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Research Article

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Oral diadochokinetic rates for real words and non-words in Greek-speaking children

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Abstract: This study examined the performance of Greek monolingual typically developing (TD) children on diadochokinetic (DDK) rates in real words and non-words and attempted to establish normative data for Greek. The effects of age, type of stimuli and gender were investigated. A total of 380 children aged 4.0–15.0 years as well as a control group of 313 adults participated in the study. Age significantly affected DDK performance, yet normative data differ from other studies. DDK rates for bisyllabic stimuli were faster than DDK rates for trisyllabic stimuli and real words were articulated faster than non-words. Adolescents aged 13.0–15.0 years were slower than adults both in real word and in non-word /'pataka/ repetition. Additionally, overall boys were significantly faster than girls. These findings show the need to: (a) implement real word stimuli in DDK tasks in order to better depict an individual's oral-motor abilities and (b) establish language-specific normative data for TD children.

Keywords: DDK rates, oral-diadochokinesis, typically developing children, articulation rate, speech stimuli

1 Introduction

Diadochokinetic (DDK) rates or maximum repetition rates (MMRs) are the most frequently used structured measurements for the evaluation of motor speech skills in children with speech and language disorders (Bernthal et al. 2017, Williams and Stackhouse 2000, Yaruss and Logan 2002). Speech DDK rates refer to one's ability to accurately articulate different speech sounds, syllables or utterances at a maximum rate of utterance (Williams and Stackhouse 2000). In clinical research, the speech DDK measures include the iterations of single consonant or vowel sounds such as /a/, /p//j/, /l/ and/or the repetition of syllables, words or non-words such as /pətə/, /təkə/, /pətəkə/. Even though these kinds of tasks are used extensively, the following remain unclear: (a) which of these stimuli have better diagnostic utility according to clinical research findings (Bertagnolli et al. 2015, Tiffany 1980, Williams and Stackhouse 2000), and (b) how the repetition of real words and non-words differs in typically developing (TD) children and adolescents across different ages (Cohen et al. 1998, Icht and Ben-David 2015, 2017, Williams and Stackhouse 2000).

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A thorough examination of the existing protocols reveals many inconsistencies with respect to the stimuli used to assess diadochokinesis (e.g., repetition of single sounds or simple syllables consonant-vowel (C-V)or non-words and/or real words), the DDK tasks (e.g., DDK accuracy, DDK rates, DDK consistency) and the measurement techniques (e.g., time-by-count or count-by-time method), which may be the reason behind these disparities in experimental results (Cohen et al. 1998, Icht and Ben-David 2015).

1.1 Demographic factors affecting DDK rate performance

The maturity of the oral-motor system seems to significantly affect DDK performance (Cohen et al. 1998, Williams and Stackhouse 2000, Yaruss and Logan 2002). As maturational changes in lip and jaw movement are taking place, children modify the spatial and temporal features of articulation movements during childhood and adolescence. These kinetic modifications include decreases in duration and movement variability and increases in kinetic velocity (Reuterskiöld and Grigos 2015). Several researchers report that younger TD children aged 3-7 years show more unstable performance in DDK rates and noteworthy individual differences compared to older school-age children, since children younger than 8 years do not have the complete motor maturation to execute speech DDK tasks with velocity and precision (Diepeveen et al. 2019, Wertzner et al. 2013, Williams and Stackhouse 1998, 2000, Yaruss and Logan 2002).

Generally, the few normative studies that exist concern mainly the English language (Canning and Rose 1974. Fletcher 1972. Icht and Ben-David 2015. Irwin and Becklund 1953. Modolo et al. 2011. Prathanee et al. 2003) and show that DDK rates improve with age, while mixed results have been found when the factor of participant gender is investigated (Fletcher 1972, Icht and Ben-David 2015, Modolo et al. 2011, Prathanee et al. 2003, Williams and Stackhouse 2000, Zamani et al. 2017). Specifically, Fletcher (1972) in his study reported that girls tended to be faster in younger ages than boys, while the opposite result was observed for older children. Furthermore, he noted that girls were faster in iterations of syllables, whereas boys were faster in repetitions of polysyllabic non-words. On the other hand, Prathanee et al. (2003) found that Thai school-age boys were faster than girls in the repetition of syllables and in silent oral-motor tasks. Finally, Icht and Ben-David (2015), Modolo et al. (2011) and Zamani et al. (2017) did not find a main effect of gender on DDK rates for Hebrew-speaking, Brazilian-Portuguese-speaking and Persian-speaking children, respectively.

In addition to the aforementioned factors, mother language seems to be a factor significantly affecting DDK performance, since notable differences in normative data were reported across different languages (Icht and Ben-David, 2014, Prathanee et al. 2003, Williams and Stackhouse 2000). In English, different studies have shown that TD children reached adult-like rates at the age of 9-10 years (Canning and Rose 1974), or even later at the age of 15 years (Fletcher 1972). It should be noted, however, that these studies used simple syllables or non-word stimuli.

1.2 Lexical and sublexical factors affecting DDK rate performance

It is well documented that phonological complexity, phonotactic probability, word frequency and consonant age of acquisition influence repetition performance in real words (Coady and Evans 2008, Sasisekaran et al. 2010, Moore 2018, Moore et al. 2017). Specifically, shorter, more frequently used words with simpler phonotactic structure are retrieved faster from phonological short-term memory and articulated more accurately than longer, less frequent words with more complex phonotactic structures (Coady and Evans 2008, Moore 2018, Moore et al. 2017, Sasisekaran et al. 2010). Moreover, research has proved that if the phonological structure of non-words assimilates that of real words or if non-words show high wordlikeness, then children tend to produce these meaningless items more easily (Coady and Evans 2008). Additionally, Moore (2018) and Moore et al. (2017) suggested that the acquisitional pattern in consonants affects the accuracy of non-word repetition tasks, since non-word repetition accuracy is lower for sounds acquired later than for sounds acquired earlier.

