Geminate Acquisition and Representation by Ammani Arabic-Speaking Children

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Abstract: *This study investigates the acquisition and representation of geminate plosives and geminate liquids in the speech of Ammani Arabic (AA) children aged from 2;6 (year; month) to 5 years, at six months intervals. Although gemination is perceived properly by AA children at an early stage, in which they produce words including geminates significantly longer than words with singletons, the acoustic measurements indicate that the children's phonetic/acoustic representations start to be noticeable (in comparison with adults) at the age-stage of 3;7-4, and much closer to that of the adults by the age-stage 4;7-5. In terms of phonological representation, it is found that gemination is implemented as a main strategy by AA children for word-medial clusters at syllable boundaries. Interestingly, if the medial cluster is not pronounced faithfully, it will be pronounced as a geminate consonant where the second member of the cluster compensates for the deleted consonant to rescue the moraic weight and the segmental length that would be achieved by producing the target of two distinct consonantal gestures. This strategy offers an intriguing piece of evidence for the two-root node composite modal which combines moraic representation of geminates (by preserving weight to the syllable) and prosodic representation (by preserving segmental length to the geminate consonant).*

Keywords: Ammani Arabic, child's speech, geminate, language acquisition, phonological development

1. Introduction

Geminate or 'long' consonants have been accounted for from different perspectives, including the prolongation/lengthening of a consonant (Blanc 1953; Al-Ani 1970), reinforcement of the segment intensity (Ferrat 2005), tense/tension as a feature of geminate consonants (Jakobson, Fant and Halle 1952; Jessen 1998), segment strengthening (Khalil 1999), a sequence of two identical consonants but not a long consonant, e.g., /dd/ but not /d:/ (Abdo 1980), or simply as a long or doubled consonant (Davis 2011).

Cross-linguistically, some languages (including but not limited to Arabic, Italian, Japanese, and Finnish) share phonologically contrastive length effects of consonants, as in (1):

(1)	/daras/ 'to study'	/darras/ 'to teach'	Arabic	(Mashaqba 2015: 134)
	/fato/ 'fate'	/fatto/ 'fact, done'	Italian	(Bertinetto and Loporcaro 2005: 133)
	/kako/ 'past'	/kakko/ 'brackets'	Japanese	(Kunnari, Nakai and Vihman 2001: 14)
	/mAto/ 'worm'	/mAtto/ 'mat'	Finnish	(Kunnari et al. 2001: 14)

However, languages may differ in terms of the cues of geminate production and acquisition. Although children start to perceive singleton-geminate contrast at a very early stage of language development (typically by the end of the one-word stage, at roughly 13 through 16-17.5 months of age, after being exposed to 50 words including this contrast), children vary in the rate of acquisition of geminates across languages (Kunnari et al. 2001). For instance, during the one-word period, it has been reported that Finnish children acquire the contrast between singleton stops and geminate stops more rapidly than Japanese children (Vihman and Velleman 2000). Aoyama (2000) found that Finnish-speaking children could distinguish the geminate nasal from its singleton counterpart at the age of three, whereas Japanese-speaking children could not. It has been proposed that the source of this variance is the high frequency of geminates in Finnish and the longer duration ratios between geminates and singletons.

Language acquisition is a complex and puzzling developmental process (Mashaqba, Al-Khawaldeh, AlGhweirien and Al-Edwan 2020). In terms of phonetic and phonological development, children gradually acquire the articulation and the phonological processes required to produce cognates that match those of adults. Given the articulatory and acoustic nature of geminate consonants in Arabic dialects (detailed in §2), studying the acquisition of Arabic geminates is quite challenging in Arabic phonological development. Difficulty in the acquisition of geminate consonants lies in the complex articulation which is characterized by a great articulatory stability that is directly correlated with a greater durational value. In addition to the prolongation of the 'hold' phase, geminates are a product of greater energy and stronger articulation of a sound segment (Ridouane 2007; Khattab 2013; Davis and Ragheb 2014). More importantly, the mispronunciation of geminate consonants poses a problem to the lexical content and threatens oral interaction. For example, the production of the geminate /bb/ in /h̲abba/ 'piece of' as a singleton /b/, i.e. /h̲aba/ 'to crawl' causes misinterpretation and confusion, which therefore threatens the spoken dialogue and creates a communication breakdown. For details on the importance of geminate consonants in the interaction among phonology, morphology and syntax in Jordanian Arabic, see Mashaqba, Huneety, Zuraiq, Al-omari and Al-Shboul (2020).

Studying the acquisition of quantitative contrast between singleton and geminate consonants lends support to frameworks which integrate segmental and prosodic language phenomena. However, few studies have been done on the acquisition of geminate consonants in Arabic (Khattab 2007; Khattab and Tamimi 2015). The main concern of the current study is to explore geminate acquisition by typically developing Ammani Arabic (AA)-speaking children from two perspectives: acoustically, to determine approximately the age of mastering geminates, and theoretically to show how they use geminates as a repair strategy to compensate for the inability to produce consonant clusters. Hopefully, the findings of this empirical study will contribute to speech pathology with conclusions which are potentially helpful in improving clinical efficiency. The results may also help both language acquisitionists and speech therapists in understanding the problem of late acquisition (cf. §7).

The outline of the current paper is as follows: Section 2 briefly offers a phonetic and acoustic overview of geminates in Arabic. Section 3 presents the method implemented in the study, and the results are presented in Section 4. Section 5 adds a brief theoretical background to the main phonological frameworks of geminate representation, and Section 6 discusses the results within the two-root node composite representation of geminates. Section 7 summarizes the findings and indicates the implications for speech therapists and language pathologists.

2. Acoustic correlates of geminate consonants

Geminates in Arabic are durationally longer than their singleton counterparts (Davis and Ragheb 2014; Aldubai 2015). However, some studies have found that geminate and singleton consonants of the same type overlap in durational analysis (Khattab 2007: 153), or report that consonant duration in the children's emerging lexicon shows very little distinction between short and long targets in the early stages (Khattab and Tamimi 2015: 1).

