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ARTICLE

An Acoustic Analysis of Singleton and Geminate Emphatic and Non-Emphatic Consonants in Arabic

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ABSTRACT

Differences in length between singleton and geminate consonants with the same feature have received considerable attention in the literature. However, little work has been done to analyze differences in duration between singleton and geminate consonants with distinct features. This acoustic study sought to examine the differences in duration between singleton and geminate emphatic and non-emphatic consonants in Standard Arabic. The target consonants consisted of emphatic /sˤ/, /tˤ/, and /ðˤ/ (in singleton and geminate form) and their non-emphatic counterparts: /s/, /t/, and /ð/ (in singleton and geminate form). The stimuli consisted of 12 words, six of which contained a singleton and the other six of which contained a geminate, in order to test the closure/friction duration of those sounds. Seven native-speaking Arabic students from Prince Sattam bin Abdulaziz University were recruited as participants for the study. They were recorded while producing the target words containing intervocalic singleton and geminate consonants in a carrier phrase. The results generally showed a large singleton-to-geminate ratio difference in closure/friction duration. The singleton-to-geminate ratios showed that a geminate consonant was approximately twice the duration of a singleton. However, the results showed no difference between the ratios and means of emphatic and non-emphatic singleton consonants or between the closure/friction durations of emphatic and non-emphatic geminate consonants.

Keywords: Arabic; Closure; Consonant; Duration; Emphatic; Geminate; Gemination; Singleton

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1. Introduction

1.1. Background

In many languages, the phonetic characteristic of segment duration is phonemic, with speakers using short (singleton) and long (geminate) sounds to distinguish minimal pairs. Therefore, this phonemic contrast can be examined within a phonetic framework. Several studies have examined the phonetic cues that indicate whether a given sound is geminate or singleton, namely intensity and closure duration [1–5]. The present study focused on the closure/friction duration of singleton and geminate emphatic (i.e., pharyngealized) and non-emphatic (non-pharyngealized) consonants in Arabic.

Arabic grammarians have traditionally referred to gemination with the term /taʃdid/, which means "emphasizing" or "intensifying." Orthographically, gemination is represented by placing a diacritic, called the shadda, over letters to indicate a longer consonant. This phonemic distinction can be seen in Examples 1 and 2.

1. /kasara/ "he broke" /kassara/ "he caused to break";
2. /fatˤara/ "he had breakfast" /fatˤtˤara/ "he fed someone breakfast."

The Standard Arabic phonemic inventory comprises 28 consonants, all of which can be articulated with geminate length [6, 7]. In the phonological literature, a geminate consonant is typically represented either as a long consonant or as a sequence of two singleton consonants. Phonologically, the geminate is a sequence of two singletons, with the first part in the coda of one syllable and the second part in the onset of the next syllable. This can be seen in **Figure 1**, adapted from Catford [8] and Trubetzkoy [9].

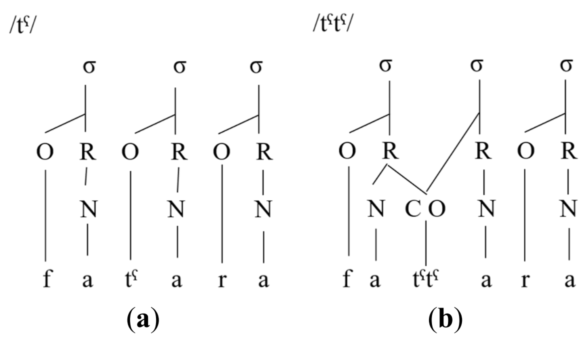

Figure 1. (**a**) Syllable structure of the singleton /tˤ/; (**b**) Syllable structure of the geminate /tˤ tˤ/.

Phonologically, Standard Arabic does not allow syllables to begin with geminates, meaning no geminates are allowed word initially [10]. However, geminates are allowed word medially (or intervocalically), where they are distinguished phonemically from their singleton counterparts, as in /xaser/ "he lost" vs. /xasser/ "he caused someone to lose." This type of gemination (i.e., intervocalic) is more common than marginal gemination [11, 12]. While it is accepted that geminates can occur intervocalically and not word initially, it is debated whether geminates occur word finally. Some researchers have argued that geminates can occur word finally in the pausal form [7, 10]. For example, the word /ʕaam/ "year," with a final singleton, contrasts with the word /ʕaamm/ "public," with a final geminate [7]. The words /ħaad/ "deviated" and /ħaadd/ "sharp" are another example of final non-geminates contrasting with geminates in Standard Arabic [10]. Other researchers have argued that the final geminate/non-geminate contrast in Standard Arabic is not actually distinctive or significant [13, 14], but this question was outside the scope of the current study.

