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Closure Duration, Voicing, and Speaking Rate in Central Najdi Arabic Stops

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ABSTRACT

Closure duration is a context-sensitive correlate of stop voicing. In many languages, voiceless stops have longer oral closures than voiced stops, but this pattern varies with prosodic position, place of articulation, and speaking rate. This study examines closure duration in Central Najdi Arabic stops in three contexts: word-medial intervocalic position in trochaic words, the same position in iambic words, and utterance-final position. Thirty-two native speakers from Riyadh produced /b d g t k/ at normal and fast rates. Closure duration was measured from the offset of the preceding vowel to the onset of the release burst and analysed with linear mixed-effects models for each context. Fast speech shortened closures in every context, by about 9 ms in trochaic and 10 ms in iambic medial stops and by about 26 ms in final stops. The voicing effect differed across contexts. Medially, voiced stops tended to have shorter closures than voiceless stops, but the voicing coefficient did not reach significance (trochaic: −3.8 ms, p = .055; iambic: −3.3 ms, p = .213). In final position, voiced stops had longer closures than voiceless stops (+9.8 ms, p = .001), an effect driven mainly by the alveolar pair /d/–/t/. Because the models were additive, they do not test whether rate affects the two voicing categories differently. The results suggest that absolute closure duration is not a stable, context-free cue to voicing in Najdi Arabic and that its interpretation depends on prosodic position and place of articulation.

KEYWORDS

Najdi Arabic; stop closure; voicing; speaking rate; prosodic position; linear mixed-effects models

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1. Introduction

Stop voicing is one of the most widely studied contrasts in phonetics, yet its acoustic basis remains difficult to pin down. Voiced and voiceless stops differ in several temporal and spectral properties at once, and the weight of each property varies across languages, across prosodic positions, and with the rate at which speech is produced (Abramson & Whalen, 2017; Cho et al., 2019). A cue that separates the two categories reliably in one context may therefore be weak, absent, or even reversed in another. Closure duration illustrates the problem well. Since Lisker (1957), it has been treated as a correlate of voicing, with voiceless stops typically showing longer closures than voiced stops between vowels, but its duration changes with speaking rate, and listeners interpret it relative to speaking tempo (Port, 1979).

This raises both a practical and a theoretical problem. In practical terms, if closure duration changes substantially with speaking rate and position, no single millisecond value can be used to classify a stop as voiced or voiceless, and results from studies that differ in speaking style or in the position of the target stop are difficult to compare. In theoretical terms, it is unclear whether a closure-duration difference reflects the laryngeal specification of the stop or is a by-product of general timing, such as the duration of the neighbouring vowels or the compression that accompanies fast speech (Coretta, 2019; Al-Gamdi, 2026). Distinguishing these possibilities requires data in which voicing, speaking rate, and prosodic position vary within the same speakers.

Arabic offers a useful testing ground, but the evidence is uneven. Work on Arabic laryngeal contrasts has concentrated on word-initial stops and on prevoicing and aspiration (Al-Gamdi et al., 2019; Kulikov, 2020; Bahrani & Kulikov, 2024), and much less is known about how closure duration behaves in medial and final positions or how it responds to speaking rate. In Najdi Arabic, a major variety of central Saudi Arabia, closure duration in medial and final stops at two speaking rates was examined by Al-Gamdi (2022) as one of several correlates of the voicing contrast, and the utterance-final results were reported in Al-Gamdi et al. (2024), who found longer closures for voiced than for voiceless final stops. The present paper reanalyses these data with a specific focus on closure duration and on whether its relation to voicing is stable across positions. Without such an analysis, it is not possible to

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say whether closure duration contributes to the Najdi voicing contrast in the way reported for other languages, or whether its behaviour is governed mainly by timing and position.

This paper examines the issue in Central Najdi Arabic, a variety whose stop contrast has clear laryngeal timing correlates: voiced /b d g/ are frequently prevoiced, whereas voiceless /t k/ are aspirated word-initially (Al-Gamdi et al., 2019). Such a system makes it possible to ask whether closure duration behaves as a uniform secondary correlate of voicing or whether its contribution depends on prosodic position and speaking rate.

