The physiology of voiced apical trills: implications for sound change

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1. Introduction and aims of the study

Voiced trills are strongly preferred over voiceless ones in the languages of the world: according to Maddieson (1984), only 1.5% of the trills are voiceless, which means that voicelessness is not only much less frequent in trills than in stops or fricatives, but also in comparison to other sonorant segments, where voicelessness is present in 3.5% of the cases.

The preference for apical trilling to co-occur with voicing rather than voicelessness is also visible in language acquisition and change. In first language acquisition, trills are among the very last sounds to be produced (Jakobson 1941), and the voiceless even later than the voiced ones (e.g., Ruke-Dravina 1965 for Czech). Trills represent a challenge also for second language learners; unvoiced trills are absent from learners' varieties, since trill devoicing automatically entails detrilling (/r/ > [χ]; e.g., Major 1986). In diachrony, voiceless trills develop into /r/ (voicing) or /h/ (debuccalization) (e.g., Solé 2002:680).

Despite the typological, acquisitional and diachronic preferences for voicing in apical trills, voiced apical trills are known to be based on more restrictive production requirements in comparison to their voiceless counterparts, and also to be less robust to changing articulatory and aerodynamic conditions. Extensive research on the production of apical trills has demonstrated that maintaining voicing and trilling at the same time is effortful and needs fine articulatory control (e.g., Catford 1977, McGowan 1992, Recasens & Pallarès 1999, Solé 2002, Recasens 2013).

Although the articulatory and aerodynamic mechanisms required for the production of voiced and voiceless trills have been thoroughly studied, the mechanical activity at the glottal level and the phonatory dynamics for this class of sounds have received little attention so far.

This paper aims at filling in this gap, by providing an investigation of the laryngeal activity and tongue-root dynamics involved in the production of voiced apical trills.

2. Methodology

We analyse the laryngeal and tongue root activity of native Italian speakers producing sustained /r/ and /r/ + vowel syllables. The methodologies used are digital video laryngoscopy (LS) and laryngostroboscopy (LSS), electroglottography (EGG), sound spectrography, and ultrasound tongue imaging (UTI).

Six female speakers of Tuscan Italian, aged 30-40, were recorded while producing several repetitions of (i) sustained vowels /a/, /i/, /u/ and apical trill /r/ (average duration of each phone: 4 seconds); (ii) nonwords composed of six /ra/ or /ri/ or /ru/ syllables, i.e. /rararararara/, /ririririri/, /rururururuu/. The speakers were also asked to keep volume, pitch and speech rate as uniform as possible during their production.

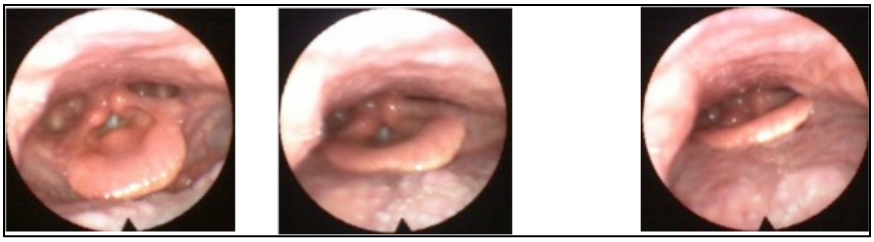
Each speaker was recorded in two different experimental sessions. The first session was run at the ENT Audiology Phoniatrics Unit, Department of Neuroscience, University of Pisa. The speakers were sitting in the laryngoscopy lab for clinical examination. The audio signal was recorded using a KayPENTAX Computer Speech Lab (CSLTM) 4500 supported by a personal computer including a Shure-Prolog SM48 microphone, located at a distance of 15 cm and at an angle of 45°. Background noise (< 30dB) was constantly monitored. The EGG signal was recorded by collar electrodes on the speakers and captured by means of KayPENTAX's Real-Time EGG Analysis, Model 5138, connected to Computer Speech Lab (CSLTM) 4500. The LS data was captured through a flexible rhino-pharyngo-laryngo-endoscope (Olympus®) connected to KayPENTAX Digital Video Stroboscopy System, Model 9295. Videoendoscopy permits a static and dynamic evaluation of the pharyngolaryngeal structures. The camera allowed the visualization of the vocal fold (true vocal cords), ventricular folds (false vocal cords), ventricle, arytenoids, the corniculate tubercle, the cuneiform tubercle, the top and the tubercle of epiglottis and the base of tongue (Vandyke Carter & Gray 1918). Each stimulus was repeated at least three times by each speaker, with the endoscope placed at three different heights of the oropharyngeal cavity. Finally, larynx vertical displacement was externally measured during the production of sustained vowels and /r/ only.