Acoustically, the main characteristic of the geminate consonant is the intensity and phonetic length of the segment in addition to the strong release of the sound with greater air pressure [7–9]. Since a geminate consonant is a sequence of two consonants that have the same place and manner of articulation, these sounds are associated with a longer closure and higher air pressure [15].

This brief background has shown that phonologically geminates appear intervocalically and that acoustically the phonetic length of the closure duration of a geminate consonant is longer than that of its corresponding singleton consonant. To see the difference between singleton and geminate sounds, it is necessary to look at singleton-to-geminate ratios. Thus, this study presents the average durations and ratios for these consonants.

1.2. Literature

In the literature, studies on geminate closure duration have generally based their analyses on the ratios of singleton-to-geminate consonant durations. Some have observed that geminate consonant duration was double that of singleton duration [7], while other scholars have observed geminate duration to be triple that of a singleton [4, 16, 17].

Numerous languages contrast consonants by phonetic length. Regarding the ratio of singleton-to-geminate length, some languages have geminates that are three times longer than singletons, as in Japanese[2, 18, 19], Turkish[4], and Swiss German[3], while other languages have a lower difference, with a geminate being only twice as long as a singleton, as in Hindi[5] and Italian[1]. For example, one study found that Hindi geminate stop closure was longer than that of singletons by a ratio of 1:1.96, indicating that a geminate was slightly less than twice as long as a singleton[5].

Languages with a high ratio difference between geminates and singletons are worth mentioning because they are similar to the current study's results. Such languages have singleton-to-geminate length ratios higher than 1:2. A study on geminate stops in Turkish, for example, found that the geminate closure duration was nearly three times longer than a singleton, with a ratio of 1:2.93[4], while a study on Swiss German found that geminates had longer closure duration by a ratio of 1:3[3].

Other studies have shown geminate consonants to be longer than singletons based on place or manner of articulation. One, for instance, found longer duration for Cypriot Greek word-medial geminate stops, fricatives, affricates, and sonorants than their singleton counterparts[20]. A study on Guinaang Bontok found the temporal ratio of singleton to geminate to be the highest in nasals (1:2.08), liquids (1:1.90), and stops (1:1.87), whereas the lowest was in glides (1:1.56)[21]. Another study found that the durational ratio for singletons and stops was 1:2 for /p t k/ in Italian[1]. The singleton-to-geminate durational ratio in Japanese was found to be nearly 1:2.5 for nasals and 1:1.80 for fricatives[22], and word-medial geminate stops in Rembarrnga were found to be longer than singletons[23]. A study on Berber found a 1:3.68 singleton-to-geminate durational ratio for /t/ and 1:2.9 for /k/[24], while a study on Jordanian Arabic differences in closure duration and preceding vowels revealed a singleton-to-geminate durational ratio of 1:2.76[25].

Another factor related to gemination is when vowels differ depending on whether they precede a geminate or a singleton. Some researchers have observed that vowels preceding a geminate are shorter than before a singleton in Italian[1, 26], certain languages in Indonesia[27], Tashlhiyt Berber[28], Hindi[29], Sinhalese, Bengali, Hausa, Amharic, and Arabic[30]. One study consistently found that Italian vowels were shorter before geminate stops[1], while another considered the durations of the consonant and preceding vowel to be the strongest cues for the singleton-geminate contrast[31]. Similarly, Swedish vowels preceding singletons have been shown to be significantly longer than vowels preceding geminates[32]. Although this seems to be a general pattern cross-linguistically, one study found that only Japanese vowels did not differ in length when preceding or following geminate and singleton consonants[30].

In summary, the main elements from the literature cited above that were relevant to the current study were the determined phonetic cues, such as the length of the preceding vowel, and the fact that a geminate consonant tends to be around twice as long as a singleton.

1.3. Research Questions

To the researcher's knowledge, no previous studies have looked at the durational difference between singleton and geminate emphatic and non-emphatic consonants in Standard Arabic. Therefore, no phonetic cues have been associated with such a contrast. Thus, this experimental acoustic study sought to address that gap in the literature. It investigated whether emphatic and non-emphatic singleton and geminate consonants showed different closure/friction duration or other phonetic cues. As such, the study was guided by the following research questions:

(1) Does the closure duration of geminate and singleton consonants differ in Standard Arabic?
(2) Does the closure duration of singleton non-emphatic consonants differ from singleton emphatic consonants in Standard Arabic?
(3) Does the closure duration of geminate non-emphatic consonants differ from geminate emphatic consonants in Standard Arabic?

In order to answer those questions, the researcher conducted a production study, as detailed in the next section.

