Development of Voice Onset Time in Arabic

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ABSTRACT

The research investigated development of Voice Onset Time (VOT) contrasts in children who spoke Jordanian Arabic. The factors investigated were: (1) the age at which VOT contrast is acquired; and (2) the role of place of articulation and emphasis on VOT development. One hundred and twenty children (60 males, 60 females; age range 2;0- 7;11) produced word-initial plosives. Linear Mixed Model (LMM), Bonferroni *post hoc* and *t* test analyses were conducted on the data. Results revealed that age, place of articulation and emphasis had significant effects on VOT. In addition, Arabic appeared to follow the general trend of VOT development reported for other voicing languages.

Key words: VOT, Arabic, Development. Diversity

1. Introduction

Voice onset time (VOT) is an objective temporal acoustic parameter that, among other cues, differentiates between voiced and voiceless plosives in speech production (Whiteside and Marshall, 2001) and speech perception (Nearey and Rochet, 1994). In the case of plosives, VOT represents the time at which voicing occurs relative to when closure in the oral cavity is released. VOT can take negative values (voicing occurs prior to release, pre-voicing) and positive values (voicing occurs after release). Researchers report that VOT duration increases gradually as vowel openness decreases (Klatt, 1975; Port and Rotunno, 1979). VOT also increases gradually as the constriction for the plosive moves farther back in the vocal tract; VOTs are the shortest for bilabial plosives, intermediate for alveolar plosives and the longest for velar plosives (Kent, 2002).

VOT has been a focus of interest in several speech disorders because it requires coordination between laryngeal activity and supralaryngeal cavity control, which is a complex maneuver (Auzou et al., 2000). Consequently, VOT provides "an inferential estimate of speech motor control, requiring fine motor coordination of the respiratory, phonatory and articulatory structures" (Robb et al., 2005: 125) any of which can go awry in people with speech disorders or pose problems when children acquire VOT control.

VOT has been studied extensively in many languages and several different patterns have been described (Lisker and Abramson, 1964; Zlatin, 1974). However, few VOT studies have been conducted on Arabic; those that have often investigated different dialects making comparison of results difficult (AlDahri, 2013; Rifaat, 2003; Mitleb, 2001; AlDahri and AlOtaibi, 2010; Alghamdi, 2006; Yeni-Komshian et al., 1977). The available studies were small-scale and included few, if any, child participants. The current study examined VOT development in Jordanian Arabic across different child agegroups to determine any developmental trends. The influences of place of articulation, plosive nature (plain vs. emphatic) and age on VOT values were examined. The usual effects these factors have on VOT duration over development are described next. VOT values increase as the place of articulation moves farther back in the oral cavity (Chao and Ladefoged, 1999; Cooper, 1991; Nearey and Rochet, 1994; Weismer, 1979). Chao and Ladefoged (1999) relate these changes in VOT across the different places of articulation to the difference in cavity sizes behind and in front of the occlusion working jointly with the aerodynamics of the laryngeal system during production of the different plosives. In this account, emphatic plosives are produced with primary coronal constriction and there is secondary constriction in the posterior region of the vocal tract. VOT duration of emphatic plosives is shorter than that of their plain counterparts (AlDahri, 2013). The secondary posterior constriction, aerodynamic mechanisms and laryngeal states might have effect on VOT duration of voiceless and voiced plosives in comparison with their plain counterparts. Emphatics involve complex articulations which make them difficult to produce and acquire by children (Odisho, 1973). They are acquired later than their plain counterparts (Amayreh and Dyson, 1998).Age at which children acquire voicing contrasts varies between languages and has been reported for Greek (Okalidou et al., 2010), English (Kewley-Port and Preston, 1974; Zlatin and Koenigsknecht, 1976; Gilbert, 1977), Spanish (Macken and Barton, 1980), French (Allen, 1985), Thai (Gandour et al., 1986), Hindi (Davis, 1995), and Korean (Jun, 2007). Children's VOT productions gradually achieve the adult-like forms over development. Accordingly, age has featured extensively in studies of VOT acquisition in different languages, with some findings universal but others being specific to a particular language.

A few studies have examined the relationship between gender and VOT development (Yu et al., 2015) with inconsistent results and conclusions (Koenig, 2000; Karlsson et al., 2004; Whiteside and Irving, 998; Oh, 2019; Morris et al., 2008; Smith and Kenney, 1998; Herd, 2020). Studies that have reported longer VOT for females ascribe this to females' "careful" speech (Whiteside and Irving, 998) or to anatomical and aerodynamic differences between males and females (Koenig, 2000). On the other hand, those who have reported longer VOT values for males (Oh, 2019) relate this to sociophonetic and language specific factors rather than the laryngeal anatomy and physiology. Puzzlingly, the "careful" speech of female speakers has been proposed by Oh (2019) as the reason behind their longer VOT, whereas the same reason is used by Li (2013) as an explanation for the females demonstrating shorter VOT. Accordingly, gender was not investigated in the current study and was excluded statistically by including it as a control factor in the statistical analyses.

2. VOT Patterns across Different Languages

Languages that contrast plosives according to voicing employ forms that fall into three main classes (Lisker and Abramson, 1964):

1- zero or short lag VOT for voiceless unaspirated plosives (approximately 0 to +30 ms VOT).

2- negative or lead VOT for voiced unaspirated plosives (approximately -125 to -75 ms VOT).

3- positive or long lag VOT for voiceless aspirated plosives (approximately +60 ms to +100 ms VOT).

Types 1-3 are often called voiced, pre-voiced and voiceless plosives, respectively. The start of voicing for these three patterns for stop consonants is specified relative to the plosive release burst. The delay of voicing onset needs to be longer than +25-30 ms for a plosive to be categorized as voiceless aspirated (Laver, 1994; Hewlett and Beck, 2006).

With respect to classes of VOT contrasts, some languages employ two-, some three- and others four-way contrasts. Arabic has a two-way contrast (voiced and voiceless unaspirated) (Gandour et al., 1986; Abramson and Whalen, 2017). The two-way contrast languages are divided into two further language sub-groups (Lisker and Abramson, 1964):

1- Group A: long positive VOT, >+50 ms, for voiceless stops but short positive VOT for voiced stops <+30 ms (e.g. English).
2- Group B: negative VOT for voiced stops (approximately -125 ms) but short positive VOT, <+30 ms, for voiceless stops (e.g. Spanish, Arabic).

Languages that have a two-way contrast can be divided into true voiced languages (e.g. Russian, Spanish, Arabic.) and aspirating languages (e.g. German, English, Mandarin) (Hunnicutt and Morris, 2016). The true voiced languages contrast between prevoiced stops (i.e., voicing starts before plosive release) and voiceless unaspirated stops (i.e., voicing starts at the time of plosive release). In the aspirating languages (delay in voicing; voicing starts after plosive release), the contrast is between voiceless aspirated and unaspirated stops. This classification is not clear-cut; several studies report an overlap between VOT boundaries for these contrasts (Khattab, 2000; Kong et al, 2012; Chao and Chen, 2008).

3. VOT Development

The age at which VOT is mastered in true voiced languages depends on control of co-contractions of the laryngeal muscles, the aerodynamics of subglottal and intraoral pressure flow, and achievement of supralaryngeal configurations. These requirements constitute spatial articulatory gestures that achieve gradual precise temporal coordination over age (Lowenstein and Nittrouer, 2008).

