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The contested fifth liquid in Malayalam: a window into the lateral-rhotic relationship in Dravidian languages

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Abstract

Apart from Tamil, Malayalam is the only Dravidian language that still retains a fifth liquid in its inventory (denoted as /ɻ/), a sound that can be traced back to Proto-Dravidian. The phonetic and phonological status of this sound has been the subject of considerable debate, both in terms of its rhotic vs. lateral status and its phonetic realisation. Studies to date have been impressionistic, so this is the first acoustic study of all five liquids in Malayalam. Production data from eight male speakers reveal that while /ɻ/ is realised as a central post-alveolar approximant, its ambiguous phonotactic patterning and mixed acoustic profile are contributors to its mixed identity. An understanding of the complex patterning of this sound, which straddles the rhotic/lateral divide, requires an appreciation of the role of secondary acoustic resonance in distinguishing members of a crowded liquid system and in preventing a /ɻ/ - /ɭ/ merger.

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1. Introduction

Malayalam is one of India's twenty two official languages, spoken by approximately 32 million people in the southern state of Kerala. Unlike most Dravidian languages (Krishnamurti, 2003: 52-53; Asher and Kumari, 1997: 405), Malayalam has a five member liquid inventory: two rhotics, two laterals and a fifth liquid, most commonly transcribed as /ʐ/ (Table 1). In the Malayalam alphabet, /ʐ/ is the 35th consonant, placed between /ɭ/and /r/ (Asher and Kumari, 1997).

The phonetic and phonological nature of the fifth liquid has remained controversial in the limited literature that exists on Dravidian languages. /ʐ/ has been variably referred to as a 'voiced retroflex palatal fricativised lateral' (Kumari, 1972:27-28), a 'voiced sublamino-palatal approximant' (Asher & Kumari, 1997:419), or simply a continuant (Namboothiri, 2002). While these studies are impressionistic, two relatively recent experimental studies on the liquids in the Brahmin Dialect of Tamil argue that the controversial liquid is in fact a third rhotic, more specifically a central retroflex approximant (McDonough & Johnson, 1997; Narayanan, Byrd & Kaun, 1999). Both studies also find some acoustic similarities between /ʐ/ and /ɭ/ in Tamil, and McDonough & Johnson report on perceptual identification of /ʐ/ as /ɭ/ by speakers of dialects where /ʐ/ has been lost. In a preliminary articulatory study of the 5th liquid in Malayalam (Scobbie, Punnoose and Khattab, 2013), /ʐ/ was also found to be a retroflex approximant, but an examination of the whole tongue further suggested advanced root and raised tongue body for /l/, /ɾ/, and /ʐ/ as opposed to a retracted tongue root and lowered tongue body for /ɭ/ and /r/. This makes it less likely for /ɻ/ in Malayalam to share secondary resonance patterns with /ɭ/, but further acoustic work is required to unravel the acoustic profile of the two sounds. Furthermore, the relationship between /ɻ/ and the rest of the liquid system is still far from clear, as is the role of its spectral characteristics in setting it aside from the remaining rhotics and laterals in the language.

Table 1: Inventory of (non-geminate) liquids in Malayalam

/l/	/ɭ/	/ɻ/	/ɾ/	/r/
/kali/ *anger*	/kaɭi/ *game*	/kaɻi/ *eat*	/kaɾi/ *soot*	/kari/ *curry*

In what follows we begin with a review of the phonological and phonetic characteristics of the fifth liquid in light of the rhotic-lateral relationship in Malayalam. We then present details of the first auditory and acoustic study looking at the production of the five (non-geminate) liquids in Malayalam and which, together with articulatory results from Scobbie et al (2013), offers evidence for rhotic characteristics for the fifth liquid. Focus then turns to the resonance patterns of the liquids and their surrounding vowels; here we explore the role these characteristics play in distinguishing between members of each of the rhotic and lateral sub-categories on the one hand and between the fifth liquid and either category on the other. The discussion highlights the role of secondary resonance characteristics in distinguishing between the fifth liquid and the retroflex lateral, and in maintaining a system of maximal contrast in Malayalam within a crowded liquid system and a limited set of phonetic implementations.

2. Origin of the fifth liquid and the rhotic-lateral relationship in Malayalam

The origin of the fifth liquid in Malayalam can be traced back to the Proto-Dravidian consonant inventory (Fig. 1). Krishnamurti (2003: 152) classifies the original proto-Dravidian sound, denoted in his book as /ẓ/, as being a “retroflex approximant (frictionless continuant)”, patterning with a series of other retroflexes with various manners of articulation, mainly: /ṭ ṇ ḷ ẓ/. He also refers to /ẓ/ as being an 'apical' consonant which, together with /r/, was considered as one of the most marked apical segments due to not having a geminate counterpart. This sound has over time merged with /ɭ/, /ɳ/, /ɖ/, /r/, or /j/ in other Dravidian languages, but survives in all dialects of Malayalam and some dialects of Tamil (McDonough & Johnson, 1997; Narayanan et al, 1999). One of the earliest suggestions of the fifth liquid in Malayalam having rhotic affiliation is in Varma's *Keralapaniniyam* (1896 cited in Pillai, 1996: 33), where the liquids are classified into two groups, the 'r' group (/ɾ/,/r/,/ɻ/) and the 'l' group (/l/,/ɭ/). In descriptions of Modern Malayalam, however, researchers have disagreed on the fifth liquid's rhotic/lateral affiliation and the fricative symbol that is used for this sound's phonemic symbol (/ɻ/) reflects a degree of friction that has been reported in some impressionistic studies (Asher and Kumari, 1997; Kumari, 1972).