Results vary concerning the vowel durations in pre- and post-geminate contexts. Some studies report that vowel shortening affects long vowels but not short ones (Khattab and Tamimi 2014). Other studies (e.g., Al-Deaibes 2016: 178) show that vowels in geminate contexts are significantly shorter than those in singleton contexts, while long vowels in geminate contexts are significantly longer than those in singleton contexts. On the other hand, some studies have concluded that gemination influences the quality and length of the neighboring vowels (Khattab & Al-Tamimi, 2014; Al-Deaibes, 2016). For instance, in Algerian Arabic, the production of the vowel following geminate consonants is acoustically different from the vowel following the singleton counterpart in three respects: a longer duration, a decrease in F1 and F2 values and a rise in F3 values (Ferrat and Guertie 2017: 576). Contrary to Ferrat and Guertie (2017), some investigations have found that the vowel following a geminate is shorter than the vowel following a singleton (Abdulrahman and Ramamoorthy 2018; Khattab 2007). By comparison, other studies suggest that the duration of a vowel preceding a geminate is shorter than its singleton counterpart (Hassan 1981, 2002; Trigui, Maraoui and Zrigui 2010). Others have concluded that the vowels surrounding the geminate consonants undergo shortening (Aldubai 2015).

The suggestion that differences between vowel duration occurring in geminate and singleton contexts brings about the notion of temporal compensation between corresponding consonants and vowels (Local and Simpson 1999; Al-

Mashagbah 2010). To highlight such attested temporal compensation, Al-Tamimi, Abu-Abbas and Tarawnah (2010) and Al-Deaibes (2016) suggest that temporal compensation is only maintained in the preceding vowel with no assessment regarding the vowel following the geminate consonant. On the contrary, Khattab and Al-Tamimi (2008: 10) conclude that no evidence is attested for temporal compensation between medial geminate consonants and the preceding vowels.

In view of the above review, Arabic geminates are a milestone in the production and acquisition of the phonetic and phonological system of Arabic. However, little work has been devoted to examining the role of geminates by Arabic-speaking children in shaping early word patterns. More importantly, the child's long phonetic durations in the early stages of production do not necessarily translate into contrastive acquisition of segmental length (Khattab and Al-Tamimi 2013: 3 for Lebanese Arabic). Even though gemination may occur in early stages of the child's speech, it may not reflect the full progression of acquisition of the acoustical phenomena attested with a more developed stage of language acquisition. Although many research studies have addressed the segmental phenomenon of gemination, no single work has been carried out on the acoustic cues of gemination in child speech of AA. Given that the acoustic attributes are a direct reflex of the articulatory gestures of speech sounds, this paper examines four major issues within plosives and liquids: (i) the acoustic differences between singletons and geminates within each group, (ii) the acoustic differences between geminate plosives and geminate liquids, (iii) the age-stage of child speech by which the acoustic measurements become statistically close to adults' acoustic measurements, and (iv) the phonological representation of geminate consonants as produced by AA-speaking children to demonstrate how they use geminates to compensate for the inability to produce consonant clusters.

3. Methodology

3.1 Participants

To explore gemination in child speech, 50 typically developing children were recruited, 25 males and 25 females, who are native speakers of AA. The participants were divided into five age-stages (years; months): 2;7-3, 3;1-3;6, 3;7-4, 4;1-4;6, and 4;7-5, with 10 participants, five boys and five girls, in each age-stage. All participants live with their families; all are monolingual, with normal vision, hearing, cognition, motor skills, and no behavioral conditions (such as anxiety disorder, psychosis, epilepsy) according to reports from their caregivers, family doctors, and classroom teachers. One participant's data were deleted after it was noted that the participant had a hereditary speech disorder. A sample of randomly selected ten normal adult speakers, five females and five males, also participated; their ages ranging between 38 and 40 (M=39;2).

3.2 Data collection

Data collection was limited to two distinct groups of consonants: plosives (/t/, /d/, /k/, /g/, /b/, and /ʔ/) and liquids (/r/ and /l/) in singleton and geminate environments. The emphatic plosives /t̠/, and /d̠/ were excluded because their articulation involves a complex co-articulation (the so-called pharyngealization) which results in a delay of their correct production by AA-speaking children. For details on emphatic consonants in Jordanian Arabic dialects, refer to Al-Masri and Jongman (2004), Al-Tamimi, Alzoubi and Tarawnah (2009), and Huneety and Mashaqba (2016a). The selection of the two groups (a subgroup of obstruents vs. a subgroup of sonorants) was particularly motivated by the assumption that manner (closure) of articulation affects geminate production (for details, refer to §2), bearing in mind that plosives are acquired earlier than liquids (McLeod and Crowe 2018). For details on the characteristics on these consonants, see Mitleb (2001), Al-Wer (2007: 507), Al-Wer and Herin (2011), Mashaqba (2015), and Thnaibat (2019).

Three tasks were used in collecting the data. In the first task, spontaneous speech tapes were recorded between February 2018 and August 2018, and took place in the participants' natural settings in a comfortable room. Each session involved one participant and the examiner (the first author). Recordings lasted for 4-6 minutes for each session, and they involved common themes including the participant's toys, games, friends, foods, drinks, clothes, animals, family members, etc. School-oriented topics were completely avoided to ensure the usage of a pure colloquial dialect, AA, rather than Modern Standard Arabic, the official language in education, media, and formal correspondence. In the second task, a set of 50 pictures of common objects (e.g., animals and toys) were prepared; these pictures referred to objects having geminates and singleton counterparts in word-internal positions, and objects having consonant clusters. The final group of 12 pictures was included to check the extent to which the participants use geminates to compensate for the inability to produce consonant clusters. Participants were asked to identify the object in each picture. If the child could not name the picture, he/she was given some clues to name it.

To account for the differences in acoustic measurements between children and adults in plosives and liquids, the third task involved two main groups of 48 minimal pairs having singletons and their geminate counterparts. Each group had three subgroups comprising the three main Arabic vowels: /a/, /i/, and /u/. The speech of 20 children covering the five age-stages was recorded while articulating the minimal pair sets. A USB Desktop microphone (Sensitivity: -67 dBV/ pBar, -47 dBV/ Pascal +/ -4 Db and Frequency response: 100-16 KHz) was used to record data.