The study focuses on three contexts in which the closure can be delimited acoustically: word-medial intervocalic stops in trochaic words, word-medial intervocalic stops in iambic words, and utterance-final stops. It asks whether faster speech shortens closure duration, whether the voicing-related closure difference holds in each context, and how place of articulation conditions the pattern. A rate-related reduction in closure duration is expected under ordinary temporal compression and does not by itself show that closure duration is a laryngeal cue. A voicing difference that changes sign across positions is more revealing, because it would show that closure duration cannot be interpreted without reference to the position of the stop in the word and utterance.

In the data analysed here, which were originally recorded for Al-Gamdi (2022), 32 native speakers from Riyadh produced the voiced stops /b d g/ and the voiceless stops /t k/ at normal and fast rates, and closure duration was analysed with linear mixed-effects models. The study contributes in three ways. It brings together closure-duration evidence for Najdi Arabic stops outside word-initial position, building on Al-Gamdi (2022) and Al-Gamdi et al. (2024); it separates the effect of speaking rate from that of voicing within each position; and it shows that the direction of the voicing difference is not constant across positions. The paper is organised as follows. Section 2 reviews previous work on closure duration, speaking rate, and prosodic position and states the research questions. Section 3 describes the method, Section 4 presents the results, Section 5 discusses them in relation to previous studies, and Section 6 concludes.

2. Literature Review

2.1 Closure duration as a cue to stop voicing

The acoustic distinction between voiced and voiceless stops is multidimensional. Voice onset time (Lisker & Abramson, 1964), closure voicing, release properties, vowel-onset F0, phonation, and formant transitions can all contribute to the contrast, and their relative importance differs across languages and prosodic contexts (Abramson & Whalen, 2017; Cho et al., 2019). Closure duration, the interval from the onset of oral constriction to release, is one such cue. It is often longer for voiceless than for voiced stops in intervocalic position. This pattern has been reported in classic production studies and is compatible with the view that maintaining voicing during closure favours a shorter oral constriction (Lisker, 1957; Port, 1981).

The medial pattern should not, however, be treated as a phonetic universal or as an isolated diagnostic of [voice]. Closure duration reflects the coordination of oral constriction, laryngeal state, surrounding vowels, and prosodic structure. It can vary with place of articulation, because a posterior constriction may take longer to form or release, much as VOT varies with place (Cho & Ladefoged, 1999). It can also vary with stress, word position, and the duration of adjacent vowels. Moreover, the boundary between the preceding vowel and the stop closure is shared by the two segments. An account of closure duration must therefore distinguish a contrastive temporal pattern from general changes in speech timing and from effects of the measurement procedure.

2.2 Speaking rate and temporal coordination

Speaking rate systematically modifies the temporal structure of speech. Faster production generally shortens segments and syllables, increases gestural overlap, and can reduce the size of contrasts expressed in absolute time. Rate effects are not necessarily uniform, however. Port (1979) showed that the perceptual relevance of stop closure duration depends on tempo: listeners shifted the /b/–/p/ boundary toward shorter closures in a fast carrier sentence, which suggests that closure duration is interpreted relative to the overall timing of the utterance. Rate effects on stop timing are also language-specific; Kessinger and Blumstein (1997) found that speaking rate affected VOT in Thai, French, and English differently depending on the VOT category.

Relative timing has also been examined in studies of consonant–vowel coordination. Coretta (2019) found that closure duration and preceding-vowel duration covaried in Italian and Polish, while the interval between consecutive releases showed no clear voicing effect. This result suggests that voicing-related durational differences can arise from the placement of a shared vowel–consonant boundary within a larger interval. For Saudi Arabic, Al-Gamdi (2026) found that the closure-to-vowel ratio distinguished voiced and voiceless stops and remained comparatively stable across normal and fast speech, although absolute closures were shorter at the fast rate.

Rate effects are also cue-specific. In spontaneous Japanese, Tanner et al. (2025) showed that a faster speaking rate reduces or neutralises several temporal and spectral cues to the stop contrast, while the informativeness of individual cues shifts across rate conditions. Rate can also interact with place of articulation, as in its effects on burst amplitude in English and Tamil (Narayan, 2023). A cue can therefore remain relevant to a contrast even when its absolute value is rate-sensitive, and a significant rate effect does not show that the cue independently encodes the contrast.

Research on laryngeal timing in Arabic has concentrated on prevoicing and aspiration. Qatari Arabic shows rate-sensitive prevoicing and aspiration (Kulikov, 2020), and in Khuzestani Arabic slower speech lengthens prevoicing and aspiration, while other laryngeal measures do not show the same pattern (Bahrani & Kulikov, 2024). In Arabic coronal stops, the voicing contrast also

interacts with emphasis (Kulikov, 2022). Closure duration is therefore not expected to pattern like VOT by default. It may respond mainly to temporal compression, or it may provide a supplementary voicing cue whose role depends on prosodic position.