Finally, Sundström et al. (2014), Yuzawa and Saito (2006) and Yuzawa et al. (2011) proposed that prosodic features significantly influence both word and non-word repetition accuracy. Sundström et al. (2014) found that younger Swedish-speaking children repeated words with accent II (a double peaked tone, which occurs in words where a stressed syllable is followed by an unstressed one) more accurately than words with accent I (a single-peak falling tone such as in monosyllabic words or in words with a primary stress on the ultimate syllable). The same effect of accent II was also observed in older children who repeated words and non-words with accent II more easily. Also, Yuzawa and Saito (2006) and Yuzawa et al. (2011) showed that Japanese children repeated more accurately bisyllabic non-words under an accented condition than under a flat-accent condition. The above results indicate that a pitch or stress accent helps children to produce non-words more easily (Yuzawa and Saito 2006, Yuzawa et al. 2011).

2 Diagnostic utility of different DDK measures

Some researchers cast doubt on the clinical utility of repetition of syllables, even though it is one of the most frequently used tasks, since speech strings are rarely repetitive and do not consist of equally stressed syllables (Tiffany 1980, Williams and Stackhouse 2000). Furthermore, clinical evidence reveals that the repetition of more complex speech stimuli has better diagnostic value, since it has been shown to identify more effectively children with deficits in motor programming (Bertagnolli et al. 2015, Williams and Stackhouse 2000). Moreover, several researchers used real word stimuli (e.g., patticake/pattycake, patacake or buttercup) instead of /'pʌtʌkʌ/, in order to test DDK skills in younger children aged 3-7 years, as these kinds of stimuli seemed to be more easily comprehendible by preschoolers (Cohen et al. 1998, Williams and Stackhouse 1998, 2000, Yaruss and Logan 2002, Zamani et al. 2017).

3 Issues from the use of different types of speech stimuli (non-words vs real words)

Two principal issues arise by the use of different types of stimuli (non-words and real words). Stackhouse and Wells (1997) in their psycholinguistic assessment framework argue that the iterations of non-words and real words cannot be used as interchangeable tasks as they tap different levels of language processing. According to this model, non-word repetition assesses one's ability to create a new motor program for an unknown word, as well as speech motor planning skills, while real word repetition evaluates the access to an already known stored motor program and relates to stored lexical knowledge, as well as to speech motor planning skills. Furthermore, it has been argued that the repetition of syllabic non-word sequences, e.g., /'pʌtʌkʌ/, is free from prosodic features, which real words carry and, therefore, is more likely to comprise a clear measure for articulatory ability, independent from linguistic factors (Tiffany 1980, Williams and Stackhouse 2000, Yaruss and Logan 2002). Finally, research has shown conflicting evidence with respect to whether DDK rates improve when children repeat real words in relation to non-words, with some researchers supporting this case (Icht and Ben-David 2015, 2017, Williams and Stackhouse 1998, Yaruss and Logan 2002, Zamani et al. 2017), while others reporting no improvement (Williams and Stackhouse 2000). The above brings to the fore that only a handful of studies (Icht and Ben-David 2015, Williams and Stackhouse 2000, Zamani et al. 2017) have directly compared the performance of TD children in DDK rates applying both non-word and real word stimuli, using rather restricted samples. Specifically, Icht and Ben-David (2015) examined 60 Hebrew-speaking TD school-age children (9-11 years), while Williams and Stackhouse (2000) and Zamani et al. (2017) evaluated 30 English-speaking and 142 Persian-speaking TD preschoolers (3–5 and 4–6 years old, respectively). The aforementioned studies tried to use non-word and

real word stimuli, which were as similar as possible in terms of phonotactic complexity, age of acquisition of the speech sounds and prosody. Icht and Ben-David (2015) and Zamani et al. (2017) found similar results supporting faster repetition rates for real words in comparison to non-words, but Williams and Stackhouse's (2000) research showed mixed results. Specifically, Williams and Stackhouse (2000) reported similar performance in bisyllabic non-word and real word stimuli in 3- and 4-year-old children as well as in trisyllabic nonword and real word stimuli in 3-year-old children. Only the 5-year-old children produced the bisyllabic real word stimuli significantly faster than the bisyllabic non-word stimuli, while only the 4-year-old and the 5-year-old group repeated the trisyllabic real words significantly faster than the non-words.

Conclusively, the nature of the segmental speech structures, the age of acquisition of phonemes, participant gender, complexity and length of syllables and syllabic sequences of words and non-words, as well as articulation errors module DDK rates, creating thus a very complex picture (Diepeveen et al. 2019, Kent et al. 1987, Nip 2013, Prathanee et al. 2003, Tiffany 1980, Williams and Stackhouse 1998, 2000). Given the conflicting results in the relevant literature and the lack of data for the Greek language in TD children, the aims of this study are the following:

- 1. First, the study sets out to examine the DDK performance of Greek-speaking monolingual TD children in non-words and real words, since previous work reveals that the language and the type of speech stimuli (non-words/real words) affect DDK performance differently at various ages (Icht and Ben-David 2015, 2017, Williams and Stackhouse 1998, 2000, Yaruss and Logan 2002, Zamani et al. 2017). To the best of our knowledge, this is the first study that examines the effect of type of stimuli in such a wide age range.
- 2. Second, the study aims at presenting normative data for Greek-speaking monolingual TD children aged 4.0-15.0 years old, since lexical and sublexical factors such as phonological complexity, phonotactic probability, wordlikeness, lexical prosody and consonant age of acquisition, which are unique for each language influence DDK non-word and real word rates (Coady and Evans 2008, Jones and Witherstone 2011, Moore 2018, Moore et al. 2017, Reuterskiöld and Grigos 2015, Sasisekaran et al. 2010, Sundström et al. 2014, Yuzawa et al. 2011). In this line of investigation, we also examined the age at which DDK rates reach adult-like performance.
- 3. Finally, the study aimed at investigating the effect of gender on DDK skills in Greek-speaking monolingual TD children, since mixed results have been reported for other languages (Fletcher 1972, Prathanee et al. 2003, Icht and Ben-David 2014, 2015).