3.3 Data analysis

A sample of 190 words containing geminate plosive and geminate liquids from 57 records was collected, transcribed and translated into English. To achieve reliable testing and avoid researcher bias, the transcription was double-checked by co-authors, and any case of pronunciation disagreement was excluded. Also, the values of words that children do not produce properly were eliminated. PRAAT software (version 6.1.01) was used to analyze data acoustically.

The acoustic differences between geminate plosives and geminate liquids and their corresponding singleton consonants in AA child speech were calculated and analyzed statistically. The analysis involved: the mean duration of geminates vs. singletons, the mean duration of the vowel that precedes geminates vs. singletons (V1), the mean duration of the vowel that follows geminates vs. singletons (V2), the mean duration of the word with geminates vs. singletons, and formant frequencies (F1 and F2) of the vowels surrounding the target consonants. Excel sheets were used to document measurements and calculate t-tests in order to reject or fail to reject the null hypotheses presented in Section 4. The study was not designed to have cross-sectional tests (inter-correlations) between all child age groups, because the target was not to examine the results across age groups. Hence, each age group was examined separately in comparison with adults (intra-correlation test). Bearing this in mind, the t-test was used to determine the significance between the means of two groups (one age-stage in comparison with the adult group). To reduce the power of the test/error rate each time the same set of data is reused statistically, the Bonferroni post hoc correction test was used ($\alpha'=1-(1-.05)^{1/5}$; the new alpha significance level: $\alpha' = .01$). The key point in using the t-test instead of ANOVA was that the recorded data followed a normal distribution with 'unknown' variances, i.e., the standard deviation (SD) and the mean are not known (p-assumption was unknown as SD and mean differ among the five age groups and differ from the adults). The t-test serves the objective of the experiment since its results can be generalized, and the assumptions based on the results would be applicable for the population for each age-stage. Recall that the main aim was to determine when the acoustic results of gemination become closer to the adult group results. By comparing each age group with the adult group, the t-test is adequate to determine whether or not the two samples have statistically similar characteristics.

It is well known that vowel formants differ as a function of gender and/or age because of the differences in vocal tract sizes (Maurer et al. 2015). Direct sex/gender spectral (formant) comparisons are not useful – and can be meaningless – without performing normalization in order to eliminate the effect of sex and age (the vocal tract biological factor: female vs. male, children vs. adults) and keep the intended gender and age factors. Thus, to eliminate variation caused by physiological differences (i.e. differences in mouth sizes) raw formant frequencies of all vowels for all speakers were normalized using the speaker extrinsic Labov ANAE method available within the online vowel normalization suite, NORM version 1.1 (Thomas and Kendall 2007). This statistical procedure is able to account for anatomical and physiological variation between speakers while it preserves sociolinguistic differences (Thomas and Kendall 2007). We utilized Labov ANAE to normalize formant means (F1 and F2) for the vowels (at the onset, midpoint and offset of the vowel) for each participant. The normalization software NORM uses the formula laid out by Labov Ash and Boberg (2006: 39-40): 'A logarithmic grand mean, *G*, is calculated from the geometric mean of the natural log of the F_1 and F_2 values of all vowels for all speakers. A logarithmic mean value, *S*, is then calculated for each speaker by taking the natural log of the F_1 and F_2 values for all of that speaker's vowels. The anti-log of the difference, *G* - *S*, is taken for *F*, the scaling factor for that speaker. Each speaker's formant values are then multiplied by the scaling factor *F* to obtain her or his normalized values'.

4. Acoustics of geminate consonants in AA child speech

In this section, five major acoustic correlates have been measured: the mean duration of geminates vs. singletons, the mean duration of V1 before geminates vs. singletons, the mean duration of V2 after geminates vs. singletons, the mean duration of the word with geminates vs. singletons, and F1 and F2 of V1 and V2.

4.1 Temporal acoustics

Table 1 presents the mean durations of geminate/singleton plosives and liquids as produced by the AA children in comparison with the adult mean durations.

Table 1: Mean duration (in seconds) of geminate/singleton plosives and liquids by AA children

	Geminates		Singletons		Ratio G to S		T-test comparing G-plosives & G-liquids		Bonferroni Correction test	
	Plosive	Liquid	Plosive	Liquid	Plosive	Liquid	Plosive	Liquid	Plosive	Liquid
Adults	.20	0.177	.088	0.044	2.27	4.02	<.05	<.05	<.01	<.01
4;7-5	.218	0.179	.0986	0.042	2.2	4.26	<.05	<.05	<.01	<.01
4;1-4;6	.405	0.27	.115	0.055	3.52	4.9	<.05	<.05	<.01	<.01
3;7-4	.499	0.338	.111	0.063	4.495	5.36	<.05	<.05	<.01	<.01
3;1-3;6	.590	0.42	.120	0.077	4.92	5.46	<.05	<.05	<.01	<.01
2;7-3	.605	0.465	.125	0.079	4.84	5.88	<.05	<.05	<.01	<.01

AA adults' results show that the mean duration of geminate plosives is 2.27 times longer than their corresponding singletons, and geminate liquids are 4 times longer than their corresponding singletons. Such results are consistent with those of Davis and Ragheb (2014) and Aldubai (2015), but opposed to the results of Khattab (2007) and Khattab and Tamimi (2015), who found no significant durational differences between singletons and geminates; such inconsistency could be an artefact of different dialects. In terms of the age-stages, it can be observed that age 4;7-5 results are extremely close to the adults' results where geminate plosives are 2.2 times longer than their corresponding singletons, and geminate liquids are 3.26 times longer than their corresponding singletons. The deviation of results starts to be noticeable at age-stage 3;7-4, when the ratio of geminate plosives to their corresponding singletons is 2:22 times higher than the adults' ratio of geminate plosives to their singleton counterparts. In the same age group, the ratio of geminate liquids to their corresponding singletons is 1.33 times longer than the adults' ratio. At age-stage 2;7-3, it can be observed that the ratio of geminate plosives to their corresponding singletons is 2.52 times higher than the adults' ratio, and the ratio of geminate liquids to their singleton counterparts is 1.86 times higher than the adults'. This result would indicate that children perceive the 'temporal' distinction between singleton plosives/liquids and geminate plosives/liquids at a very early stage of language acquisition, by which they produce longer closure duration for medial geminate consonants than for singleton counterparts, which happens after the age of one-word acquisition (cf. Vihman and Velleman 2000; Vihman and Majorano 2017 for similar results).

