Another look at the structure of [ɾ]: Constricted intervals and vocalic elements

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Abstract

This study investigates the hypothesis that the rhotic segment containing one constricted interval, [ɾ], has a more complex internal phonetic structure that includes vocalic elements flanking the constriction, as suggested in classic studies, as well as more recent ones (Stolarski 2011 and references cited therein). The current experiment focuses on the quality of the vocalic elements of the sound in Romanian (contexts #rV, Cr, rC) and the acoustic analysis shows them to systematically stay mid-high and central (to front) across contexts. The paper also briefly touches on a phonological implication of this structure of the tap.

1. Previous studies: Putting contexts together

[ɾ] is described as the sound involving "a fast, ballistic tongue-tip raising movement and a single, short apicoalveolar contact" (Recasens & Espinosa 2007:1). When the segment is in intervocalic position (context VrV), this is seen as a very brief constricted interval on a spectrogram.

This paper argues for the claim that the tap actually contains two vocalic elements, one on each side of this constricted interval, as pointed out in classic studies by Polish authors and recently maintained in newer ones (see Stolarski 2011 and others this author cites). Thus, I aim to show that the tap's structure is actually 'vocoid-constriction-vocoid'.

Studies indicate that when [ɾ] is bordered by a consonant on one side, while having a vowel on the other side, spectrograms show a vowel-like element intervening between the consonant and the constricted interval of the tap. This means that a vocoid appears to the left of the constriction in Cr, and to the right of it in rC. The phenomenon is consistent cross-linguistically for clusters (V)CrV and VrC(V) (see Avram 1993; Ramírez 2006; Baltazani 2009, and others).

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The appearance of the vocoids has also been reported where [ɾ] has a word-boundary (pause) on one of its sides instead of a consonant (see Vago & Gósy 2007, among others). The vocoid is positioned between the pause and the constriction of the tap, in word-initial and word-final /r/ (contexts #rV, Vr#). For example, a word that begins with [ɾ] actually begins with the vocoid (see Figure 3 below).

This vocalic element has received various interpretations. Ramírez (2006) labels it "epenthetic", though its systematic appearance across languages and contexts suggests that this is not the case.

Schmeiser (2009) prefers the term "intrusive vowel" because, from a synchronic point of view[1], this vocoid does not add an extra syllable to the word, which is what happens with vowel epenthesis. This may be another argument against considering the vocalic elements epenthetic. Bradley & Schmeiser (2003) explain the appearance of this "intrusive vowel" as the result of a less than maximal overlap between the two articulatory gestures performed to produce the tap and the adjacent consonant. While this explanation could account for Cr and rC clusters, it does not account for the #rV and Vr# cases, where there is no other consonant in the immediate vicinity of the tap. In these cases it would be difficult to consider the vocoid as an effect of the gestural transition from one consonant to the next.

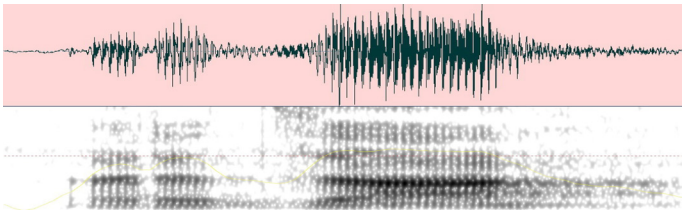
Avram (1993) and Baltazani (2009) regard it as part of another realization of /r/, different from the intervocalic tap. Note that, under this view, we would be dealing with four realizations of the rhotic: one in intervocalic position, where it is just a short constriction, another in Cr and #rV, containing a constriction and a vocoid to its left, another realization for contexts rC and Vr# (a constriction and a vocoid to its right), and yet another for contexts Cr#, #rC and CrC (presented below), with two vocoids flanking a constriction.

None of these interpretations considers the vocalic element as part of the tap proper. In what follows I attempt to show that the vocalic element observed in Cr, rC, #rV and Vr# is one of the two vocalic parts a tap normally contains. Thus, I attempt to unify the contexts described above, with seemingly unrelated phenomena, and argue that, when considered globally, they lead to just one realization of the tap.