Vocal fold abduction and adduction caused by the reciprocal contraction of the posterior cricoarytenoid and interarytenoid muscles, respectively, are primarily responsible for the distinction between voiceless and voiced plosives (Hirose, 1976). The control of these abduction and adduction laryngeal adjustments is acquired gradually during development. Physiological changes in the anatomy of the structures involved in speech , and improved coordination between respiratory and laryngeal actions are two reasons for these gradual developmental changes. At about the age of 1;0, infants are able to produce a "consistent voiced-voiceless contrast" and at two years of age, the "coordination between the respiratory and laryngeal activity" is improved (Tobey and Rampp, 1987: 159). The coordination continues to improve as the larynx descends from its horizontal position at vertebrae C3/C4 in the neck after year two until it achieves its adult position at vertebrae C4/C5 by the age of six years (Figure 1).

Insert Figure 1 Here

Changes in larynx position and the control of laryngeal and sublaryngeal activities explain why "the development and the regularization of VOT values, and consequently the acquisition of the adult voicing contrast, occurs sometime between the ages of 2–4 years" (Okalidou et al., 2010: 504). In typical development of the complex motor gestures and aerodynamic activities, adult-like VOT gradually emerge and stabilize (Lowenstein and Nittrouer, 2008). In short lag/long lag VOT languages such as English, the acquisition of VOT contrast is usually accomplished before short lag/long lead languages such as Dutch, Spanish and Arabic (Allen, 1985). Children acquire the short lag/long lag contrast around the age of 2;0 (Macken and Barton, 1980). In languages that have VOT contrast similar to that of Arabic (e.g. Dutch, Standard Greek) with short lag/long lead, children develop VOT contrasts around the age of 4;0 (Okalidou et al., 2010). However, there are no large-scale Arabic monolingual VOT developmental studies that report the period over which the VOT contrast develops. These are required to confirm that this pattern applies in Arabic.

Different studies have reported physiological and aerodynamic reasons behind this early acquisition of short lag/long lag VOT (Macken, 1980;; Westbury, 1983; Westbury and Keating, 1986; Keating, 1983; Allen, 1985; Davis, 1995). Kewley-Port and Preston (1974: 205) explicitly state that "the articulatory gestures underlying short voicing lag stops are in specific ways less complicated than for the other types of stop. Voicing lead stops require muscle gestures in addition to those needed for short voicing lag stops."

4. Arabic Plosives

Arabic falls within the category of two-way contrast languages (voiced vs. voiceless plosives). Standard Arabic has voiceless /t, k, q/ and voiced /b, d/ plosives. Arabic /t/ and /d/ plosives have voiceless and voiced emphatic alveolar /tˤ/ and /dˤ/ counterparts, respectively. From an articulatory perspective, the emphatic sounds are complex. They have a primary coronal contact that they share with the non-emphatic /t/ and /d/, and an additional secondary pharyngeal contact (author 1 et al., 2009). In terms of place of articulation, /b/ is labial, /t, tˤ, d, dˤ/ are coronal, /k, q/ are dorsal.

The emphatic plosives /tˤ, dˤ/ and the uvular /q/ are mastered around the age of 4;0 (author 1, 2006). Emphasis is achieved using complex articulatory movements that lead to a rapidly shifting and complicated configuration of the vocal tract (Odisho, 1973). Different normative studies (XXX, Author 1, XXX. 2006; AlDahri, 2013) report that emphatic plosives have shorter VOT values than their non-emphatic counterparts. This may be due to the complex aerodynamic and physiological mechanisms manifested in the production of the emphatic plosives. /tˤ/ is produced with a small glottal opening, while /dˤ/ witnesses early voicing inhibition due to the accumulated supralaryngeal pressure (Ridouane, 2012). These may lead to shorter VOT durations. In addition to leading to shorter VOT, these complex aerodynamic mechanisms accompanying emphasis, delay the acquisition age of /tˤ/ and /dˤ/ VOT. The restricted region of contact and short constriction time of uvular /q/ make its VOT difficult for children to acquire before the age of 4;0. In everyday Jordanian Arabic, standard Arabic /q/ is realized as [g] or [ʔ] (Table 1). Although /ʔ/ is phonemic in Arabic, it is also one of the allophonic realizations of /q/.

Insert Table 1 Here

4.1.VOT in Arabic

As mentioned earlier, there is a dearth of large-scale studies investigating VOT development in the speech of monolingual Arabic-speaking children. The few available Arabic VOT studies (AlDahri, 2013; Mitleb, 2001; Alghamdi, 2006; Yeni-komshian, 1977; Al-Ani, 1970) use data from adult speakers. The only study on child participants focused on bilinguals (Khattab, 2000). It also reported on three monolingual Arabic children aged 5;4, 7;4 and 10;3 corresponding roughly with two of the age groups investigated in our current study. The productions of Khattab's (2000) three Arabic monolinguals were compared to the productions of three bilingual (Arabic and English) and three English monolingual children. The limited sample size and different goals of the study did not permit definite conclusions about VOT development in the speech of monolingual children.

The remaining adult Arabic VOT studies reported inconsistent results. This may be due to dialectal or methodological factors and the size and nature of the study sample. For example, Al-Ani (1970) noted that VOT value increased as the place of articulation moved farther back in the oral cavity. Emphatic consonants, /tˤ, dˤ/, had shorter VOT values than their plain, /t, d/, counterparts. Mitleb (2001) reported that VOT value was not affected by place of articulation. His results showed that VOT hardly changed as the constriction moved backward in the oral cavity. Contrary to Mitleb's results on Jordanian Arabic, Rifaat's (2003) results indicated that VOT increased as the place of articulation moved from dental to velar positions for voiced and voiceless plosives. Yeni-Komshian et al.'s (1977) study reported that the emphatic /tˤ/, /dˤ/ plosives had VOT values shorter than their plain /t/, /d/ counterparts. /q/ was longer than /k/, but this did not appear to be significant. Al-Ani (1970) found that /k/ had longer VOT values than did /q/ despite /q/ being produced farther back in the oral cavity. Al-Nuzaili (1993) reported similar results in Yemeni Arabic. This review of current work on VOT in Arabic highlights the need for developmental studies with sufficient sample sizes to draw definitive conclusions.

5. Methods

5.1. Participants

One hundred and twenty typically developing monolingual rural Jordanian male and female children participated in the study. They ranged in age from 2;0 to 7;11 (Table 2). Participants were divided into twelve age groups; each age group included five male and five female children. Ten adult participants aged between 20;0 and 25;0 years were also recruited as a control group (group 13) to compare the children's productions to those of adult speakers.

Insert Table 2 Here

Adults of the control group were relatives of some of the children involved in the study. A power analysis test was conducted to verify the suitability of the sample size to the study (Table 3). Results revealed that all values in the current study exceeded the 80% power at the 0.05 level of significance. Conventional practice considers that sample sizes with power higher than 80% to be representative (Suresh and Chandrashekara, 2012).

Insert table 3 here

All participants reported no speech or hearing problems. The age ranges adopted in this study were intended to match approximately the age ranges (2;0 – 6;4) of Amayreh and Dyson (1998) on the acquisition of Arabic consonants. The study protocol was approved by the IRB committee (reference number 25/132).