2. Materials and Methods

2.1. Participants

The researcher recruited seven male native speakers of Arabic through convenience sampling. All participants were students of the researcher, who volunteered after the researcher informed them of the study and asked if they would like to participate. The participants were between 20 and 25 years old and were all undergraduate students at Prince Sattam bin Abdulaziz University, Saudi Arabia.

2.2. Instruments

All test words were of the form CVCVCV or CVC-CVCV, which were presented to participants as pairs differing in the presence or absence of a geminate consonant. Target sounds consisted of non-emphatic /s/, /t/, and /ð/; emphatic /sˤ/, /tˤ/, and /ðˤ/; and their geminate counterparts (see **Tables 1** and **2**). Stops and fricatives were used as target phonemes because their boundaries would be easier to determine on waveforms and spectrograms compared to other segments, such as nasals and liquids.

Table 1. Examples of non-emphatic singleton and geminate consonants in Arabic.

Phoneme	Singleton	Meaning	Geminate	Meaning
/s/	kasara	He broke	kassara	He caused to break
/t/	fatara	He calmed down	fattara	He caused to calm down
/ð/	baðara	He sowed	baððara	He spent lavishly

Table 2. Examples of emphatic singleton and geminate consonants in Arabic.

Phoneme	Singleton	Meaning	Geminate	Meaning
/sˤ/	qasˤara	He shortened	qasˤsˤara	He caused to shorten
/tˤ/	fatˤara	He had breakfast	fatˤtˤara	He fed someone breakfast
/ðˤ/	naðˤara	He looked	naðˤðˤara	He theorized

2.3. Data Collection Procedures

Since this study was concerned with the production of Standard Arabic singleton and geminate emphatic and non-emphatic obstruents, the participants were asked to provide the data individually. Data were collected at Prince Sattam bin Abdulaziz University. Participants met the researcher in a lab in the English Language and Literature Department at a previously agreed date and time. They were asked to look at the sentences they would be reading in order to familiarize themselves with the distinction between singleton and geminate consonants, marked by the gemination diacritic, the shadda. The researcher used Praat software to record, perform duration measurements, and analyze the tokens of the production data. The participants were provided with an independent microphone to record the tokens. They were asked to record 12 tokens consisting of trisyllabic words. Moreover, filler tokens were added to distract the participants from the target sounds. Each token was produced in a carrier phrase in Arabic, which was repeated three times. The carrier phrase was [sawfa ʔaqulu __ maratən ʔoxra] "I will say __ again." Intentionally, the target tokens were placed in the middle of the carrier phrase to avoid a listing intonation or other effects that could cause the geminate feature to disappear.

2.4. Data Analysis Procedures

To differentiate singleton and geminate consonants, the recordings were annotated manually by the author. Praat was utilized to analyze and measure the closure/friction duration of all target consonants. The annotation comprised two tiers: a phone tier and a word tier. For each token, the researcher focused on annotating the singleton and geminate word-medial consonants. The onset and offset of the consonants were determined by using waveforms and spectrograms.

3. Results

3.1. Results for the Non-Emphatic Voiceless Alveolar Stops /t/ and /tt/

In the present study, the stimuli included only one stop, the voiceless alveolar stop /t/, to be able to compare it to its emphatic counterpart /tˤ/, as discussed later. To measure the average closure duration for the singleton /t/, the participants had to produce the word [fatara] "He calmed down," which had an average closure duration of 98 ms. To measure this, waveforms and spectrograms were used to show the beginning and end of the closure duration of the singleton consonant. **Figure 2** shows how the closure duration of /t/ was measured.

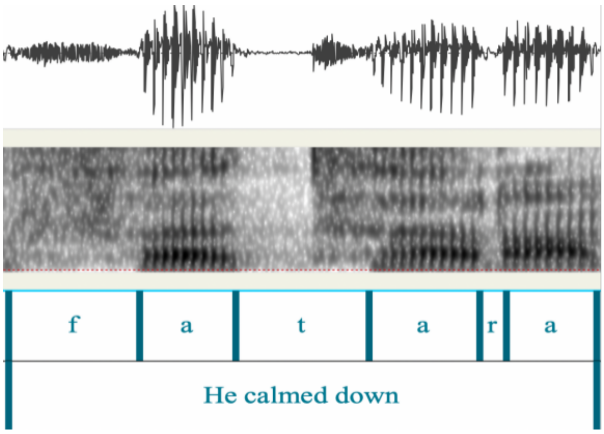

Figure 2. Closure duration of the non-emphatic voiceless singleton stop [t].