Slavic data indicate two vocoids, one on either side of the constriction when [ɾ] does not border with a vowel at all, but only consonants or pauses. We have the opportunity to see this in the rarer contexts #rC, CrC, Cr#, which I consider to

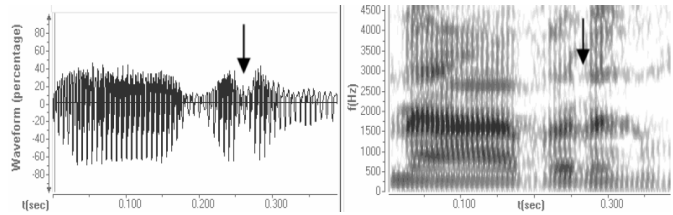
[1] An anonymous reviewer points out that diachronically, these vocoids may add syllables to the word or, on the contrary, the reverse may happen. Indeed, this is an interesting instance of reanalysis of (part of) the vocoids as full vowels, or, in the reverse case, full vowels may be reanalyzed as parts of the tap. For reasons of space I do not elaborate on this topic here, but the interested reader may consult Savu (2012).

be the most important piece of the puzzle. The two vocoids appear in syllabic /r/ in Serbo-Croatian and Slovak (see Gudurić & Petrović 2005 and Pavlík 2008 respectively), as well as non-syllabic /r/ in Polish (see Stolarski 2011). Figures 1 and 2 below illustrate two examples.



[ɾ dz a]

Figure 1 – The Polish word *rdza* 'rust', non-syllabic [ɾ] in #rC (from Stolarski 2011).



[n a v ɻ ɦ]

Figure 2 – The Slovak word *navrh* 'proposal', syllabic [ɾ] in context CrC (from Pavlik 2008).

What the data appear to suggest, when taking all the contexts into consideration, is that the tap's structure may include vocalic elements on both sides of the constriction. They are clearly delimited and salient on the side(s) where it does not border with a full vowel. Thus, CrC, #rC and Cr# show both vocoids because the consonants or pauses flanking the rhotic contrast with the vocoids and emphasize them. Cr, rC, #rV and Vr# show only one vocalic element, either on the left or on the right, depending on where the consonant or pause which renders the vocoid salient occurs. VrV would show only the constriction, the tap having nuclear vowels on both sides for the tap's vocoids to 'melt into'. Therefore, under this view, the structure of the tap is always the same: 'vocoid-constriction-vocoid', and the phonetic context reveals or hides different parts of it.

2. The experiment on [ɾ] in Romanian

2.1 Purposes

The main purpose of the current experiment is to measure the formant structure of the vocalic elements of the tap in order to determine how much their quality can vary. Another aim is to measure the mean duration of the salient vocoids and the constrictions in Romanian words. A third aim is to investigate the possibility of the structure argued for in Section 1 being detectable in context VrV as well.

2.2 Setup

Recordings of Romanian words in isolation were made, containing /r/ in contexts #rV, (V)CrV, VrC(V) and VrV, where C is a stop (/p, t, k, b, d, g/) and V is one of the seven vowels of Romanian (/a, e, i, o, u, ə, ɨ/). Additionally, recordings of nonsense VrV sequences and sustained tokens of each Romanian vowel were obtained from each speaker. Clusters Cr and rC were flanked by either the same vowel on both sides, or by a vowel and a word-boundary. The idea behind this is to have the tap in the immediate vicinity of only one vowel, so as not to have it influenced by two vowels of different qualities at once. This gives the vocalic part the opportunity to have a quality as similar as possible to that of the vowel that *is* in its vicinity. For example, the way to find out how much the vocalic element can approach the quality of [i] is to include the sequences /iCri/ or /#Cri/, rather than /aCri/. Examples of words used in the experiment are given below:

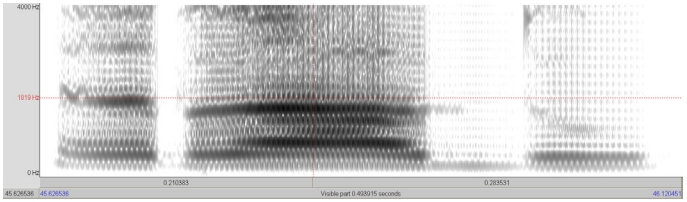
Cr:	/**abra**'ziv/	'abrasive'
	/**grə**'dinə/	'garden'
rC:	/k**or**'**do**n/	'belt'
	/ t**ɨrg**/	'bazaar'
#rV:	/'**ra**du/	proper name
VrV:	/p**e**'**re**te/	'wall'

The 5 participants (4 female, 1 male) read the words and sequences off PowerPoint slides 4 seconds apart[2] and the recording session was repeated three times for each speaker, the quality of the recordings being adequate for the purposes of the analysis. The process resulted in a corpus of 1680 words that were subject to acoustic analysis with the software PRAAT (Boersma & Weenink 2011).

[2] The time between slides was introduced in order to exclude coarticulation effects, especially for context #rV. Frame sentences were not used for the same reason.

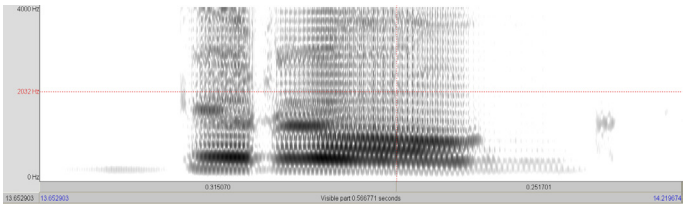
2.3 Results

The realization of /r/ was that of one constriction with the accompanying salient vocalic element in 86.66% of the tokens for contexts #rV, Cr, rC (1470 words). Examples are given in the spectrograms below. Other realizations included trills and approximants, but they were not included for acoustic analysis.



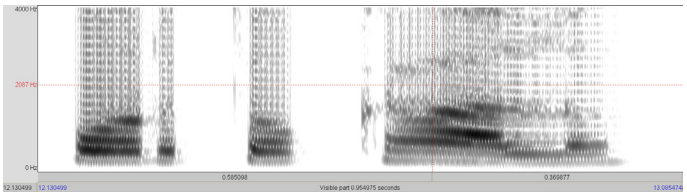
[ɾ a d u]

Figure 3 – The word /'radu/ (proper name), context #rV.



[d ɾ o g]

Figure 4 - The word /drog/ ‘drug’, context Cr.



[p o ɾ t o k a l ə]

Figure 5 – The word /porto'kalə/ ‘orange’, context rC.

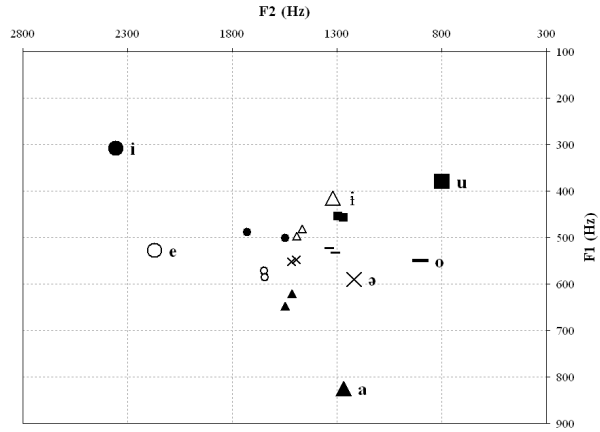
2.4 Quality of the vocalic elements

The vocalic elements have been reported to have qualities similar to that of [ə] and [ɨ] (Avram 1993; Vago & Gósy 2007; Stolarski 2011). However, they have also been reported to be similar to the nuclear vowels in their vicinity, albeit more central (Quilis 1993 cited in Schmeiser 2009; Baltazani 2009, among others).