5.2. Stimuli

The experimental stimuli were eight bi-syllabic pseudo words that included eight Jordanian Arabic plosives. Data were collected over two periods of time: the first period was in 2019 and included 72 children, while the second period was in 2020 and included 48 children. All the plosives occurred word initially and were followed by the Arabic long vowel /a:/ (Table 4). Several previous studies have examined VOT in single vowel environments (Carey and Bartlett, 1978; Okalidou et al., 2010).

Insert Table 4 Here

5.3. Design Consideration

The researchers first attempted to design a picture naming test, but it turned out to be inappropriate since some target sounds were absent. Accordingly, pseudo words were employed rather than picture naming. The pseudo words were used within the context of a fast-mapping procedure (Dollaghan, 1985). The same procedure was used in previous studies (Okalidou et al., 2010) to examine the development of VOT in Standard-Greek and Cypriot-Greek speaking children. Fast mapping builds on typically developing children's ability to use a new word based on their single exposure to it. Studies show that children can retain a newly learned word a week after they were exposed to it once (Dollaghan, 1985; Carey and Bartlett, 1978). The fieldworker, accompanied by the first author, produced a pseudo word to the child four times. The child was then required to produce three correct and intelligible tokens. For example,

A. Fieldworker*: /ba:ba/, /ba:ba/, /ba:ba/, /ba:ba/;*

B. Child*: /ba:ba/*

A- Fieldworker*: /ba:ba/*

B- Child*: /ba:ba/*

A- Fieldworker*: /ba:ba/*

B- Child*: /ba:ba/*

The fieldworker and the first author are native speakers of rural Jordanian Arabic.

5.4. Procedures

Children’s productions were recorded in a quiet room at the child’s home, nursery, or school. All age groups produced /t, k, b, d, g, tˁ, dˁ, q/ pseudo words aloud at a normal speech rate. Following Kewley-Port and Preston (1974), a token was included in the data analysis whether it was produced in full by the child or whether its first syllable alone (plosive and vowel) was produced. In certain cases, the child was asked to try again due to incorrect or unintelligible productions. Unintelligible or incorrect productions were judged perceptually by the fieldworker and the first author during recording; they were the result of a vowel or an article preceding the target plosive or the fieldworker's speech overlapping with the child production. This happened during the recording sessions with the first two age groups, mainly. These two age groups constitute 6% (20 out of 120 children) of the total study sample. Sixteen children of the first two age groups had to repeat the tokens for each of the target plosives more than three times. However, data included in the acoustic analysis were the first three correct tokens produced by a child out of his/her different productions for a single target plosive. Tokens that were produced in full or with the appropriate first syllable were marked correct when they were produced without any vowel or article preceding the target plosive. A total of 24 tokens (8 plosives × 3 repetitions each) were elicited from each child. All responses were analyzed acoustically. Lead VOT was measured from the onset of glottal vibration to the plosive burst, while lag VOT was measured from the onset of the plosive burst to the first visible glottal vibration pertaining to the adjacent vowel (Figure 2).

Inset Figure 2 Here

The acoustic analysis involved 2880 intelligible pseudo word tokens collected from 120 children split into twelve age groups. All measurements were made with Praat (Boersma and Weenink, 2007). VOT duration was measured using waveform and wide-band spectrograms simultaneously. Regardless of the duration of VOT, plosives produced with partial phonation lasting less than 100% of the closure duration, or complete, phonation occurring throughout the entire closure duration, were included in the analysis. Docherty's

(1992) extensive study on the production of phonation in obstruents in Southern British English collapsed fully and partially voiced tokens together. In the current study, the total VOT duration of any individual plosive included any partial or complete voicing occurring in the productions of a child for this individual plosive.

As for the emphatic plosives, the current study included all emphatic realizations. As part of their developmental acquisition process, emphatics appear in children's early productions with partial or no emphasis. Gradually, children gain physiological, aerodynamic and laryngeal control making them able to produce fully emphatic plosives. The focus of the current study is on developmental changes rather than patterns of acquisition. Accordingly, all realizations of the emphatics, as well as VOT durations, were included in the analysis.

To ensure accuracy, a trained phonetician remeasured lead and lag VOT values for 10% of randomly chosen items from the token database measured previously. Pearson's correlation coefficient showed that both measurements were positively correlated ($r = .96$, $p < .001$).

5.5. Statistical Analysis

Means of each child's VOTs for the independent variables age, place of articulation and emphasis were obtained and analyzed using Linear Mixed Model (LMM), Bonferroni *post hoc* tests and *t* tests. LMM is an extension of the linear regression models. It is a multiple level regression model that accounts for two types of variations that have different parameters (average, slopes and intercepts). LMM analysis distinguishes variations that can be explained by the independent variables separately from variations that cannot be explained by the independent variables, known as fixed, and random, effect factors, respectively. In the current study, 8 plosives were examined separately for different places of articulation and within different age levels of children. The statistical analysis of these variables adhered to the following procedure: child age groups were compared to adult age groups, plain plosives were compared to the emphatic plosives VOT, and the different plosives places of articulation of children were compared to each other to determine how VOT duration varied when the plosive place of articulation moved farther back. Variations resulting within and across these multiple levels require an LMM statistical regression model to establish any effects. Because of LMM's advantage in dealing with these different multiple leveled effects, it is often preferred over more traditional approaches such as ANOVA in physical, biological, cognitive neuroscience and social science disciplines. In the current study, variations within and across factors resulted in 345 levels. Due to these multi- levels and effects, pitfalls and spurious associations are possible. Bonferroni correction is an approach to correct these potential pitfalls. It was used in the current study to compare between plosives' places of articulation and nature (plain/emphatic) and their effect on VOT. As the place of articulation and plosive nature factors involve repeated measures, the critical value [q] of Bonferroni test within the 28 cells of pairwise comparisons of plosives in the current study is (* $p \leq$ (0.05/[28 cells]=0.00178). Accordingly, the null hypothesis (H_0= no effect for place of articulation, for example), on VOT is accepted if differences between means (MD) of all VOTs are less than [q=0.00178]. If q is greater than 0.00178, the null hypothesis is rejected. *t* tests were used to find out at what level within the combinations of subgroups the significant difference was.

The level of significance, α, is specified as .05; the critical value for a *t* test occurs when it is > 1.96 and < - 1.96. Conversely, the differences in VOT means between children and adults (age as an independent variable), are non-significant if they fall within the region +/- 1.96 and the null hypothesis (H_0= no effect for age on VOT) is accepted; otherwise H_0 is rejected.

Developmental studies involve parsing out how much change in VOT value is attributable to the normative process of child development which is why age is considered a main independent factor in these studies.

6. Results

The plosives included in this study (b, d, g, t, k, q, tˤ, dˤ) were examined in the initial positions of 2880 pseudo word tokens of 120 children split into twelve age groups. There was a control group of 10 adults aged 20-25 years. All groups had equal numbers of males and females. The study investigation included the age of VOT acquisition by Jordanian children. It also included an examination of the role of place of articulation and emphasis on VOT (Table 5).

Insert Table 5 Here

LMM analysis revealed significant effects for VOT of place of articulation and age, (Table 6).