Since only very few studies (Icht and Ben-David 2015, Williams and Stackhouse 2000, Zamani et al. 2017) directly compared the performance of TD children in DDK rates using different types of stimuli (nonwords vs real words) with rather small samples and restricted age bands, the current study constitutes the first attempt to examine this issue in a larger pool of TD children, including all age bands (preschoolers, school-age children and adolescents) and using well-matched bisyllabic speech stimuli as well as trisyllabic speech stimuli; thus providing an evidence for the clinical utility of the use of real word stimuli in DDK tasks in another language. This is important, since lexical and sublexical factors, which are distinctive for each language, affect DDK rate performance. The contribution of the study is also related to the establishment of normative data for the Greek language.

4 Methods

4.1 Participants

The participants of this study were 380 (191 boys, 189 girls) Greek-speaking TD children (mean age = 9.79, standard deviation [SD] = 3.28) and 313 (169 males, 144 females) healthy young adults of 20-30 years of age (mean age = 23.75, SD = 3.22). All non-adult participants were recruited from regular public nurseries and schools, while all adult participants were students of higher institutions or employees. All participants were

monolingual Greek speakers, without neurological, sensory or language problems, who accepted to participate voluntarily in this study. Before DDK assessment, all participants had undergone a speech language assessment which verified that they did not face language or speech deficits. Children were divided into 12 age bands (4.0-4.11, 5.0-5.11, 6.0-6.11, 7.0-7.11, 8.0-8.11, 9.0-9.11, 10.0-10.11, 11.0-11.11, 12.0-12.11, 13.0-13.11, 14.0-14.11 and 15.0-15.11 years old), while young adults, served as a control group for DDK performance, since MRRs are associated with a mature adult motor system (see Section 1.1).

4.2 Data collection

In Greek, most words tend to be trisyllabic or bisyllabic and to have open syllables (Geronikou 2016, Holton et al. 1997, Nikolopoulos et al. 2006, Setatos 1974). For this reason, the oral DDK tasks included the repetition of (a) four bisyllabic non-words /'gaba/, /'taka/, /'kata/, /'baga/, (b) four real Greek words /ˈkapa/, /ˈtapa/, /kaˈla/, /ˈpaka/ and (c) the trisyllabic non-word /ˈpataka/. The speech stimuli (non-words vs real words) were matched as closely as possible in phonotactic structure, prosody and phonetic similarity. All non-words followed the phonotactic rules of the Greek language, since non-words with low phonotactic probability are harder to be accurately repeated (Coady and Evans 2008). Furthermore, all the stimuli used in this dual DDK protocol (non-words and real words) had simple phonotactic structure and included early acquired speech sounds in Greek (by the age of 4.0) and the central vowel /a/ (Levanti et al. 1995). The real words used in this repetition task presented mixed frequency (two were very frequently used, one was frequently used and one was used rather rarely) according to the Institute for Language and Speech Processing PsychoLinguistic Resource (Protopapas et al. 2012), which is an online database for Greek words or pseudowords where a variety of features can be accessed for each item. In Greek, the stimuli /'paka/ is a real word and means a pile of documents. The non-word /'pataka/ was used to examine the influence of word length in DDK rates (Icht and Ben-David 2014, 2017).

4.3 Procedure

All participants were thoroughly informed of the purpose and the aims of the current study. A written consent form was signed by the children's parents and by the adult participants prior to the administration of the test. Every child participant was assessed individually by two experienced monolingual Greek-speaking speechlanguage pathologists in a quiet room in his/her school for approximately 30 min. Adult participants were also evaluated by the same examiners in a quiet room in their house or work environment. Each task required that the participant produces as fast and accurately as possible a given speech stimulus after he/she had heard it from the speech-language pathologist who is also the primary investigator (Dionysios Tafiadis). For every task the instruction was: "Repeat after me as many times as you can whatever I say, until I tell you to stop." Only one practice item was given to the participants. If the participant did not repeat the stimuli correctly, the examiner re-said it and asked the participant to repeat it after him. Then the task could begin. No other practice round was given, as recent literature proposes (Icht and Ben-David 2017). The second speech-language pathologist measured the first 30 s of every task, using a hand-held stopwatch.

4.4 Data analysis

4.4.1 Data processing and measurements

All speech responses were recorded by an audio writer (model Olympus LS-P1) and transcribed to a record form, using the International Phonetic Alphabet symbols. To correctly and precisely spot the beginning and the end points of a sequence the first and last 5 s of each production were excluded from the analysis, where possible. Only accurate productions were scored for each participant. Spoken responses were taken as correct if they followed the local adult model. The time taken in seconds to produce ten correct repetitions of each stimulus was measured for each participant. The DDK rates were calculated for each speech stimulus by dividing the total number of correct repetitions by the duration of the trials (the difference between the onset and offset times). The time-by-count method has also been used by previous studies (Canning and Rose 1974, Fletcher 1972, Logan and Conture 1995, Tafiadis et al. 2021, Williams and Stackhouse 1998).

4.4.2 Statistics

Continuous variables are presented with mean and SD. Quantitative variables are presented with absolute and relative frequencies. The normality assumption was evaluated using the Kolmogorov-Smirnov test, which returned no significant deviation from normality for the study variables (p > 0.05). For the comparison of mean values between two age groups (specifically, preschoolers aged 4-7 years vs children, aged 8-15 years old, as well as adolescents aged 13-15 years old vs adults aged 20-30 years) an independent sample's t-test was computed. A one-way ANOVA was executed for the comparison of mean scores of nonword stimuli or real word stimuli in all age groups. To investigate the effect of the type of speech stimuli on DDK rates, an Eta-squared analysis was performed alongside with a linear regression analysis and bivariate Pearson correlations. The effects of age and gender on mean DDK rates of non-words and real words were examined by two separate univariate ANOVAs. Finally, a simple size effect analysis was calculated in order to reveal if the gender differences were significant for all age groups. The statistical significance was set at p < 0.05 and all reported p values were two-tailed. The analysis was conducted using SPSS statistical software (version 19.0; Armonk, NY, USA).

5 Results

5.1 Age-related effects

Table 1 presents the mean values, SDs and 95% confidence intervals for all speech stimuli (bisyllabic and trisyllabic non-words and real words) per second.