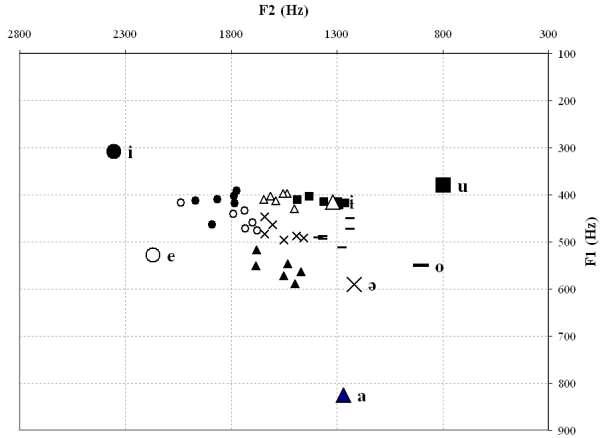
These studies were done on languages like Spanish and Modern Greek, which do not include mid or high central vowels in their inventories. It would, therefore, be interesting to see what happens when the nuclear vowels surrounding the tap are themselves central and mid or high. This is an opportunity which a language like Romanian provides, with its /ə/ and /ɨ/. Could we narrow down the possible space of variation of the vocalic elements?

The graphs below plot the average quality of the vocalic element in each word, for all participants, all three times the recording session was repeated, as compared to the average quality of the sustained tokens of the seven Romanian vowels uttered by the same speakers.

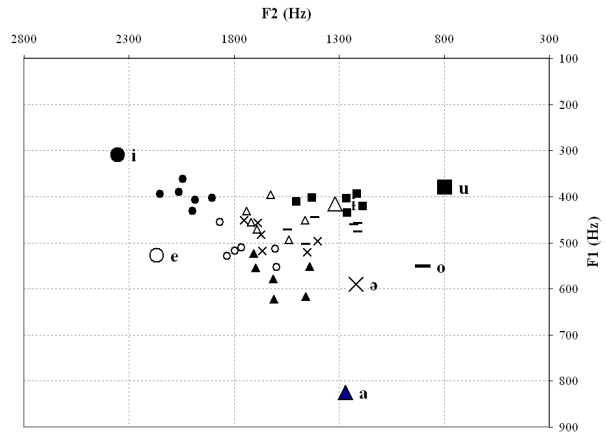
In the three graphs, the vocalic elements (small size) match the shape of the nuclear vowel (large size) they have in their immediate vicinity. For example, the small filled triangles correspond to vocoids in sequences /#ra/, /(a)Cra/, /arC(a)/. Each small-sized symbol is dedicated to one word used in the experiment and its position on the graph represents the average formant values of the vocoid in the respective word, across participants and recording sessions. For context #rV, there were two words used per full vowel, hence two small shapes for each large one. Cr and rC have six words per full vowel, one for every stop consonant (/p, b, t, d, k, g/).



Graph 1 – Vocalic elements in context #rV.



Graph 2 – Vocalic elements in context rC.

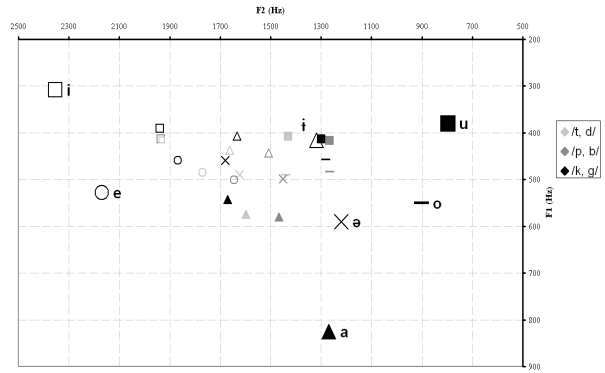


Graph 3 – Vocalic elements in context Cr.