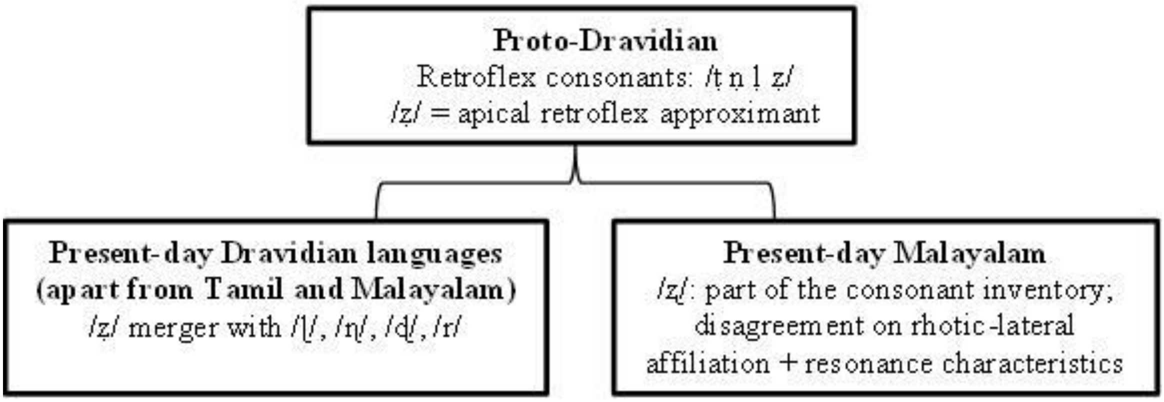

Figure 1: Historical origin of the fifth liquid

A potential contributor to the contested lateral/rhotic identity of the fifth liquid is its phonotactic patterning. On the one hand, the most noticeable difference between rhotics and laterals in Malayalam is that rhotics are the only consonants in the language that do *not* occur as geminates (Sadanandan 1999, Asher and Kumari, 1997). In this respect, the fifth liquid patterns with the rhotics. On the other hand, /ɻ/ and /ɭ/ also tend to alternate in certain morpho-syntactic contexts (Varma 1896, reported in Pillai, 1996) suggesting that the two can be used interchangeably (e.g. 1), although more work is required on stylistic and dialectal factors governing the occurrence of each.

(1) /ap:o:ɭ/ *then* → /ap:o:ɭa:ɳə/ or /ap:o:ʐa:ɳə/ *it was then that*

/vaɾumpo:ɭ/ *when (it) comes* → /vaɾumpo:ɭa:ɳə/ or /vaɾumpo:ʐa:ɳə/ *when (it) will come*

/karajumpoɭ/ *when (it) cries* → /karajumpo:ɭa:ɳə/ or /karajumpo:ʐa:ɳə/ *when (it) will cry*

Furthermore, while /ʐ/ co-occurs with three of the liquids in polysyllabic non-compound words (e.g. 2), it never co-occurs with /ɭ/ (Warrier Bhattathiry & Warrier, 2006), potentially due to an OCP effect prohibiting two identical consonants in the stem (McCarthy, 1986).

(2) /niʐal/ *shadow*; /kuʐal/ *flute;* /kaʐala/ *groin*; /kaʐuve:ri/ *donkey*; /kaʐumaɾam/*gallows*.

But the fact that /ʐ/ seems to occur with both rhotics and laterals in polysyllabic non-compound words is puzzling, as there is a general lack of co-occurrence of two laterals or two rhotics in the stem (Warrier et al, 2006). It could be that the OCP effect referred to above is a result of the /ʐ/ and /ɭ/ having a similar place of articulation, i.e. retroflexion, rather than a similar manner of articulation, given that neither occurs word-initially (apart from a few lexical items with initial /ɭ/ that are loan words). Furthermore, there is a general trend for liquids of opposing secondary acoustic resonance to co-occur in Malayalam (Punnoose, 2011; Warrier et al, 2006), i.e. only /ɾ-ɭ/, /ɭ-ɾ/ or /l-r/, /r-l/ combinations (e.g. 3), whereby one liquid is alveolar and has secondary palatalised or 'clear' resonance and the other is post-alveolar and has secondary pharyngealised or 'dark'[1] resonance; once again, here /ʐ/ co-occurs with both 'clear' and 'dark' liquids (e.g. 2 above), leading to ambiguous resonance characteristics.

[1] The terms 'clear' and 'dark' here are used to refer to the auditory impression of a secondary resonance that is driven by the presence or absence of a velo-pharyngeal constriction in the liquid and which manifests itself as an acoustic resonance in the F2 frequencies, which are typically high for clear liquids and low for dark ones.

(3) /kalavara/ *store-room*; /kaɭaɾi/ *training centre for Kerala's traditional form of martial art*; /ka:ral/ *staleness of food*; /kalar/ *to mix*; /poɾuɭ/ *essence*; /po:ral/ *tear*; /viɾaɭa/ *rare.*

While the lack of co-occurrence of /ɻ/ and /ɭ/ may suggest dark resonance for /ɻ/, the realisation of /ɻ/ as [j] has also been reported in the speech of illiterate people and in casual speech in certain dialects (Pillai, 1996). [j] realisation of /ɻ/ is also common in baby talk and in the speech of young children acquiring this sound, e.g. /maɻa/ as [maja], /paɻam/ as [pajam] etc. From a perceptual point of view, this might suggest that /ɻ/ is categorised (and consequently reproduced) as a clear/palatalised sound, which is at odds with its phonotactic patterning. The /ɻ/ symbol also suggests retroflexion, which in other retroflexes in the language involves sublaminal post-alveolar articulation, and is at odds with the articulation of a palatal glide. Note, however, that retroflexion might be implemented differently in stops and rhotics within and across languages (e.g. Espy-Wilson, Boyce, Jackson, Narayanan and Alwan 2000; Hamann, 2002; Zhou, Espy-Wilson, Boyce, Tiede, Holland and Choe, 2008). Retroflexion is a graded phenomenon with various subcomponents e.g. lowered tongue body, retraction of tongue-tip and/or root, tongue tip raising, tongue tip flexion, laminal or sub-laminal constriction; these can vary across speakers and vowel contexts, influencing the shape of the tongue and the actual degree of retroflexion, particularly the degree of tongue tip retraction and direction of movement (or lack thereof) and release (Cathcart, 2012).

The fifth liquid in Malayalam therefore has a mixed phonological profile which may be responsible for the debate around its identity. In terms of its contrastive behaviour and the lack of a geminate counterpart, /ɻ/ patterns most closely with the profile of a post-alveolar dark rhotic; however, other phonotactic, morphosyntactic, and dialectal patterns also suggest potential confusion with /ɭ/ or /j/, raising questions around the secondary resonance characteristics of this sound, and the rhotic-lateral divide in Malayalam.

3. Phonetic characteristics of /ʐ/

To the best of the present authors' knowledge there are no existing phonetic studies of the fifth liquid in Malayalam. There are two relatively recent studies on a comparable sound in Tamil which has undergone the same controversy in its description in the literature (McDonough & Johnson, 1997; Narayanan et al, 1999). These are reviewed here and their findings will be compared with our study on Malayalam.

