermann et al., 1995) were characterized with reduced oral-DDK scores.

1.1.4. Current study

A brief glance on the literature reveals that normative data for oral-DDK rates in English are available for children (aged 6–13 years, Fletcher, 1972; 4:6 to 14:6 years, Canning & Rose, 1974), yet such a baseline for adults (in the general healthy population) is unavailable for clinicians. Instead, studies examining performance in non-normative populations derive their own baselines for healthy performance based on study-specific control-group data (see Kent, 2008, for a review). Other studies provide a qualitative analysis of oral-DDK performance, rather than a quantitative one, due to the lack of general norms (Gadesmann & Miller, 2008). In the current paper (see Section 2), we analyze oral-DDK data collected from the literature for English speakers. To generate a normative baseline that can be used in the clinic, we focus on individuals without any neuro-motor deficits or oral structure impairments. However, such deficits do not form the only cause for changes in oral-DDK performance. In the next sections we examine demographic factors, such as age and gender, and socio-demographic factors, such as language and culture, as other possible sources for variations of performance in this task.

1.2. Demographic factors: gender and age-related differences in oral-DDK scores

1.2.1. Gender effect

Will gender have an impact on articulation rates? On one hand, gender appears to be related to speech fluency, with higher prevalence of stuttering among males (McKinnon & McLeod, 2007). On the other hand, in a meta-analysis of 165 studies, Hyde and Linn (1988) conclude that gender differences do not exists in tasks measuring verbal abilities including speech production (for speaking and articulation rates in non-clinical population, see Tsao & Weismer, 1997). Indeed, in studies examining articulation rates by the oral-DDK, no gender differences were noted (Lass & Sandusky, 1971; Ptacek, Sander, Maloney, & Jackson, 1966; Robb, Hughes, & Frese, 1985; Topbas, 2010). Given the aforementioned evidence, as the first step of analyses in the current paper (prior to pooling studies), we verified that gender does not impact on oral-DDK rates. As a consequence, we analyzed the data in each study, averaged across gender-groups (see Sections 2.1, 3.1 and 4.2). As the next step, we ensured that age-ranges in the culled studies also did not have an impact on the analysis as discussed next.

1.2.2. Age-related effects

It is not surprising to find that speech and articulation rates change across the life span. As children develop, they acquire new motor abilities, including speech. These abilities gradually maturate, expressed by increased speed and consistency of performance. These changes are noted to stabilize at around the age of 8–11 years (Kent & Former, 1987), and by the age of 15 years, adult-like oral-DDK rates are achieved (Fletcher, 1972). On the other extreme, in adult aging (65 years old and above) both the speed of processing (Cerella & Hale, 1994) and motor speed (Salthouse & Earles, 1996) are noted to slow down (see a discussion in Ben-David & Schneider, 2009, 2010). To avoid these noted age-related changes (both in younger and older age) this study is limited to speakers aged 15–65 years of age.

In sum, for healthy adult speakers (15–65 years old), demographic variables most likely do not alter articulation rates, as measured by the oral-DDK. Yet, socio-demographic variables, such as language and culture, may still have an impact on oro-motor performance, as discussed next.

1.3. Socio-demographic factors: culture and cross-language differences in oral-DDK scores

Culture has a vast impact on the speed of performance. A series of famous studies by Robert Levine suggests that the pace of life, as examined across different behaviors (including speech rate), varies across cities, countries and cultures

(Levine, 1999). In a similar vein, languages and dialects were found to affect the rate of speech in various ways. For example, Jacewicz et al. (2009) found faster articulation rate for northern USA English speakers (Wisconsin) than for southern speakers (North Carolina). Similarly, Byrd (1994) demonstrated differences in speech rate (using the TIMIT database) across eight broadly defined dialect regions in the US. Examining speech rates by radio newscasters also indicates possible differences across languages and cultures. For instance, in Hebrew, an average of 5.5 syllables/s was reported (Finkelstein & Amir, 2013), whereas in Portuguese, a nominally faster speaking rate of 5.86–6.00 syllables/s was found (Castro, Serridge, Moraes, & Freitas, 2010).

This influence of culture and region on articulation rates can be linked to cross-language (and cross-dialect) variation in segmental speech structures, as well as non-segmental features. First, consider *segmental structures*. The frequency of phonemes may vary across languages (Maddieson, 2013), and the different frequency within a specific language can impact the ease and accuracy of their rapid articulation, where common phonemes may be pronounced faster and more accurately than less common ones. There are several phonemes frequent in some languages (e.g., the fricative [x] in Hebrew, Farsi, Arabic and Dutch), which are totally absent from the consonant inventories of English (Pye, Ingram, & List, 1987). Moreover, phoneme clusters in the initial position of syllables, which are common in English, do not exist in other languages (e.g., Farsi; Seifpanahi, Dadkhah, Dehqan, Bakhtiar, & Salmalian, 2008). Language differences in segmental structures might have a direct impact on the specific production of the /pataka/ sequence, as tested in the oral-DDK task. The English language contrasts the voiceless stops (/p, t, k/) in aspiration in initial position. This is true for most Germanic languages (e.g., Danish and German). Other "true voice" languages (such as Hebrew, Russian, and Polish) exhibit no aspiration and have prevoicing in initial stops (see a review in: Helgason & Ringen, 2008).