The graphs show that, for all contexts, the vocalic elements tend to approach the quality of the full vowels they are surrounded by, but there appear to be certain limits to this variation. They remain mid-high, central to front[3] and seem to consistently stay away from [a], [o] and [u]. This is especially easy to observe

[3] As pointed out by an anonymous reviewer, the quality of the tap's vocoids, as shown by the graphs, raises a phonological question: what is their featural specification, if we are to consider that the complex acoustic structure is mirrored in phonology? Are the vocoids underspecified for height and backness? One way to approach the issue would be through statistical analysis, as suggested by the reviewer, or by phonological study. I leave this matter for further research.

when looking at what happens to the vocalic parts surrounded by [ə] and [ɨ]. Having these full vowels around pushes the vocalic elements to a slightly more front area than the central vowels are in themselves, which is a strong indication that the point where the vocoids cannot reach further back is near. Indeed, as mentioned above, the vocoids corresponding to [o] and [u] are much more front than these two vowels. Actually, it appears that when the full vowel around the tap is [o] or [u], the vocoids are very similar to, or show overlap with, [ə] and [ɨ]. The vocoids are also much higher than [a] in all contexts, remaining mid.
Though there are limits to the backness of the vocalic elements of the tap, they can be quite front, approaching [i] and, to a lesser extent, [e].
The graphs also show variation according to context. Cr allows the vocalic elements to vary and approach the quality of the surrounding vowel the most. The most front and high vocoids may be found in this context, namely those in the /(i)Cri/ sequences. The /(e)Cre/ words also appear to contain vocoids that are closer to [e] than other contexts.
Context rC keeps the vocoids closer together than Cr. However, context #rV clusters them together in a tighter, mid-central area (in agreement with Baltazani & Nicolaidis 2013).
Let us now see if the place of articulation of the consonant has an influence on the vocoid in the word in which it occurs. This is shown in Graph 4 below.



Graph 4 – Average vocoid by place of articulation of the C in Cr and rC.

In Graph 4, the smaller symbols represent the average vocoid according to the vowel flanking the cluster Cr or rC (shape of the symbol), and according to the place of articulation of the C(onsonant) in the cluster. The light gray shapes stand for the vocoids when C is a dental stop. The dark gray shapes represent clusters with bilabial stops, while the black symbols are for velar stop clusters.

The vocalic elements in contexts Cr and rC have been averaged together for the same place of articulation of the C. For instance, the small light gray filled triangle represents the vocoids in sequences /art(a)/, /(a)tra/, /ard(a)/, /(a)dra/, again across participants and recording rounds.
As Graph 4 shows, there appears to be a tendency for the vocoids in bilabial stop-rhotic combinations to be slightly more back, while vocalic elements in clusters with dental and velar stops tend to be more front. That said, the C in Cr and rC clusters does not seem to have a significant effect on the tap's vocoids. The influence of the full vowel flanking each cluster is clearly stronger.

2.5 Durations

On average, measurements show that the duration of the constricted interval is smaller than the duration of the vocalic element. Table 1 shows that the vocoid in a word-initial tap (context #rV) has the longest average duration, and the difference between the vocoid in this context and other contexts is quite significant (more than 20 ms), as reported for Greek in Baltazani & Nicolaidis 2013. The average vocoid in Cr and rC has about the same duration, while Cr has the shortest constricted interval.

Average duration	#rV	rC	Cr	VrV
Vocalic element	49,0	31,0	30,3	
Constriction	27,3	26.9	24,0	28,8

Table 1 – Average durations (ms) of constrictions and vocalic elements.

The current experiment did not control for factors like speech rate, word length and stress placement, which could influence the durations, so more investigation is needed in order to elaborate further on this issue.

2.6 Context VrV: formant changes

"Abrupt formant changes" have been reported during the first vowel, towards the constriction, when the tap is in context VrV (Baltazani & Nicolaidis 2013). It would be expected that this phenomenon should occur systematically if the tap has vocoids of its own in the intervocalic context as well. Specifically, one would expect the formants to change, when nearing the constricted interval, towards a configuration similar to that of a mid-high, central (to front) vowel, which is the area in which the vocoids of the tap are.
This would indeed appear to be the case, as Figures 6-8 below show for the nonsense sequences.