Insert Table 6 Here

Bonferroni *post hoc* tests showed that differences in mean VOT for place of articulation (Figure 3) and plosive nature (Figure 4) were significant (differences were greater than the critical Bonferroni [q] value of 0.00178). VOT values increased significantly as the place of articulation moved farther back towards the velum with the bilabial plosives being shortest and the velar plosives being longest. Although VOT increased as the place of articulation moved farther back in the oral cavity, the voiceless uvular /q/ had a significantly shorter VOT value (+6.54 ms) than that of the voiceless velar /k/ (+10.12 ms). The difference in means (+3.58 ms) between /q/ and /k/ was significant. This result coincides with the general findings from studies that have reported a systematic increase in VOT as the place of articulation moves from bilabial to alveolar to velar contact (Klatt, 1975; Port and Rotunno, 1979; Zlatin, 1974, Macken and. Barton, 1980; Flege and Port, 1981). Other studies have also reported further decrease in VOT as the place of articulation moves from the velum towards the uvula (Bóna and Auszmann, 2014; Flege and Port 1981).

Insert Figure 3 Here

Turning to plosive nature results (Figure 4), the voiceless emphatic plosive /tˤ/ had shorter VOT (+3.27 ms) than that of /t/ (+8.77 ms). The voiced emphatic plosive /dˤ/ had shorter VOT (-27.27 ms) than that of /d/ (-93.92 ms). Based on Bonferroni *post hoc* test results, the differences in means between /t vs tˤ/ (+5.5 ms) and /d vs dˤ/ (-66.65 ms) were significant (differences were again greater than the critical Bonferroni [q] value of 0.00178). This showed a significant effect of emphasis on VOT in which VOT was reduced on the emphatics /tˤ/ and /dˤ/ relative to their cognate plain consonants.

Insert Figure 4 Here

As discussed earlier, age is a factor that has nested values, and *t* tests can be used to determine which individual and combined factor levels show a significant effect on VOT.

Null results on VOT occur when *t* values fall within the critical region > 1.96 and < -1.96. Positive or negative VOT of every voiceless or voiced plosive was examined separately across every single age group to reach the age group that had no significant difference with the adult age group. This would then be the adult-like VOT age group of the plosive. Results for 'age' showed that children started producing adult-like VOT at different ages; this occurred when the significant VOT differences between a child age group and the adult age group for an individual plosive disappeared (Table 7). For example, VOT of /b/ was significantly different between the adult age group (13) and child age groups 1 (t= -6.55) and 2 (t= -5.88). However for age group 3, the difference with the adult age group (3 vs 13) disappeared (t= 0.09). Accordingly, this suggests that adult-like VOT production of /b/ starts at around age group 3 (3;6 -3;11). Looking at all plosives, significant differences between child and adult groups disappeared in age group 2 (2;6 – 2;11) for /t, k/, age group 3 (3;0 – 3;5) for /b, d, g/, age group 4 (3;6 -3;11) for /tˤ/, age group 5 (4;0 – 4;5) for /q/ and age group 9 (6;0–6;5) for /dˤ/.

Insert Table 7 Here

7. Discussion

To understand the development of VOT in Jordanian Arabic, the study used 2880 pseudo word tokens. Findings were based on 120 children who were divided into 12 age groups that ranged from 2;0 to 7;11. A group of 10 adult participants (5 male, 5 female) aged between 20;0 and 25;0 acted as a control group to assess at what age children start producing adult-like VOT. Different developmental VOT studies employed samples similar or smaller in size than that in the current study. For example, Whiteside and Marshall (2001), Okalidou et al. (2010), Markson and Bloom (1997) examined VOT development in the speech of 30 Hungarian, 24 Greek (including standard and Cypriot), and 30 English-speaking children, respectively. The present study examined the effects of place of articulation, plosive nature and age on VOT.

7.1. Effect of Place of Articulation and plosive nature on VOT

The place of articulation results in the current study agree with findings of previous Arabic adult studies (e.g. Rifaat, 2003; Odisho, 1973; Khattab, 2000): VOT increased significantly as the constriction moved farther back in the oral cavity. Different Arabic VOT studies reported significant effect for place of articulation on VOT, with an increase in VOT as the place of articulation moved farther back in voiced and voiceless stops (Rifaat 2003; Al-Nuzaili 1995). In the current study, results revealed an increase in VOT values as the place of articulation moved from bilabial (/b/, -84.49 ms) to dental (/d/, -93.92 ms) and finally to velar (/ɡ/, -128.19 ms) in voiced stops, and from alveolar (/t/, +8.77) to velar (/k/, +10.12 ms) in voiceless stops. However, Mitleb (2001) claimed that /t/ VOT values did not differ from /k/ VOT values in his study. It is worth noting that Mitleb's study differs from the current study with regard to data, sample size, age and target plosives. Mitleb’s data were from four adult university students who read Arabic words with initial /t, d, k, g/. Rifaat (2003), Al-Ani (1970) and Al-Nuzaili (1993) reported an increase in VOT values as the place of articulation moved farther back in the oral cavity for Egyptian, Iraqi and Jordanian, and Yemeni Arabic, respectively. Although VOT values reported in the present study and other studies on Arabic - Lebanese (Yeni-komshian et al., 1977),Iraqi and Jordanian(Al-Ani, 1970), Saudi (Flege and Port, 1981) and Yemeni(Al-Nuzaili, 1993) vary, they are still within the short positive lag and long negative lead values. Cross-dialectal variation is possibly the reason behind differences in VOT values (Mitleb, 2001). The only exception for the effect of place of articulation on VOT was the uvular /q/; its VOT value was significantly shorter than that of the velar /k/. The cavity volume, extent of contact and constriction time might be the reasons behind shorter /q/ VOT. Compared to /k/, Taff et al. (2001) relate the shorter /q/ VOT value to the fact that the volume of the cavity in front of /q/ constriction is larger than the volume lying behind it. Cho and Ladefoged (1999) considere the extent of /q/ contact another reason behind its short VOT values. An extended contact has long constriction time and entails longer VOT values. The velar plosive /k/ has an extensive contact between the tongue body dorsum and the soft palate. Due to the Bernoulli Effect, the articulators forming this extensive contact are sucked together, leading to more constriction time and longer VOT values. In the production of /q/, the tongue dorsum moves faster in its contact with the uvula than with the velum. This faster articulatory velocity results in shorter time for building up pressure and shorter VOT values, accordingly.

With regard to the plosive nature, VOT values of the emphatic plosives were significantly shorter than VOT values of their plain counterparts. This has been reported by researchers who have examined other Arabic dialects (Al-Ani, 1970; Zeroual et al., 2007). The small glottal opening of /t^{ʕ}/ is the main reason behind its shorter VOT compared to that of /t/ (Ridouane, 2012). As for /d^{ʕ}/, the supralaryngeal air pressure should be lower than the sublaryngeal pressure to maintain airflow through the glottis and then voicing. However, this voicing is inhibited earlier due to the accumulation of supralaryngeal pressure in the pharynx. As a result, /d^{ʕ}/ exhibits VOT values shorter than /d/.

7.2.Effect of Age on VOT

In the current study, age plays a significant role on VOT. The significant role of age has been reported for different languages, e.g. Hungarian (Bóna and Auszmann, 2014), Swedish [Hammarström et al., 2012), English (Whiteside and Marshall, 2001), for a number of plosives or certain age groups. To the best of the researchers' knowledge, there are no large-scale developmental Arabic monolingual VOT studies to compare the results of the current study with. Studies investigating VOT in Arabic have used adult speakers as participants (AlDahri, 2013; Mitleb, 2001; Alghamdi, 2006; Yeni-komshian et al., 1977) or have had small sample sizes (Khattab, 2000).