Table 1: Mean (±SD) with 95% CI for repetition of speech stimuli per second – TD Greek children (4–15 years old)

Speech stimuli	Mean (SD)	95% CI
Non-words per second		
/ˈgaba/	1.98 (± 0.89)	1.89-2.07
/ˈtaka/	2.07 (±0.81)	1.99-2.15
/'kata/	2.11 (±0.73)	2.04-2.19
/ˈbaga/	1.86 (±0.82)	1.77-1.94
Total scores bisyllabic non-words per second	2.00 (±0.68)	1.94-2.08
/'pataka/	1.56 (±0.65)	1.50-1.63
Real words per second		
/'paka/	1.97 (±0.75)	1.90-2.05
/'tapa/	2.14 (±0.74)	2.06-2.21
/ˈkapa/	2.11 (±0.69)	2.04-2.18
/kaˈla/	2.23 (±0.66)	2.16-2.29
Total scores real words per second	2.11 (±0.60)	2.05-2.17

SD = standard deviation; CI = confidence interval.



Figure 1: Total scores of real word stimuli per second by age.

A one-way ANOVA was used to evaluate the effect of age on DDK rates for non-words and real words accordingly. A significant effect of age was detected for both real words F (11, 364) = 3.988, p = 0.000 and non-words F (11, 364) = 4.036, p = 0.000. Specifically, the performance on DDK rates improves with age for all speech stimuli in TD children (see Graphs 1–5).

As Figure 1 shows, DDK performance on real words improves significantly with age (see also Table A2). Specifically, a main effect of age is detected for /'paka/F(11, 364) = 4.900, p = 0.000, for /'tapa/F(11, 364) = 2.023, p = 0.025, for /'kapa/F(11, 364) = 2.903, p = 0.001) and for /ka'la/F(11, 364) = 5.113, p = 0.000) (Figure 2).

The repetition rate of non-word stimuli improves significantly across the different ages, as one can observe in Figure 3 (see also Table A1). The ANOVA revealed a significant effect of age across the 12 age bands for the non-words /'gaba/F (11, 364) = 2.586, p = 0.004, /'taka/F (11, 364) = 3.157, p = 0.000, /'kata/F (11, 364) = 4.674, p = 0.000 and /'baga/F (11, 364) = 3.816, p = 0.000 (Figure 4).

Repetition rates on the trisyllabic non-word stimuli /'pataka/ improved significantly with age (F (11, 364) = 3.536, p = 0.000), as shown in Figure 5 (see also Table A1). Moreover, in order to investigate DDK skills in preschoolers and school-age children, we divided participants into two large age bands, preschoolers, aged 4–7 years old and school-age children, from 8 to 15 years old. An independent t-test (t (374) = -4.812, p = 0.000) was executed to compare the mean total scores of the two age groups on non-words.

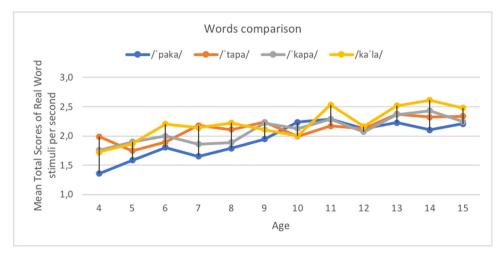


Figure 2: Real word stimuli repetition per second by age.

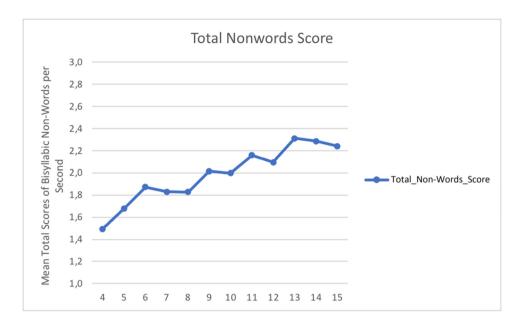


Figure 3: Total scores of non-word stimuli repetition per second by age.

For non-word repetition rates, results showed that school-age children performed significantly better than preschoolers (mean = 2.11, SD = 0.63 vs mean = 1.75, SD = 0.72). A second independent t-test (t (374) = -4.959, p = 0.000) revealed the same pattern of performance in real word stimuli; thus school-age children repeated significantly faster real word stimuli in comparison to preschool participants (mean = 2.21, SD = 0.56 vs mean = 1.87, SD = 0.65).

5.2 Adult-like performance

In order to investigate whether adolescent participants had reached adult-like performance on DDK rates, an independent t-test was conducted between adolescents and adults. The results of this analysis are presented in Table 2.

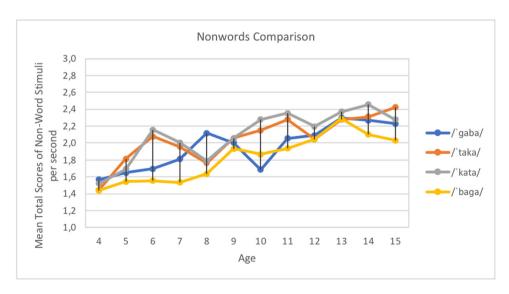


Figure 4: Non-word stimuli repetition per second by age.

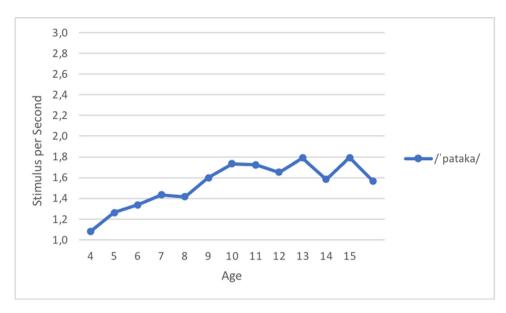


Figure 5: Repetition of /'pataka/per second by age.

The adult group produced the bisyllabic non-word stimuli /'taka/ and /'kata/, as well as the polysyllabic /'pataka/ significantly faster than the adolescent group, but overall, the mean DDK rates on bisyllabic non-words did not differ between the two groups. Furthermore, the control group was significantly faster in the repetition of the real words /'tapa/ and /'kapa/ and in the overall mean DDK rates in real words compared to the adolescent group (Table 2). These results show that the Greek-speaking adolescents had not yet reached adult-like performance on DDK rates either in the non-words or in the real word tasks.

