Interdental Substitution and the Feature [±distributed]

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1 Introduction

This study examines why speakers of different first languages substitute the English interdental /θ/ with either /s/ or /t/. We test the hypothesis that the feature [±distributed], as phonetically realised through constriction length, in a speaker's L1 coronal stop system predicts patterns of interdental substitution. Specifically, we argue that interdental fricatives and L1 stops produced with a long constriction share the feature [+distributed], making such segments well-suited as substitutes for interdentals. Our results provide partial support for this hypothesis, showing a systematic relationship between constriction length and substitution patterns, while also indicating that constriction length alone is insufficient to account for all of the observed variation. This study thus examines how a non-contrastive phonological feature in the L1 can shape the acquisition and production of unknown L2 sounds.

2 Interdental Substitution

The phenomenon of systematic non-native sound substitution across languages (henceforth differential substitution) has long posed a challenge for linguistic theory. Speakers of different first languages that lack interdental fricatives often substitute them with different native sounds, even when both potential substitutes are available in their phoneme inventories. In other words, speakers of language A may replace a non-native segment x with y, while speakers of language B replace the same segment x with z, even though both y and z are available in the phoneme inventories of languages A and B. The central question, then, is why speakers of one language consistently opt for one substitute, while speakers of another language systematically select a different one. One might initially assume that both y and z are equidistant from the target sound x, and that the different distributions are purely accidental. Such an account, however, is not only theoretically unsatisfying, but would also predict substantial inter- and intra-speaker variation within a language (Hyman, 1970). This, however, is not the case, as only moderate variation exists between speakers and languages in their substitution patterns.

A well-documented example of differential substitution involves the English interdental fricatives, which L2 learners commonly replace with either /t/ or /s/. German and Egyptian Arabic speakers, for example, overwhelmingly substitute English interdentals with /s/, whereas Dutch, Moroccan Arabic, and Turkish speakers mostly substitute them with /t/, exhibiting only limited variation. These language-specific patterns strongly indicate that interdental substitution is governed by systematic principles rather than chance.

A wide range of theoretical accounts has been proposed to explain this phenomenon. Some approaches are primarily phonological, appealing to differences in feature hierarchies (Archibald,

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2023; Lombardi, 2000), feature matching (Lahiri & Kennard, 2019), or feature prominence (Hancin-Bhatt, 1994). Others favour a phonetic perspective, focusing on articulatory or acoustic similarities between the interdental target and potential L1 substitutes, particularly L1 /t/ and /s/ (Brannen, 2011; Teasdale, 1997). Despite their insights, many existing proposals encounter difficulties: some face internal theoretical challenges, others fail to generalise once additional languages are considered, and many lack direct articulatory or acoustic evidence to support their claims. These limitations motivate the search for a more widely applicable account of interdental substitution grounded in empirically measurable and testable properties.

3   The Feature [±distributed]

The feature [±distributed] may offer a novel insight into these discussions. We adopt the definition of the feature proposed by Chomsky & Halle (1968):

> Distributed sounds are produced with a constriction that extends for a considerable distance along the direction of the air flow; non-distributed sounds are produced with a constriction that extends only for a short distance in this direction. (p. 312)

While the feature is often taken to correspond loosely to the distinction between laminal and apical consonants (apical consonants are produced with only the tongue tip, while laminal consonants are produced with the blade of the tongue), Chomsky and Halle explicitly note that the apical–laminal distinction does not map straightforwardly onto the [±distributed] contrast. Rather, what unites distributed sounds is not the use of the tongue tip vs blade per se, but the extent of the constriction created during articulation. As an example, they cite the difference between soft and hard dentals in Polish, which can be characterised by the length of the constriction and not necessarily an apical vs laminal distinction, as both are laminal in nature. Similarly, Keating (1991) notes that in principle, a laminal constriction can be made with a constriction shorter than an apical constriction, if the former is made with a very arched tongue.

It should be noted that, here, the feature [±distributed] is treated as non-contrastive in the sense that it is not assumed to be phonologically contrastive within the segmental inventory of the languages under investigation. That is, we do not adopt a minimally specified phonological representation in which features are present only when required to distinguish phonemic contrasts (e.g. between apical and laminal stops, or between dental and retroflex coronals). Instead, [±distributed] is taken to be a phonetic feature that specifies the articulatory realisation of a segment, even in the absence of a phonological contrast. This type of non-contrastive articulatory specification may vary both between speakers and within a single speaker, and may thus also account for inter- and intra-speaker variation in interdental substitution.