Second, consider differences in *non-segmental features*, including syllable and word structure (Laver, 1994). Different languages use different combinations of consonants and vowels for creating syllables and words (as well as different syntactic rules, for creating sentences). Such language-dependent features directly affect speaking rate and may impact oral-DDK rates as well. A common oral-DDK sequence is made of a string of three syllables. As the frequency of trisyllabic words varies across languages (e.g., higher in Spanish than in French; Lleó & Demuth, 1999) spoken language may alter oral-DDK scores. Furthermore, it is not clear how to compare the rate of speech in tonal languages (such as Thai and Cantonese/Mandarin), where different tones alter the meaning of words, to non-tonal languages (such as almost all of the European languages), where word meaning is mainly based on segmental features (Prathanee, Thanaviratananich, & Pongjanyakul, 2003). As a consequence this study focuses on non-tonal languages only.

The evidence presented above suggests that oral-DDK scores might vary across spoken languages. However, only scant literature is available concerning the performance of speakers of different languages (i.e., other than English), and no comparison of performance across languages has yet been offered for clinicians. Consequently, the second goal of this paper is to further examine cultural differences on this task. Section 2.2 presents a review of existing literature and offers insights on the impact of cultural difference on the oral-DDK measure. In the next section we present Hebrew as a test-case for the effect of culture and language.

1.4. Oral-DDK – Hebrew norms

Hebrew is a West Semitic language of the Afro-Asiatic language family. It is the most commonly spoken language in Israel, with an estimate of over 5 million speakers worldwide (Paul, Simons, & Fennig, 2013). Modern Hebrew pronunciation includes 23 voiced and voiceless consonants (stops, fricatives, affricatives, nasals, approximants and lateral) and five vowels. Among the unique phonological features of Hebrew, one can find a rich word-initial consonant clusters system. Hebrew has also an identifiable supra-segmental feature, with two main kinds of stress: on the last syllable and on the penultimate syllable (the one preceding the last), that can change the meaning of a word. That is, the trisyllable /pataka/ tested in the oral-DDK is most commonly pronounced with a stress on the /ta/ or the /ka/, possibly changing articulation rate. Moreover, the trisyllable /pataka/ is similar in its structure to many Hebrew words, as it includes a pseudo-consonantal root (e.g., /XaZaKa/, /DaXaFa/ *strong* and *pushed*). In Hebrew morphology, the consonantal root carries the core meaning of many words, appearing in other semantically related words that differ in their phonological pattern (Frost, Forster, & Deutsch, 1997). The similarity of the sequence /pataka/ to a common morphological structure increases the external validity of this test in Hebrew, as it closely mimics speech (while preserving the non-verbal quality of the string).

Speech measurements in Hebrew can be related to performance in West Semitic language family including Ethiopic, South Arabian (often grouped as South Semitic) and Arabic – widely used across the middle-east and northern Africa. Current evidence on the rate of oral performance among Hebrew speakers is limited (see a pair of examples for speech rate study in Hebrew in: Amir & Grinfeld, 2011; Finkelstein & Amir, 2013). The only study examining oral-DDK in Hebrew so far (Icht, Maltz, & Korecky, 2013) was limited in its scope. Clearly, more research of oral-DDK performance is important, as a means of validating the existing results and offering normative data suitable for a clinical use for Hebrew speakers. Consequently, the third goal of this paper was to establish a standard for oral-DDK performance in Hebrew for non-pathological adults.

Finally, Hebrew in this study served as a test-case for non-tonal non-Germanic languages. Similarities between oral-DDK rates in English and Hebrew can hint on the possibility to generalize English standard rates to other languages, when no other standard is available. On the other hand, a significant difference between the two, serves to caution from using English-based standards for oral-DDK with speakers of other languages. As language-based standards are scarce, this test-case can make clinical evaluations in non-English communities more knowledgeable.

Table 1
Data extracted from the five studies used in the analysis of native English speakers. Oral-DDK rate is given as syllables/second.

Study	No. of participants	Age range (in years)	Oral-DDK rate	
			Mean	SD
Icht et al. (2013)	10 (5 males)	20–43, $M = 31.8$	6.15	1.03
Lass and Sandusky (1971)	40 (20 males)	19–28, $M = 21$	6.3	.36
Ptacek et al. (1966)	62 (31 males)	18–39[a]	6.05	.88
Robb et al. (1985)	5 (3 males)	15–18, $M = 16.1$	6.25	.21
Topbas (2010)	24 (12 males)	20–29, $M = 22.8$	6.55	.94
Weighted average for English	*141 (70 females)*	*15–43*	*6.23*	*.82*

[a] We were not able to obtain the average age for this study.

1.5. Current study

The oral-DDK is a simple task that can easily be used in the clinical environment to gauge oral-motor abilities. As such, it is widely used by Speech-Language Pathologists across the world. Oral-DDK scores are useful in detecting several neuro-motor speech disorders, as well as a measure for progress and improvement of oro-facial functions within therapy. However, it appears that this tool is understudied and normative data are missing. In the current study, we first examined the literature on oral-DDK for English speakers and established a norm for healthy young adults. In the second step, we investigated the impact of language on oral-DDK norms. We culled oral-DDK studies across three different languages, and compared them to the English sample. In the third step, we generated normative data for Hebrew-speaking young adults, and suggest a standardized administration protocol.

2. Analysis of oral-DDK for English speakers

The goal of this section was to establish a norm for oral-DDK for English speakers by reviewing data available in the literature. In order to focus our analysis, we examined only data for healthy adults. We found data in five different studies conducted in different labs, all taken from native speakers residing in the USA.

2.1. Method

Studies were collected (in January 2013) by consulting electronic databases (PubMed and Scopus), and by reviewing the references in the retrieved articles. We selected only studies that included data for: (1) healthy young-middle aged adults (15–65 years old); (2) native English speakers, all residents of the USA; and (3) a sequential motion rate task, with the specific syllable sequence /pataka/. We note the importance of the instructions given to participants, but unfortunately, these were not reported in most of the studies. Due to the simple nature of the oral-DDK task, we did not exclude studies for this criterion. The five studies that met these criteria are listed in Table 1. From each of these studies, we retrieved data to represent one group of participants. These groups include a total of 141 participants.