Results showed that children acquired short lag VOT of the plain voiceless /t, k/ before long lead VOT of /b, d, g/. Within short lag VOT plosives, /q/ was the latest to be acquired. In addition, VOT of the emphatic voiceless /tˤ/ and the emphatic voiced /dˤ/ had shorter vlaues than their plain counterparts and were acquired later than their plain /t, /d/ counterparts. This is due to the complex articulatory mechanism of emphasis. The acquisition of long lead after short lag VOT, and the late acquisition of /q/ VOT may be due to physiological, aerodynamic (Kewley-Port and Malcolm, 1974; Keating, 1983; Allen, 1985; Davis, 1995; Kehoe et al., 2004) and exposure factors. In lead VOT, the vocal folds vibrate when the supra-glottal air pressure is lower than the sub-glottal air pressure. This aerodynamic state is difficult to maintain with the oral closure gesture needed for the production of the plosive (Kong et al., 2012). Accordingly, lead VOT is acquired after children can to control and maintain these gestural and aerodynamic properties. Children start producing adult-like /q/ VOT at age group 5. The reasons behind this late acquisition of /q/ might be due to the aerodynamics, frequency of occurrence and exposure time to /q/.

It is produced with fast articulatory velocity; children gradually improve their spatial and temporal speech control skills until they become able to produce /q/ VOT. In addition, /q/ is not used frequently in the everyday vocabulary of Jordanian children (Amayreh and Dyson, 1998). According to the articulatory learning theory, sounds heard less often are acquired late. /tˤ. dˤ/ VOTs are mastered later than /t, d/. This late mastery is due to the articulatory complexity in the production of /tˤ. dˤ/ and the frequency of occurrence of /dˤ/ in Jordanian Arabic. As with /q/, /dˤ/ is heard less often in Jordanian Arabic. As for the articulatory complexity of emphatics, studies reveal that Arabic emphatics are pharyngealized with the tongue root retracting into the oropharynx and the hyoid bone elevating and the larynx raising (author 1 et al., 2006). Odisho (1973: 37) believes that emphasis is achieved through "a complex of articulatory movements leading to a rapidly shifting and complicated configuration of the vocal tract beginning from a slightly raised larynx and ending with slightly rounded and protruded shape of the lips". These articulatory features are mastered late by children. /dˤ/ VOT is the latest to be mastered by children due to the aerodynamic requisite needed to maintain vocal folds vibration and the complex articulatory movements needed to achieve emphasis.

8. Conclusion

Results showed that place of articulation, emphasis and age played a significant role on VOT. Arabic follows the general trend of VOT development with the voiceless and plain plosives being acquired earlier than the voiced and emphatic ones. Future developmental studies that build on natural data and track the patterns of variation in VOT acquisition are required.

Declaration of Interest: None.

References

Abramson, A.S., Whalen, D.H., 2017. Voice onset time (VOT) at 50: theoretical and practical issues in measuring voicing distinctions. J Phonetics. 63, 75–86.

Al-Ani, S., 1970. Arabic Phonology: An Acoustical and Physiological Investigation. The Hague, Netherlands. Mouton and Co., “Janua Linguarum” Series Practica 61.

AlDahri, S.S., AlOtaibi, Y.A., 2010. A cross language survey of VOT values for stops (/d/. /t/). In: Proceeding of the 2010 IEEE International Conference on Intelligent Computing and Intelligent Systems (ICIS2010), Xiamen, China..

AlDahri, S.S., 2012. A Study of voice onset time for Modern Standard Arabic and Classical Arabic. IEEE International Conference on Signal Processing, Communication and Computing (ICSPCC 2012) . 691-695, doi: 10.1109/ICSPCC.2012.6335582.

AlDahri, S.S., 2013. A study for the effect of the emphaticness and language and dialect for voice onset time (VOT) in modern standard Arabic (MSA). SIPIJ. 4 (2), 11–29.

Alghamdi, M., 2006. "Voice Print": Voice onset time as a model. AJSS. 21 (42), 89-118.

Allen, G.D., 1985. How the young French child avoids the prevoicing problem for word-initial voiced plosives. J Child Lang. 12, 37-46.

Al-Nuzaili, A.M., 1993. Experimental Study of Emphasis and Voicing in the Plosives of Yemeni Spoken Arabic with some Implications for Foreign Language Teaching and Learning (Ph.D. thesis). University of Leeds. UK.

Al-Tamimi, F. 2006 Consonant Acquisition in Jordanian Spoken Arabic. Unpublished Msc thesis. The University of Sheffield. UK.

Al-Tamimi, F., Alzoubi, F., Tarawnah R. 2009 A videofluoroscopic study of the emphatic consonants in Jordanian Arabic. Folia Phoniatr Logo. 61 (4): 247-253.

Amayreh, M.M., Dyson, A.T. 1998. The acquisition of Arabic consonants. J Speech Lang Hear Res. 41, 642-653.

Auzou, P., Ozsancak, C., Morris, R.J., Jan, M., Eustache, F., Hannequin, D., 2000. Voice onset time in aphasia, apraxia of speech and dysarthria: a review. Clin Linguist Phonet. 14, 131–150.

Boersma, P., Weenink, D., 2007. Praat: Doing phonetics by computer.Version 4.6.09

Bóna, J., Auszmann, A., 2014. Voice onset time in language acquisition: Data from Hungarian. In: Fuchs, S., Grice, M., Hermes, A., Lancia, L., Mücke, D. (Eds.), Proceedings of the 10th International Seminar on Speech Production (ISSP), Köln. PP. 41-44.

Carey, S., Bartlett, E., 1978. Acquiring a single new word. In: Proceedings of the Stanford Child Language Conference, 15.

Cho, T., Ladefoged, P., 1999. Variation and universals in VOT: Evidence from 18 languages. J Phon. 27, 207-229.

Chao, K. Y., Chen, L. M., 2008. A cross-linguistic study of voice onset time in stop consonant productions. IJCLCLP, 13, 215–232.

Cooper, AM., 1991. An Articulatory Account of Aspiration in English. (Ph.D. thesis). Yale University, Connecticut.

Davis, K., 1995. Phonetic and phonological contrasts in the acquisition of voicing: Voice onset time production in Hindi and English. J Child Lang. 22, 275-305.

Docherty, G. 1992. The Timing of Voicing in British Obstruents. Fortis publications, Berlin

Dollaghan, C.A. 1985. Child meets word: "Fast mapping" in preschool children. J Speech Hear Res. 28, 449-454.

Flege, J., Port, R., 1981. Cross-language phonetic interference: Arabic to English. Lang Speech. 2, 125-146.

Gandour, J., Petty, S.H., Dardarananda, R., Dechongkit, S., Mukngoen, S., 1986. The acquisition of the voicing contrast in Thai: A study of voice onset time in word initial plosive consonants. J Child Lang. 13, 561-572.

Gilbert, J. H. V. 1977. A voice onset time analysis of apical stop production in three-year-olds. J. Child Lang. 4, 103–110.