Importantly, Chomsky & Halle (1968) observe that "the length of a constriction along the direction of the airflow has obvious acoustical consequences, and it would be highly plausible that these should be controlled by a special feature, which we shall call 'distributed.'" It is precisely these acoustic consequences and the resulting natural class of sounds that are produced with a long constriction that are relevant for the present discussion of interdental substitution (note, however, that an acoustic analysis examining the similarities between the sounds is underway).

4   Hypothesis

Our theory hinges upon three observations:

1. Cross-linguistically, interdental fricatives are most commonly substituted by dental or laminal stops, while purely apical stops are rarely used as replacements (Brannen, 2011).

2. Dental stops, as noted by Dart (1991), are articulatorily difficult to produce with a truly apical closure. Instead, most dental stops are produced with substantial tongue-blade contact. While rare cases of apico-dental stops have been reported (e.g. for Temne; (Ladefoged, 1964))[1], many

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[1] Ladefoged (1964) notes that other researchers, such as Wilson (1961), describe these stops as interdental

languages exhibit a systematic association between purely apical articulations and an alveolar place of articulation, and non-apical (upperapical, apicolaminal, laminal) articulations and a dental place of articulation. Laminal stops, regardless of place of articulation, are usually formed with a longer constriction length.

3. Lastly, interdentals themselves are defined as [+distributed] in most phonological frameworks (Shaw, 1991; Hall, 1997). Thus, what seems to unite interdentals, dental and laminal stops is that they match in the feature [+distributed] (see Table 1).

On the basis of these observations, we hypothesise that interdental substitution is governed by the non-contrastive feature [±distributed], as phonetically realised through constriction length. If a language possesses a coronal stop /t/ that is [+distributed] – that is, produced with a relatively long constriction – this stop constitutes a good substitute for an interdental fricative, which is likewise [+distributed]. In languages where /t/ is [–distributed] expressed through a short constriction length, on the other hand, interdental fricatives are predicted to be less well matched by stops and are therefore more likely to be replaced by an alternative segment, most commonly a sibilant fricative such as /s/ or a labiodental fricative /f/.

	θ	apical t̪	alveolar t	dental t̪	laminal t̪
[distributed]	+	−	−	+	+

Table 1: Feature specification for interdental fricatives and anterior coronal stop variants.

Constriction length here is treated as a continuous, relative measure rather than a categorical articulatory label. It is defined as the proportion of the teeth or palatal surface contacted during the closure of /t/, measured from static palatograms (see the Methodology section for more detail). This measure captures the extent of the lingual constriction along the direction of the airflow, corresponding directly to Chomsky and Halle's notion of [±distributed]. "Long" constrictions in this sense are those that extend for a longer proportion of the teeth/palate relative to other speakers and languages in the sample, rather than exceeding an absolute anatomical threshold.

A natural question is why the feature [±distributed] should be relevant for interdental substitution, rather than other featural differences between the target and potential substitutes. English interdental fricatives differ from /t/ in the feature [±continuant] and from /s/ in the feature [±strident], and are thus equally distant from the target sound, and both segments differ categorically from interdentals along these dimensions across all languages considered. By contrast, [±distributed] represents a dimension along which the substitutes themselves may pattern differently across languages: interdental fricatives and segments produced with longer constrictions share the feature [+distributed], whereas apical alveolar stops with short constrictions pattern as [–distributed].

The acoustic basis for this hypothesis lies in the fact that both dental and laminal coronals produce bursts with lower intensity, less peaked spectra, and greater diffuseness, which makes them acoustically more similar to interdentals (Sundara, 2005; Hamann, 2003). An acoustic analysis of our data is ongoing.

To test this hypothesis, two questions must be addressed in sequence. First, we examine whether dental and/or laminal stops are indeed produced with longer constrictions than alveolar and/or apical stops. Second, we assess whether languages whose /t/ is characterised by a relatively long constriction are more likely to substitute interdental fricatives with /t/ rather than with alternative segments.

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rather than dental, which would be compatible with an apical closure. Unfortunately, Ladefoged does not provide palatographic images for Temne in this work. This distinction raises the question of how stopped interdentals should be classified, and whether they should be termed dental stops at all; after all, interdental fricatives are typically treated differently from dental sibilants.