McDonough & Johnson (1997) carried out a small scale study to investigate the articulatory and perceptual characteristics of the five Tamil liquids in [VCV] contexts, with a particular focus on the fifth liquid. The liquids were denoted phonemically as /r/ (for both tap and trill, which are thought to have lost their phonemic distinction), /l/, /ḷ/, and /z/ and phonetically as [ɾ], [ɽ], [l], [ɭ] and [ɻ] respectively. Using EPG and static palatography with one speaker, the study showed that the articulation of the fifth liquid in Tamil involves tongue contact on the hard palate, as is typical for retroflex sounds; but unlike /ɽ/ there was no evidence of forward motion during the consonant closure, and unlike /ɭ/ there was no lateral opening at the back of the pseudopalate in the EPG data. /ʐ/ was also found to be different from /ɽ/ and /ɭ/ in that the linguogram and EPG data showed a mid-sagittal gap between the tongue and the palate, suggesting a dip behind the main constriction. The authors therefore described this sound as being "an apical retroflex central approximant with static articulation, no laterality and only incidental frication" (McDonough & Johnson, 1997: 22). In the perception part of their experiment, speakers of Tamil dialects that do not have a fifth liquid confused this sound with the retroflex lateral. McDonough and Johnson (1997: 22) suggested that this could be due to the longer duration and retroflexion that is specific to the Tamil fifth liquid and /ɭ/.

In another study on Tamil liquids, Narayanan et al (1999) examined sustained productions of each of the liquids in a final /paC/ context as produced by the first author using static palatography, magnetic resonance imaging (MRI), and magnetometry (EMMA). Their results concurred with those of McDonough and Johnson regarding the fifth liquid being a retroflex post-alveolar approximant (for which they also use the [ɻ] symbol). They report the narrowest constriction as being in the palatal region, but the exact location was inconsistent; the fifth liquid was also found to have a larger back cavity than the other liquids in Tamil, which was partly due to a depressed tongue behind the retroflex constriction, creating a pitted posterior cavity. However, unlike McDonough & Johnson's findings, the fifth liquid and the retroflex lateral in this study exhibited a dynamic fast release involving a counter-clockwise movement, i.e. from back- to-front. Acoustically, the fifth liquid was also found to be similar to /ɭ/, both of which were characterised by a relatively higher F2 than for the other liquids due to the palatal constriction, and a low F3 due to the larger front cavity and retroflexion, bringing F2 and F3 together. However, unlike /ɭ/, the spectra of /ɻ/ had a higher F4 and exhibited no zeros in the high frequency region (2.5-5kHz).

The two studies above suggest articulatory and acoustic affinity between /ʐ/ and /ɭ/, with both sounds in Tamil having a raised and retracted anterior tongue body articulation, retroflexion and, in Narayanan et al's (1999) study, counter-clockwise release. According to Narayanan et al, the higher variability in constriction location for the fifth liquid, along with the more complex tongue shape requirement due to pitted tongue cavity, may lead some speakers to neutralise the constriction difference between the two sounds, leading to a potential merger. These results differ from those reported in Scobbie et al (2013) for Malayalam, who carried out a preliminary ultrasound study of one speaker from Central Travancore dialect of Malayalam producing all five liquids in various intervocalic contexts. As was found for the Tamil speakers investigated by McDonough and Johnson (1997) and Narayanan et al (1999), the Malayalam speaker produced the fifth liquid as a post-alveolar approximant with a closing phase that is typical of slight retroflexion (tongue blade retraction and raising in a curve). However, the tongue root seemed to play an important role in grouping the five liquids into two, with /ɾ/, /l/ and /ɻ/ being produced with advanced tongue root and a raised tongue body while /r/ and /ɭ/ were produced with a retracted tongue root and a lowered tongue body position (Fig. 2). The retroflex lateral and the fifth liquid in Malayalam are therefore expected to show different secondary acoustic resonance profiles (dark in the case of the former and clear in the case of the latter), potentially making them less perceptually similar to each other than their Tamil counterparts. These results, together with parallel controversy around the phonetic and phonological patterning of /ɻ/ in Malayalam, provide the impetus for this study.

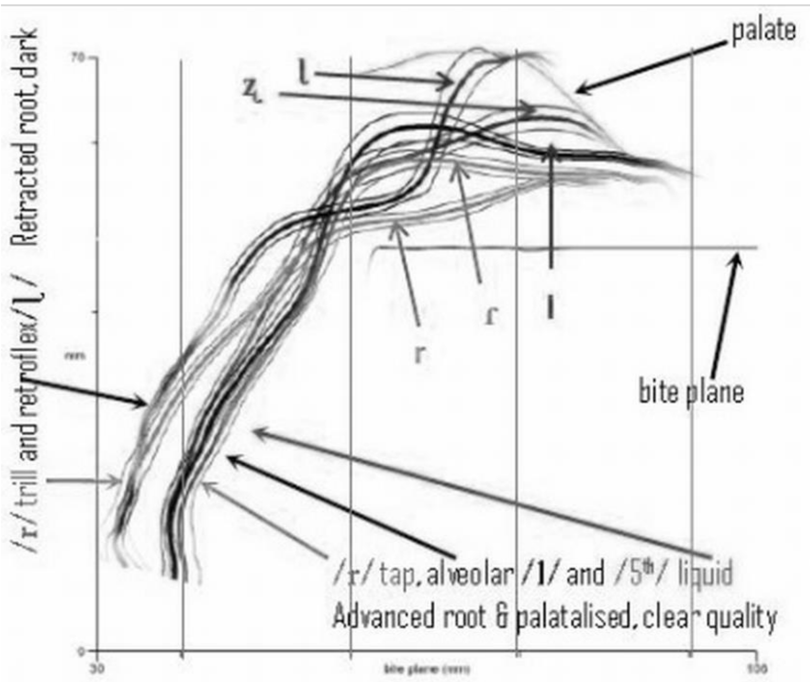

Figure 2: Ultrasound tongue traces of the 5 liquids produced by one Malayali speaker from Scobbie et al (2013). Thick lines are mean tongue shapes, flanked by ±1s.d.