Hammarström, I.L., Larsson, M., Wiman, S., McAllister, A., (2012). Voice onset time in Swedish children and adults. Logop Phoniatr Voco. 37 (3), 117- 122.

Herd, W., 2020. Sociophonetic voice onset time variation in Mississippi English. J Acoust Soc Am. 147, 596. https://doi.org/10.1121/10.0000545

Hewlett, N., Beck, M., 2006. An Introduction to the Science of Phonetics. Lawrence Erlbaum Associates, New Jersey.

Hirose H., 1976. Posterior cricoarytenoid as a speech muscle. Ann Oto Rhinol Laryn. 85, 334-342.

Hunnicutt, L., Morris, P., 2016. Pre-voicing and Aspiration in Southern American English. In: University of Pennsylvania Working Papers in Linguistics. 22, 215–224.

Jun, S. 2007. Phonological development of Korean: a case study. In: UCLA Working Papers in Phonetics, 105, 51–65.

Karlsson, F., Zetterholm, E., Sullivan, K.P.H., 2004. Development of a gender difference in voice onset time. In: Proceedings of the 10th Australian International Conference on Speech Science & Technology.

Keating, P., 1983. Patterns in allophone distribution for voiced and voiceless stops. J Phonetics. 11, 277–290.

Kehoe, M.M., Lleo, C., Rakow, M., 2004. Voice onset time in bilingual German-Spanish children. Biling Lang Cogn. 1263, 71–88.

Kent, R.D., Read, C., 2002. Acoustic analysis of Speech, Australia. Thomson Learning.

Kewley-Port, D.K., Malcolm, S.P., 1974. Early apical stop production. J Phonetics. 2,195-210.

Khattab, G., 2000. VOT production in English and Arabic bilingual and monolingual children. In: Nelson, D.C., Foulkes, P., (Eds.), Leeds Working Papers in Linguistics and Phonetics. University of Leeds, UK, PP. 95-122.

Khattab, G., Al-Tamimi, F., Heselwood, B., 2006. Acoustic and auditory differences in the /t/- /T/ opposition in male and female speakers of Jordanian Arabic. In S. Boudelaa (Ed.), Perspectives on Arabic Linguistics XVI: Papers from the sixteenth annual symposium on Arabic linguistics. Cambridge, UK: John Benjamins. PP. 131-160.

Klatt, D.H., 1975. Voice onset time, frication, and aspiration in word-initial consonant clusters. J Speech Hear Res. 18, 686-706.

Koenig, L., 2000. Laryngeal factors in voiceless consonant production in mean, women, and 5-year olds. J Speech Lang Hear Res. 43 (5), 211-28.

Kong, E.J., Beckman, M.E., Edwards, J., 2012. Voice onset time is necessary but not always sufficient to describe acquisition of voiced stops: The cases of Greek and Japanese. J Phon. 40, 725-744.

Laver, J., 1994. Principles of Phonetics. Cambridge University Press, Cambridge.

Lee, S., Iverson, G.K., 2008. Development of stop consonants in Korean. Korean Linguistics. 14 (1), 21-39.

Li, F. 2013. The effect of speakers' sex on voice onset time in Mandarin stops. J Acoust Soc Am. 2, 142-7.

Lisker, L., Abramson, A.S., 1964. A cross-language study of voicing in initial stops: Acoustical measurements. Word. 20, 384-422.

Lowenstein, J.H., Nittrouer, S., 2008. Patterns of acquisition of native voice onset time in English-learning children. J Acoust Soc Am. 124, 1180–1191.

Ma, J., Chen, X., Wu, Y., Zhang, L., 2018. Effects of age and sex on voice onset time: Evidence from Mandarin voiceless stops. Logop Phoniatr Voco. 43, 56-62

Macken, M.A., 1980. Aspects of the acquisition of plosive systems: A cross-linguistic perspective. In: Yeni-Komshian, G.H, Kavanagh, J.F, Ferguson, C.A. (Eds.), Child Phonology: Volume 1, production. Academic Press: New York, PP. 143-168.

Macken, M.A. Barton, D., 1980. The acquisition of the voicing contrast in English: A study of voice onset time in word-initial stop consonants. J. Child Lang. 7, 41–74.

Markson, L., Bloom, P., 1997. Evidence against a dedicated system for word learning in children. Nature, 385 (6619), 813–815.

Mitleb, F.M., 2001. Voice onset time of Jordanian Arabic stops. J Acoust Soc Am. 109 (5), 2474.

Nearey, T., Rochet, B., 1994. Effects of place of articulation and vowel context on VOT production and perception for French and English stops. J Int Phon Assoc. 24 (1), 1-18.

Odisho, E.Y., 1973. The Role of the Rear Section of the Vocal Tract in Baghdadi Arabic (M. Phil. thesis). Leeds University, UK.

Oh, E. 2019. Effects of gender on the use of voice onset time and fundamental frequency cues in perception and production of English stops. Linguistic Res. 36, 67-89.

Okalidou, A., Petinou, K., Theodorou, E., Karasimou, E., 2010. Development of voice onset time in Standard Greek and Cypriot Greek speaking preschoolers. Clin Linguist Phonet. 24 (7), 503 – 519.

Piccardi, D. 2017. Sociophonetic factors of speakers' sex differences in voice onset time. A Florentine case study. In Bertini, C., Celata, C., Lenoci, G., Meluzzi, C., Ricci, I., (Eds.), Fattori sociali e biologici nella variazione fonetica. Social and biological factors in speech variation. Milano: Officinaventuno, PP. 83–106.

Port, R.F., Rotunno, R., 1979. Relation between voice-onset time and vowel value. J Acoust Soc Am. 66, 654-662.

Ridouane, R., 2003. Suites de consonnes en berbere: phonetique etphonologie. (Ph.D. thesis), Université de la Sorbonne nouvelle. France.

Rifaat, K., 2003. Voice onset time in Egyptian Arabic: a case where phonological categories dominate. In: Proceedings of the 15th International Congress of Phonetic Sciences. Barcelona, Spain..

Robb, M., Gilbert, H., Lerman, J., 2005. Influence of gender and environmental setting on voice onset time. Folia Phoniatr Logo. 57, 125–133.

Smith, B.L., Kenney, M.K., 1998. An assessment of several acoustic parameters in children's speech production development: longitudinal data. J Phon. 26, 95-108.

Suresh, K., Chandrashekara, S., 2012. Sample size estimation and power analysis for clinical research studies. J Hum Reprod Sci. 5 (1), 7–13. https://doi.org/10.4103/0974-1208.97779

Taff, A., Rozelle, L., Cho, T., Ladefoged, P., Moses, D., Wegelin, J., 2001. Phonetic structures of Aleut. J Phon. 29 (3), 231–271.

Tobey, E., Rampp, D., 1987. Neuroanatomy and neurophysiology: An overview of the neurological correlates of speech. In: Gottleib, M., Williams, J., (Eds.), Concise Textbook of Developmental Pediatrics. Medical Examination Publishing Company, pp. 153-166.

Weismer G., 1979. Sensitivity of voice onset measures to certain segmental features in speech production. J Phon (7), 194–204.

Westbury, J., 1983. Enlargement of the supraglottal cavity and its relation to stop consonant voicing. J Acoust Soc Am. 73, 1322–1336.

Westbury, J., Keating, P., 1986. On the naturalness of stop consonant voicing. J Linguist. 22, 145–166.