2.3 Closure duration, voicing, and prosodic position

Intervocalic and utterance-final stops occur in different aerodynamic and perceptual environments. Intervocalically, a voiced stop is supported by vocalic airflow before and after the closure, and the speaker may use supralaryngeal adjustments that help sustain phonation during the closure. In a true-voice system, a shorter closure in the voiced category may therefore form part of a set of properties that also includes closure voicing and lower F0 in the following vowel.

Utterance-final position is different. A final stop is not followed by a vowel in the same prosodic unit, and the realisation of a coda can include release reduction, aspiration, or final devoicing. The interval from vowel offset to burst must therefore be interpreted as a coda closure interval rather than as the closure phase of a VCV sequence, and a voicing pattern that holds medially need not hold in this position. Word-level structure more generally can affect how oral stops are realised (Davidson & Parker Jones, 2024). For Najdi Arabic, Al-Gamdi et al. (2024) examined utterance-final stops in these terms and reported longer closures for voiced than for voiceless stops at both rates, together with aspiration in final voiceless stops.

These considerations fit the view that laryngeal contrasts are best analysed as sets of coordinated cues rather than through a single acoustic parameter (Cho et al., 2019; Schertz & Khan, 2020). The present study therefore does not assume that a shorter medial closure directly indexes a phonological [voice] feature. Instead, it examines whether closure duration shows a reliable voicing-related pattern within each context, how it responds to speaking rate, and whether the voicing pattern is the same across positions.

2.4 Research questions

The study addresses three questions:

1. How does speaking rate affect closure duration in Najdi Arabic stops? Closures are expected to be longer at the normal rate than at the fast rate in all three contexts.

2. Is there a voicing-related difference in closure duration within each context, and does its direction differ between medial and final positions?

3. How does place of articulation condition the pattern? Velars are expected to have longer closures than alveolars in at least some contexts.

The models reported below were fitted separately for each context and without interaction terms. They therefore estimate the rate and voicing effects within each context, but they do not test whether the rate effect differs between voicing categories or whether the voicing effect differs across positions. These two interactions are discussed in Section 5.5 as questions for further analysis.

3. Method

3.1 Speakers

Forty speakers of the sedentary Central Najdi variety of Riyadh took part, 20 women and 20 men, all university students aged 19–25 years. All were born and raised in Riyadh, reported no speech or hearing difficulty, and had received no formal foreign-language instruction after secondary school. Eight recordings were excluded before analysis because signal quality or background noise prevented reliable segmentation, so the analysis is based on 32 speakers (15 men and 17 women).

The data collection was approved through the research ethics procedures of Newcastle University, United Kingdom, as part of the second author's doctoral research (Al-Gamdi, 2022); the recordings were made at King Saud University, Riyadh. All participants were informed about the aims and procedures of the study and gave written informed consent before recording.

The recordings are those originally collected for the second author's doctoral thesis (Al-Gamdi, 2022), and the utterance-final closure-duration results were previously reported in Al-Gamdi et al. (2024). The present paper reanalyses these data. These recordings are not those analysed in Al-Gamdi (2026). Each speaker read every target sentence three times at each rate, so every speaker contributed repeated tokens of every target word in both rate conditions. In total, the analysis is based on 8,640 tokens: 2,880 trochaic medial, 2,880 iambic medial, and 2,880 utterance-final. All target tokens had a visible release burst, so no tokens were excluded from the analysis. The mixed-effects models described in Section 3.4 estimate the fixed effects from all of these tokens while allowing them to vary across speakers and words. The sample is nevertheless restricted to young, university-educated speakers from Riyadh, a point taken up in Section 5.5.

3.2 Materials and speech-rate manipulation

The target stops were /b d g t k/. The voiced series was represented at bilabial, alveolar, and velar places, and the voiceless series by alveolar /t/ and velar /k/, since the variety has no phonemic /p/. Target words were embedded in natural colloquial Najdi sentences of three to four words, and three native speakers checked that all items were familiar and natural for speakers of the Riyadh variety.