Table 1 also compares statistically the duration of geminate plosives with geminate liquids. Attested adult data have proven that the ratio of geminate plosives to geminate liquids is 1:1.13 ($p< .01$, $\alpha=.01$) which indicates that the durational means of geminate liquids and geminate plosives are statistically significant. The attested children's data display the same notion. All age groups also registered a significant difference between the means of consonant durations of geminate liquids vs geminate plosives ($p<.01$). This result confirms that children were able to perceive not only a contrastive consonantal length but also the phonological distinction between 'natural classes': although the results vary among the age groups, they significantly produced geminate liquids longer than geminate plosives.

Table 2 presents the mean durations of V1 before geminate/singleton plosives and liquids as produced by the AA children in comparison with the adult-like mean durations. The table addresses the notion of temporal compensation in geminates and singletons regarding V1.

Table 2: Mean duration of V1 (in seconds) in geminate/singleton plosives and liquids by AA children

	Geminates		Singletons		Ratio G to S		T-test		Bonferroni Correction test	
	Plosive	Liquid	Plosive	Liquid	Plosive	Plosive	Liquid	Plosive	Liquid	Plosive
Adults	.058	.128	.060	.076	0.96	1.68	>.05	>.05	>.01	>.01
4;7-5	.057	.084	.056	.078	1.017	1.076	>.05	>.05	>.01	>.01
4;1-4;6	.066	.072	.058	.068	1.14	1.058	>.05	>.05	>.01	>.01
3;7-4	.064	.0796	.061	.066	1.05	1.20	>.05	>.05	>.01	>.01
3;1-3;6	.081	.105	.085	.092	0.95	1.14	>.05	>.05	>.01	>.01
2;7-3	.0898	.114	.093	.106	0.96	1.075	>.05	>.05	>.01	>.01

Acoustic analysis confirmed that no statistical difference was found between the duration of V1 before geminate plosives and geminate liquids compared to that before singleton plosive and singleton liquid by AA children and AA adult forms. Statistically, there was no significant difference between the mean durations of V1 before geminate plosives and singleton plosives, and between the mean durations of V1 before geminate liquids and singleton liquids in the adults' and all children's age-stages ($p>.01$). Such results are consistent with Khattab and Al- Tamimi (2008), yet contrast with the results of Local and Simpson (1999), Al-Mashagbah (2010), Al-Tamimi et al. (2010), Al-Deaibes (2016), and Trigui et al., (2010) who reported a considerable amount of temporal compensation of the vowels surrounding the geminate consonants.

Returning to Table 2, the investigation regarding the adults' results has shown that the mean duration of V1 before geminate liquids is 2.21 times longer than its plosive counterpart. The mean duration of V1 before geminate liquids is 128ms, whereas the mean duration of V1 before geminate plosives is 58ms. Intriguingly, the mean duration of V1 before geminate liquids is significantly longer than V1 before geminate plosives ($p<.01$). Results of all age-stages (2;7 through 4;7-5) consistently exhibit a longer V1 before geminate liquids than V1 before geminate plosives; however, the difference was insignificant ($p>.01$). This proves that perceptual analysis is not precise enough to evaluate geminate production in child speech.

Table 3 presents the mean durations of V2 geminate/singleton plosives and liquids as produced by the AA children in comparison with the adult-like mean durations. The table highlights the notion of temporal compensation in geminates and singletons regarding V2.

Table 3: Mean duration of V2 (seconds) in geminate/singleton plosives and liquids by AA children

	Geminates		Singletons		Ratio G to S		T-test		Bonferroni Correction Test	
	Plosive	Liquid	Plosive	Liquid	Plosive	Liquid	Plosive	Liquid	Plosive	Liquid
Adults	.084	.075	.094	.089	0.89	0.84	>.05	>.05	>.01	>.01
4;7-5	.086	.089	.087	. 082	0.98	1.08	>.05	>.05	>.01	>.01
4;1-4;6	.112	.105	.106	.092	1.05	1.14	>.05	>.05	>.01	>.01
3;7-4	.10	.095	.087	.083	1.15	1.14	>.05	>.05	>.01	>.01
3;1-3;6	.119	.125	.121	.116	0.98	1.08	>.05	>.05	>.01	>.01
2;7-3	.125	.144	.133	.132	0.93	1.09	>.05	>.05	>.01	>.01

As for the V2 durations by adults, no statistical difference between the mean duration of V2 after geminates (plosives and liquids) and their singleton counterparts was registered ($p>.01$). Such results indicated the non-existence of residue of temporal compensation in geminate liquids at the expense of V2 after geminates. Our results are consistent with those of Ferrat and Guertie (2017), yet contradict those of Aldubai (2015), Abdulrahman and Ramamoorthy (2018), and Khattab (2007). Although mean V2 duration varies among the five age groups, no age groups reported a significant difference between the mean V2 durations of geminates (plosives and liquids) and singletons, which confirms the non-existence of any noticeable residue of temporal compensation.

Production of geminate plosives/liquids by AA children shows no sign of temporal compensation between geminate plosives/liquids and their surrounding vowels. Instead, it has been noticed that the children tend to produce longer words in geminate environments compared to words with singleton counterparts. Table 4 presents the mean word durations containing geminate/singleton plosives and liquids as produced by the AA children in comparison with that of the adults.