The vowels that appeared before and after the target singleton stop [t] helped the researcher determine the beginning and end of the closure duration of that segment. In addition to that phonetic cue, the voicing bar in the spectrogram and the waveform also showed no continuation or presence of a voiced sound, indicating that the target segment was voiceless. More precisely, the spectrogram showed little to no energy at the low frequency compared to the energy of the vowel [a] before and after the target segment [t]. Moreover, the spectrogram showed that the segment had three parts, an onset, a closure, and a release, meaning that this sound was a stop. The closure duration of the segment [t] was 98 ms with a release of about 43 ms. As expected, the non-emphatic singleton stop [t] had a lower F1 value than the vowel /a/. In the data, the /t/ segment had an F1 of about 367 Hz, an F2 of about 1700 Hz, and an F3 of about 2800 Hz.

In a similar vein, to measure the geminate version of this consonant, the participants were asked to produce the token [fattara] "He caused to calm down," with the target segment [tt] in medial position. The measurements showed that the non-emphatic geminate stop [tt] had an average closure duration of 183 ms. Thus, there was a difference of about 85 ms between the singleton and the geminate. **Figure 3** shows an example closure duration of the geminate stop [tt].

The geminate stop [tt] was examined with the same phonetic cues as its singleton counterpart. The vowels next to the target segment helped the researcher determine the beginning and end of its closure duration. In addition, the voicing bar showed no energy in the low frequency of the spectrogram, which indicated that [tt] was a voiceless sound. The spectrogram also showed that the sound consisted of an onset, closure, and release, as with the singleton stop. The closure duration of about 225 ms for the geminate stop [tt] was much longer than that of its singleton counterpart. Its release of 35 ms, however, was shorter than the release of the singleton, which was 43 ms.

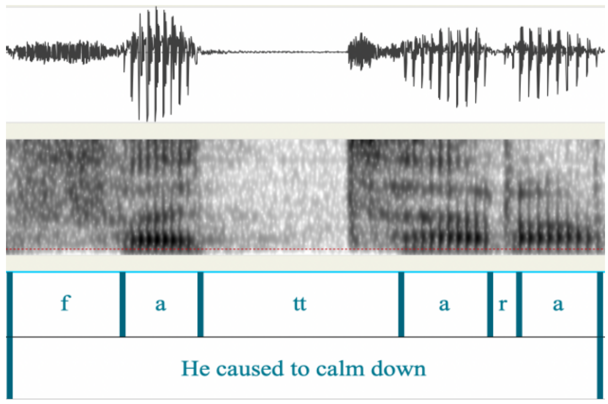

Figure 3. Closure duration of the non-emphatic voiceless geminate stop [tt].

3.2. Results for the Non-Emphatic Voiceless Alveolar Fricatives /s/ and /ss/

In addition to the stops described above, four fricatives were examined as well: the voiceless alveolar fricative [s], the voiced interdental fricative [ð], and their emphatic counterparts [sˤ] and [ðˤ], which are discussed later. The measurement of the voiceless alveolar fricative [s] was similar to the stops since it is voiceless but lacks the three parts that stops have (i.e., an onset, closure, and release). The recordings of the word [kasara] "He broke" revealed that the singleton segment [s] had an average friction duration of 111 ms. Waveforms and spectrograms were used to show the beginning and end of the friction duration of the target sound. The spectrogram showed a lot of dark striations at the centroid frequency at about 4334 Hz. **Figure 4** shows an example of friction duration for the non-emphatic singleton fricative [s].

The same phonetic cues were employed when measuring the recordings of the geminate fricative [ss]. As with the singleton [s], the vowels next to the geminate [ss] helped determine the beginning and end of its closure duration. As apparent in the spectrograms, another similarity was that the geminate [ss] showed no energy at the low frequency of the voicing bar, and there were a lot of dark striations at the centroid frequency and high frequency, at about 4577 Hz. A major difference between the two target segments was that the geminate [ss] had an average closure duration of 177 ms, which was longer than the average 111 ms of the singleton form /s/. **Figure 5** shows an example of friction duration for the non-emphatic geminate fricative [ss].

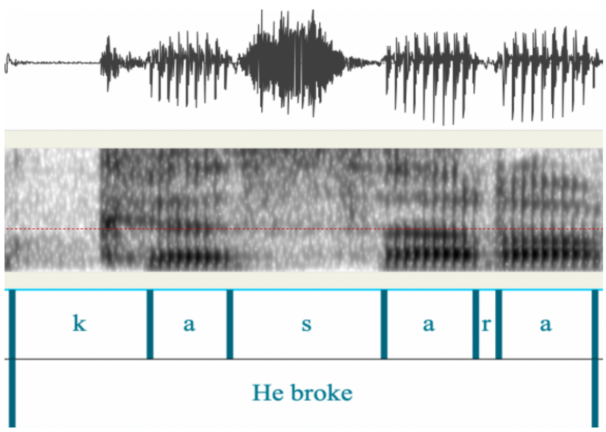

Figure 4. Friction duration of the non-emphatic voiceless singleton fricative [s].