The medial-stop items were disyllabic words with two stress patterns. In the trochaic condition, stress fell on the initial syllable (ˈCVː1CV2C); the vowel after the target stop was /a/, and the preceding long vowel was /iː/, /aː/, or /uː/. In the iambic condition, stress fell on the second syllable (CV1ˈCVː2C); the vowel before the target stop was /a/, and the following long vowel was /iː/, /aː/,

or /uː/. The final-stop items were monosyllabic CVːC words. Short-vowel items were avoided because a final CVC syllable in this variety can involve geminate timing.

Participants read the sentence list at a natural pace and then as quickly as possible without compromising intelligibility. Each sentence was produced three times, and sentence and repetition order were randomised so that the same target did not occur twice in a row. The normal-rate task always preceded the fast-rate task, with a ten-minute break in between.

Recordings were made in a sound-treated studio at King Saud University with a Zoom H6 recorder placed about 15 cm from the speaker, in mono at 44.1 kHz and 16-bit resolution. Stimuli were presented in colloquial Arabic orthography, and speakers were asked to use their habitual Najdi pronunciation.

3.3 Segmentation and measurement

Tokens were segmented manually in Praat using the waveform and spectrogram. Closure duration was measured from the offset of the preceding vowel, identified by the end of the vowel formants including their transitions, to the onset of the first release burst, identified as the first vertical transient in the spectrogram. Bursts less than 5 ms apart were treated as a single release. The measure was not applied to utterance-initial stops, which have no preceding vowel boundary.

This definition separates oral closure from post-release aspiration. In medial position, it captures the oral constriction between the preceding vowel and the release; in final position, it captures the interval from vowel offset to the release of the final coda. Because the measure ends at the onset of the release burst, it presupposes a visible release.

3.4 Statistical analysis

Closure duration (in ms) was analysed separately for trochaic medial, iambic medial, and utterance-final stops with linear mixed-effects models in R using lme4 (Bates et al., 2015). Each model had the form:

closure duration ~ voicing + speech rate + oral place + vowel + gender + (1 + voicing + speech rate + oral place + vowel || speaker) + (1 + gender | word)

Fixed effects were voicing, speech rate, oral place, vowel context, and gender. Speakers and words were random effects, with uncorrelated by-speaker slopes for the main phonetic predictors to avoid estimating an unstable correlation matrix (Barr et al., 2013). Predictors were contrast-coded and centred. For rate, the coefficient represents the fast-minus-normal difference; for voicing, it represents voiced relative to voiceless stops. Estimates, standard errors, t-values, and p-values for the principal effects are reported in Table 2. The p-values were obtained from the normal (Wald z) approximation to the t distribution, and 95% confidence intervals were computed as Wald intervals.

Interaction terms were not retained, because models with interactions did not improve fit by the Akaike Information Criterion. Two consequences follow. First, an additive model assumes that the rate effect is the same for both voicing categories, so it does not test a rate × voicing interaction. Second, because each context was modelled separately, the analysis does not test formally whether the voicing effect differs across positions. Finally, because the voiced series includes /b/, which has no voiceless counterpart, category-level voicing comparisons are partly confounded with place. Place-matched comparisons (/d/–/t/ and /g/–/k/) are therefore reported in Section 4.4.

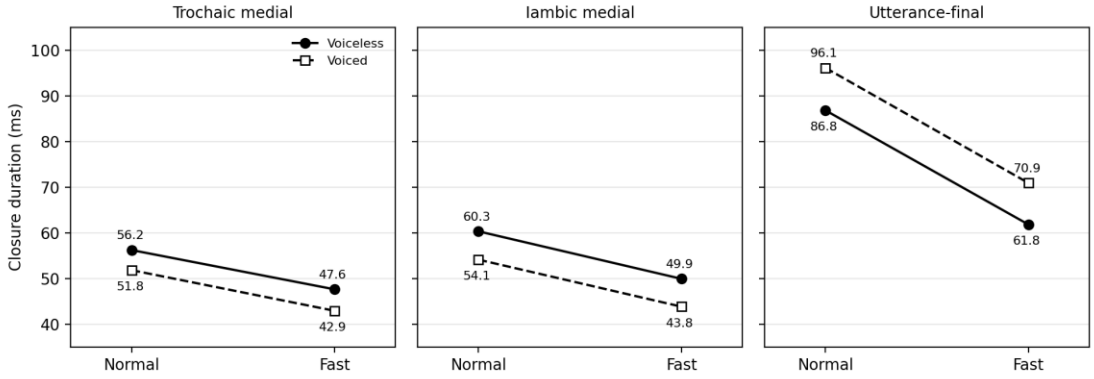
4. Results

4.1 Overview

Three results stand out. First, closures were shorter at the fast rate in every context. Second, in medial position voiced stops tended to have shorter closures than voiceless stops, but the voicing coefficient did not reach significance. Third, in final position voiced stops had significantly longer closures than voiceless stops, an effect concentrated in the alveolar pair. Figure 1 shows the model-predicted means for each context, rate, and voicing category, and Tables 1 and 2 give the predicted means and the principal coefficients.