4. Experimental Study

4.1 Research Questions

The controversy surrounding the fifth liquid in Malayalam and preliminary findings from studies on its Tamil counterpart lead to the following questions:

1) What are the auditory and acoustic properties of the fifth liquid in Malayalam and how do they compare with the properties of the other liquids in the language?

Regarding the acoustic properties we predict F2 for /ɻ/ to pattern with that of the palatalised/advanced tongue root liquids in the language (/l/ and /ɾ/) and its F3 and F4 to pattern with /ɭ/ and /r/ due to its retroflexion and post-alveolar articulation. We expect F1 to reflect a slightly raised tongue body position that is halfway between the high tongue body position for /l/ and the low position for /r/. We also expect the formants of the surrounding vowels to exhibit the influence of the predicted formant differences in the liquids.

2) How does the mixed acoustic profile for /ɻ/ help distinguish this sound from the other liquids in the language and how do its phonetic characteristics align with its phonotactic behaviour?

4.2 Method

4.2.1 Participants

Eight male speakers were recorded in Central Kerala, India. They were aged between 45 and 65 years, belonged to rural middle-class families, and were born and settled in the Kottayam district of Kerala. The speakers were all educated in institutions where Malayalam is the medium of instruction (at least throughout the school years) to ensure minimum influence from English. The speakers had a minimum of class 12 qualification, which is equivalent to A-levels/High School in the UK/US system of education, and some had attended or completed their Bachelor's degree. Adults living in rural neighbourhoods were chosen to reduce degree of English influence on their Malayalam and because of their low use of English in day-to-day life. Kottayam was selected because the first author is a native of the district and is most familiar with this dialect of Malayalam. Secondly, due to the geographically central position of Kottayam, the variety of Malayalam spoken here is relatively free of influences from languages spoken in neighbouring states, unlike Northern and Southern dialects.

4.2.2 Materials and procedure

A word-list was compiled containing six words for each of the five Malayalam liquids in word-medial position preceded by one of three vowels (/a/; /i/; or /u/) and followed by one of two (/a/ or /i/). 32 fillers were added to the target tokens which were then randomised and elicited as part of the carrier sentence /avaɾoːdə ______ enːə parajuka/ *Say ______ to them* (Appendix A). The task was repeated twice, yielding a total of 480 tokens across speakers. However, some tokens were later discarded due to noise in the recording or mispronunciations by the speakers, yielding a final count of 396 analysable tokens.
The participants were recorded in their homes using an R1 Edirol digital recorder and a SONY MS907 microphone, placed 15cm away from the corner of their mouth. The participants were asked to maintain this distance from the microphone, but some moved closer to the mike during some productions, resulting in slight clipping. Clipped tokens were still included in the analyses in order not to lose too much of the data. The recordings were carried out using a mono channel at a sampling frequency of 22,050Hz and a 16 bit quantization per sample. The target utterances were presented on a laptop via PowerPoint slides in order for the experimenter to control the speed of data presentation. The participants were informed that the fieldworker was interested in the Malayalam language but were not aware of any more specific details regarding the study.

4.2.3 Analysis

Auditory analysis was carried out by the first author and narrow phonetic transcriptions were made of the medial liquid with special attention to the surrounding vowels in each of the target tokens. 178 tokens, to include all speakers and all five liquids, were re-transcribed by the second author in order to test for inter-transcriber reliability. Results are reported in the next section.

In terms of acoustic analysis, the data were labelled in Praat (Boersma and Weenink, 2009) and boundaries were added to mark the beginning and end of each of the 5 liquids and their surrounding vowels. Boundaries were determined by inspecting spectrograms for relative decrease in amplitude in the liquids with respect to the neighbouring vowels. Onset and offset of periodicity in the waveform and corresponding glottal pulses in the spectrogram were used as additional criteria to mark the boundaries of vowels while formant transitions were used as additional criteria to mark the beginning and end of laterals. Canonical trills and taps were more clearly demarcated due to gaps in acoustic energy and striations indicating contacts; but many realisations for both categories were ‘weak’ taps (Punnoose, 2011), having more approximant-like structures and requiring boundaries to be identified by relative changes in amplitude compared to surrounding sounds. Formant frequencies were extracted using the following settings: A 25ms Gaussian window with a 5ms step was applied on the waveform. A maximum of 5 formants were requested in the formant analysis using the default Burg method and the highest ceiling was 5000Hz.

F1 and F2 formant frequencies (in Hz) were measured for each of the target consonants and their surrounding vowels at onset, mid-point and offset portions. For the same subset of the liquids used in the reliability check (178 tokens), F3 and F4 were also measured[2]. These measures were chosen in order to compare the spectral properties of /ɻ/ with those of the other Malayalam liquids and to assess their varying influence on surrounding vowels. Acoustic profiling of the formant patterns of /ɻ/ was also applied, checking for continuous formant structure as a window into the manner of articulation of /ɻ/ as well as its clear/dark

[2] This subset was more tightly controlled for the number of vowel tokens from a given vowel category which preceded and followed the liquid. This was done because F4 was often hard to measure or absent altogether in the liquid, and the authors needed to make sure that the measures taken for this formant was in the most tightly controlled data to rule out other variables.

resonance characteristics. Measurements were taken at specific locations around the onset, midpoint and offset of each sound depending on its duration, set in an automated Praat script[3].

Formant measurements were obtained from the estimated frame positions at the onset, midpoint and offset of consonants and surrounding vowels (following Al-Tamimi, 2007). The average duration of a complete cycle was estimated for each speaker from voiced portions only, which was in the range of 8-10ms for male speakers. Then from the actual position of the onset, midpoint and offset, a portion with a length corresponding to the average duration was left/right aligned to the onset/offset and centred at the midpoint. If the duration of a segment was less than 30ms, then half the length of the average duration was used. Then the time location of the maximum intensity in this portion was used as the measurement position at the onset, midpoint and offset. All measurements are obtained at the estimated positions. Measurements obtained from the script were then checked manually through inspection of spectrograms and FFT spectra in order to correct for potential errors. Approximately, 10% of the data were corrected and measured manually, especially F3 and F4 of the subset[4].

Our statistical design looked at the effect of multiple formant frequencies in distinguishing the liquid categories; Multivariate General Linear Model (MANOVA test) was used. Two separate MANOVAs were used. The first was a 1-way MANOVA that looked at the effect of the combination of F1, F2, F3 and F4 obtained at the temporal midpoint of the liquids in separating between the five consonant categories, with the Manner of articulation of the target consonant as an independent variable and the first 4 formant frequencies as dependent

[3] The scripts used in the present study were adapted by the third author from scripts used in his research (Al-Tamimi and Khattab, 2011).