5   Methodology

Articulatory and acoustic data were collected from 6–10 speakers for each of five L1 backgrounds: German, Dutch, Turkish, Egyptian Arabic, and Moroccan Arabic. These languages were selected because they represent well-documented differences in interdental substitution patterns and suspected differences in coronal stop articulation (to confirm these patterns L2 English production data were also collected for each speaker, but will not be discussed here). Static palatography and linguography were used to obtain articulatory data for L1 /t/. Constriction length was measured from the palatographic images as the length of contact along the midsagittal line and normalised relative to palate size, as depicted in Figure 1. All values were z-scored across the dataset.

Categorical data were classified categorically and subsequently collapsed into a binary contrast between dental and non-dental and apical and non-apical articulations. Statistical analyses were conducted using linear mixed-effects models with random intercepts for Speaker and Item.

Measurement	Description
Measurement a	Spans from the tip of the incisors to the first point of contact on the midsagittal line.
Measurement b	Includes the contact area along the midsagittal line.
Measurement c	Starts at the endpoint of the contact zone and extends to line h.
Line h	Represents the horizontal line between the second premolar and first molar.
Line v	This line represents the vertical calibration measurement extending from the tip of the front incisors to line h.

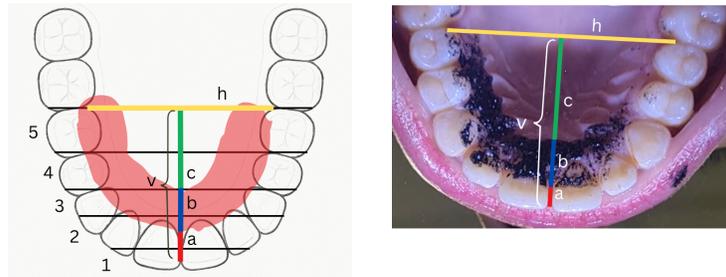Table 2: Description of Measurements Used in the Study

Figure 1: Illustration of constriction length measurement. Left: measurement schematic. Right: Real example.

6   Preliminary Results

This section presents the results in three stages. First, categorical patterns in place and tongue configuration are described based on palatographic and linguographic evidence. Second, numerical measures of constriction length are summarised and compared across languages. Finally, mixed-effects modelling is used to test the hypothesis that apical stops are produced with a shorter constriction length than non-apical stops, and the relationship between constriction length and typological interdental classification is examined at the language level.

6.1 Categorical Results. Figure 2 presents representative palatograms and corresponding linguograms for one speaker per language. The images reflect greater trends: German /t/ was predominantly apical and alveolar, whereas Dutch, Turkish, and Egyptian Arabic showed dental or denti-alveolar articulations with non-apical tongue configurations. Moroccan Arabic exhibited mostly denti-alveolar articulations with a fronted laminal tongue configuration. Chi-square analyses confirmed that these distributions differed significantly across languages ($p < .001$), with German showing a strong bias toward apical and alveolar realisations, and Moroccan showing a strong bias toward laminal and denti-alveolar articulations.

(a)   Moroccan denti-alveolar laminal /t/ (b) German denti-alveolar apical /t/ (c) Dutch dental laminal /t/ (d) Turkish dental non-apical /t/ (e) Egyptian dental non-apical /t/
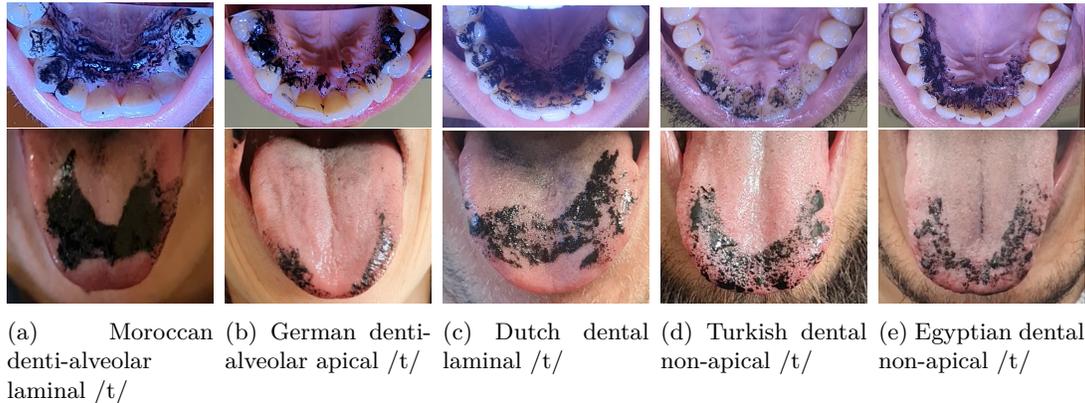
Figure 2: Palatograms (top row) and corresponding linguograms (bottom row) for selected speakers