Figure 1

Model-Predicted Closure Duration by Context, Speaking Rate, and Voicing



Note. Points are model-predicted means. Because the models are additive, the predicted rate effect is by design the same for voiced and voiceless stops within each context.

4.2 Word-medial closure duration

In trochaic words, the model-predicted means were 56.2 ms for voiceless and 51.8 ms for voiced stops at the normal rate, and 47.6 ms and 42.9 ms at the fast rate. Fast speech shortened closures by 8.78 ms (SE = 0.64, t = −13.78, p < .001; 95% CI [−10.03, −7.53]). The voicing coefficient was −3.77 ms (SE = 1.97, t = −1.92, p = .055; 95% CI [−7.63, 0.09]), so the tendency for voiced closures to be shorter did not reach significance once place, vowel, gender, speaker, and word variation were taken into account.

Iambic words showed the same ordering with somewhat longer closures overall: 60.3 ms for voiceless and 54.1 ms for voiced stops at the normal rate, and 49.9 ms and 43.8 ms at the fast rate. Fast speech shortened closures by 10.39 ms (SE = 0.85, t = −12.19, p < .001; 95% CI [−12.06, −8.72]). The voicing coefficient was −3.28 ms (SE = 2.64, t = −1.24, p = .213; 95% CI [−8.45, 1.89]), and the place, vowel, and gender coefficients were not significant. In both medial contexts, then, the evidence for rate compression is strong, while the evidence for a voicing effect is weak.

4.3 Utterance-final closure duration

Final stops differed from medial stops in two respects. First, the direction of the voicing difference was reversed: the predicted means were 96.1 ms for voiced and 86.8 ms for voiceless stops at the normal rate, and 70.9 ms and 61.8 ms at the fast rate. The voicing coefficient was +9.83 ms (SE = 3.05, t = 3.22, p = .001; 95% CI [3.85, 15.81]). Second, the rate effect was much larger than medially: fast speech shortened final closures by 25.54 ms (SE = 1.52, t = −16.75, p < .001; 95% CI [−28.52, −22.56]). The place, vowel, and gender coefficients were not significant.

Table 1

Model-Predicted Closure Duration (ms) by Context, Rate, and Voicing

Context	Rate	Voiceless	Voiced	Voiceless − voiced
Trochaic medial	Normal	56.2	51.8	+4.4
Trochaic medial	Fast	47.6	42.9	+4.7
Iambic medial	Normal	60.3	54.1	+6.2
Iambic medial	Fast	49.9	43.8	+6.1
Utterance-final	Normal	86.8	96.1	−9.3
Utterance-final	Fast	61.8	70.9	−9.1

Note. Values are model-predicted means. Category means average over places; the voiced series includes /b/, which has no voiceless counterpart. Positive differences mean that voiceless closures were longer. Predicted means were obtained by averaging the fitted values over the tokens in each cell. Because the distribution of places and vowels differs slightly across cells, the voiceless − voiced differences vary slightly between rates and do not equal the voicing coefficients in Table 2, which hold place, vowel, and gender constant.

Table 2

4.5 Principal Linear Mixed-Effects Estimates

Context and predictor	Estimate (ms)	SE	t	p	95% CI
Trochaic: fast rate	−8.78	0.64	−13.78	< .001	[−10.03, −7.53]
Trochaic: voiced vs. voiceless	−3.77	1.97	−1.92	.055	[−7.63, 0.09]
Iambic: fast rate	−10.39	0.85	−12.19	< .001	[−12.06, −8.72]
Iambic: voiced vs. voiceless	−3.28	2.64	−1.24	.213	[−8.45, 1.89]
Final: fast rate	−25.54	1.52	−16.75	< .001	[−28.52, −22.56]
Final: voiced vs. voiceless	+9.83	3.05	3.22	.001	[3.85, 15.81]

Note. Confidence intervals are Wald intervals (estimate ± 1.96 × SE). Rate estimates are fast relative to normal speech; voicing estimates are voiced relative to voiceless stops.