The second experimental session was run at the phonetics laboratory of the Scuola Normale Superiore of Pisa. The speakers produced several repetitions of sustained vowels and trills. Their tongue body and root were captured through a Mindray ultrasound tongue imaging system connected to a microconvex probe.

3. Results

Epilaryngeal inspection through LS (Figure 1) showed that /r/ production requires a constricted pharyngeal configuration, with anteriorization of the pharyngeal wall; the epiglottis moves backwards and downwards compared to the production of /i/ and /u/, whereas it moves forward compared to the production of /a/, possibly because of lower tongue position in /a/ than in /r/. The pharynx seems however laterally more constricted compared to the production of

/a/. In some instances, the recordings show evidence of an asymmetric epiglotto-pharyngeal contact on one side of the throat. The epilaryngeal configuration required for the production of /r/ is therefore in clear conflict with that required for the production of high vowels and particularly of /i/. This is consistent with the observation that tongue-tip trilling maintenance in the context of high vowels is difficult and often gives rise to detrilling (Recasens & Pallarès 1999, Recasens 2013). Generally this has been related to the lingual requirements for /r/ that are in conflict with those required for /i/, /u/ (in the production of /r/, the tongue predorsum must be lowered and the postdorsum must be retracted to a sufficient extent in order for the tongue tip and blade to be raised and vibrate against the alveolar or postalveolar zone). Our data suggest that trills and high vowels have also conflicting epilaryngeal configurations.



/i/ /a/ /r/

Figure 1.

Larynx vertical displacement (mm)		
/u/	3	
/a/	6.8	cranial
/i/	7.7	cranial + anterior
/r/	11.3	cranial

Figure 2.

Inspection of the anatomical structures immediately above the glottal plane (i.e. LS inspection with endoscope at a lower position) additionally showed that there is some tube narrowing over the glottal plane in the production of /r/ as compared to vowels. Arytenoid cartilages rotate and move to the front, covering most of the glottal plane; the posterior surface of the arytenoids is wider; in some cases, there is asymmetric arytenoid-epiglottis contact. Ventricular folds (false vocal cords) appear to be more contracted and more displaced towards the median line (antero-posterior and latero-lateral contraction). Further analyses are however needed to assess the degree of vocal and vestibular fold stiffness during the vibratory dynamics involved in trill production.

Larynx vertical displacement as externally measured showed that trills are articulated with the larynx in its highest position, compared to vowels (Figure 2). This is consistent with the hypothesis of a constricted larynx configuration, since larynx height has been shown to be synergistic with larynx constriction in ATR languages and tense-lax vowel contrasts (Moisik 2013 and bibliography therein). In addition, our data suggest that larynx height in trills is not a direct consequence of tongue root retraction, because if it was, we shouldn't expect larynx to be higher than in /a/. In fact, our UTI data showed that tongue root retraction is almost the same in /r/ and /a/ (whereas it is minimal in /u/ and /i/) (Figure 3). Therefore, we can hypothesize that the upward movement of the larynx in the production of /r/ is an independent mechanism leading to increased larynx constriction and not a consequence of lingual dynamics.

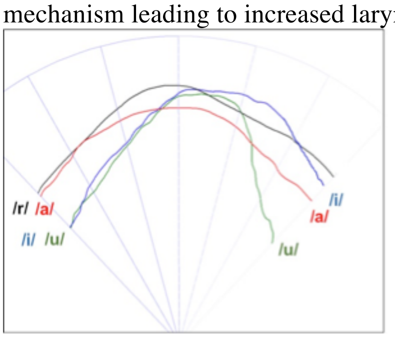


Figure 3. Tongue tip on the right.

Thus according to these preliminary LS observations, the cavity immediately above the glottal plane is restricted during the production of /r/ as a consequence of both upwards movements of the larynx and downwards and backwards of the epiglottis. It is therefore likely that pressure above the glottal plane increases during the production of trills, particularly at its initiation. Further analyses are needed to support this hypothesis. One possible interpretation is that these laryngo-pharyngeal adjustments could be seen as maneuvers finalized to maintaining the necessary transglottal pressure drop that allows vocald folds to vibrate simultaneously with tongue tip vibration.

We conclude by remarking that the analysis of glottal, epiglottal and tongue root activity in trills supports the view that there are structures occupying the space between the glottal plane and the tongue, that are actively involved in the production of oral sounds and possibly facilitate the maintenance of critical trade-offs between articulation and aerodynamics. These structures appear to be necessary to explain diachronic and synchronic events of the language, thus entering the phonetic and phonological domain to the same extent that the tongue tip, blade or the vocal folds do.

They also strive for us to move on from the mainstream phonological conceptualization of a "glottocentrism" as opposed to a "linguocentrism" (Moisik 2013, Gick 2011), and adopt instead an integrated account of speech production mechanisms from the glottal plane to the lips.