2.1.1. Averages

The data were averaged to represent the mean oral-DDK rate in a count-by-time scale for one group representing each of the studies. In one study (Robb et al., 1985), the data were reported in a time-by-count scale, and they were converted to a count-by-time scale. Specifically, as the data was available as the time it takes (in s) for ten repetition of the trisyllable sequence (=30 syllables), we performed the following transformation: oral-DDK (syllables/s) = 30/reported average time. In the other four studies, we used the reported averages, which represent the mean number of syllables per second.

2.1.2. Standard deviations

In four of the studies, we used the reported standard deviations. In Robb et al. (1985), SDs were reported in a time-by-count scale, and were converted to a count-by-time scale as follows: the converted count-by-time means were multiplied by the original ratio between the SD and the mean, in order to preserve the original coefficient of variation (see Ben-David, Nguyen, & van Lieshout, 2011, for a similar transformation). That is,

$$\text{Estimate-of-SD}_{\text{count-by-time}} = \frac{M_{\text{count-by-time}} \times \text{SD}_{\text{time-by-count}}}{M_{\text{time-by-count}}} \quad (1)$$

2.1.3. Gender effect

In four of the studies (Icht et al., 2013; Lass & Sandusky, 1971; Ptacek et al., 1966; Topbas, 2010), data were given separately for male and female speakers. As expected, no gender-differences were found, using meta-analysis statistics (gender effect was non-significantly different than zero, $-.41 < 95\%\ \mathrm{CI} < .27$).[2] Thus, we averaged data across gender groups, means are given as weighted mean averages, and standard deviations are given as S_{pooled} (2):

$$S_{\text{pooled}} = \sqrt{\frac{(S^2_{\text{male}} \times (N_{\text{male}} - 1)) + (S^2_{\text{female}} \times (N_{\text{female}} - 1))}{N_{\text{male}} + N_{\text{female}} - 2}} \tag{2}$$

2.2. Results and discussion

First, we verified that all studies could be taken to represent the same population of native English speakers in a one-way ANOVA ($F(4, 137) = 1.78$, $p > .05$). Second, we ensured that the age-range of speakers presented by Robb et al. (1985; 15–18 year old) did not bias the data (in a one-way post hoc t-test, comparing Robb et al. to the weighted mean of all other studies, $t < .5$). Thirdly, we calculated the weighted average across five groups as 6.23 syllables/s with a pooled standard deviation of .82 syllables/s. These averages can be used as a benchmark for clinicians, taking a confidence interval of 95% to be 4.6–7.85 syllables/s. Yet, one should bear in mind that speech involves highly complex mechanisms. As it includes the planning of accurate and rapid movements, the execution of such movement plans, and finally muscles contractions and structural displacements, speech can be impacted by a variety of factors (Kent, 2000). Accordingly, minor variations from the mean oral-DDK rate may have clinical implications. For that reason, we suggest considering a more conservative range of 5.4–7.05 syllables/s representing the mean ± 1 SD. In other words, a rate slower than 4.6 (or in some cases, even 5.4) syllables/s should be carefully examined as a possible indicator (among a battery of tests) of oro-facial dysfunction.

3. Analysis of cultural differences

In the previous section, we set a norm for USA-English adult oral-DDK rates. Here, we tested whether clinicians worldwide can use this norm, or should they adopt separate norms for each language/culture. Broadly speaking, does the oral-DDK test represent a general anatomically-physiologically based ability, or is it impacted by the language (the phonetic system) a person uses? For that end, we added to the sample of USA-English studies presented above, oral-DDK studies in three other languages: Portuguese, Greek and Farsi, as found in the literature and met our inclusion criteria. These samples reflect cultural and not only language-based differences. Following Hofstede's cultural dimensions theory (Hofstede, 2001), one can note various differences between these cultures on various of Hofstede dimensions such as differences on the "individualism vs. collectivism" dimension, encompassing the degree to which individuals are integrated into groups, which may, in turn, affect speaking rate. For example, silence in speech creates tension in some cultures such as Germany and is thus tried to be avoided, while it is used as a sign of respect in Japan (a more collectivistic culture) where it is consciously used (Ting-Toomey, 1999). Indeed, Endrass (2012) analyzed 5 min recorded conversations in several languages and found that pauses lasting for over 2 s occurred more often in Japanese (9.18 times) compared to German (0.52 times). Such cultural differences may be expressed in oral-DDK rates as well.

3.1. Method

Data collection replicated that described in Section 2.1, with a single change, instead of selecting data for native English speakers we selected data for groups of native speakers of other languages. These groups include a total of 140 participants, collected from five studies conducted in three different countries (using respective languages), and the mean of five studies (presenting 141 participants) conducted in USA English taken from Section 2.2. See Table 2 for details.

3.1.1. Means

Data processing followed Section 2.1. As we were able to obtain three different studies that collected data for native Portuguese speakers, we include a weighted average of the three in Table 2. That is,(3)$M_{\text{weighted}} = \frac{1}{N_{\text{tot}}} \times \sum_{i=1}^{n} N_i \times M_i$

When data were reported in a time-by-count scale (Seifpanahi et al., 2008), they were converted to a count-by-time scale (see Section 2.1).

3.1.2. Standard deviations

In three studies (Konstantopoulos, Charalambous, & Verhoeven, 2011; Meurer, Osório Wender, von Eye Corleta, & Capp, 2004; Padovani, Gielow, & Behlau, 2009) no standard deviations were given in the original publication. In order to include these studies in our analysis, we estimated their standard deviations, based on the pooled SD (see Eq. (2)) calculated across all of the studies (following Furukawa, Barbui, Cipriani, Brambilla, & Watanabe, 2006; $SD_{\text{pooled}} = .85$ syllables/s).[3]

[2] To verify effects sizes, weighing-in the variance of the means within each study and the number of participants, the analysis of gender-differences was performed by a meta-analysis of standardized effect sizes, with a syntax developed by Alferes (2003).