4.4 Place of articulation

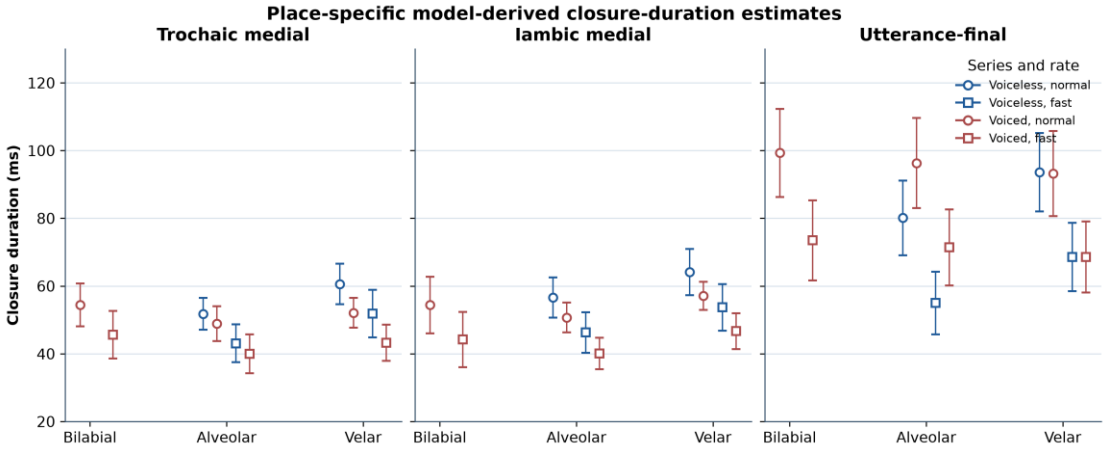
Place-matched comparisons qualify the category-level patterns. In trochaic medial position, the voiceless velar had a longer closure than the voiced velar at both rates (60.6 vs. 52.1 ms at the normal rate; 51.9 vs. 43.3 ms at the fast rate), while the alveolar difference was smaller (51.8 vs. 48.9 ms; 43.1 vs. 40.0 ms). Among the voiced stops, the bilabial had the longest closure at both rates. In iambic medial position, velars were descriptively longer than alveolars in both voicing categories (voiceless velars exceeded voiceless

alveolars by 7.5 ms at the normal rate and 7.4 ms at the fast rate), although the place coefficient in the iambic model was not significant.

In final position, the voicing reversal came mainly from the alveolars: final /d/ was longer than final /t/ by 16.2 ms at the normal rate and 16.4 ms at the fast rate, whereas /k/ and /g/ had nearly identical predicted means at both rates. The voiced bilabial was longer than the other final voiced stops, but it has no voiceless counterpart. The final voiced-longer pattern is therefore not a property of every place. Figure 2 shows the place-specific predicted means.

Figure 2

Model-Predicted Closure Duration by Place of Articulation



Note. Points are model-predicted means. Vertical bars show the standard deviation of the predicted values and are not confidence intervals. There is no voiceless bilabial condition, because Central Najdi Arabic has no phonemic /p/.

5. Discussion

5.1 Rate and closure compression

The clearest result is the effect of speaking rate. Closures were reliably shorter at the fast rate in both medial contexts and in final position, by about 9 ms in trochaic words, 10 ms in iambic words, and 26 ms in final position. Closure duration is thus strongly sensitive to the time available for the oral constriction. This complements Port's (1979) perceptual finding that listeners interpret closure duration relative to tempo: in production, too, the physical duration of the closure changes markedly with rate.

Whether rate shortens voiced and voiceless closures by the same amount cannot be decided from the present models, which assume that it does. The predicted voicing differences are similar at the two rates in each context (Table 1), but this similarity follows from the additive model structure rather than providing evidence for it. A model that includes a rate × voicing term is needed to answer this question.

5.2 Medial closures

In both medial contexts, voiceless stops had longer predicted closures than voiced stops at both rates, the ordering familiar from earlier work on intervocalic stops. The difference was small, about 4–6 ms, and the voicing coefficient was not significant in either model once place, vowel, gender, speaker, and word variation were included. The data therefore do not support the claim that medial closure duration alone separates the voicing categories. A more defensible conclusion is that closure duration may participate in the medial contrast as a minor temporal correlate, alongside closure voicing, burst properties, and the properties of the neighbouring vowels.