[4] Where an additional formant was visible in the consonant or vowel transition due to additional resonance cavities in liquids, this was considered as F3 as is justified in Stevens (1998: 539).

variables.[5] The second statistical test was a 2-way MANOVA that looked at the combination of F1 and F2 formant frequencies across all vowels, with the Manner of articulation of the target consonant and the preceding and following vowel types as independent variables and F1 and F2 formant frequencies as dependent variables. For each MANOVA, Wilks's Lambda (λ) test statistic is reported; Wilks's Lambda is highly significant when its value is close to 0. Each MANOVA was followed by individual 2-way ANOVA tests to account for the effect of each dependent variable, e.g. F1 formant frequencies alone, to separate between liquid categories. These were then followed by Bonferroni pairwise comparison tests in order to evaluate the low level differences between each liquid category in each ANOVA test. In order to control for Type I errors, the probability level of each MANOVA and follow up ANOVA was level was lowered to $p<0.01$ in order to report on true differences (Fields, 2009). Finally, the magnitude of differences among all groups is reported with two effect size measures; the unbiased omega-squared (ω^2) effect size measure for the omnibus MANOVA and ANOVA tests and Cohen's *d* on the pairwise comparisons. Cohen's benchmarks are used to evaluate the size of the effect. Omega-squared measures are interpreted as follows: 0.01-small effect, 0.06- medium effect, 0.15-large effect. Cohen's *d* values are interpreted as follows: 0.2-small effect, 0.5-medium, 0.8-large effect (Sheskin, 2003: 284).

5. Results

5.1 General auditory and acoustic properties of the fifth liquid

All tokens of the fifth liquid produced by all speakers had the auditory impression of a post-alveolar central approximant. Slight retroflexion was heard, though further articulatory work is required to pinpoint the part of the tongue involved in the primary constriction and the

[5] Speaker was added as a fixed factor in a separate MANOVA, and all the interactions were non-significant, which suggests no direct effect of speaker on the observed differences. This model, based on fixed factors, only was deemed more appropriate as in a separate analysis using both random slopes and intercepts (i.e. a mixed effects model), the estimates of the residual contributed more to the estimates of the covariance parameters than any other random factor (Field, 2009, p.737). Subsequently, a second MANOVA was applied with Speaker being excluded from the model.

movement back to rest position. The approximant nature of this sound gives a different impression of retroflexion from the other retroflex consonants in Malayalam in which sublaminal contact with the palatal region provides stronger impression of a retroflexed tongue. /ɻ/ also had a palatalised resonance, and the vowels surrounding it sounded fronted and raised relative to the same vowels in the /ɭ/ and /r/ environment. Our intuition is that /ɻ/ is similar in its realisation to what is normally described as a bunched /r/ in American English (e.g. Zhou et al, 2008), but that it lacks the pharyngeal constriction that is typical of /r/ in many varieties English. Therefore the narrow phonetic transcription for the fifth liquid was noted as [ɹ̠ʲ].

Results from the rhotics are described in detail elsewhere (Punnoose 2011) but are briefly summarised here: the target tap was mostly realised as a clear (palatalised) alveolar tap with fronted and raised surrounding vowels while the target trill varied between trill and tap realisations but the binding characteristic for these realisations was a post-alveolar articulation with dark resonance in the target trill and retracted/centralised surrounding vowels. For the purposes of this paper, the differences in realisation of trills were irrelevant and therefore ‘trill’ in this paper refers to target trill.

With regards to inter-transcriber comparison, both transcribers heard /ɻ/ tokens as central post-alveolar approximants with palatalised resonance (agreement was 98%, with only two out of the 40 /ɻ/ tokens being heard as lateral by the second author but central approximant by the first). Agreement on the resonance characteristic of the remaining liquid categories was high (94%), but two interesting differences emerged in the categorisation of the manner of articulation, where agreement was 72%: a) 6 out of 40 target trills were transcribed as trills by the first transcriber but taps by the second, even though both transcribers labelled them as having a dark resonance. This is not surprising considering the fact that trills in Malayalam vary in their realisation considerably more than target taps; b) the area of largest disagreement between the two transcribers was in the transcription of the retroflex lateral tokens, which were categorically transcribed as retroflex and dark by the first transcriber while the second heard 45% of them as alveolar while still labelling them as dark (i.e. dark [ɫ]'s). These two findings suggest that the resonance characteristics of the retroflex lateral and the trill may be more salient than their place/manner of articulation, which is an issue that will be revisited in the discussion.

Spectrographic characteristics of the fifth liquid exhibited vowel-like continuous formant structure in all of the tokens (Figs. 3 and 4), providing further evidence for its approximant nature. Its formant measures showed mixed patterns in terms of their similarity to the alveolar liquids (tap and alveolar lateral) on the one hand, and to the post-alveolar ones (trill and retroflex lateral) on the other (Fig. 5). This resulted in a distinct profile for /ʐ/: a high F2 like that of the alveolar lateral and tap, suggesting clear resonance, but a relatively low F3 and F4 due to its retracted post-alveolar articulation. Due to these mixed patterns, /ʐ/ showed more approximation of F2, F3, and F4 than all the other liquids. The next section looks at the formant results in more detail and presents the statistical analyses.