Whiteside, S., Irving, C., 1998. Speaker's sex differences in voice onset time: A study of isolated word production. Percept Mot Ski. 86, 651-654.

Whiteside, S.P., Marshall J., 2001. Developmental trends in voice onset time: some evidence for sex differences. Phonetica. 58 (3), 196–210.

Yeni-komshian, G.H, Caramazza, A., Preston, M.S., 1977. A study of voicing in Lebanese Arabic. J Phonetics. 5 (1), 35-48.

Yu, V.Y., De Nil, L.F., Pang, E.W., 2015. Effects of age, sex and syllable number on voice onset time: Evidence from children's voiceless aspirated stops. Lang Speech. 58 (2), 152–167.

Zeroual, C., Hoole, P., Fuchs, S., Esling, J.H. 2007. EMA study of the coronal emphatic and non-emphatic plosive consonants of Moroccan Arabic. In: Trouvain, J., Barry, W.J, (Eds.), Proceedings of the 16th International Congress of Phonetic Sciences. Saarbrücken: Universität des Saarlandes. PP. 397-400.

Zlatin, M.A., 1974. Voicing contrast: Perceptual and productive voice onset time characteristics of adults. J Acoust Soc Am. 56, 981-984.

Zlatin, M. A., Koenigsknecht, R. A. 1976. Development of the voicing contests: a comparison of VOT in stop perception and production. J Speech Hear Res, 19, 93–111.

Table and Figures

Table 1: Jordanian Arabic Plosives

		Bilabial		Labio-dental		Dental		Alveolar		Post-alveolar		Palatal		Velar		Uvular		Glottal	
Plosive	Plain		b					t	d					k	[g]	q		ʔ [ʔ]	
	Emphatic							$t^{\text{ʕ}}$	$d^{\text{ʕ}}$										

Table 2: Participants Age and Gender

Age Range		Participants	
Age Group	**Children**	**Male**	**Female**
(I)	2;0 – 2;5	5	5
(II)	2;6 – 2;11	5	5
(III)	3;0 – 3;5	5	5
(IV)	3;6 – 3;11	5	5
(V)	4;0 – 4;5	5	5
(VI)	4;6 – 4;11	5	5
(VII)	5;0 – 5;5	5	5
(VIII)	5;6 – 5;11	5	5
(IX)	6;0 – 6;5	5	5
(X)	6;6 – 6;11	5	5
(XI)	7;0 – 7;5	5	5
(XII)	7;6 – 7;11	5	5
(XIII)	**Adults**	**Male**	**Female**
	20;0	2	2
	22;0	2	2
	25;0	1	1

Table 3: Sample Size Power

Source	Sum of Squares	df	Mean Square	F	Sig.	Partial η^2	Noncentrality Parameter	Observed Power [a]
VOICE	2,201,858.676	7	314,551.239	**48,176.660**	0.000	0.998	337,236.623	1.000
VOICE × GENDER	115.830	7	16.547	**2.534**	0.014	0.024	17.740	0.886
VOICE × AGE	93,051.162	84	1,107.752	**169.663**	0.000	0.951	14,251.714	1.000
VOICE × GENDER × AGE	725.008	84	8.631	**1.322**	0.035	0.132	111.042	1.000
Error of Measurement for (VOICE)	4,753.200	728	6.529					

[a]. Computed using α = 0.05

Table 4: Study Stimuli

Plosives	/a:/	Plosives	/a:/
/b/	ba:ba	/g/	ga:ga
/t/	ta:ta	/q/	qa:qa
/d/	da:da	/tˤ/	tˤa:tˤa
/k/	ka:ka	/dˤ/	dˤa:dˤa

Table 5: Segmentation Criteria

<table>
<tr><th>Age Group</th><th>Children</th><th>Male</th><th>Female</th><th>Plosives</th><th>Place of Articulation</th><th>Plosive Nature</th></tr>
<tr><td>(I)</td><td>2;0 – 2;5</td><td>5</td><td>5</td><td>/tˤ/</td><td rowspan="4">alveolar</td><td rowspan="2">emphatic</td></tr>
<tr><td>(II)</td><td>2;6 – 2;11</td><td>5</td><td>5</td><td>/dˤ/</td></tr>
<tr><td>(III)</td><td>3;0 – 3;5</td><td>5</td><td>5</td><td>/t/</td><td rowspan="7">plain</td></tr>
<tr><td>(IV)</td><td>3;6 – 3;11</td><td>5</td><td>5</td><td>/d/</td></tr>
<tr><td>(V)</td><td>4;0 – 4;5</td><td>5</td><td>5</td><td>/b/</td><td>bilabial</td></tr>
<tr><td>(VI)</td><td>4;6 – 4;11</td><td>5</td><td>5</td><td>/k/</td><td rowspan="2">velar</td></tr>
<tr><td>(VII)</td><td>5;0 – 5;5</td><td>5</td><td>5</td><td>/g/</td></tr>
<tr><td>(VIII)</td><td>5;6 – 5;11</td><td>5</td><td>5</td><td rowspan="2">/q/</td><td rowspan="2">uvular</td></tr>
<tr><td>(IX)</td><td>6;0 – 6;5</td><td>5</td><td>5</td></tr>
<tr><td>(X)</td><td>6;6 – 6;11</td><td>5</td><td>5</td><td></td><td></td><td></td></tr>
<tr><td>(XI)</td><td>7;0 – 7;5</td><td>5</td><td>5</td><td></td><td></td><td></td></tr>
<tr><td>(XII)</td><td>7;6 – 7;11</td><td>5</td><td>5</td><td></td><td></td><td></td></tr>
<tr><td>Total</td><td></td><td>120</td><td></td><td></td><td></td><td></td></tr>
</table>

Table 5: Segmentation Criteria

Table 6: Effect of Study Factors on VOT

Type III Tests of Fixed Effects[a]				
Source	**Numerator df**	**Denominator df**	**F**	**Sig.**
Intercept	1	129.361	299,598.07	0
Place of articulation	7	183.311	313,306.95	0
VOT×age	96	110.872	1,869.17	0
VOT×gender	8	112.67	70.681	0
VOt×age×gender	96	109.999	3.993	0
a. Dependent Variable: VOT.				