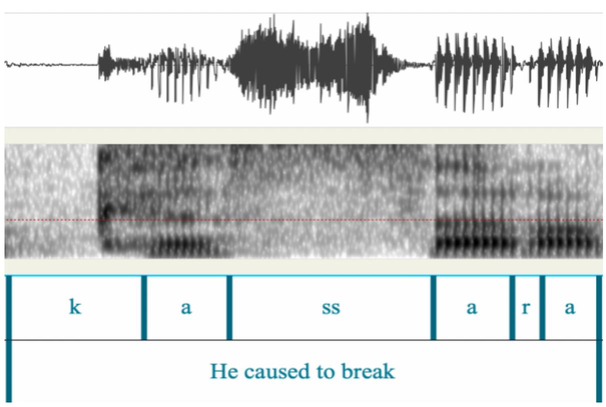

Figure 5. Friction duration of the non-emphatic voiceless geminate fricative [ss].

3.3. Results for the Non-Emphatic Voiced Interdental Fricatives /ð/ and /ðð/

The process of measuring the voiced interdental fricatives [ð] and [ðð] was different from and more difficult than measuring the voiceless fricatives [s] and [ss]. This was because the interdental fricatives were voiced and adjacent to vowels. Thus, the spectrograms showed a lot of energy at the low frequency on the voicing bar spread through the friction duration of the voiced fricatives.

Some of the same phonetic cues for adjacent vowels were used to determine the beginning and end of the singleton segment [ð]. Some phonetic cues for [ð] differed from those of [s]. While this fricative was voiced, it was still distinguishable from the surrounding vowels, where the vowels had darker energy and u-shapes in the waveform, while [ð] had less energy at the low frequency than vowels. Unlike [s], [ð] did not have dark striations at the centroid frequency but rather had noise all over the spectrogram, similar to what one could expect with the voiceless fricative [f]. The average friction duration for the non-emphatic voiced singleton fricative [ð] was 62 ms. It thus had the lowest average out of all of the non-emphatic singleton consonants targeted in this study, namely [t] and [s], discussed above. An example of the non-emphatic voiced singleton fricative [ð] is illustrated in **Figure 6**.

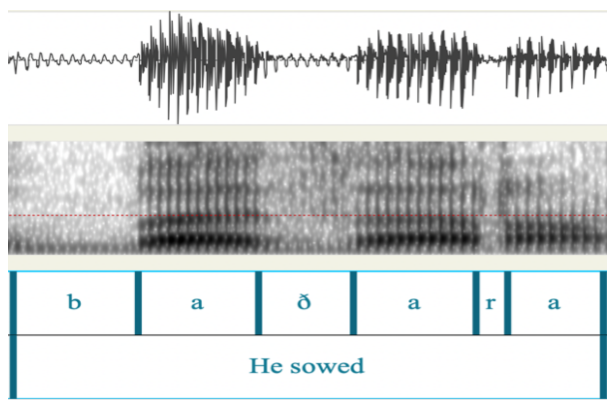

Figure 6. Friction duration of the non-emphatic voiced singleton fricative [ð].

Geminate [ðð] did not show major differences in terms of phonetic cues compared to its singleton counterpart, except that it had a longer average closure duration of 150 ms, compared to the singleton's average of 62 ms. Thus, there was an average difference of 88 ms in closure duration between the singleton [ð] and geminate [ðð]. An example of the non-emphatic voiced geminate fricative [ðð] is given in **Figure 7**.

Now that the non-emphatic singleton and geminate sounds targeted in this study have been discussed (i.e., [t, tt, s, ss, ð, ðð]), the following sections examine the results for the emphatic versions of these six sounds (i.e., [tˤ, tˤtˤ, sˤ, sˤsˤ, ðˤ, ðˤðˤ]).

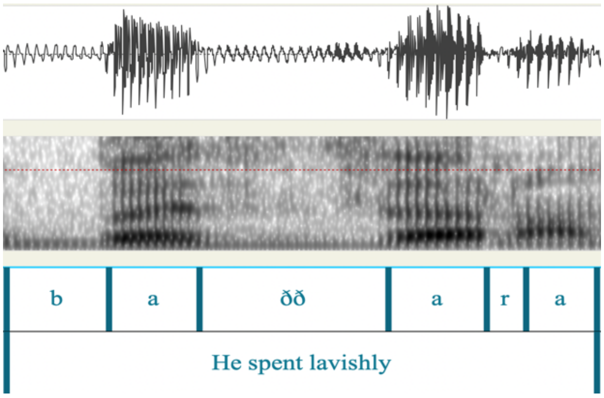

Figure 7. Friction duration of the non-emphatic voiced geminate fricative [ðð].