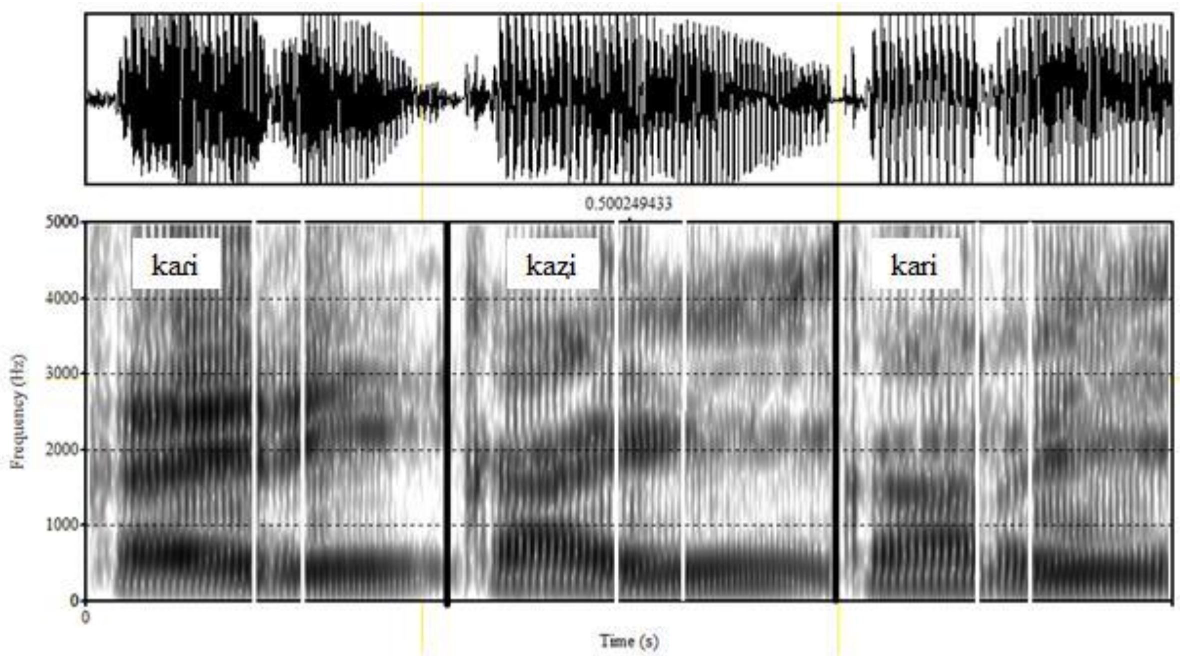

Figure 3: Spectrographic examples of the rhotics and the fifth liquid in Malayalam. White lines demarcate the liquid in each case.

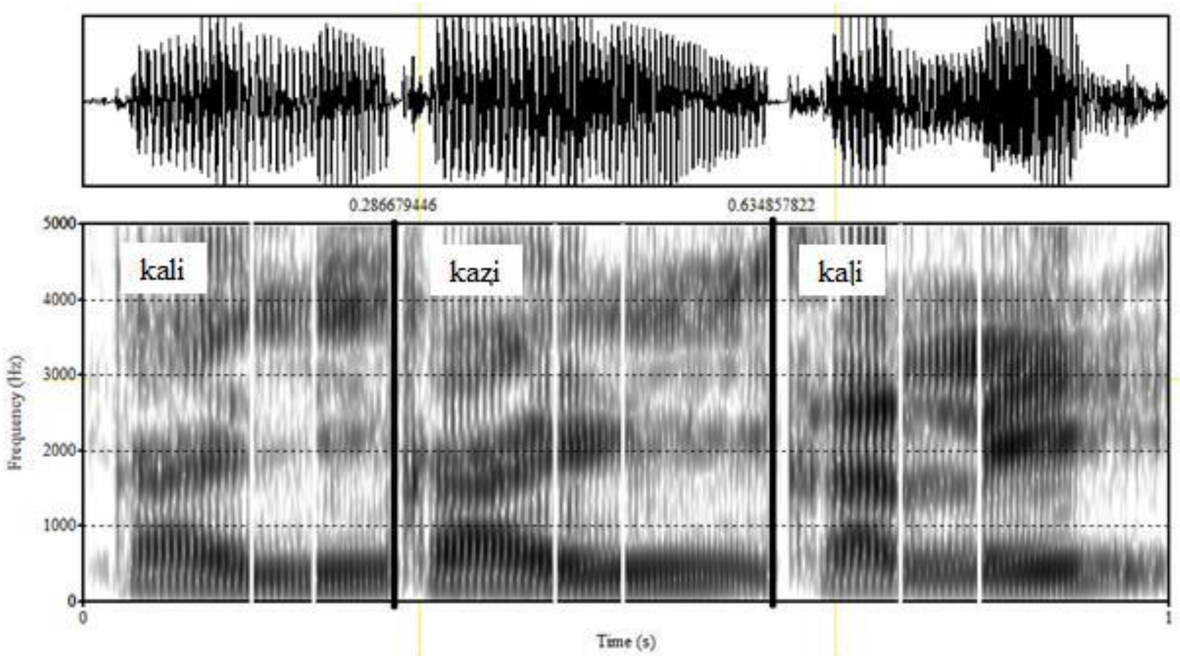

Figure 4: Spectrographic examples of the laterals and the fifth liquid in Malayalam. White lines demarcate the liquid in each case.