5.3 Type of stimuli-related effects

As one can observe in Table 1, the length of speech stimuli affects DDK rates of TD children (e.g., 1.56 repetitions per second for /'pataka/ vs 2.07 repetitions per second for /'taka/). To further examine this finding, a linear regression analysis was conducted with the repetition performance of the trisyllabic non-

Table 2: Adolescent and control group DDK rates of speech stimuli per second

	Group	ps		<i>p-</i> value
Speech stimuli	Adolescent group n = 97	Control group n = 313	t-values (df)	
Non-words per second	Mean (SD)	Mean (SD)		
/ˈga-ba/	2.27 (0.86)	2.30 (0.83)	-0.34 (408)	0.740
/ˈta-ka/	2.33 (0.85)	2.64 (0.80)	-3.26 (408)	0.001***
/ˈka-ta/	2.36 (0.69)	2.58 (0.74)	-2.62 (408)	0.009*
/ˈba-ga/	2.17 (0.83)	2.18 (0.83)	-0.11 (408)	0.911
TS non-words per second	2.28 (0.69)	2.43 (0.70)	-1.78 (408)	0.075
/ˈpa-ta-ka/	1.75 (0.64)	2.19 (0.74)	-5.27 (408)	0.000***
Real words per second				
/ˈpaka/	2.20 (0.71)	2.32 (0.82)	-1.34 (408)	0.183
/ˈtapa/	2.35 (0.67)	2.74 (0.77)	-4.50 (408)	0.000***
/ˈkapa/	2.34 (0.72)	2.66 (0.70)	-3.92 (408)	0.000***
/kaˈla/	2.52 (0.62)	2.51 (0.95)	-0.13 (408)	0.895
TS real words per second	2.35 (0.59)	2.56 (0.67)	-2.72 (408)	0.007*

TS = total score; *p < 0.05; **p < 0.005; ***p < 0.001.

word /'pataka/ as a dependent variable and the performance (mean total scores per second) on non-word and real word stimuli as independent variables. The model showed that 46.5% of the dependent variable was predicted by the two factors (non-words, b = 0.377, p = 0.000 and real words, b = 0.335, p = 0.000). The beta coefficient analysis showed that the predictive value of the two predictors (mean total scores in nonwords and real words) was estimated approximately at the same level ($\beta = 0.392$, $\beta = 0.309$ for non-words and real words, respectively) with respect to the performance on the repetition of /'pataka/. Furthermore, a bivariate Pearson correlation revealed a significant positive relationship between the DDK rates on the trisyllabic non-word stimulus and the bisyllabic non-word stimuli (r = 0.67, p = 0.01), as well as between the DDK rates on the trisyllabic non-word stimulus and the bisyllabic real word stimuli (r = 0.66, p = 0.01). In order to investigate how the type of speech stimuli (non-words/real words) affected the performance on DDK rates an Eta-squared analysis was used. The analysis revealed a main effect for the type of stimuli $[F(3,378) = 11.857, p = 0.000, partial \eta^2 = 0.872]$ with faster overall performance for real word stimuli.

5.4 Gender-related effects

Finally, two separate univariate ANOVAs were executed with age and gender as independent variables and mean total scores in non-word or real word stimuli per second as dependent variable, in order to examine the effect of age and gender on speech DDK skills. The results showed that, overall, boys repeated the nonword stimuli faster than girls (mean = 2.12, SD = 0.05 vs mean = 1.86, SD = 0.05, p = 0.000), a pattern also attested in real word stimuli (mean = 2.19, SD = 0.04 vs mean = 2.00, SD = 0.04, p = 0.002). Specifically, for the non-word bisyllabic speech stimuli, the statistical analysis showed that boys were significantly faster than girls (F(1, 364) = 11.14, p = 0.000) and the same pattern was observed for real word stimuli (F(1, 364) =9.442, p = 0.002). There was not a significant effect of gender in the repetition of / pataka/ (F(1, 364) = 3.041, p = 0.082. We also investigated the interaction of age and gender in DDK rates. Interestingly, the analysis showed that the interaction of the two factors (age, gender) was significant for both non-words (F(11, 364)) 3.824, p = 0.004) and real words (F(11, 364) = 2.829, p = 0.001). Since a significant interaction of age and gender was found, a simple main effects analysis was conducted in order to reveal whether the gender differences were significant for all age groups. This analysis yielded a main effect of gender (F(1, 356))8.992, p = 0.003 partial $\eta^2 = 0.025$) as well as a main effect of age (F(11, 356) = 3.984, p < 0.001 partial $\eta^2 = 0.025$) 0.110) for the mean total scores of real words per second (see also Figure 6). Likewise, a main effect of gender (F(1, 356) = 13.942, p < 0.001 partial $\eta^2 = 0.038$) and a main effect of age (F(11, 356) = 4.132, p < 0.001partial $\eta^2 = 0.113$) were found for the mean total scores of non-words per second (see also Figure 7).

6 Discussion

Oral DDK tasks are used widely in clinical practice for diagnosing speech impairments in children and adults. In fact, evaluating the oral DDK rates is the most frequently used task for the differential diagnosis of motor speech disorders in children and adults, as it is fast and easy to administer assessment tool with no cost for clinicians (Icht and Ben-David 2017). Many studies have examined the effects of age, gender and type of stimuli on DDK rate scores in children across different languages (Diepeveen et al. 2019, Icht and Ben-David 2015, Modolo et al. 2011, Prathanee et al. 2003, Zamani et al. 2017). Slower or aberrant DDK rates as well as inaccurate productions are signs of a neurological impairment in the speech mechanism, consequently, children with speech disorders show low performance on DDK rates (Prathanee et al. 2003, Tafiadis et al. 2021). Noteworthily, normative data for children in different languages are limited with most studies focusing on English language, while differences in data collection techniques, types of stimuli used and scoring methods make cross-linguistic comparisons more problematic (Cohen et al. 1998, Icht and Ben-David 2015, 2017, Prathanee et al. 2003). This study is the first attempt to establish normative data on DDK rates for Greek-speaking TD children, aged 4.0 to 15.0 years and to examine how the variables of age, type of

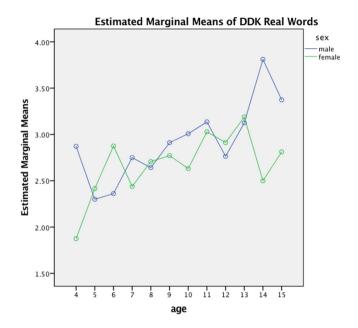


Figure 6: Age and gender effects in mean total scores of real word stimuli repetition per second.

stimuli and gender affect the performance on speech diadochokinesis in the Greek language. Additionally, to the best of our knowledge, this is the first study that examines the effect of speech stimuli (real words/non-words) at such a wide age range, in Greek TD children and adolescents.