3.4. Results for the Emphatic Voiceless Alveolar Stops /tˤ/ and /tˤtˤ/

The emphatic voiceless alveolar stop [tˤ] showed the same phonetic cues as its non-emphatic counterpart [t]. While both had an onset, a closure, and a release, the emphatic stop showed a shorter release duration compared to the non-emphatic stop. The release for the emphatic sound showed a burst similar to a voiced stop. Thus, there was a little energy at the low frequency of the spectrogram, which might be a phonetic cue for emphatic sounds. Based on the recordings of the participants saying the word [fatˤara] "He had breakfast," the average closure duration for [tˤ] was 85 ms. Unlike non-emphatic [t], emphatic [tˤ] had a shorter release of only 21 ms, which might be a phonetic cue for the emphatic sounds. **Figure 8** shows an example of a closure duration for the emphatic singleton stop [tˤ].

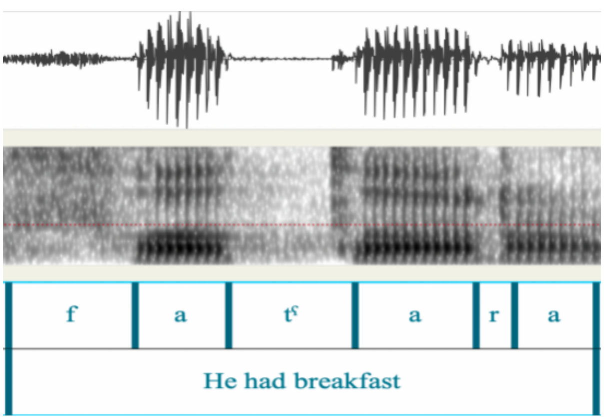

Figure 8. Closure duration of the emphatic voiceless singleton stop [tˤ].

To measure the closure duration of the emphatic voiceless geminate stop [tˤtˤ], the participants in this study produced the word [fatˤtˤara] "He fed someone breakfast." The phonetic cues observed in the singleton stop were seen in the data for the geminate stop as well. However, the geminate stop [tˤtˤ] showed an average closure duration of 172 ms, higher than the average of 85 ms for the singleton [tˤ], with a difference of 87 ms. **Figure 9** shows an example of a closure duration for the emphatic voiceless geminate stop [tˤtˤ].

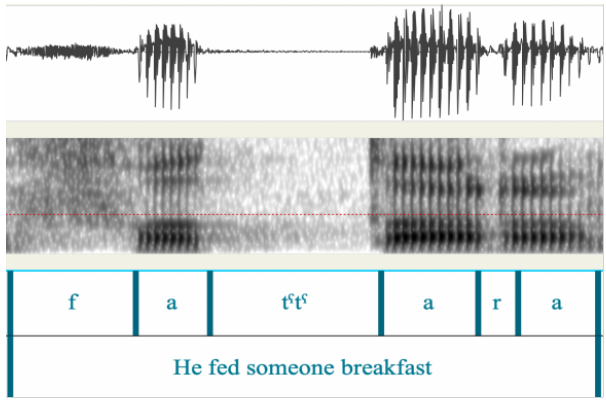

Figure 9. Closure duration of the emphatic voiceless geminate stop [tˤtˤ].

3.5. Results for the Emphatic Voiceless Alveolar Fricatives /sˤ/ and /sˤsˤ/

The emphatic fricative [sˤ] had most of the same phonetic cues as [s] but with some slight differences. The emphatic and non-emphatic fricatives had the same centroid frequency. However, while non-emphatic [s] had a lot of darker striations in the high frequency area of the spectrogram, the case was different with emphatic [sˤ], as the centroid frequency displayed in the recordings for emphatic [sˤ] was less obvious than its non-emphatic counterpart. There was no noticeable difference in friction duration between [sˤ] and [s]. Based on the recorded productions of the word [qasˤara] "He shortened," emphatic [sˤ] had an average friction duration of 115 ms. Unlike the emphatic stop [tˤ], the emphatic fricative [sˤ] did not have the same burst cue, being a fricative. One might ask what phonetic cues distinguish emphatic from non-emphatic sounds, but this was beyond the scope of the current study. **Figure 10** shows an example of a friction duration for the emphatic voiceless singleton fricative [sˤ].

The emphatic geminate [sˤsˤ] was produced in the word [qasˤsˤara] "He caused to shorten" and had an average friction duration of 178 ms, longer than its singleton counterpart. It also showed the same phonetic cues as the singleton; namely, the energy at the high frequency range of the spectrogram was not similar to that of non-emphatic [s], suggesting this could be a phonetic cue of emphatic /sˤ/ as a singleton or geminate. The data also indicated that emphatic /sˤ/ had less noise than non-emphatic /s/. **Figure 11** provides an example of a friction duration for the emphatic voiceless geminate fricative [sˤsˤ].