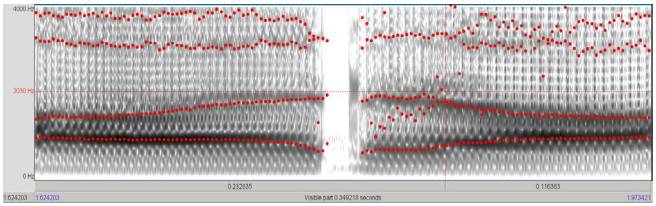


Figure 6 – The nonsense sequence [ara].

The vowel [a] has a high F1 and a low F2. Figure 6 for the sequence [ara] shows that, near the constriction, F1 decreases and F2 increases, making the target configuration higher and more front than [a].

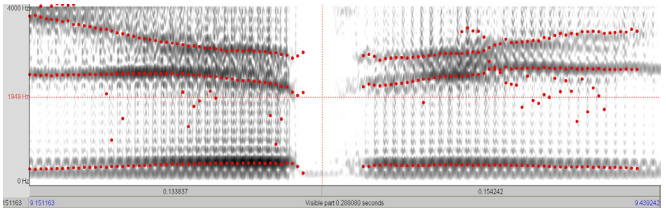


Figure 7 – The nonsense sequence [iri].

A low F1 and a high F2 are characteristics typical of the vowel [i]. In Figure 7, showing the nonsense sequence [iri], a slight increase in F1 and a decrease in F2 can be noticed, which means that, towards the constriction, formants aim for a vowel that is a little lower and more back than [i].

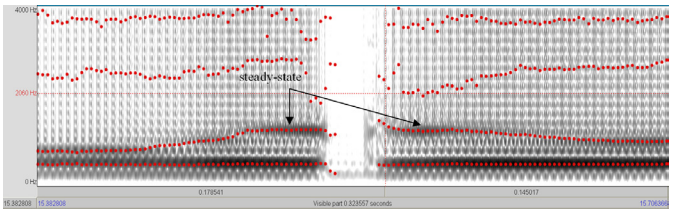


Figure 8 – The nonsense sequence [uru].

The vowel [u] has a low F1 and a low F2, which are visible at the edges of Figure 8. Towards the constriction, F2 increases, suggesting a vowel which is more front than [u]. Some tokens, such as the one in the spectrogram above, even exhibited a portion in which the formants are in a steady-state configuration near the constriction, which would support the claim that the tap has vocoids that are detectable in context VrV.

Considering Figures 6, 7 and 8 together, the formant changes suggest that, in the immediate vicinity of the constricted interval, formants tend to approach the configuration that would place the vowel in the area in which the (salient) vocoids of the tap cluster in other contexts[4], as indicated in Graphs 1-4. In addition to this, Figure 8 shows a token in which the vocoids are salient even in VrV, as suggested by the steady-state portion of the formants immediately before and after the constricted interval.

3. Phonetic conclusions

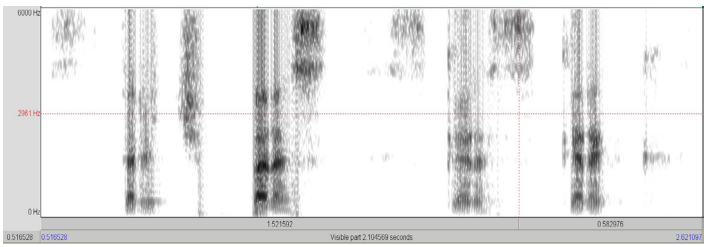
The data from Romanian, corroborated with data from other languages, seem to support the hypothesis that [ɾ] includes one vocalic element flanking each side of the constriction. The results of the current experiment on this sound in Romanian suggest that the tap's vocalic elements may vary in quality, but stay in the mid-high, central to front area.

The tap's vocoids are not clearly delimited where the rhotic borders with a vowel because on a spectrogram they show up as a continuous vocalic sequence, perhaps with formant changes. One cannot tell where the vocoid of the tap ends and the full vowel begins. However, the vocoids of the tap become salient when they border with stop consonants because the stops have different spectral characteristics. This is why one vocalic element is salient when the tap has a nuclear vowel on one side: the vocoid on the other side would not be distinguishable from the nuclear vowel. The full structure is easy to distinguish only when [ɾ] has no nuclear vowels on either side (contexts #rC, CrC, Cr#).