The comparison between the two stress patterns is consistent with this interpretation. Iambic closures were generally longer than trochaic closures, presumably because stress changes the timing of the surrounding vowels, but the voiceless-longer ordering appeared in both stress patterns and was non-significant in both.

5.3 Final-position reversal

The most notable finding concerns utterance-final stops. In this position, voiced stops had longer closures than voiceless stops (+9.83 ms) at both rates, which is the opposite of the medial ordering. This pattern was first reported for these data by Al-Gamdi et al. (2024). If this reversal is confirmed in a joint model of all three contexts, it would argue against a fixed, position-invariant relation between voicing and closure duration.

The reversal is not paradoxical, because the two positions differ in their laryngeal and temporal organisation. Medial stops are flanked by vowels, whereas final stops are codas at the end of the utterance, where closure timing is linked to the preceding vowel, to the presence or absence of an audible release, and to aspiration or devoicing. One possibility is that voiceless final stops have shorter closures because part of their contrastive timing is realised after the release, as aspiration. The present measurements

cannot test this directly, since they do not include oral pressure, glottal aperture, or release and aspiration durations; aspiration-related redistribution, articulatory undershoot, and phrase-final lengthening all remain possible explanations.

The reversal was also place-specific: it was strong for alveolars and absent for velars. This suggests that it is not simply a general property of final codas. Differences in release, constriction formation, or audible post-release noise between places may affect how the temporal intervals are distributed, which is one reason to keep place in the model and to avoid conclusions based on category averages alone.

5.4 Absolute and relative timing

Absolute closures changed considerably with speaking rate, especially in final position. A fixed millisecond threshold is therefore of limited use as a definition of a voicing category across rates: a 50-ms closure can be typical of a voiceless medial stop in fast speech and short for the same stop in normal speech. Relative measures such as the closure-to-vowel ratio reduce the influence of global rate by relating the closure to the duration of an adjacent vowel, and Al-Gamdi (2026) found that this ratio preserves a clear voicing distinction across rates in Saudi Arabic. Relative and absolute measures answer different questions, however: absolute duration shows how much time is allocated to the oral constriction, while a ratio shows how that time is balanced against neighbouring vocalic time. How a contrast is implemented can also affect how variable its cues are (Hauser, 2021), which is a further reason to examine both kinds of measure.

5.5 Implications and limitations

The results do not require closure duration to be represented as an independent phonological feature, but they show that it is a context-sensitive phonetic correlate of the contrast. Prevoicing and aspiration have been used as diagnostics of laryngeal specification under rate manipulation (Kulikov, 2020; Bahrani & Kulikov, 2024). Closure duration, by contrast, shortened at the fast rate in both voicing categories. Its rate response is therefore more consistent with general temporal compression, although the additive models assumed rather than tested equal shortening in the two categories, and it does not by itself diagnose a [voice] or [spread glottis] specification (cf. Jessen & Ringen, 2002).

Several limitations follow from the design and the analysis. First, the models were additive and fitted separately by context, so neither the rate × voicing interaction nor the voicing × position interaction was tested; a joint model of all three contexts with these interactions, reporting estimated marginal means with confidence intervals, is needed to test both. Second, category-level voicing comparisons are partly confounded with place, because the voiced series includes /b/; the place-matched comparisons in Section 4.4 address this only descriptively. Third, the rate tasks were always performed in the same order, so rate cannot be fully separated from task order or practice; a follow-up study should counterbalance the order and include a measure of local articulation rate. Finally, the final-stop analysis should be complemented by measurements of release and aspiration duration, which would show whether shorter final voiceless closures are associated with longer post-release intervals.

In addition, the size and composition of the sample limit the conclusions that can be drawn. Although the 32 speakers each contributed repeated tokens at both rates, the medial voicing estimates remained imprecise: their 95% confidence intervals ranged from about −7.6 to +0.1 ms in trochaic words and from about −8.5 to +1.9 ms in iambic words. These intervals are compatible both with no voicing effect and with a voiceless-longer difference of several milliseconds, so the non-significant medial results should not be read as evidence that the difference is absent. A larger sample of speakers would be needed to estimate an effect of this size precisely. The speakers were also all university students aged 19–25 from Riyadh, so the results may not extend to older speakers, to other Najdi communities, or to less formal speech. Future work should therefore expand the sample in both size and range, ideally with a power analysis based on the estimates reported here.