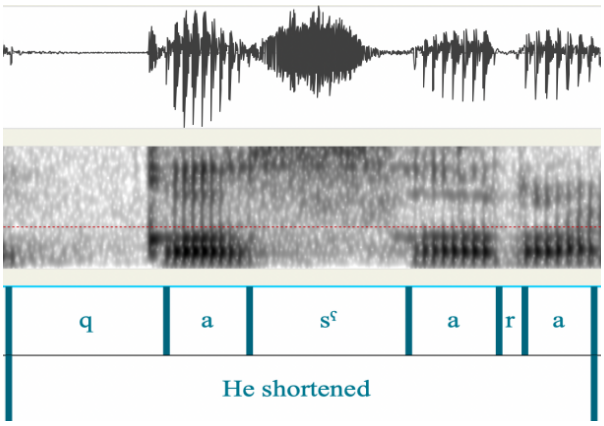

Figure 10. Friction duration of the emphatic voiceless singleton fricative [sˤ].

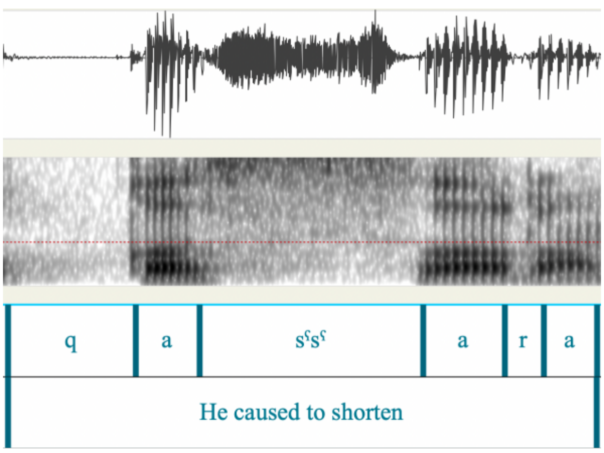

Figure 11. Friction duration of the emphatic voiceless geminate fricative [sˤsˤ].

3.6. Results for the Emphatic Voiced Interdental Fricatives /ðˤ/ and /ðˤðˤ/

As expected, there was a lot of energy at the low frequency range in the spectrogram for the emphatic voiced singleton interdental fricative [ðˤ], indicating that this sound was voiced. The waveform also showed vibration, further supporting the presence of a voiced segment in the specified area. Regarding formants, the spectrograms for emphatic [ðˤ] differed from its non-emphatic counterpart [ð]. In the case of non-emphatic [ð], the F1 and F2 did not appear to merge. In contrast, the F1 and F2 of emphatic [ðˤ] clearly merged, behaving like an F2 and F3 and causing a velar pinch. The target emphatic sound was produced in the word [naðˤara] "He looked" and had an average friction duration of 63 ms. **Figure 12** gives an example of the emphatic voiced singleton fricative [ðˤ] with a friction duration of 65 ms.

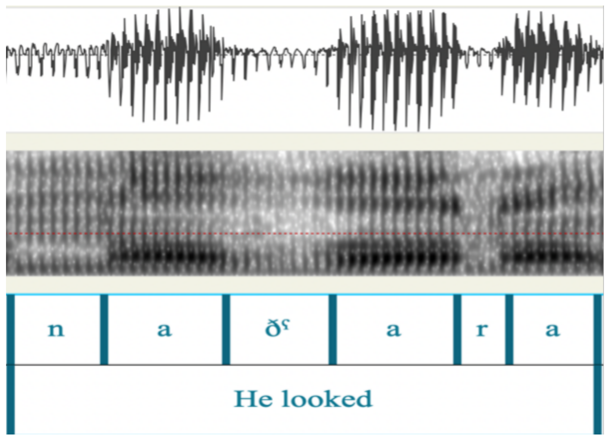

Figure 12. Friction duration of the emphatic voiced singleton fricative [ðˤ].

The same phonetic cues for singleton [ðˤ] were observed with its geminate counterpart [ðˤðˤ], except the geminate had a longer friction duration. The F1 and F2 were also shown to merge. Based on the productions of the word [naðˤðˤara] "He theorized," the geminate [ðˤðˤ] showed an average frication duration of 149 ms, much higher than its singleton counterpart. **Figure 13** provides an example of a friction duration for the emphatic voiced geminate fricative [ðˤðˤ].