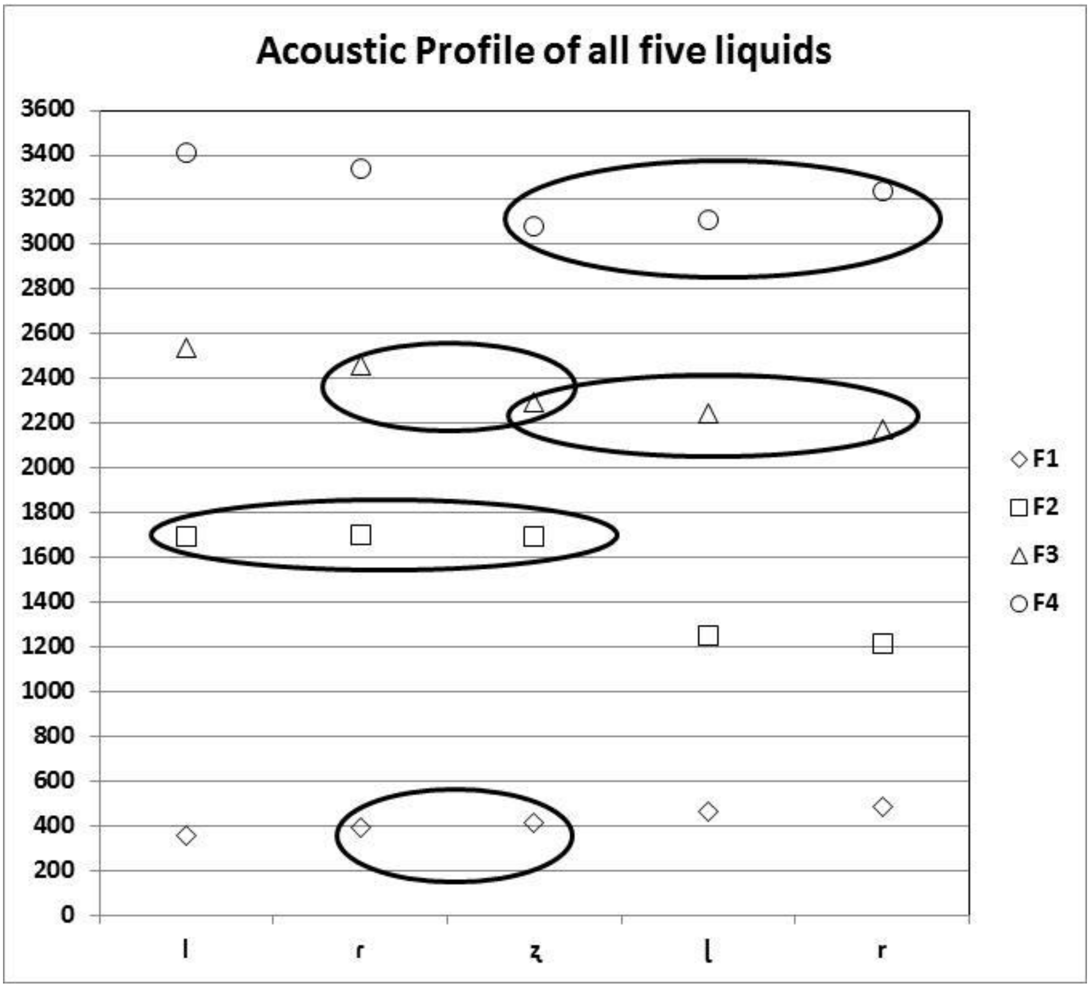

Figure 5: Average F1, F2, F3 and F4 mid-point values of the five liquids in Malayalam. Ellipses group formant results that show no significant difference between /ʐ/ and another liquid.

5.2 Formant patterns of the three liquid categories

Results of the 1-way MANOVA on the subset of comparable environments showed that when the two rhotics, the two laterals and the fifth liquid were compared, manner of articulation of the target consonant had a significant main effect on distinguishing the five consonants based on the combination of F1, F2, F3 and F4 at the temporal midpoint of the consonant (λ=0.282, F(16,520)=16.7, p<0.001, ω^2 =0.689(Large)). When looking at the effects of each formant frequency in distinguishing the five consonants, results of the follow up ANOVAs showed that all formant frequencies were significantly different according to the manner of articulation of the target consonant (on F1: F(4,173)=21.7, p<0.001, ω^2 =0.29(Large); on F2: F(4,173)=56.1, p<0.001, ω^2 =0.49(Large); on F3: F(4,173)=11.3, p<0.001, ω^2 =0.18(Large) and on F4: $F(4,173)=7.8$, p<0.001, ω^2 =0.13(Moderate to Large)). These results suggest that the five consonant categories can be distinguished based on all formant frequencies in combination or separately with a relatively large effect size.

Our aim was to evaluate how close the fifth liquid is to any of the four other categories; this was looked at using the Bonferroni pairwise comparison (Table 2). Starting with the comparison between the formant patterns of /ʐ/ and taps, the fifth liquid tokens were found to have significantly lower F4 values (*p*<0.005, *d*=0.84; Large) and a tendency to show lower F3 values but with non-significant differences (*p*=0.093, *d*=0.69; Moderate) due to the large Standard Deviation. There were no significant differences between the F1 or F2 patterns of /ʐ/ and taps (Table 2 and Fig. 5). Moving on to the comparison between the fifth liquid and the trill, pairwise comparison results showed the fifth liquid to have significantly lower F1 frequencies (*p*<0.001, *d*=0.97; Large) and significantly higher F2 frequencies (*p*<0.001, *d*=2.89; Large) than the trill category. No other significant differences were observed with regards to F3 or F4 (Table 2 and Fig. 5).

Table 2: Means and SD of F1, F2, F3, F4 at the temporal midpoint of the fifth liquid compared with the other 4 liquids. Comparisons are based on Bonferroni pairwise comparisons.

	/ʐ/	**/ɾ/**		**/r/**		**/l/**		**/ɭ/**	
	Mean (SD)	**Mean (SD)**	**comp. with ʐ**	**Mean (SD)**	**comp. with ʐ**	**Mean (SD)**	**comp. with ʐ**	**Mean (SD)**	**comp. with ʐ**
F1	413 (63)	394 (52)	ns	485 (88)	higher	360 (33)	lower	465 (74)	higher
F2	1698 (181)	1700 (179)	ns	1218 (148)	lower	1695 (243)	ns	1251 (238)	lower
F3	2295 (258)	2462 (228)	ns	2173 (257)	ns	2542 (260)	higher	2241 (338)	ns
F4	3082 (368)	3338 (235)	higher	3239 (294)	ns	3410 (260)	higher	3107 (345)	ns

Moving on to the comparison between the fifth liquid and the laterals, the fifth liquid tokens were found to have significantly higher F1 frequencies (*p*<0.006, *d*=1.07; Large) and lower F3 and F4 frequencies (for F3: *p*<0.001, *d*=0.95; Large; for F4: *p*<0.001, *d*=1.03; Large) than the alveolar lateral, but no significant differences were observed with F2 frequencies (see

Table 2 and Fig. 5). On the other hand, the fifth liquid had significantly lower F1 frequencies (p<0.007, d=0.76; Moderate to Large) and significantly higher F2 frequencies (p<0.001, d=2.14; Large) than the retroflex lateral, with a similar range of F3, and F4 frequencies (see Table 2 and Fig. 5).

Based on comparisons between the fifth liquid and all other four liquids, /ʐ/ seems to be most similar to the tap in its formant frequency pattern. Although its F3 and F4 seem to pattern more closely with those of the retroflex lateral and the trill than the alveolar tap and lateral, its F2 frequency places it firmly in the latter group of sounds and as will be seen in the results for surrounding vowels below, makes a significant contribution to its secondary resonance patterns.