6.1 Normative data

As previously mentioned, despite the wide use of DDK tasks as clinical assessment tools, normative data on languages other than English are sparse (see for example Canning and Rose 1974, Fletcher 1972, Irwin and

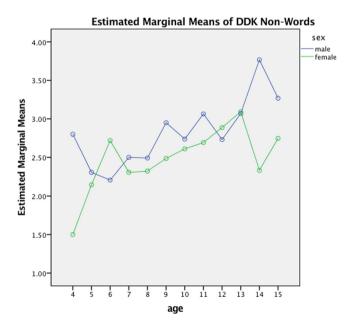


Figure 7: Age and gender effects in mean total scores of non-word stimuli repetition per second.

Becklund 1953, for normative data in English Prathanee et al. 2003, for normative data in Thai). Furthermore, hardly any studies have compared DDK rates between real words and non-words in a wide age range of TD children. Icht and Ben-David (2015) compared DDK rates between real words and non-words in school-aged TD children, aged 9-11 years, while Williams and Stackhouse (1998) and Zamani et al. (2017) assessed DDK rates (real words vs non-words) in younger preschool TD children, aged 3-5 and 4-6 years, respectively. Icht and Ben-David (2014) suggests that DDK rate is sensitive to mother language variations and culture. In the current study, DDK rate performance was examined between real words and non-words in a wide age range of Greek-speaking TD children. The results suggest that Greek-speaking children produced the bisyllabic stimuli /'taka/ and /'paka/ somewhat slower in comparison to Fletcher's norms for English (Table A2) while the trisyllabic / pataka/ was produced faster in comparison to the same norms (Fletcher 1972). Fletcher's norms are the most-widely used normative data for DDK rates in TD English-speaking children aged 6–13 years. These subtle differences in repetition rate may be attributed to the different vowel system of the Greek language, since /e/ (which is often transcribed as /a/ for ease of typing, as and in this research) is a near-open central unrounded vowel, more similar to centralized [\(\bar{a}\)] in English. In Fletcher's norms (1972) two different vowels were used, namely the central(ized) open-mid unrounded vowel [\(\bar{a}\)] for stressed syllables and the central mid unrounded [\(\theta\)] for unstressed syllables, the latter of which may require less time for articulation. Another reason for these disparities is that DDK rate tasks are sensitive to language-specific variations, such as differences in phonotactic patterns and constraints of each language, variability in frequencies of phonemes and word length, which affect performance (Icht and Ben-David 2014, 2017). In Greek, trisyllabic and polysyllabic words with open syllables are the most-frequently used types of words (Geronikou 2016, Setatos 1974) and this fact may have led to improved DDK rates in /'pataka/. Finally, English and Greek have different prosody features and some researchers (Sundström et al. 2014, Yuzawa et al. 2011) propose that prosody may affect DDK repetition accuracy. For the above reason, cross-linguistic comparisons and analogies are difficult to be drawn, which supports Icht and Ben-David's (2017), recommendation for use of language-specific performance rate norms.

6.2 Age-related effects

Normative studies in other languages (Canning and Rose 1974, Diepeveen et al. 2019, Fletcher 1972, Icht and Ben-David 2015, Modolo et al. 2011, Prathanee et al. 2003) have shown that age decisively affects the performance on DDK rates. In line with previous research, the results of this study have shown that the performance on DDK rates improves with age for all types of speech stimuli in TD children. An additional analysis for preschoolers (4.0 to 7.11 years) and school-age children (8.0 to 15.0 years) revealed that schoolage TD children produced non-word and real word stimuli significantly faster than preschoolers in all cases. Finally, we found that Greek-speaking adolescents aged 13–15 years had not yet reached adult-like performance in the repetition of real words and in the repetition of the trisyllabic non-word /'pataka/, a result which differentiates our data from English norms (Canning and Rose 1974, Fletcher 1972). The above finding may be a result of the type of stimuli used, since in the English norms the speech stimuli were syllables, and not complex wordlike stimuli as in the current study (Bertagnolli et al. 2015, Diepeveen et al. 2019, Sasisekaran et al. 2010). Another reason for this difference may lay on the Greek language system, which has different phonetic and phonotactic rules than English.

6.3 Type of stimuli-related effects

With respect to the length of the stimuli, the analysis revealed that performance on the repetition of the trisyllabic non-word /'pataka/ was significantly predicted by the mean total scores of both non-words and

real words. The standardized beta coefficients showed that the predictive value of the two predictors (total scores of non-words and real words) was estimated approximately at the same level for the repetition of /ˈpataka/. This fact, paired with the findings on group differences in the repetition of /ˈpataka/, is a proof that complex stimuli present better discriminatory ability than simpler stimuli and that the production of longer words requires more mature orofacial musculature control, a finding which is in agreement with other studies (Bertagnolli et al. 2015, Diepeveen et al. 2019, Williams and Stackhouse 2000). Moreover, with respect to the contrast between non-words and real words, we found that preschool and school-age children tended to produce significantly faster bisyllabic real words than bisyllabic non-words. Several studies in different languages (Icht and Ben-David 2015, Williams and Stackhouse 1998, Zamani et al. 2017) maintain that children articulate real word stimuli faster than non-word stimuli and this study adds to this body of research. Finally, adolescents had overall similar performance to that of the adults in the repetition of non-words but presented significantly slower DDK rates in the repetition of real words. This difference may be attributed to the semantic differences between stimuli, since both kinds of stimuli had the same phonotactic structure and length.