Table 4: Mean word duration (in seconds) in geminate/singleton plosives and liquids by AA children

	Geminates		Singletons		Ratio G to S		T-test		Bonferroni Correction Test	
	Plosive	**Liquid**	**Plosive**	**Liquid**	**Plosive**	**Plosive**	**Liquid**	**Plosive**	**Liquid**	**Plosive**
Adults	0.567	0.562	0.484	0.439	1.17	1.28	<.05	<.05	<.01	<.01
4;7-5	0.533	0.564	0.451	0.43	1.18	1.31	<.05	<.05	<.01	<.01
4;1-4;6	0.545	0.583	0.445	0.422	1.22	1.38	<.05	<.05	<.01	<.01
3;7-4	0.592	0.683	0.489	0.498	1.21	1.37	<.05	<.05	<.01	<.01
3;1-3;6	0.692	0.752	0.536	0.505	1.29	1.48	<.05	<.05	>.01*	>.01*
2;7-3	0.795	0.869	0.611	0.601	1.30	1.44	<.05	<.05	>.01*	>.01*

***= not significant at the post hoc Bonferroni test ($\alpha' = .01$)**

The adults' results show that words in geminate plosive environments are 1.17 times longer than their singleton plosive counterparts. Words having geminate liquids exhibit similar results, being 1.28 times longer than their liquid singleton counterparts. A statistically significant difference between the word mean durations of geminate plosives/liquids and singletons does exist ($p<.01$). Intriguingly, the two youngest age groups, 2;7-3 and 3;1-3;6, tend to produce longer words, which is expected because their speech rate is slower than that in the older children; however, their results were significant at the original alpha level, .05, but not at the new alpha level, .01. We attribute this to the notion that children up to this age-stage are still in the phase of progressive acquisition of the phoentic inventory of AA vowels and consonants, which makes the word production unstable. Regarding AA children's results in the age-stages 3;7-4, 4;1-4;6, and 4;7-5, it is statistically proven that words with geminate plosives and geminate liquids are significantly longer than words with their singleton counterparts in all age groups. In terms of the temporal properties of words length, the acquisition system of children is very active and sensitive in an early stage of language processing. Thus, it should be one of the easiest tasks for children to master. Recall that no significant temporal compensation is registered for V1 before singletons as compared to geminate plosives and liquids. This result would suggest that such temporal compensation was not sufficiently significant to reduce duration at word level.

4.2 Vowel formants in AA child speech

The collected data provides evidence of acoustic cues of gemination in the early stages of language acquisition. Nevertheless, the occurrence of gemination in the early stages of the child speech may not reflect the full progression of the acquisition of the acoustical phenomena attested in a more developed stage of language acquisition (cf. Khattab and Al-Tamimi 2013 for similar results). Tables 5 and 6 represent the mean F1 and F2 values of the attested vowels in the five age groups in comparison with the adults' values. The tables also include t-test results which compare the adults' and children's F1/F2.

Table 5: Mean F1 values of vowels before and after (geminate/singleton) plosives and liquids

Age Group	Mean F1-*a* preceding	Mean F1-*a* following	Mean F1 *i* preceding	Mean F1-*i* following	Mean F1-*u* preceding	Mean F1-*u* following	T-test *a* preceding	T-test *a* following	T-test *i* preceding	T-test *i* Following	T-test *u* preceding	T-test *u* Following
Adult	708	635	433	486	435	561						
4;7-5	741	712	480	511	511	545	>.05	>.05	>.05	>.05	>.05	>.05
4;1-4;6	792	811	523	621	638	642	<.05	<.05	<.05*	<.05*	<.05*	<.05
3;7-4	884	927	596	739	653	713	<.05*	<.05*	<.05	<.05	<.05*	<.05
3;1-3;6	896	896	621	744	816	843	<.05*	<.05	<.05*	<.05	<.05	<.05*
2;7-3	922	838	656	760	864	927	<.05	<.05	<.05*	<.05	<.05	<.05

*= not significant at the post hoc Bonferroni test ($\alpha' = .01$)

The measured mean F1 values of vowels before and after (geminate/singleton) plosives and liquids indicate that only age group 4;7-5 shows consistency with the results of the adults group in the t-test (p>.05), and the post hoc Bonferroni test (p>.01). Although age group 4;1-4-6 approximates the adults' values, the reported measurements were not statistically significant. Age groups 3;7-4, 3;1-3-6, and 2;7-3 show an extreme significant difference in comparison with adults' values (p<.05). Acoustically, the age group 4;7-5 is the proper period of phonological development by which F1 of the pre-geminate and post-geminate vowels starts to become statistically close to adults' production.

Table 6: Mean F2 values of vowels before and after (geminate/singleton) plosives and liquids

Age Group	Mean F2-*a* preceding	Mean F2-*a* following	Mean F2 *i* preceding	Mean F2-*i* following	Mean F2-*u* preceding	Mean F2-*u* following	T-test *a* preceding	T-test *a* following	T-test *i* preceding	T-test *i* Following	T-test *u* preceding	T-test *u* Following
Adult	1671	1647	2202	2205	1238	1353						
4;7-5	1550	1546	2127	2160	1448	1371	>.05	>.05	>.05	>.05	>.05	>.05
4;1-4-6	1565	1559	2154	2130	1420	1312	>.05	>.05	>.05	>.05	>.05	>.05
3;7-4	1436	1477	1997	1980	1413	1317	>.05	>.05	>.05	>.05	>.05	>.05
3;1-3;6	1522	1517	1989	1834	1518	1598	>.05	>.05	>.05	<.05	<.05*	<.05*
2;7-3	1522	1517	1874	1834	1588	1627	>.05	>.05	<.05*	<.05	<.05*	<.05

*= not significant at the post hoc Bonferroni test ($\alpha' = .01$)

Statistically, age groups above 3;7 register no significant difference between the mean F2 values in comparison with the mean F2 values of the adult group at the original alpha level, .05. Age groups 2;7-3 and 3;1-3-6 have p-values fluctuating between being lower and higher than the alpha significance level. This fluctuation denotes the non-consistency and incomplete acquisition of the acoustical aspects of gemination, until the age of 3;6. Cumulatively and acoustically, age group 4;7-5 is the period of proper phonological development when F1 and F2 of the pre-geminate and post-geminate vowels start to become statistically close to adult readings. The acquisition development and accuracy of this group shows a positive trend towards geminate mastery, which significantly increases across age groups.

