An Aerodynamic Explanation for the Uvularization of Trills?

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Abstract

The origin of the uvular trill [ʀ] in the languages of Western Europe is a matter of some debate. The diachronic change from an alveolar trill to a uvular trill is widely believed to be standard and the reverse process seems unattested. The present study approaches this diachronic asymmetry by examining the aerodynamics of uvular and alveolar trills produced under laboratory conditions.

1 Introduction

Despite its presence in German and French, two well-studied Western European languages, the uvular trill is a relatively rare sound in human language. The trill appears in Abkhaz (Northwest Caucasian), Batak (Austro-Tai), Moghol (Ural-Altaic), Ashkenazic and Tiberian Hebrew, some dialects of Italian, Portuguese, Caribbean Spanish, Dutch, and Swedish [13, 10, 8, 7, 14, 1, 4]. Unspecified "back /r/" (which may or may not be realized as a uvular trill) is reported in Estonian and Czech [4].

One long-observed phenomenon is the interaction of apical and uvular trills. For example, it has been noted that few, if any, languages contrast the two phonemically and that there is a typological bias favoring the apical trill [10, 23, 6, 4, 13]. It has also been noted that in Western European languages, at least, the diachronic tendency is to uvularize apical trills rather than apicalize uvulars [1]. For example, the alveolar trill is still heard in rural parts of France and Canada, but younger speakers are shifting to a uvular variant [5, 18].

The relationship of apical and uvular trills has captured attention because the sounds do not share a common formant structure (e.g. F3 lowering) [11] yet the replacement of apical /r/ by uvular /ʀ/ is well-attested. The reverse process is unknown.

Numerous articulatory and acoustic-perceptual hypotheses have been put forward to explain the relationship between the trills (e.g. [1, 11, 3, 4]). These discussions often consider the entire "rhotic" class, which includes approximants as well as trills. The thrust of such arguments has been to unite all rhotics using principled phonetic criteria (e.g. [22, 11, 4]). Unlike these studies, this paper will concentrate exclusively on the trills.

From an articulatory point of view, there are several structures in the vocal tract that can be positioned in such a way so as to give rise to an aerodynamically-driven, oscillatory sound source. These include the vocal folds [24], the epiglottis [21], the uvula, the tongue tip, and the lips [10]. Of these possibilities, only the uvular and apical trills also happen to be lingual. Hence, the kinematic and physiological relationship between uvular and apical trills may not be entirely surprising, since they are composed of a similar source vibration and are produced with the tongue as a primary articulator.

From an acoustic-perceptual point of view, it has been demonstrated that the filter characteristics of uvular and apical trills are different (e.g. they do not share lowered F3) [11]. As a first pass, it may be argued that speakers key in to the *source* rather than the *filter* of the trill when they "misreconstruct" (to use [4]'s term) a heard apical trill as a uvular. However, a *filter*-based explanation for the confusion of dorsal and coronal rhotic approximants has also been forwarded. The results, which suggest that speakers re-map the articulatory configuration of rhotics based on perceptual ambiguity in the F2–F3 space, may apply generally to trills as well, though this has not yet been verified [4].

Sociolinguistic arguments are also common in the discussion of apical and uvular trills, though they are necessarily more concerned with the *transmission* of sound change rather than its *phonetic bases*. To the extent that transmission can trump phonetic naturalness, however, such facts must not be disregarded. The sociolinguistic debate over /ʀ/ has to do with the geographic origins of the sound and its subsequent spread throughout Western Europe. Either the uvular trill spread as a prestige variant from France to Germany and beyond or it cropped up in a number of locations independently [7, 4].

The fact that uvularization of apical trills is not well attested outside of Western Europe may support the monogenetic hypothesis. Polygenetic models, on the other hand, assume that the uvularization of apical trills is a natural phonetic phenomenon which does not require the force of prestige or social contact to be realized. Supporters of the polygenetic model should be concerned with the typological scarcity of uvular trills and the geographic limitations on the /r/ > /ʀ/ sound change.

The present study will contribute to these ongoing discussions about the phonetic naturalness of rhotics and the transmission of /r/ > /ʀ/ by addressing a smaller, though related issue: the aerodynamics of uvular and apical trills. The paper will consider aerodynamic explanations for why the change /ʀ/ > /r/ appears unattested, even in languages where the uvularization of trills has been in effect for several hundred years [7]. Some hypotheses take into account confusion of /r/ in Parisian French with another apical sound, /z/, necessitating the move to /ʀ/ [17, 7]. While [17] considers the sound change gradual, [7] argues it occurred abruptly, as soon as the structural opposition of /r/ and /z/ became threateneed. [1] provides a functional explanation of /r/ > /ʀ/ by citing the need for "as much freedom of the tongue as possible" in order to avoid consonantal coarticulation of vowels, a motivation he claims to be particularly strong in French (564).

2 Aerodynamics of trills

X-ray studies have shown that in French and German, at least, the uvular trill is produced by retracting the tongue root, lifting the tongue body, and moving the uvula forward, perhaps through contraction of *musculus uvulae* [2, 24]. If air moves through the channel at sufficient speed, resulting low pressure in the channel can draw the uvula towards the tongue, which the uvula then strikes. Momentary contact between the two articulators is disrupted by mounting pressure behind the uvula. High-speed air flow once again lowers the pressure in the channel and the cycle repeats itself.

It has been shown that the production of trills is sensitive to intra-oral air pressure and that excessive air flow can result in frication rather than trilling [19, 20]. [12] concludes, "Since several factors have to be within critical limits for the vibration to occur it is not surprising that trilling quite often fails to take place and instead a uvular fricative or approximant is pronounced" (32).