6.4 Gender-related effects

The statistical analysis showed a significant effect of gender with boys being overall faster than girls on DDK rates. The interaction of age and gender was also significant for all types of bisyllabic stimuli (non-words and real words), meaning that in most age groups boys articulated the speech stimuli faster than girls. Specifically, non-word stimuli were repeated faster by boys in almost all age groups, while girls articulated faster real word stimuli than boys at the ages of 5, 6, 8, 12 and 13 years old, respectively. The results are in agreement with Fletcher's (1972) and Modolo's et al. (2011) studies, who proposed that boys are faster than girls in the repetition of polysyllabic non-words but oppose the findings in Icht and Ben-David's (2015), Prathanee et al.'s (2003) and Zamani et al.'s (2017) studies, who did not find a main effect of gender on DDK rates. The above findings support further the use of specific DDK norms for each language.

7 Conclusion

The present study is the first one which attempts to establish normative data for Greek-speaking monolingual TD children, aged 4.0-15.0 years. In this study, complex non-word stimuli and real word stimuli were used, as it has been suggested that it taps on different underlying processes of the speech mechanism (Williams and Stackhouse 1997, 1998). The rationale is that the use of this dual protocol allows the comparison of motor programming skills (non-word repetition) to skills related to stored language knowledge (real word repetition). To make our protocol more reliable, real word stimuli and non-word stimuli were as similar as possible in phonetic, phonological and prosodic features. The results indicated that TD children produced real words faster than non-words in all cases. The implications of this finding are important for clinical research, since it is shown that real word stimuli should be implemented in DDK tasks to better depict a client's oral-motor abilities and improve the clinical utility of DDK assessment, in line with previous findings from other languages (Icht and Ben-David 2017). Additionally, non-word stimuli should be used too, since they can facilitate the more accurate diagnosis of impairments in motor programming skills in child and adult populations, as should polysyllabic stimuli because they present better discriminatory value. Conclusively, the aims set were achieved, since the study: (1) offers the first normative data for Greek-speaking TD children, aged 4.0–15.0 years, (2) provides evidence of the clinical importance of dual protocols, i.e., including both real words and non-words in DDK assessment, since improved performance was attested in real words in a wider age range and (3) reports gender-related differences which are also modulated by age in participant performance. As for future research, it is suggested that: (a)

further investigation should be carried out in Greek, also given the lack of data presently, with studies focusing on other TD populations such as young and elderly adults, before we can draw conclusions on how age, gender and stimuli function in DDK measurements and (b) the normative DDK data provided should be evaluated by future studies on Greek-speaking TD children, monolingual and/or bilingual.

Conflict of interest: All authors declare no conflict of interest.

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Appendix

Table A1: Normative data (mean values \pm SDs) of non-word stimuli repetition per second

Age	n	/ˈgaba/	/ˈtaka/	/ˈkata/	/ˈbaga/	/'pataka/
4.0-4.11	18	1.57 (1.05)	1.44 (1.00)	1.52 (0.74)	1.44 (0.95)	1.08 (0.66)
Boys		2.40 (0.32)	1.87 (0.29)	1.86 (0.26)	2.21 (0.29)	1.43 (0.24)
Girls		1.04 (0.26)	1.17 (0.23)	1.31 (0.20)	0.95 (0.23)	0.86 (0.19)
5.0-5.11	27	1.65 (0.88)	1.82 (0.85)	1.69 (0.61)	1.54 (0.91)	1.26 (0.73)
Boys		1.81 (0.23)	1.91 (0.21)	1.64 (0.18)	1.55 (0.20)	1.13 (0.17)
Girls		1.48 (0.24)	1.71 (0.21)	1.75 (0.19)	1.54 (0.21)	1.40 (0.17)
6.0-6.11	29	1.70 (0.88)	2.08 (0.88)	2.16 (0.86)	1.56 (0.80)	1.34 (0.55)
Boys		1.32 (0.24)	1.94 (0.21)	2.05 (0.19)	1.33 (0.21)	1.19 (0.17)
Girls		2.00 (0.21)	2.19 (0.19)	2.24 (0.17)	1.74 (0.19)	1.46 (0.16)
7.0-7.11	31	1.81 (0.93)	1.96 (0.91)	2.00 (0.83)	1.54 (0.61)	1.44 (0.58)
Boys		1.97 (0.20)	2.02 (0.18)	1.96 (0.16)	1.59 (0.18)	1.49 (0.15)
Girls		1.59 (0.24)	1.87 (0.21)	2.06 (0.19)	1.45 (0.21)	1.36 (0.17)
8.0-8.11	37	2.12 (0.81)	1.77 (0.64)	1.79 (0.58)	1.64 (0.65)	1.42 (0.55)
Boys		2.18 (0.17)	1.78 (0.16)	1.83 (0.14)	1.68 (0.16)	1.53 (0.13)
Girls		2.01 (0.24)	1.73 (0.21)	1.70 (0.19)	1.56 (0.21)	1.20 (0.17)
9.0-9.11	39	2.00 (0.79)	2.06 (0.68)	2.06 (0.55)	1.93 (0.73)	1.60 (0.56)
Boys		2.26 (0.20)	2.21 (0.18)	2.14 (0.16)	2.20 (0.18)	1.72 (0.15)
Girls		1.78 (0.19)	1.93 (0.17)	1.99 (0.15)	1.70 (0.17)	1.50 (0.14)
10.0-10.11	32	1.68 (0.95)	2.15 (0.44)	2.28 (0.55)	1.87 (0.68)	1.73 (0.68)
Boys		1.71 (0.24)	2.17 (0.21)	2.39 (0.19)	1.94 (0.21)	1.66 (0.17)
Girls		1.67 (0.19)	2.14 (0.18)	2.21 (0.16)	1.82 (0.18)	1.78 (0.14)
11.0-11.11	28	2.05 (0.86)	2.28 (0.79)	2.35 (0.91)	1.94 (0.77)	1.73 (0.75)
Boys		2.08 (0.23)	2.38 (0.21)	2.49 (0.18)	2.24 (0.20)	1.81 (0.17)
Girls		2.04 (0.23)	2.19 (0.21)	2.22 (0.18)	1.64 (0.20)	1.64 (0.17)
12.0-12.11	38	2.09 (0.80)	2.05 (0.65)	2.20 (0.57)	2.05 (0.87)	1.65 (0.62)
Boys		2.15 (0.18)	1.91 (0.16)	2.10 (0.14)	2.00 (0.16)	1.53 (0.13)
Girls		2.01 (0.21)	2.23 (0.19)	2.42 (0.17)	2.10 (0.19)	1.82 (0.16)
13.0-13.11	46	2.30 (0.82)	2.28 (0.77)	2.37 (0.59)	2.29 (0.76)	1.79 (0.74)
Boys		2.27 (0.19)	2.24 (0.17)	2.31 (0.15)	2.38 (0.17)	1.79 (0.14)
Girls		2.32 (0.17)	2.31 (0.15)	2.42 (0.13)	2.22 (0.15)	1.79 (0.12)
14.0-14.11	18	2.27 (1.20)	2.31 (1.14)	2.46 (1.01)	2.10 (1.07)	1.58 (0.57)
Boys		2.80 (0.28)	2.87 (0.26)	3.07 (0.23)	2.54 (0.25)	1.89 (0.21)
Girls		1.73 (0.28)	1.76 (0.26)	1.84 (0.23)	1.67 (0.25)	1.28 (0.20)
15.0-15.11	33	2.23 (0.71)	2.42 (8.22)	2.28 (0.63)	2.03 (0.76)	1.79 (0.54)
Boys		2.44 (0.19)	2.70 (0.18)	2.43 (0.16)	2.21 (0.18)	1.94 (0.14)
Girls		1.94 (0.23)	2.06 (0.21)	2.06 (0.18)	1.79 (0.20)	1.59 (0.17)