5. Phonological representation of geminates

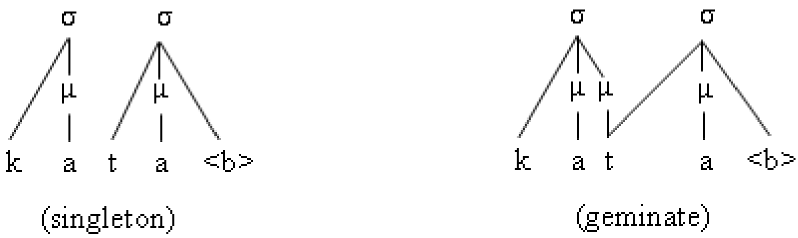
Two types of geminate consonant are attested in Arabic: fake and proper (real) geminates (Al-Tamimi, Abu-Abbas and Tarawnah 2010: 114). Fake gemination occurs as a by-product of the assimilation of the definite article /ʔil/ and the following coronal consonant, as in (2a) (cf. Al-Tamimi et al. 2010; Heselwood and Watson 2013), or the assimilation of one of the root consonants /w/, /y/ or /ʔ/ and the following –t in the derived verb pattern fta^{c}al, as in (2b) (cf. Zemánek 2007). By comparison, proper gemination takes place as part of the lexical root of the word (Alqattan 2015: 102), and appears intervocalically, as in (2c) and word-finally, as in (2d) (Davis and Ragheb 2014).

(2)	a.	**fake gemination**		
		*ʔil+ti.li.fo:n	ʔit.ti.li.fo:n	'the phone'
		*ʔil+sham.^{c}a	ʔish.sham.^{c}a	'the candle'
		*ʔil+sam.ma:.^{c}a	ʔis.sam.ma:.^{c}a	'the headphones'
	b.	*wtaws̲al	tta.s̲al	'to connect'
		*wtas̲af	ttas̲af	'to be described'
		*wtah̲ad	ttah̲ad	'to unite'
	c.	**intervocalic gemination**		
		s̲uffe:ra	'whistle'	
		h̲amma:m	'bathroom'	
		rumma:n	'pomegranate'	
	d.	**word-final gemination**		
		^{c}ushsh	'nest'	
		s̲aff	'classroom'	
		kull	'every'	

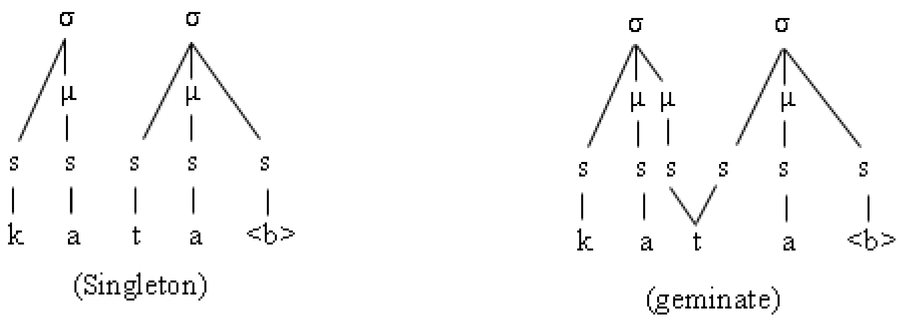
The phonological representation of geminates has been a debatable issue for many linguists; the main concern is to capture the difference between geminates and their singleton counterparts in an attempt to handle the cross-linguistic phonological structure of geminates (Davis 2011: 873-876; Guba 2020). Phonologically, three contrastive viewpoints of geminates are reported: (i) prosodic length representation where a geminate is linked to two C-slots on a skeletal tier as in (3), (ii) moraic weight representation where a geminate has an inherent weight and is assigned a mora, as in (4) (Hayes 1989; Watson 2002; Davis and Ragheb 2014), and (iii) the two-root node composite model that combines insights from the above two views, as in (5) (Guba 2020 following Curtis 2003). The following grids exemplify the minimal pair *katab* and *kattab* comprising the representations of geminates and singletons depicting the contrastive representations.

(3) Prosodic length representation

(4) Moraic representation



(5) Two-root node composite model (s = segmental)

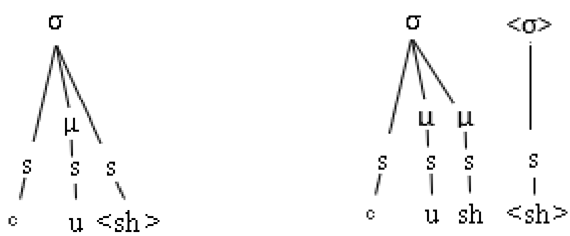


Based on the diagrams above, the prosodic length representation determines geminates as two separate elements (/tt/) linked to two C-slots on a skeletal tier, whereas singletons (/t/ here) are linked to one C-slot only, as in (3). This representation cannot differentiate between two-consonant clusters and geminates, and mistakenly predicts that a geminate can occupy positions that CC-clusters have. On the other hand, the moraic weight representation considers that the geminate /tt/ has an inherent weight and is assigned a mora (i.e., the prosodic tier is moraic rather than segmental), whereas the singleton /t/ is not assigned a mora, as in (4). This representation also predicts that a geminate consonant may not pattern with CC-clusters in weight-sensitive processes (Davis 2011; Guba 2020). For example, word-final CC-clusters in AA are broken up by an epenthetic vowel (e.g. *bint* 'girl' > *binit*), whereas final geminate consonants do not undergo the same process (e.g., *sitt* 'grandmother' > *sitt*) (cf. Guba 2020). However, moraic analysis has a problem in dealing with contained geminate (the one that syllabifies as coda as in *sitt.na* 'our grandmother') because this analysis could not distinguish it from a simple moraic coda (as in *bit.na* 'we slept'). The two-root node composite model, obtaining the segmental and moraic representation, accounts successfully for geminates in Arabic, by which geminates have their moraic weight, but they are linked to two-root nodes (but not two X-slots) (Guba 2020).