6.2 Numerical Results   Numerical measurements of constriction length mirrored the categorical patterns. After z-scoring, German showed a strongly negative mean constriction length, indicating relatively short constrictions, while Moroccan Arabic, Turkish, and Dutch exhibited positive mean values, indicating longer constrictions (see Figure 3). Egyptian Arabic patterns closer to the overall mean. These descriptive results suggest that German /t/ is characterised by a shorter constriction length relative to the other languages in the sample.

A linear mixed-effects model including Language, syllable position, Gender, and Vowel confirmed that constriction length varied systematically. Language significantly affected constriction length, and onset position was associated with longer constrictions than non-onset position. Gender showed a marginal effect, while vowel height did not significantly influence constriction length.

6.3 Hypothesis Testing   To test the first hypothesis directly, constriction length (z-scored) was analysed using a linear mixed-effects model with tongue configuration as the predictor. Dental stops exhibited greater constriction length values than alveolar stops ($p = 0.034$) and non-apical stops exhibited significantly greater constriction length values than apical stops ($p = .003$). These effects remained stable even after controlling for syllable position, gender, and vowel context.

The second hypothesis was the connection between constriction length and interdental substitution. It was predicted that a longer constriction length of /t/ increased the likelihood of /t/ substitution. At this stage of the study, interdental substitution was defined at the language level and not the speaker level, i.e. a language was classified as a /t/ or /s/ substituting language based on the majority of substitutions obtained in our production data. However, variation existed between speakers so that in the future, speakers' individual articulations will be tied to their individual substitution patterns. Due to the low number of languages at this stage, only a rather broad typological comparison could be employed. For this, constriction length values were averaged by language, which showed a clear difference between the two interdental substitute categories: languages classified as t-languages exhibited higher mean constriction length values than s-languages (mean z-score = 0.17 vs. 0.01).
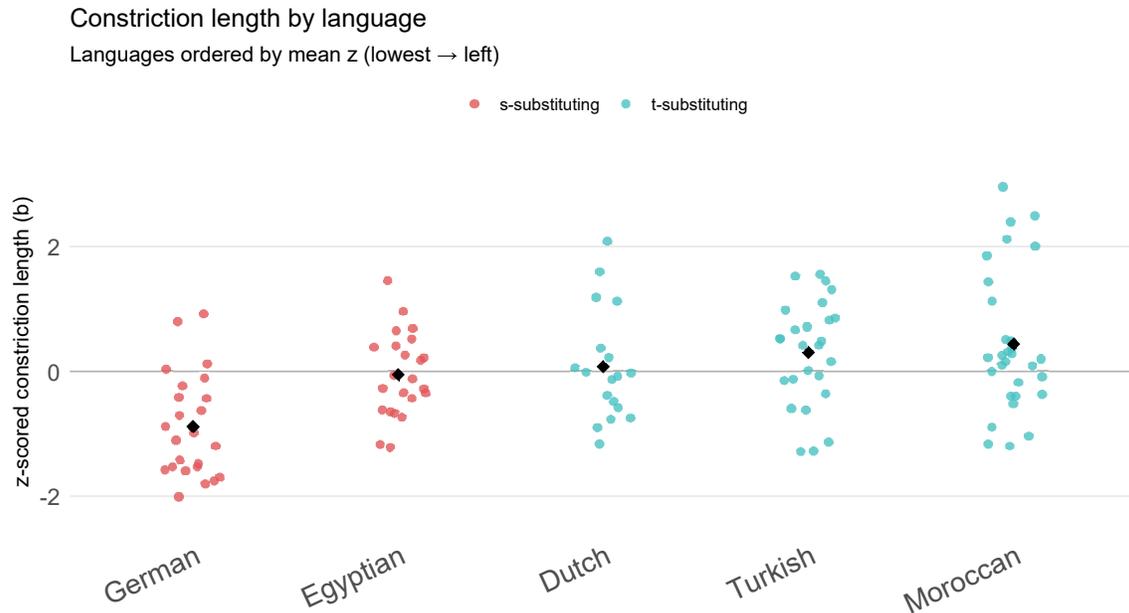
Figure 3: Z-scored constriction length (b) by language. Languages are ordered by mean z-score (lowest to highest). Points represent tokens; black diamonds represent language means.