[3] Note that we adopted the assumption of equality of variance between studies, given our inclusion criteria (e.g., non-pathological population).

Table 2
Data extracted from the studies used in our analysis.

Study	Language (country)	No. of participants	Age range (in years)	Oral-DDK rate	
				Mean	SD
Padovani et al. (2009)	Portuguese (Brazil)	23 (14 females)	30–46, $M = 35$	.85[b]	6.58
Meurer et al. (2004)		45 females	30–40, $M = 35$	.85[b]	6.3
Louzada et al. (2011)		30 females	19–54[a]	1.05	6.87
Weighted average		*98 (81 females)*	*19–54*	*.91*	*6.54*
Konstantopoulos et al. (2011)	Greek (Greece)	27 (gender not provided)	20–65, $M = 35$	.85[b]	6.97
Seifpanahi et al. (2008)	Farsi (Iran)	15 males	15–18[a]	.52	7.12
Weighted average of English (Table 1)	*English (USA)*	*141 (70 females)*	*18–43*	*.82*	*6.23*

[a] We were not able to obtain the average age for these studies.
[b] SDs were calculated based on the SD-pooled of all the other studies.

3.1.3. Gender effects

None of the international studies provided averages separately for male and female speakers. As Section 2.1 describes the lack of gender affects in the English sample of studies, we assume the same effects occur here.

3.2. Results and discussion

In a one-way ANOVA of oral-DDK rate, with language as a between-samples factor (four languages: Portuguese, Greek, Farsi and English), we found a significant difference between the four languages ($F\,(3, 277) = 10.21$, $p < .001$, $\eta^2 = .11$). To ensure that this difference was not artificially manufactured by our estimate of variance, we replicated the ANOVA with a smaller set of two non-English studies that provided original standard deviations (Louzada, Beraldinelle, Berretin-Felix, & Brasolotto, 2011 and Seifpanahi et al., 2008, in Portuguese and Farsi, respectively) and the English set from Section 2. Again, we found a significant language difference ($F(2, 183) = 13.44$, $p < .001$, $\eta^2 = .15$). We also note that the data by Seifpanahi et al. (2008) might have biased the analysis, as it only includes younger adults, aged 15–18 years old. To ensure this language-related difference was not generated by this single study, we replicated the ANOVA with a set that does not include Seifpanahi et al., and again found the same significant language-difference ($F(2, 263) = 10.1$, $p < .001$, $\eta^2 = .08$). Finally, in post hoc (Bonferroni corrected for six possible comparisons) paired t-tests, we found means on Farsi, Greek and Portuguese to be each significantly different than the average mean in the English sample (Greek: $t(166) = 4.32$, $p < .001$; Portuguese: $t(237) = 2.8$, $p = .03$; Farsi: $t(153) = 4.16$, $p < .001$).

Our findings suggest that one universal oral-DDK norm (USA English) *cannot* be a priori used across languages and cultures. Without assessing the fit of the English norm to the tested language, it may bias the diagnosis of patients. Namely, a rate that is considered within the normal range for English speakers might be slow relative to a different language-based range. Oral-DDK performance, at least in this sample, appears to be impacted by differences in language (or culture). It is, therefore, important to set language-specific norms that can meet the needs of the clinical practice, as done in the next section in Hebrew.

4. Oral-DDK Hebrew norms

The main goal of this section was to examine oral-DDK rates in native Hebrew-speaker adults and establish norms that can be reliably used by clinicians in Israel. For this end, we recruited a large sample of 115 Hebrew speakers. Furthermore, in this data set we could replicate analysis on the possible impact of demographic variables on oral-DDK rates. Note, in the previous analyses we averaged data across these factors, as specific information was not available in all the collected studies. Finally, collecting a large set of oral-DDK rates for native Hebrew speakers can serve as a test-case for other non-English languages.

4.1. Method

4.1.1. Participants

One hundred and fifteen (53 males) young-middle aged adults (age range 20–45 years old, $M = 31.4$, SD = 6.5 years) participated in the study. They were Israeli university undergraduates, or their peers, and received either course credit or volunteered for the study. All participants were native Hebrew speakers, as assessed by a self-report and by an interview with Speech-Language Pathology students. None of the participants suffered from neurological disease, abnormal oral structure/function, or phonetic (articulation) disorder, as confirmed by a questionnaire. The study was approved by the local ethics committee, and informed consent was obtained from each participant.

4.1.2. Apparatus, procedure and analysis

The participants were tested individually in a quiet room in a university's clinic. Upon arrival, each participant read and signed the informed consent form. Next, the oral-DDK task was demonstrated to each participant by the examiner, and he or she was allowed to practice the task for 1 min. Next, the participants were asked to repeat the trisyllable /pataka/, as fast and accurate as they can for 10 s. Count-by-time oral-DDK rates were audio-recorded for each participant, using a Sony ICD-PX312 digital recorder placed on a table, 15 cm from the participant's mouth. The whole session (including informed consent and debriefing) lasted approximately 10 min.

Oral-DDK rate (syllables/s) was calculated by multiplying the total number of trisyllables produced by each participant in 10 s by 0.3. In case that a trisyllable was only partially completed by the time 10 s elapsed, it was excluded. Counting was performed manually from the digital recordings by two experienced Speech-Language Pathologists. When the two did not agree on a specific sample, it was recounted by both until a consensus was reached.