6. Two-root node composite representation of geminates

In this section, we argue for the way AA-speaking children use geminates as a repair strategy to compensate for the inability to produce consonant clusters. Adopting the two-root node composite model (Guba 2020), segmental length is represented independently of prosodic weight. Hence, a geminate consonant has its moraic weight and is linked to two-root nodes. In terms of moraic theory, words in AA should meet the minimal bimoraicity condition and should contain at least one foot which is maximally assigned two moras (cf. Hayes 1995; Watson 2002). Examples in (6) are originally monomoraic, and thus cannot construct a foot by themselves and are rendered degenerate. Since Arabic has a strong prohibition against degenerate feet, the coda consonant undergoes a process of gemination (cf. Hayes 1995; Watson 2002; Davis 2011; Huneety and Mashaqba 2016b; Mashaqba and Huneety 2018). Metrically, the word ^{c}*ushsh* 'nest' has a mora assigned to the short vowel /u/ and another mora is assigned to /sh/ by the Weight by Position Rule (WBP), which states that a coda consonant in non-final positions receives a mora (Hayes 1989). The coda consonant in the word-final position is deemed extra-syllabic preventing the syllable from being peripheral. Then, the word has met the bimoraicity condition and is eligible to receive the main stress. The following metrical trees demonstrate the word ^{c}*ushsh* before and after the gemination process.

(6)



Gemination can also be attested in cases of repair processes produced by normally developing children (Mashaqba, Shdifat, Huneety and Abu Alhala 2019). In AA, children resort to reducing consonant clusters for ease of articulation. Remarkably, the segment deletion process is directed towards the preservation of the second element (Abwini 2012). The cluster segments occur at syllable boundaries, by which the first member occupies a coda position in the left-hand syllable and the second member occupies an onset position in the right-hand syllable: $C_xV\boldsymbol{C_1.C_2}VC_x$. Since Arabic does not allow onsetless syllables to surface (Watson 2002; Broselow 2009; Mashaqba 2015), children tend to delete the segment acquiring the non-final coda position and not the onset. This process preserves syllable weight via two slots by lengthening as a strategy to cope with cluster production. The gemination process of the preserved segment yields a $C_xV\boldsymbol{C_2.C_2}VC_x$ syllable pattern in an attempt to preserve the underlying moraic weight (as in 7). Data in (8) exemplify some attested cases involving the deletion of coda consonants and replacing them by a compensatory lengthening of the adjacent segment to fill in the C slot which is left empty regardless of the sonority hierarchy.

(7) **Rule:**

[C1] [C2]-----------------------	[-] [C2]-----------------------------	[C2] [C2]
(A)	(B)	(C)
$C_xV\mathbf{C_1.C_2}VC_x$	C_xV [-].$\mathbf{C_2}VC_x$	$C_xV\mathbf{C_2.C_2}VC_x$

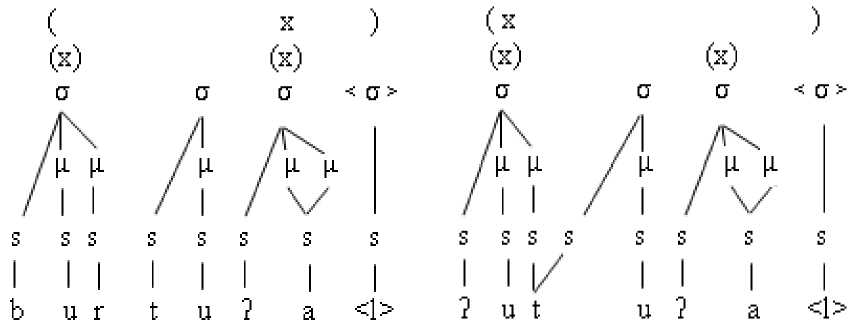
(8) Cluster reduction and gemination

/ʔar.nab/	[ʔan.nab]	‘rabbit’
/shan.ta/	[shat.ta]	‘bag’
/ʔaṣ.far/	[ʔaf.fal]	‘yellow’
/fur.sha:y/	[fush.sha:y]	‘brush’
/lu^{c}.ba/	[ʔub.ba]	‘toy’
/kat.shab/	[ʔash.shab]	‘catchup’
/ban.do:.ra/	[bad.do:.la]	‘tomato’

Metrically, a mora is inherently assigned to non-final coda consonants by WBP. When the non-final coda is deleted by the child, the weight of the syllable fluctuates because of the loss of its second mora; therefore, the process of gemination compensates for the deleted segment to capture the underlying prosodic structure by keeping the moraic weight of the syllable (see Davis and Ragheb 2014 for final clusters). The compensatory consonant occupies the non-final coda position to rescue weight, and thus receives a mora by WBP. The segmental length of the surface geminate is represented by a two-root node. The metrical trees in (9) demonstrate the underlying and surface forms of the word

/bur.tu.ʔa:l/ ‘orange’ and the surface form [ʔut.tu.ʔa:l] as produced by a three-year-old participant.

(9)



Another example is the word mar.ha.ba ‘hello’, which undergoes the process of cluster reduction and gemination mah.ha.ba. Figures 1 and 2 are spectrograms of both words (mar.ha.ba ‘hello’ produced by a native AA adult speaker and mah.ha.ba produced by a native AA 3-year-old child, respectively).