Table 7: *t* test results for the age at which children start producing adult-like VOT for individual plosives.

	t	k	b	d	g	tˤ	q	dˤ
Age Groups	t	t	t	t	t	t	t	t
1	3.9	-9.03	-6.55	62.74	-111.51	-6.73	-4.86	-90.85
2	0.65	-0.97	-5.88	61.12	-118.01	14.21	14.21	-90.85
3			0.09	0.65	-0.98	-2.99	-2.99	-90.85
4						-1.12	-2.99	-53.46
5							-1.12	-47.86
6								-57.2
7								-59.07
8								-47.86
9								-1.12

t test critical region > 1.96 and < - 1.96

Figure 1: Child's Larynx Compared to Adult's

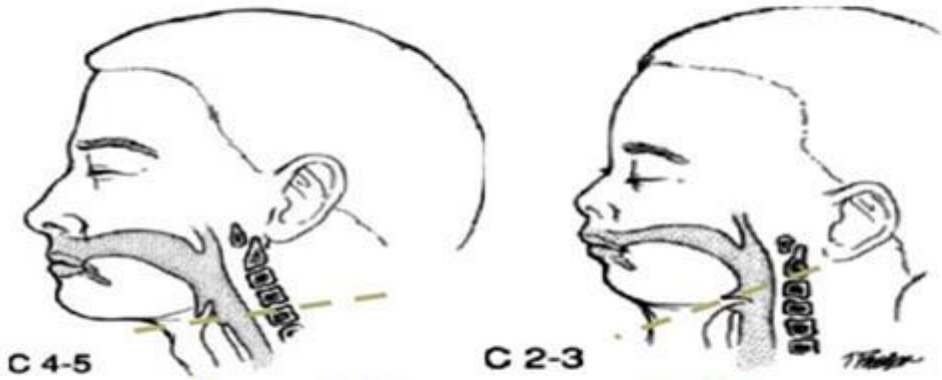

Figure 1: Child's Larynx compared to Adult's

Figure 2: Schematic Representation of Long Lead and Short Lag in Jordanian Arabic

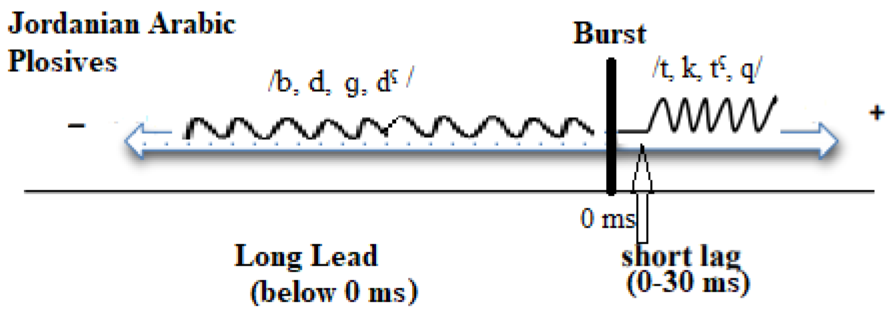

Figure 2: Schematic representation of long lead and short lag in Arabic

Figure 3: Bonferroni Results for the Effect of Place of Articulation on VOT Differences in Means (MD are > 0.00178

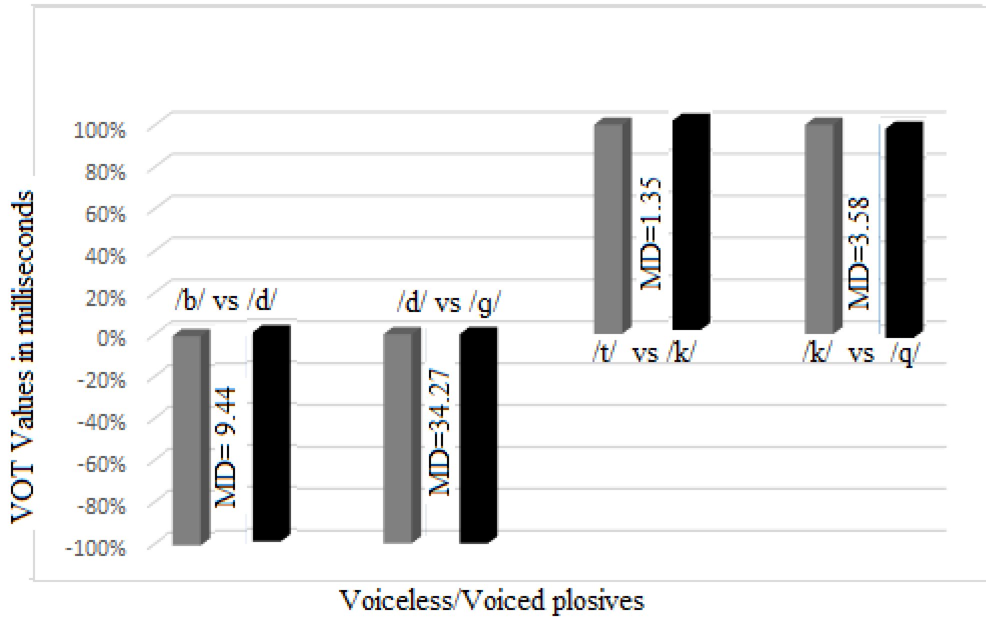

Figure 3: Bonferroni Results for the effect of place of articulation on Children VOT Differences in Means (MD) are > 0.00178

Figure 4: Bonferroni Results for the Plosive Nature Effect on VOT

Differences in Means (MD are > 0.00178

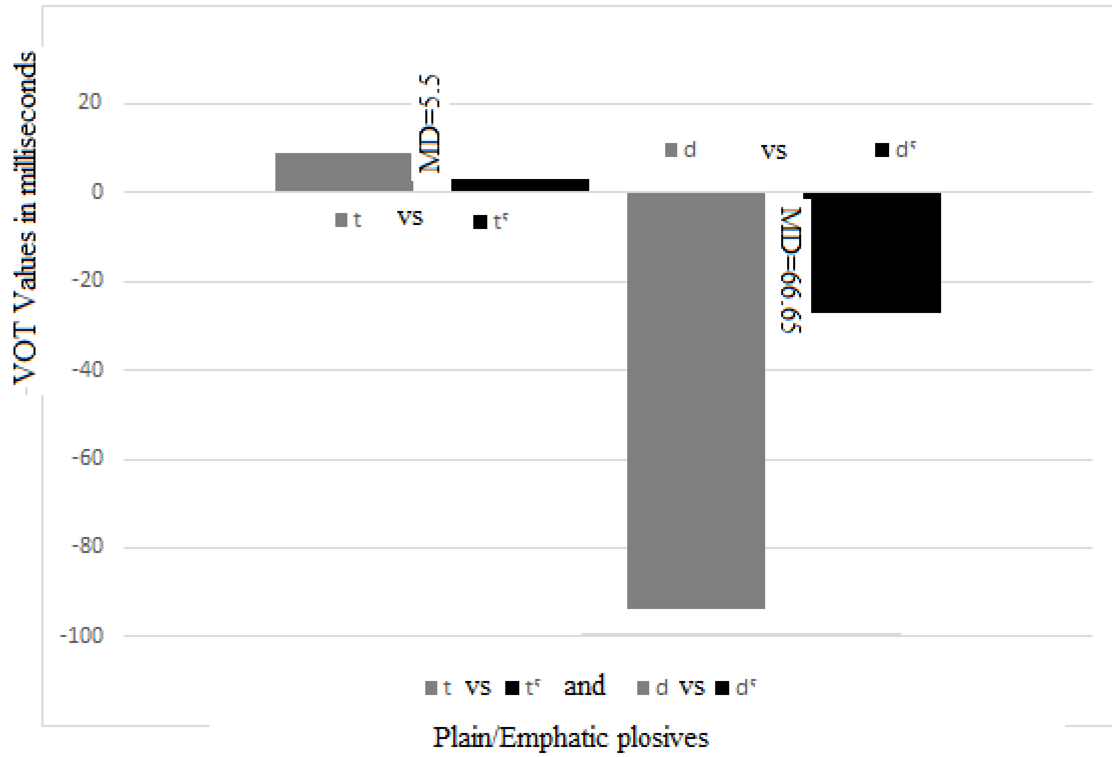

Figure 4: Bonferroni results for plosive nature effect on children VOT Differences in Means (MD) are > 0.00178