7 Discussion

The aim of this study was twofold: first, to test whether dental and laminal articulations, as opposed to alveolar and apical articulations, are associated with longer constriction lengths. This observation was confirmed through palatographic evidence and a statistical analysis. Second, we aimed to assess whether interdental substitution patterns can be predicted from the non-contrastive feature [±distributed], as expressed through constriction length in native coronal stops. The motivation for this proposal was the observation that the majority of languages reported to substitute English /θ/ with /t/ are described as exhibiting dental or laminal realisations of /t/. The results provide partial but converging support for this hypothesis. Languages whose speakers predominantly substitute English /θ/ with /t/ – namely Turkish, Moroccan Arabic, and Dutch – indeed exhibited longer constriction lengths associated with dental and/or laminal articulations of /t/ (it should be noted that the majority of laminal articulations were also denti-alveolar in nature). By contrast, German, whose /t/ is apical and alveolar and correspondingly characterised by a short constriction length, consistently favoured sibilant substitution.

At the same time, the results indicate that constriction length alone does not fully determine interdental substitution. Egyptian Arabic presents a clear counterexample: despite exhibiting relatively long constriction lengths in its stops, speakers overwhelmingly favoured sibilant substitution. Thus, while none of the languages that used /t/ as a substitute exhibited short constriction lengths of /t/, some of the languages that used /s/ did exhibit long constriction lengths. This suggests that constriction length is not a sufficient factor in determining substitution behaviour, and that it likely interacts with other properties of the coronal system in the L1, such as the place and realisation of /s/. Preliminary results show that Egyptian /s/ is also dental in nature – an investigation of the whole coronal inventory and the possibility of the feature applying to sibilants or possible differences in stridency as suggested by Teasdale (1997) will be necessary in the next step of the investigation. Scrutinising these interactions, as well as speaker-level variation in constriction length and substitution behaviour, will be an important part of future research.

Several limitations of the present study must also be acknowledged. The number of languages examined is necessarily small due to the practical challenges involved in collecting palatographic data. As a result, the statistical power of the analyses is limited, and the typological findings in particular should be interpreted with caution until replicated on a broader language sample. Future work should therefore expand the typological scope of the study to include more apical languages. The acoustic analysis of the data is ongoing.

Finally, one might reasonably question whether interdental substitution should be framed in terms of a non-contrastive phonological feature at all, rather than being analysed purely in terms of phonetic measures such as constriction length. This concern is well-founded. Accounts that rely exclusively on a fixed, contrastive phonological feature system for all speakers of a language struggle to capture the fact that interdental substitution is not fully homogeneous, as documented in previous work (Hanulikova & Weber, 2010; Graeppi & Leemann, 2019) and confirmed by the production data we obtained. In contrast, phonetic measures show a lot of within-language and speaker variability, which could account for variability in interdental substitution. Therefore, framing the feature [±distributed] as a phonetic rather than a phonological feature might be better at capturing the gradient and variable nature of the observed patterns. At the same time, framing it in terms of [±distributed] allows us to relate it to an established featural distinction that groups interdentals, dental stops, and laminal stops into a natural class.

8   Conclusion

The study set out to test whether articulatory properties of L1 coronal stops, specifically constriction length as an exponent of the feature [±distributed], predict patterns of interdental substitution. The results show that alveolar apical stops are indeed associated with shorter constriction lengths than dental non-apical stops, and that, in the present sample, languages whose /t/ is realised with longer constriction lengths tend to favour stop substitution over sibilant substitution for English interdentals. At the same time, some languages, such as Egyptian Arabic, exhibited long constrictions of /t/ despite choosing /s/ as an interdental substitution, which shows that the constriction length of /t/ alone is not sufficient to determine substitution outcomes. Other factors, such as the place of articulation of L1 /s/, likely play a role. Future work will extend this analysis to the speaker level, explore the specifications of other coronal segments in the L1 inventories, and compare the acoustics of /t/ and /s/ in the languages in question to the acoustic properties of interdentals.

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