4.2. Results and discussion

As a first step, we found that gender did not have a significant impact on oral-DDK rates in this sample ($t < 1$) with averages highly similar across gender groups ($M = 6.4$ and 6.3 syllables/s for females and males, respectively). Next, we did not find an impact of age on oral-DDK rates, neither in a bivariate correlation ($r = .12$, $p > .5$) nor when age range was divided into two similar-sized groups (60 participants in a 20–30 years old group, and 55 participants in a 31–45 years old group; $t < 1$). Ruling out these factors, the average of the sample was set at 6.37 syllables/s (SD = .8). This average can serve for clinical use by Speech-Language Pathologists, considering a confidence interval of 95% to be approximately 4.8–7.9 syllables/s, or a conservative confidence interval (with 1 SD around the mean) of 5.6–7.2 syllables/s. These boundaries are highly similar to the English ones reported in Section 2. Indeed, the averages of the two samples were not significantly different (t (254) = 1.37, $p = .16$) and the variance of the two samples appears to be highly similar as well.

In sum, after taking a large sample of Hebrew speakers, their oral-DDK performance does not vary from the English norm. Even though language can potentially have an impact on oral-DDK rates, this is absent in a Hebrew–English comparison. It appears that English norms can be adapted to the Hebrew-speaker populations. To further facilitate accurate comparison between labs and clinics, in Appendix A we suggest a detailed administration protocol for the oral-DDK task in Hebrew that was used to reach the norm reported in this section.

5. General discussion

Oral-DDK tasks are widely used in both research and clinical contexts for the assessment of coordination of a patient's phonatory and articulatory systems. These tasks present a sensitive measure of motor impairments involving the muscular system required for speaking. They have been implemented by Speech-Language Pathologists in various standard assessment protocols, as one of the tools to evaluate a variety of pathologies. Indeed, the oral-DDK paradigm is quick and easy to perform, and does not require any special equipment. The most common oral-DDK measure is the *rate* of correctly producing syllables. Pathological performance is indicated when the rate for an individual is slower than the norm. Yet, to date there is no single general benchmark for non-pathological performance for adults (while this kind of baseline is available for children, Canning & Rose, 1974; Fletcher, 1972). Instead, each study and clinic adopts its own baseline rate.

5.1. English norm

In the current study we sought to rectify this by focusing on one version of the task, rapid repetitions of the trisyllable sequence /pataka/ (sequential motion rate task, Darley et al., 1975; Duffy, 1995). We analyzed data from available five studies, with a sample of 141 adult native (USA) English speakers, conducted in different labs. We suggest a norm of 6.2 syllables/s. Considering the variance in the sample, we offer a lower boundary for non-pathological performance of 4.6 syllables/s (or 5.4 syllables/s, for a more conservative boundary). Rates slower than the boundary should be further examined as a possible indicator of pathology. By using this norm, Speech-Language Pathologists can better assess performance of English speakers and relate their local result with a larger sample of speakers. The relatively low variance found in our sample of studies (SD = 0.82 syllables/s) suggests that our English norm can reliably represent the oral-motor abilities of (non-pathological) native English adult speakers. We hope that our analysis and new baseline may encourage clinicians to use oral-DDK as a diagnostic index of speech impairments, and as a measure of progressing within therapy, in English speaking countries and world-wide as discussed next.

5.2. Between-language differences

Following the examination of the performance of English speakers, we found that the oral-DDK measure is sensitive to variations in language (and potentially culture). We reviewed five studies that provided oral-DDK data in three other languages (Portuguese, Greek and Farsi) with 140 participants, alongside the English sample (141 participants). A significant variation between languages was found, suggesting that language may be an important factor in the rate of syllable production. It appears that an oral-DDK rate does not only represent a physiological ability, but also a culturally-bound trait. Consider the syllable /ta/, which is widely used in oral-DDK tasks. Its articulation (the point of constriction on the tongue) varies across languages, in French /t/ is apical-dental, while the matching English consonant is apical-alveolar (Dart, 1998). Moreover, even dialects or accents may insert additional variation in oral-DDK rate. Recasens (2010) reported that several front lingual consonants (such as /t/) show differences in constriction anteriority between different Catalan dialects (Valencian, Eastern and Majorcan). These different articulatory characteristics, for different tongue front settings, may result in variations in oral-DDK rate, using the /pataka/ sequence. Clinicians and researchers should bear in mind these possible cross-cultural differences.

The cross-language differences reported may reflect a real impact of language. Yet, we must acknowledge that the studies culled for the cross-language sample included only a limited number of participants (e.g., 27 in Greek, and 15 in Farsi). One cannot reject the option that a portion of this cross-language variation results from a statistical bias, where averages of small samples do not reliably represent the average of the population. It is also feasible that the English norm can be used in other languages, given similarity in culture and in the articulation rate of the specific trisyllabic sequence. Accordingly, we stress the importance of testing oral-DDK performance in different languages and dialects, setting language- and culture-sensitive norms.

5.3. Hebrew norm

Following the above findings, we examined a large scale sample of 115 native-Hebrew speakers. Mean oral-DDK rate was highly similar to the English norm (no significant difference), and so was the variance of the sample. This suggests that the same norms and thresholds, established for English speakers, can be used with Hebrew speakers as well. The semblance between English and Hebrew production-rates can reveal similarities in articulation specific to these two languages, or similarity between the two cultures. Indeed the Hebrew and the English samples were based on university students and their peers, relating to a western educated and industrialized culture (see a discussion in Jones, 2010). These results merit replication in future studies, as our study forms the first attempt (to the best of our knowledge) to compare rates of articulation for Hebrew speakers with speakers of other languages.