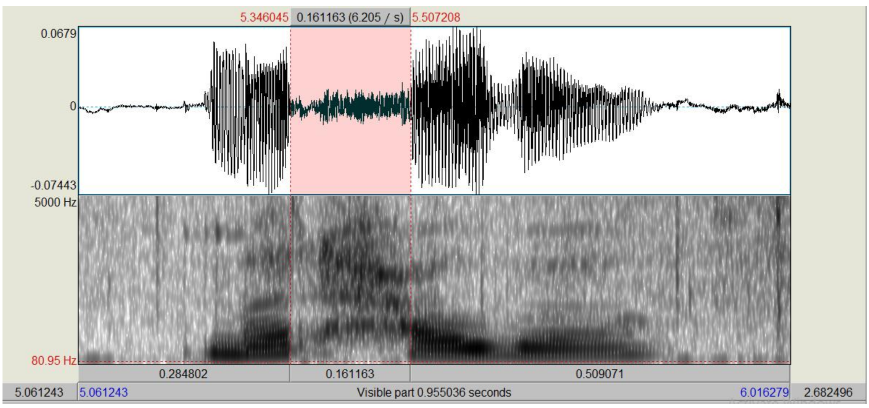


Figure 1. Spectrogram of the word *mar.<u>h</u>a.ba* ‘hello’ by native AA adult speaker

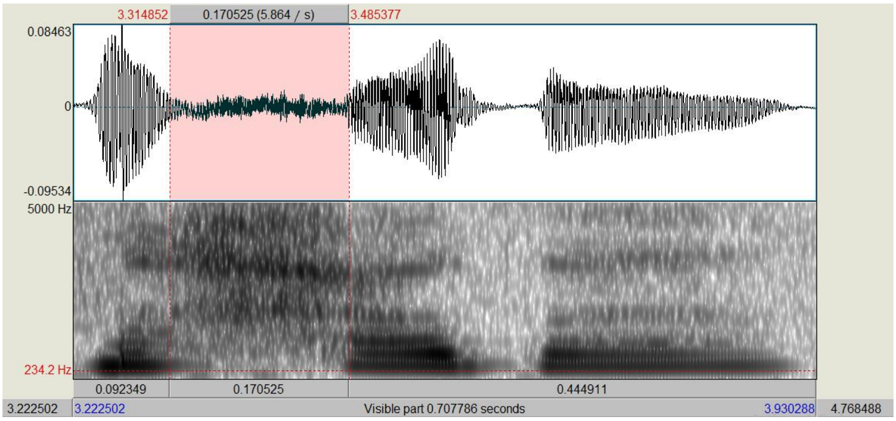


Figure 2. Spectrogram of the word *maḫ.ḫa.ba* 'hello' by native AA child speaker

Acoustically, the duration of the [rḫ] in the adult-like form *mar.ḫa.ba* is 0.16 seconds (s), where the durations of [r] and [ḫ] are 0.7 s and 0.9 s respectively. On the other hand, the compensatory lengthened consonant [ḫḫ] in the surface form [maḫ.ḫa.ba] has a total duration of 0.17 s which is very close to the total duration of [rḫ] in the adult-like form. Therefore, it can be concluded that the child did not only compensate for the weight of the deleted cluster segment; he/she compensated for the temporal/durational ratios of the attested deleted segment of the target cluster and the geminate consonant.

7. Conclusion and implications

This study registered the following acoustic conclusions concerning the geminate production by AA children: no significant temporal compensation occurs before geminate plosives at the expense of the vowel that precedes the target geminate consonant. Temporal compensation residue in geminate plosives is attested at the expense of the vowel after geminate plosives. At the word level, AA children, however, significantly produce longer words in geminate environments compared to words with singleton counterparts. The results show no sign of temporal compensation between geminate consonants and their surrounding vowels. Instead, they tend to produce longer words in geminate environments compared to words with singleton counterparts. Although children have been found to overproduce geminate consonants, the acoustic measurements indicated that F1 develops at the 4;7-5 age group. However, the age-stage 3;7-4 is the proper period of phonological development, when the F2 of the pre-geminate and post-geminate vowels start to become statistically close to adults' readings, although gemination phonetically and phonologically was perceived by AA children very early.

Although being a relatively 'marked' form, gemination is effectively manipulated by AA children as a main strategy to simplify the pronunciation of word-medial clusters at syllable boundaries. Intriguingly their behavior supports the moraic representation of geminates by adding weight to the syllable. That is, when medial clusters are not pronounced faithfully, they will be pronounced as a geminate consonant where the onset of the right-hand syllable compensates the deleted coda of the left-hand syllable to capture the prosodic weight of the two underlying distinct consonantal gestures. To this end, the study emphasized the continuous interaction between phonetics and phonology throughout language development where geminate acquisition is a leading force in shaping early word production. The phonetic/acoustic account seems to feature language-specific skills which highlight variations across languages, while the phonological account enriches abstract and bound language patterns (Vihman and Velleman 2000).

Finally, this work sets out the belief that Arabic is one of the languages with insufficient research into the phonological profile of child speech. We therefore believe that the findings in this study are fundamental for the educational curriculum concerning the early language-learning phase in the Arabic-speaking community. This will have a noticeable impact on children's progress in several aspects, such as adult control in spelling and reading tasks. Additionally, the results should be taken into consideration by parents, caregivers and language therapists/clinicians when preparing appropriate exercises, linguistic training, and treatment for children with speech disorders as early as possible, because age has a significant influence on the linguistic performance of children (Mashaqba, Abu Sa'aleek, Huneety and Al-Shboul 2020). Speech therapy clinicians mainly use perceptual judgment when dealing with impaired children (such as children with cleft palate, Down syndrome, stuttering, and hearing impairment) in their therapy sessions, which is insufficient. Hence, the acoustic cues of geminates in the present study should be taken into consideration during therapy sessions, and should be checked regularly until the results become acoustically close to the results of typically developing children. During repetition tasks, a major technique that speech language therapists resort to, words should be broken into their corresponding syllables. In geminate cases, breaking down the word into syllables will trigger the realization of the geminate environment where the two cognates occupy a coda position in the first syllable and an onset position in the second one. Where the geminate is located, a durational gap should be created by the speech therapist when the two syllables are broken down. This technique is expected to sustain an auditory processing of geminates by atypical children, and will be later reflected in their speech.

Based on these conclusions, future work on geminates comparing typically developing children with atypically developing children is recommended. Furthermore, given that children with cleft palate produce insufficient high-intra-oral-air pressure with obstruent consonants (Thnaibat 2019), the findings of the present study call for a nasometric analysis of geminates by these children in light of the standardized normative data of nasalance scores reported for Jordanian Arabic speakers (Natour, Efthymiou, Marie and Darawsheh 2020), with careful consideration of the linguistic and extralinguistic variables.

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