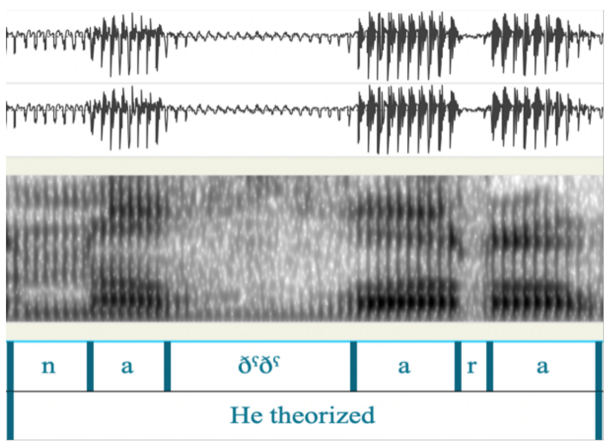

Figure 13. Friction duration of the emphatic voiced geminate fricative [ðˤðˤ].

4. Discussion

This section discusses the data in a broader scope to answer the research questions, summarizing the main points and giving the patterns for singleton and geminate sounds. This time, the averages are converted to ratios to compare them to other studies in the literature [1–5].

The first research question asked whether the closure/friction duration differed between singleton and geminate consonants in Arabic. According to the study's results, as can be seen in **Tables 3** and **4**, the singleton-to-geminate ratios indicated that geminate sounds were approximately twice the length of singletons in the case of [s, t, sˤ], a pattern similar to that found in languages such as Hindi [5] and Italian [1], in which a geminate is slightly less than twice as long as a singleton. For [tˤ, ð, ðˤ], however, the geminate sounds were nearly three times longer than the singletons, a pattern similar to that found in languages such as Japanese [2, 18, 19], Turkish [4], and Swiss German [3]. Thus, geminate consonants did show longer closure/friction duration than their singleton counterparts. The mean singleton-to-geminate ratio was 1:1.88 for non-emphatic sounds and 1:1.90 for emphatic sounds.

The second research question asked whether the closure duration differed between emphatic and non-emphatic singleton consonants. The results showed no significant differences in this regard. The mean duration was 90 ms for non-emphatic singletons and 87 ms for emphatic singletons.

The third research question asked whether closure duration differed between emphatic and non-emphatic geminate consonants. The results showed a slight, non-significant difference in this regard, with a mean duration of 170 ms for non-emphatic geminates and 166 ms for emphatic geminates.

Table 3. Mean durations and ratios for non-emphatic sounds.

Phoneme	Singleton	Ratio	Geminate
/s/	111 ms	1:1.59	177 ms
/t/	98 ms	1:1.86	183 ms
/ð/	62 ms	1:2.42	150 ms
Mean	90 ms	1:1.88	170 ms

Table 4. Mean durations and ratios for emphatic sounds.

Phoneme	Singleton	Ratio	Geminate
/sˤ/	115 ms	1:1.54	178 ms
/tˤ/	85 ms	1:2.02	172 ms
/ðˤ/	63 ms	1:2.36	149 ms
Mean	87 ms	1:1.90	166 ms

This study investigated the closure/friction duration of singleton and geminate emphatic and non-emphatic consonants in Standard Arabic based on data collected from seven native speakers. The study found a large difference in closure/friction duration between geminates and singletons in general. However, the data showed no major difference in means or ratios between emphatic and non-emphatic singletons. It also showed no noticeable difference in closure/friction duration between emphatic and non-emphatic geminates.

The findings could help Arabic instructors teach non-native speakers who face difficulties pronouncing and distinguishing singleton and geminate sounds as well as emphatic and non-emphatic sounds. For example, minimal pairs like the ones in the stimuli, where words only differ by the length of the middle consonant, could be used as practical exercises.

The findings could also inform applications that rely on speech recognition, voice command, and text-to-speech technology in Arabic, such as Microsoft Speech, Siri, and Google Maps.

Future studies could explore other aspects of this issue, such as the release portion of emphatic consonants and the vowels preceding and following these sounds. Emphatic and non-emphatic sounds showed a significant perceptual difference among native speakers, although closure/friction duration showed no effect on emphatic and non-emphatic sounds. It would be worth exploring whether this difference was due to specific phonetic features unexamined in the current study, such as center of gravity. The sample, while small, was adequate for this type of acoustic study. Nevertheless, future studies could test a larger number of participants to increase the generalizability of the findings. Furthermore, future research could gather data from female as well as male speakers to control for gender-related differences. Participants from different regions and age groups could also be assessed, and data could be gathered from native and non-native speakers to compare how they perceive and produce these sounds.

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Institutional Review Board Statement

The study was conducted in accordance with the Declaration of Helsinki, and approved by the Standing Committee of Bioethics Research (SCBR) (protocol code SCBR-432/2024, 01/10/2024).

Informed Consent Statement

Informed consent was obtained from all participants involved in the study.

Data Availability Statement

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Conflicts of Interest

The author declares no conflict of interest.

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