5.4. Demographic factors

Using this sample of Hebrew speakers, we were also able to rule out the gender factor as a possible contributor to the oral-DDK rate, as averages for men and women were highly similar. This result echoes the literature, as gender does not appear to play a significant role in speech production (e.g., Lass & Sandusky, 1971; Ptacek et al., 1966; Topbas, 2010). Interestingly, no gender-effects were found in studies examining oral-DDK in children as well (Fletcher, 1972; Modolo, Berretin-Felix, Genaro, & Brasolotto, 2011). Similarly, in the chosen age range, 15–65 years old (young to middle age) we found no effect for age.

6. Conclusions

Oral-DDK is a clinically appropriate tool for Speech-Language Pathologists to assess the coordination of a patient's phonatory and articulatory abilities, without the use of expensive equipment or invasive clinical protocols. Yet, the lack of performance norms limited the proper use of this tool, for both clinical and research procedures. This study offers norms in English as well as in Hebrew for oral-DDK rates (in young to middle-aged adults) that can be used in both clinical and experimental contexts. Even though we found similarities between the Hebrew and English norms, we note an impact of other languages on oral-DDK performance, stressing the need for further research, setting language-specific norms for the oral-DDK. Our study also clearly rules out gender effects on the oral-DDK performance. Finally, we wish to stress the need for cultural adaptation (as suggested in Appendix A) and careful validation, before one "imports" a clinical tool across languages and cultures (see a discussion in Greenfield, 1997).

Conflict of Interest Statement

The authors of this manuscript are employed by their respective institutions and have no relevant financial or nonfinancial relationships to disclose.

Appendix A

Recommended administration protocol

It is advisable to test each patient individually, in a quiet room. The oral-DDK task should be explained and demonstrated by the examiner, saying: "I will now evaluate the function of your lips and tongue, and your ability to move them fast and accurate, which is important for speech production".

"אבדוק כעת את תפקודם של הלשון והשפתיים שלך, ואת יכולתך להניעם במהירות ובדייקנות, יכולת החשובה להפקת דיבור" .

The speaker should be allowed to practice the task repeating the trisyllable /pataka/ (פה-תה-קה) as fast and accurate as they can for as much as 1 min. The examiner can provide feedback to facilitate performance. Once the speaker feels comfortable with the task, he or she will be asked to perform it for 10 s, while the examiner audio-recording it.

Oral-DDK rate (syllables/s) will be calculated by multiplying the total number of trisyllables produced by the patient (in 10 s) by 0.3. In case that a trisyllable was only partially completed, it should be excluded. We suggest that counting will be performed manually from the recording by an experienced Speech-Language Pathologists.

Appendix B. Continuing education

1. What is the main clinical limitation of oral-DDK task in the SLP clinic?
   A. Lack of normative data
   B. The task administration requires special equipment
   C. The task is considered long and difficult to perform
   D. There is a high between-subject variation of oral-DDK performance in most patient groups
2. The most commonly used measure of oral-DDK task is –
   A. Accuracy of articulation
   B. Rate (syllables per second)
   C. Syllable duration (in ms)
   D. Consistency of performance
3. True or false: There are gender differences in the oral-DDK task performance.
4. True or false: There are cultural (language) differences in the oral-DDK performance.
5. What type of oral-DDK rate should be carefully examined as a possible indicator for oro-facial dysfunction?
   A. Higher than the high threshold
   B. Lower than the low threshold
   C. Equal to the mean
   D. There is no need to compare performance to a norm

References

Ackermann, H., Hertrich, I., & Hehr, T. (1995). Oral diadochokinesis in neurological dysarthrias. *Folia Phoniatrica et Logopaedica, 47*(1), 15–23 http://dx.doi.org/10.1159/000266338

Alferes, V. (2003). *Meta-analysis: Fixed and random effects models*. Retrieved from http://www.spsstools.net.

Amir, O., & Grinfeld, D. (2011). Articulation rate in childhood and adolescence: Hebrew speakers. *Language and Speech, 54*(2), 225–240.

Baken, R. J., & Orlikoff, R. F. (2000). Speech movements. In R. J. Baken & R. F. Orlikoff (Eds.), *Clinical measurement of speech and voice* (2nd ed., pp. 511–557). San Diego: Singular Thomson Learning.

Ben-David, B., Chajut, E., & Algom, D. (2012). The pale shades of emotion: A signal detection theory analysis of the emotional Stroop task. *Psychology, 3*, 537–541 http://dx.doi.org/10.4236/psych.2012.37079

Ben-David, B. M., & Schneider, B. A. (2009). A sensory origin for color-word Stroop effects in aging: A meta-analysis. *Aging, Neuropsychology and Cognition, 16*, 505–534.

Ben-David, B. M., & Schneider, B. A. (2010). A sensory origin for aging effects in the color-word Stroop task: Simulating age-related changes in color-vision mimic age-related changes in Stroop. *Aging, Neuropsychology and Cognition, 17*(6), 730–746.

Ben-David, B. M., Nguyen, L. L., & van Lieshout, P. H. (2011). Stroop effects in persons with traumatic brain injury: Selective attention, speed of processing, or color-naming? A meta-analysis. *Journal of the International Neuropsychological Society, 17*(2), 354–363 http://dx.doi.org/10.1017/S135561771000175X

Ben-David, B. M., van Lieshout, P. H., & Leszcz, T. (2011). A resource of validated affective and neutral sentences to assess identification of emotion in spoken language after a brain injury. *Brain Injury, 25*(2), 206–220 http://dx.doi.org/10.3109/02699052.2010.536197

Bernthal, J. E., Bankson, N. W., & Flipsen, P. (2008). *Articulation and phonological disorders* (6th ed.). Boston, Mass: Allyn & Bacon Pub.