[4] An anonymous reviewer draws my attention to the fact that, in VrV, we might view the vocalic parts as simple transitions. While this is indeed the case, I consider that they are better viewed as parts of the tap, given the clearly delimited vocoids that appear in other contexts. Future research may shed more light on the matter, for example, by comparing the transitions in VrV to those in VdV, as the reviewer suggests.

4. A phonological implication

This kind of structure, which includes vowel-like parts, may be what allows [ɾ] to appear in onset and coda position, but also function as a syllabic nucleus, as is the case in Slavic languages like Czech and Serbo-Croatian. In these languages one can find entire sentences composed only of consonants (see Figure 9 below).

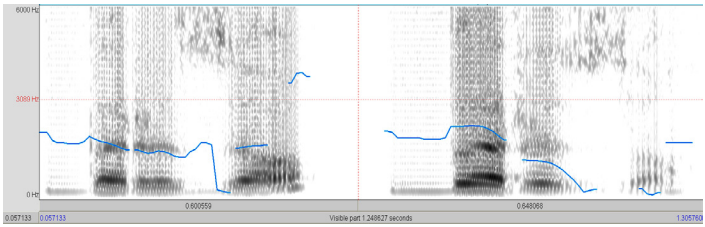


[s tɾ̩ ʧ p ɾ̩ s t s kɾ̩ z kɾ̩ k]

Figure 9 – The Czech tongue twister sentence *Strč prst skrz krk* 'Put your finger through your throat', which contains only consonants. The syllabic nuclei are rhotic taps. Source of the sound-file: http://upload.wikimedia.org/wikipedia/commons/1/12/Prst_a_krk.ogg.

/r/ may even be the locus of phonemic length and pitch distinctions in Slovak (length) and Serbo-Croatian (length and pitch) (Sussex & Cubberley 2006:187-188). If its [ɾ] realization contains vocalic elements (see Pavlík 2008 for an acoustic study of /r/ in Slovak), it would be reasonable to assume that they are the ones bearing said distinctions[5]. As an example, in Serbo-Croatian there are minimal pairs of words distinguished only by the tone on /r/. For instance, *bŕzo* (long rising) is the adjective 'quick', neuter singular form, while *bȓzo* (long falling) is the corresponding adverb, 'quickly'. Figrue 10 below shows the minimal pair uttered by a native speaker. /r/ is realized as [ɾ], and the structure 'vocalic element – constriction – vocalic element' is easily distinguishable.

[5] /r/ is not the only consonant with the ability to be a syllabic nucleus and bear length and pitch distinctions. In Czech /l/ can be syllabic as well, and in Slovak it can be a syllabic nucleus and carry length distinctions along with /r/. As is known, /l/ and /n/ are vowel-like on a spectrogram, something which I consider to be related to their ability to be syllabic nuclei, and carry length distinctions in the case of /l/. In fact, if the ability of /l/ to exhibit this behavior is linked to its vocalic character, it would be only expected for /r/ (in this case the tap) to be vocalic in character as well, which may be taken as an additional argument in favor of the 'vocoid-constriction-vocoid' structure.



[b r̆ː z o b r̂ː z o]

Figure 10 – [br̆ːzo] and [br̂ːzo], uttered by a female native speaker of Serbian.

5. Conclusion

The main focus of this paper was to establish the details of the internal phonetic structure of [r]. It was argued that the general structure of this sound is 'vocoid-constricted interval-vocoid', which would unify the seemingly different realizations of the rhotic segment with one constricted interval that appear in different phonetic contexts. An acoustic analysis of the formant structure of the aforementioned vocoids in Romanian revealed them to be mid-high and central (to front), which agrees with and completes similar acoustic studies, done on this sound in other languages. Finally, I suggested that this partly vocalic structure is what allows the tap to be a syllable nucleus and bear phonemic length and pitch distinctions, as it does in languages like Slovak and Serbo-Croatian.

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