6. Conclusion

Closure duration in Central Najdi Arabic is strongly affected by speaking rate and prosodic position. Fast speech shortened closures in trochaic medial, iambic medial, and utterance-final stops. Medially, voiced stops tended to have shorter closures than voiceless stops, but this effect was small and not significant. In final position, the ordering was reversed and significant, with voiced stops longer than voiceless stops, mainly in the alveolar pair. Closure duration is therefore not a stable, context-free cue to voicing in Najdi Arabic; its interpretation depends on where the stop occurs and on its place of articulation.

These findings both confirm and qualify previous work. The medial ordering, with voiceless closures longer than voiced closures, agrees in direction with the classic intervocalic pattern (Lisker, 1957; Port, 1981). In Najdi Arabic, however, the difference was only 4–6 ms and did not reach significance once speaker, word, place, and vowel variation were modelled, so in this variety the medial closure difference is best described as a tendency rather than a robust correlate. This is consistent with the evidence that the Najdi contrast is carried mainly by laryngeal timing, with voiced stops frequently prevoiced and voiceless stops aspirated in initial position (Al-Gamdi et al., 2019), and with the wider view that laryngeal contrasts rest on sets of cues whose weighting differs across languages and contexts (Abramson & Whalen, 2017; Cho et al., 2019; Schertz & Khan, 2020).

The rate results extend to closure duration the rate sensitivity reported for VOT across languages (Kessinger & Blumstein, 1997) and for prevoicing and aspiration in Qatari and Khuzestani Arabic (Kulikov, 2020; Bahrani & Kulikov, 2024). In those studies, rate effects have been used to identify which laryngeal properties are actively controlled. Here, by contrast, closure duration shortened in both voicing categories, which points to general temporal compression rather than to a category-specific laryngeal target,

although the additive models assumed rather than tested this. The pattern agrees with Tanner et al. (2025), who found that faster speech reduces several temporal cues to the Japanese stop contrast, and it complements Port's (1979) finding that listeners interpret closure duration relative to tempo. It is also consistent with Al-Gamdi's (2026) observation for Saudi Arabic that absolute closures shorten at the fast rate while the closure-to-vowel ratio remains comparatively stable, and with Coretta's (2019) evidence from Italian and Polish that voicing-related durational differences may reflect the placement of a shared vowel–consonant boundary rather than a property of the closure alone.

The final-position reversal confirms the pattern reported for these data by Al-Gamdi (2022) and Al-Gamdi et al. (2024); most of the other studies reviewed above examined initial or intervocalic stops. It adds Najdi Arabic to the evidence that word-level and prosodic structure shape how oral stops are realised (Davidson & Parker Jones, 2024). Its concentration in the alveolar pair also parallels the place effects reported for VOT (Cho & Ladefoged, 1999) and the interaction of rate with place in burst amplitude (Narayan, 2023). In Qatari Arabic, voicing and emphasis in coronal stops are signalled by overlapping cues, with VOT most relevant to voicing and F2 to emphasis (Kulikov, 2022), so the coronal series in Najdi, including the emphatic stop, is a natural focus for further work.

Taken together, the results caution against treating absolute closure duration as a context-free diagnostic of a [voice] or [spread glottis] specification (cf. Jessen & Ringen, 2002), and they support relational accounts in which closure timing is interpreted against the neighbouring vowels and the prosodic frame (Port, 1979; Coretta, 2019; Al-Gamdi, 2026). Future research should test the rate × voicing and voicing × position interactions in a joint model, enlarge and diversify the speaker sample, and add measures of closure voicing, release, and aspiration, so that the contribution of closure duration can be weighed against the cues that previous studies of Arabic have identified as central to the contrast.

Ethics Statement

The data collection was approved through the research ethics procedures of Newcastle University, United Kingdom, as part of the second author's doctoral research (Al-Gamdi, 2022), and the recordings were made at King Saud University, Riyadh. The study was conducted in accordance with the Declaration of Helsinki. All participants gave written informed consent before taking part, and participation was voluntary.

Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Declaration of Generative AI Use

Generative AI tools were used to improve the language, clarity, and readability of the manuscript and to assist with checking the consistency of the analysis and the presentation of the data. All analyses, data, and conclusions were reviewed and approved by the authors, who take full responsibility for the content.

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