Byrd, D. (1994). Relations of sex and dialect to reduction. *Speech Communication, 15*, 39–54.

Canning, B. A., & Rose, M. F. (1974). Clinical measurement of the speed of tongue and lip movements in British children with normal speech. *British Journal of Disorders of Communication, 9*, 45–50.

Castro, L., Serridge, B., Moraes, J., & Freitas, M. (2010). The prosody of the TV news speaking style in Brazilian Portuguese. *Proceedings of Experimental Linguistics, ExLing, 2010*, 17–20.

Cerella, J., & Hale, S. (1994). The rise and fall of information processing rates over the life span. *Acta Psychologica, 86*, 109–197.

Darley, F. L., Aronson, A. E., & Brown, J. R. (1975). *Motor speech disorders*. Philadelphia: WB Saunders.

Dart, S. N. (1998). Comparing French and English coronal consonant articulation. *Journal of Phonetics, 26*, 71–94.

Duffy, J. R. (1995). *Motor speech disorders: Substrates, differential diagnosis, and management*. St. Louis Mosby.

Endrass, B. (2012). *Cultural diversity for virtual characters: Investigating behavioral aspects across cultures.* (Ph.D. thesis) Germany: Augsburg University.

Finkelstein, M., & Amir, O. (2013). Speaking rate among professional radio newscasters: Hebrew speakers. *Studies in Media and Communication, 1*(1), 131–139.

Flanagan, K. P., & Dembowski, J. S. (2002). Kinematics of normal lingual diadochokinesis. *Journal of the Acoustical Society of America, 111*, 2476.

Fletcher, S. G. (1972). Time-by-count measurement of DDK syllable rate. *Journal of Speech and Hearing Research, 15*, 763–770.

Frost, R., Forster, K. I., & Deutsch, A. (1997). What can we learn from the morphology of Hebrew: A masked priming investigation of morphological representation. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 23*, 829–856.

Furukawa, T. A., Barbui, C., Cipriani, A., Brambilla, P., & Watanabe, N. (2006). Imputing missing standard deviations in meta-analyses can provide accurate results. *Journal of Clinical Epidemiology, 59*(1), 7–10.

Gadesmann, M., & Miller, N. (2008). Reliability of speech diadochokinetic test measurement. *International Journal of Language and Communication Disorders, 43*(1), 41–54.

Greenfield, P. M. (1997). You can't take it with you: Why ability assessments don't cross cultures. *American Psychologist, 52*(10), 1115–1124.

Hall, K. D., Amir, O., & Yairi, E. (1999). A longitudinal investigation of speaking rate in preschool children who stutter. *Journal of Speech, Language, and Hearing Research, 42*, 1367–1377.

Hartelius, L., & Lillvik, M. (2003). Lip and tongue function differently affected in individuals with multiple sclerosis. *Folia Phoniatrica et Logopaedica, 55*(1), 1–9.

Helgason, P., & Ringen, C. (2008). Voicing and aspiration in Swedish stops. *Journal of Phonetics, 36*(4), 607–628.

Hofstede, G. (2001). *Culture's consequences: Comparing values, behaviors, institutions and organizations across nations* (2nd ed.). Thousand Oaks, CA: SAGE Publications.

Howell, P., Au-Yeung, J., & Pilgrim, L. (1999). Utterance rate and linguistic properties as determinants of lexical dysfluencies in children who stutter. *Journal of the Acoustical Society of America, 105*, 481–490.