Table A2: Normative data (mean values \pm SDs) of word stimuli repetition per second

Age	n	/ˈpaka/	/ˈtapa/	/ˈkapa/	/kaˈla/
4.0-4.11	18	1.36 (0.42)	1.99 (0.84)	1.76 (0.95)	1.72 (0.58)
Boys		1.57 (0.26)	2.49 (0.27)	2.60 (0.24)	1.94 (0.23)
Girls		1.22 (0.21)	1.67 (0.22)	1.22 (0.20)	1.58 (0.18)
5.0-5.11	27	1.59 (0.69)	1.74 (0.84)	1.90 (0.77)	1.87 (0.57)
Boys		1.39 (0.18)	1.82 (0.19)	1.99 (0.17)	1.73 (0.16)
Girls		1.79 (0.19)	1.66 (0.20)	1.80 (0.18)	2.02 (0.17)
6.0-6.11	29	1.80 (0.88)	1.89 (0.81)	1.98 (0.66)	2.20 (0.91)
Boys		1.54 (0.19)	1.50 (0.20)	1.95 (0.18)	2.05 (0.17)
Girls		2.02 (0.17)	2.21 (0.18)	2.03 (0.16)	2.32 (0.15)
7.0-7.11	31	1.65 (0.62)	2.18 (0.81)	1.86 (0.73)	2.14 (0.71)
Boys		1.73 (0.16)	2.28 (0.17)	1.96 (0.15)	2.24 (0.14)
Girls		1.54 (0.19)	2.03 (0.20)	1.72 (0.18)	2.01 (0.17)
8.0-8.11	37	1.79 (0.56)	2.11 (0.71)	1.89 (0.50)	2.22 (0.44)
Boys		1.73 (0.14)	2.10 (0.15)	1.94 (0.13)	2.15 (0.12)
Girls		1.89 (0.19)	2.13 (0.20)	1.79 (0.18)	2.35 (0.17)
9.0-9.11	39	1.95 (0.63)	2.23 (0.74)	2.22 (0.49)	2.11 (0.62)
Boys		1.87 (0.16)	2.40 (0.17)	2.42 (0.15)	2.03 (0.14)
Girls		2.01 (0.15)	2.09 (0.16)	2.05 (0.14)	2.17 (0.13)
10.0-10.11	32	2.24 (0.79)	1.99 (0.74)	2.13 (0.57)	2.00 (0.67)
Boys		2.57 (0.19)	2.24 (0.20)	2.06 (0.18)	2.19 (0.17)
Girls		2.01 (0.16)	1.83 (0.16)	2.17 (0.15)	1.88 (0.14)
11.0-11.11	28	2.28 (0.87)	2.17 (0.71)	2.29 (0.83)	2.53 (0.53)
Boys		2.38 (0.18)	2.15 (0.19)	2.33 (0.17)	2.58 (0.16)
Girls		2.19 (0.18)	2.19 (0.19)	2.25 (0.17)	2.49 (0.16)
12.0-12.11	38	2.12 (0.72)	2.12 (0.57)	2.07 (0.54)	2.16 (0.50)
Boys		2.06 (0.15)	2.05 (0.15)	2.07 (0.14)	2.11 (0.13)
Girls		2.20 (0.17)	2.23 (0.18)	2.08 (0.16)	2.23 (0.15)
13.0-13.11	46	2.23 (0.71)	2.37 (0.63)	2.36 (0.65)	2.52 (0.51)
Boys		2.38 (0.15)	2.27 (0.16)	2.16 (0.15)	2.56 (0.14)
Girls		2.11 (0.14)	2.46 (0.14)	2.52 (0.13)	2.49 (0.12)
14.0-14.11	18	2.1 (0.88)	2.32 (0.76)	2.42 (0.86)	2.61 (0.93)
Boys		2.70 (0.23)	2.66 (0.24)	2.80 (0.22)	3.27 (0.20)
Girls		1.50 (0.23)	1.99 (0.24)	2.06 (0.22)	1.96 (0.20)
15.0-15.11	33	2.21 (0.63)	2.33 (0.71)	2.25 (0.74)	2.48 (0.57)
Boys		2.38 (0.16)	2.52 (0.16)	2.52 (0.15)	2.70 (0.14)
Girls		1.97 (0.18)	2.08 (0.19)	1.87 (0.17)	2.17 (0.16)

Table A3: Meaning of real words in Greek

Word	Meaning		
/'paka/	a pile of documents		
/'tapa/	a stopper		
/'kapa/	the name of the Greek letter $\langle \kappa \rangle$		
/ka'la/	fine (adverb)		