It has not been conclusively demonstrated that the uvula vibrates more quickly than the tongue tip [10]. The best evidence to this effect could be obtained from speakers of a language that supports a phonemic distinction between both kinds of trills (as noted above, such languges are difficult, if not impossible, to find). Nevertheless, [11] reports an average vibratory rate of 30.5 Hz for uvulars in Southern Swedish, while [9] report a mean vibratory rate of 26.2 Hz in Southern Swedish and Italian. [10] find these measures to be statistically indistinguishable from the vibration rates associated with measured apical trills (around 28.6 Hz).

3 Methods

To explore the source characteristics of uvular trills, a trained phonetician and near-native speaker of Portuguese (the author) produced sustained uvular and apical trills in a laboratory setting using a split flow air mask (Glottal Enterprises S/T-MA1) connected to a heated low-flow pneumotach (Biopac, TSD137F) and differential pressure transducer (Biopac, TSD160A). Signals were high-pass filtered at 10 Hz using a Krohn-Hite analog filter. Fifty repetitions of the apical and uvular trills were produced at one second each, followed by a two-second pause. The analog signals were digitized at 20 kHz and then processed in Matlab to obtain the fundamental frequency (through autocorrelation) and periodograms. The resulting data give a more focused picture of the source characteristics that characterize and differentiate uvular and apical trills.

4 Results

Figures 1 and 2 present some typical oral flow signals and accompanying periodograms for the apical and uvular trills in the production database. The first difference to note are the differing vibrational rates. Autocorrelation of the two signals puts the average vibration for the uvulars at 32.7 Hz (SD = 5.2) and the apicals at 24.9 Hz (SD = 4.1). While the findings should be treated with caution, since they are not produced by a native speaker of a language with trills, they closely approximate the range of vibration rates reported for Southern Swedish and confirm the suggestion that the uvula vibrates more rapidly than the tongue tip [11]. Statistical analysis of the two vibration rate distributions indicates that they are significantly different $F(1, 98) = 68.05$, $p < 0.001$ (see Figure 3).

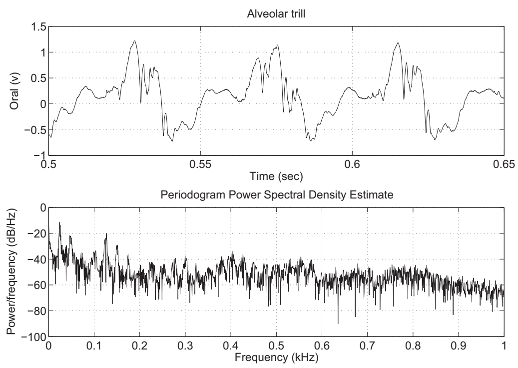

Figure 1: *Oral flow signal with accompanying spectral decomposition for the apical/alveolar trill.*

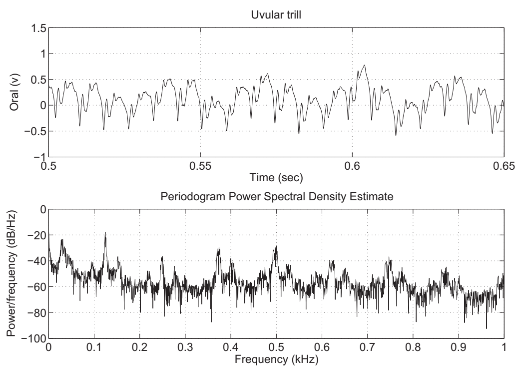

Figure 2: *Oral flow signal with accompanying spectral decomposition for the uvular trill.*

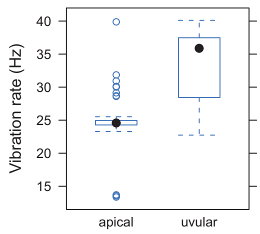

Figure 3: *Vibration rates of uvular and apical trills.*

The spectral characteristics of the uvular and apical source vibrations are also strikingly dissimilar. There are more high frequency peaks in the spectra of the uvulars, indicative of a more complex mode of vibration (note that the use of the aerodynamic technology greatly reduces the effect of the anterior filter on the signal [16]). The airflow is also lower during the uvular trills, suggesting reduced intraoral pressure.

5 Conclusion and discussion

In light of these findings, it it tempting to argue for an additional functional motivation behind /r/ $>$ /ʀ/, one that incorporates new information about their aerodynamic characteristics. However, such a hypothesis is not without complications of its own. Uvular trills may benefit from a marginal evolutionary edge over apical trills in terms of air expenditure. However, this line of reasoning is tenuous for a number of reasons. First, high airflow sounds like fricatives are not rare in the world's languages nor is it clear that speakers implement some strategy for conserving airflow during speech. Second, uvular trills are sometimes realized as uvular fricatives, which expend greater airflow than apical trills, effectively defeating any drive for conservation. Finally, expenditures of airflow (with regard to total lung volume) during speech utterances are relatively small and can be manipulated adroitly—even reversed, in the case of ingressive sounds. There is in fact a strong aerodynamic reason why apical trills should *not* be uvularized: the aerodynamic voicing constraint [15]. Because the uvular trill is articulated at a more posterior place than the apical trill, vocal fold vibration is less likely to be continuous, which naturally results in devoicing and frication of the trill [20].

Thus, the prospectus for an aerodynamic explanation of uvularization is still unclear, and depends crucially on more aerodynamic investigations into the airflow properties of other speech sounds. For example, the change from a high-airflow, high-pressure trill to a low-airflow, low-pressure trill may be viewed as a kind of lenition analogous to consonant spirantization, e.g. /b/ > /β/, if relatively high-pressure voiced stop consonants indeed become relatively low-pressure voiced fricatives. While aerodynamics may not be able to explain the prevalence of trill uvularization in Western Europe, it provides additional information for understanding the phonetic bases and transmission of the sound change.

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