Hyde, J. S., & Linn, M. C. (1988). Gender differences in verbal ability: A meta-analysis. *Psychological Bulletin, 104*, 53–69.
Icht, M., Maltz, D., & Korecky, O. (2013). Diadochokinetic rate in young and elderly Hebrew speakers. *The Israeli Journal of Language, Speech & Hearing Disorders, 32*, 69–80,. (Hebrew).
Jacewicz, E., Fox, R. A., O'Neill, C., & Salmons, J. (2009). Articulation rate across dialect, age, and gender. *Language Variation and Change, 21*(2), 233–256 http://dx.doi.org/10.1017/S0954394509990093
Jones, D. (2010). A WEIRD view of human nature skews psychologists' studies. *Science, 328*(5986), 1627 http://dx.doi.org/10.1126/science.328.5986.1627
Kent, R. D. (2000). Research on speech motor control and its disorders: A review and prospective. *Journal of Communication Disorders, 33*(5), 391–427.
Kent, R. D. (2008). Perceptual sensorymotor speech examination for motor speech disorders. In M. R. McNeil (Ed.), *Clinical management of sensorimotor speech disorders* (pp. 19–29). New York: Theime.
Kent, R. D., & Former, L. L. (1987). Speech segment duration in sentence recitation by children and adults. *Journal of Phonetics, 8*, 157–168.
Kent, R. D., Kent, J., & Rosenbek, J. (1987). Maximal performance tests of speech production. *Journal of Speech and Hearing Disorders, 52*, 367–387.
Konstantopoulos, K., Charalambous, M., & Verhoeven, J. (2011). Sequential motion rates in the dysarthria of multiple sclerosis: A temporal analysis. *The 17th international congress of phonetic sciences (ICPhS XVII)*.
Ladefoged, P. (1993). *A course in phonetics* (3rd ed.). Fort Worth, TX: Harcourt Brace and Jovanovich.
Lass, N. J., & Sandusky, J. C. (1971). A study of the relationship of diadochokinetic rate, speaking rate and reading rate. *Today's Speech, 19*(3), 49–54.
Laver, J. (1994). *Principles of phonetics*. New York: Press Syndicate of the University of Cambridge.
Levine, R. V. (1999). The pace of life in 31 countries. *Journal of Cross-Cultural Psychology, 30*(2), 178–205 http://dx.doi.org/10.1177/0022022199030002003
Lleó, C., & Demuth, K. (1999). Prosodic constraints on the emergence of grammatical morphemes: Crosslinguistic evidence from Germanic and Romance languages. In A. Greenhill, H. Littlefield, & C. Tano (Eds.), In *Proceedings of the 23rd annual Boston University conference on language development* (pp. 407–418). Somerville, MA: Cascadilla Press.
Louzada, T., Beraldinelle, R., Berretin-Felix, G., & Brasolotto, A. G. (2011). Oral and vocal fold diadochokinesis in dysphonic. *Journal of Applied Oral Science, 19*(6), 567–572.
Maddieson, I. (2013). Consonant inventories. In M. S. Dryer & M. Haspelmath (Eds.), *The world atlas of language structures online*. Leipzig: Max Planck Institute for Evolutionary Anthropology. Available online at http://wals.info/chapter/1 Accessed 15.11.13.
Mason, R. M., Helmick, J. W., Unger, J. W., Gattozzi, J. G., & Murphy, M. W. (1977). Speech screening of children in the dental office. *Journal of American Dentist Association, 94*, 708–712.
McClean, M. D. (2000). Pattern of orofacial movement velocity across variations in speech rate. *Journal of Speech, Language and Hearing Research, 43*(1), 205–216.
McKinnon, D. H., & McLeod, S. (2007). The prevalence of stuttering, voice, and speech-sound disorders in primary school students in Australia. *Language, Speech, and Hearing Services in Schools, 38*, 5–15 http://dx.doi.org/10.1044/0161-1461(2007/002)
Meurer, E. M., Osório Wender, M. C., von Eye Corleta, H., & Capp, E. (2004). Phono-articulatory variations of women in reproductive age and postmenopausal. *Journal of Voice, 18*(3), 369–374.
Modolo, D. J., Berretin-Felix, G., Genaro, K. F., & Brasolotto, A. G. (2011). Oral and vocal fold diadochokinesis in children. *Folia Phoniatrica et Logopedica, 63*, 1–8.
Padovani, M., Gielow, I., & Behlau, M. (2009). Phonarticulatory diadochokinesis in young and elderly individuals. *Arquivos de Neuro-Psiquiatria, 67*(1), 58–61.
Paul, L. M., Simons, G. F., & Fennig, C. D. (2013). *Ethnologue: Languages of the world* (17th ed.). Dallas, TX: SIL International. Online version: http://www.ethnologue.com.
Peters, H. F. M., Hulstijn, W., & Starkweather, C. W. (1989). Acoustic and physiological reaction times of stutterers and nonstutterers. *Journal of Speech and Hearing Research, 32*, 668–680.
Prathanee, B., Thanaviratananich, S., & Pongjanyakul, A. (2003). Oral diadochokinetic rates for normal Thai Children. *International Journal of Language and Communication Disorders, 38*, 417–428.
Ptacek, P. H., Sander, E. K., Maloney, W. H., & Jackson, C. C. R. (1966). Phonatory and related changes with advanced age. *Journal of Speech and Hearing Research, 9*, 353–360.
Pye, C., Ingram, D., & List, H. (1987). A comparison of initial consonant acquisition in English and Quiché. In Nelson, K., & van Kleeck, A. (Eds.), *Children's language* (Vol. 6, pp. 175–190). Hillsdale, NJ: Erlbaum.
Recasens, D. (2010). Differences in base of articulation for consonants among Catalan dialects. *Phonetica, 67*(4), 201–218.
Robb, M. P., Hughes, M. C., & Frese, D. J. (1985). Oral diadochokinesis in hearing-impaired adolescents. *Journal of Communication Disorders, 18*(2), 79–89.
Salthouse, T. A., & Earles, J. L. (1996). Age, perceived health and specific and nonspecific measures of processing speed. In A. M. Ferrandez & N. Teasdale (Eds.), *Changes in sensory motor behavior in aging*. Amsterdam: Elsevier.
Schalling, E., Hammarberg, B., & Hartelius, L. (2007). Perceptual and acoustic analysis of speech in individuals with spinocerebellar ataxia (SCA). *Logopedics, Phoniatrics, Vocology, 32*, 31–46.
Seifpanahi, S., Dadkhah, A., Dehqan, A., Bakhtiar, M., & Salmalian, T. (2008). Motor control of speaking rate and oral diadochokinesis in hearing-impaired Farsi speakers. *Logopedics, Phoniatrics, Vocology, 33*, 153–159.
Ting-Toomey, S. (1999). *Communicating across cultures*. New York: The Guilford Press.
Topbas, O. (2010). *Effects of diadochokinetic rate on vocal fundamental frequency and intensity in normally speaking young adults*. (Unpublished thesis) West Virginia University.
Tsao, Y. C., & Weismer, G. (1997). Interspeaker variation in habitual speaking rate: Evidence for a neuromuscular component. *Journal of Speech, Language, and Hearing Research, 40*, 858–866.
Wang, Y. T., Kent, R. D., Duffy, J. R., & Thomas, J. E. (2009). Analysis of diadochokinesis in ataxic dysarthria using the motor speech profile program. *Folia Phoniatrica et Logopaedica, 61*, 1–11 http://dx.doi.org/10.1159/000184539
Wang, Y. T., Kent, R. D., Duffy, J. R., Thomas, J. E., & Weismer, G. (2004). Alternating motion rate as an index of speech motor disorder in traumatic brain injury. *Clinical Linguistics and Phonetics, 18*(1), 57–84.
Ziegler, W. (2002). Task-related factors in oral motor control: Speech and oral diadochokinesis in dysarthria and apraxia of speech. *Brain and Language, 80*, 556–575.