5.3 Surrounding vowels

This section looks at effects of liquid category on preceding and following vowels respectively. Several 2-way MANOVAs[6] with follow up ANOVAs were applied on the data, on the four positions: midpoint and offset of the preceding vowel and onset and midpoint of the following vowel. As the aim of this study is to evaluate the effects of the fifth liquid on the surrounding vowels and to compare these effects to the four other consonant categories, i.e. tap, trill, alveolar lateral and retroflex lateral, vowel types were used as control. We will report on the full 2-way interaction in both the MANOVA and ANOVA, and will only report on the differences observed (or otherwise) between the fifth liquid and the four other consonant categories with respect to effects on surrounding vowels.

5.3.1 Preceding vowels

Starting with the midpoint of the preceding vowel, results of the 2-way MANOVA showed a significant main effect of the liquid category on the combination of F1 and F2; vowel type

[6] We ran separate 2-way MANOVAs on the vowels from the subset data, and the results were in the same direction. Thus we extended our analyses to the full set of vowels to be able to generalise our findings.

was also significant, however the 2-way interaction between liquid category and vowel type showed a mixed picture, i.e., the same liquid category had different effects on different vowel types (Manner: λ=0.603, $F(8,760)=27.3$, $p<0.001$, $\omega^2=0.364$(Large); Vowel: λ=0.044, $F(4,760)=719.1$, $p<0.001$, $\omega^2=0.956$(Large); Manner*Vowel: λ=0.877, $F(16,760)=3.2$, $p<0.001$, $\omega^2=0.085$(Small to Moderate)). These results suggest that overall, F1*F2 vowel spaces of the five consonant categories are significantly different. In order to evaluate the degree of difference in F1 and F2 frequencies separately, follow up ANOVAs were conducted and their results are summarised in Table 3. These results suggest that at both the midpoint and offset, manner of articulation of the consonants had a significant impact on both F1 and F2 mid-point frequencies of the preceding vowels, with small to large effects. Results of the 2-way interaction on F2 at the midpoint of the preceding vowel suggest that there are small variations linked to the identity of each vowel. This will be detailed in the pairwise comparison results.

Table 3: Results of the 2-way ANOVA at the midpoint and offset of the preceding vowel with degrees of freedom of each factor (*df*1) and the error (*df*2), *F*, *p* and effect size (S = Small, M = Moderate and L = large).

Position	Formant	Factor	*df*1, *df*2	*F*-value	*p*-value	ω^2
Midpoint	F1	Manner	4, 381	7.9	<0.001	0.01(S)
		Vowel	2, 381	1039.4	<0.001	0.69(L)
		Manner*Vowel	8, 381	1.8	*ns*	0
	F2	Manner	4, 381	46.6	<0.001	0.11(M)
		Vowel	2, 381	481.4	<0.001	0.45(L)
		Manner*Vowel	8, 381	4.1	<0.001	0.01(S)
Offset	F1	Manner	4, 381	28.1	<0.001	0.13(ML)
		Vowel	2, 381	154.9	<0.001	0.32(L)
		Manner*Vowel	8, 381	0.9	*ns*	0
	F2	Manner	4, 381	105.7	<0.001	0.34(L)
		Vowel	2, 381	131.8	<0.001	0.03(S)
		Manner*Vowel	8, 381	0.6	*ns*	0

Our aim is to compare how the fifth liquid behaves in comparison with the four other consonants with respect to their preceding vowels (Figs. 6 and 8). At mid-point, vowels preceding the fifth liquid showed significantly lower F1 value than the trill (500Hz vs. 538Hz, $p<0.001$, $d=0.26$(Small)), suggesting a more closed/raised articulation for the fifth liquid. However, a closer look at the individual vowels showed that the effect is driven by /i/, which shows the largest difference between the fifth liquid and the trill environment. No significant differences were found between F1 for the vowels preceding the fifth liquid and that preceding the tap, the alveolar lateral or the retroflex lateral. Moving on to F2 frequencies, pairwise comparisons showed that vowels preceding the fifth liquid displayed lower F2 frequencies than the tap (1406 Hz vs. 1714Hz, $p<0.001$, $d=0.85$(Large)) and higher F2 frequencies than the retroflex lateral (1406 Hz vs. 1243, $p<0.001$, $d=0.51$(Moderate)). Results linked to individual vowels suggest that the observed effect between the fifth liquid and the tap are only visible with respect to the /a/ category, while those between the fifth liquid and the retroflex lateral are visible in the /i/ and /a/ categories. Although statistical difference was not reached when looking at the comparison between the fifth liquid and the trill, the /i/ vowel did show significantly higher F2 frequencies when preceding the fifth liquid than the trill. Overall, these results suggest a more anterior articulation for the fifth liquid compared to the retroflex lateral and the trill (only /i/), but a more posterior articulation compared to the tap.

Moving on to the offset of the preceding vowel (Figs. 7 and 9), results of the 2-way MANOVA showed that the manner of articulation of the consonant and vowel type both had significant main effects on the combination of formant frequencies, with the 2-way interaction showing no significant differences (Manner: $\lambda=0.410$, $F(8,760)=53.3$, $p<0.001$, $\omega^2=0.581$(Large); Vowel: $\lambda=0.327$, $F(4,760)=142.4$, $p<0.001$, $\omega^2=0.669$(Large); Manner*Vowel: $\lambda=0.969$, $F(16,760)=0.8$, $p=0.7$(*ns*), $\omega^2=0$). These results suggest again that the observed differences in the F1*F2 vowel space are in the same direction across vowels. Results of the individual follow-up ANOVAs on F1 and F2 at the offset of the vowel are summarised in Table 3 (offset). These results suggest that manner of articulation of consonants had a significant impact on both F1 and F2 offset values of preceding vowels with moderate to large effect sizes. No significant differences were obtained for the 2-way interactions.

Looking at the offset results in more detail, pairwise comparison results suggest that vowels preceding the fifth liquid showed significantly lower F1 frequencies than both those surrounding the trill (430Hz vs. 512Hz, $p<0.001$, $d=0.94$(Large)) and the retroflex lateral (430Hz vs. 476Hz, $p<0.001$, $d=0.49$(Moderate)), while no differences were observed with those surrounding the tap or the alveolar lateral. These results show the same pattern as that obtained at the midpoint, which suggest a more close/raised articulation of vowels preceding the fifth liquid. Results of F2 patterns showed that vowels preceding the fifth liquid have lower F2 frequencies than the tap (1650Hz vs. 1837Hz, $p<0.001$, $d=0.70$(Moderate to Large)) and higher F2 frequencies than the trill (1650Hz vs. 1324Hz, $p<0.001$, $d=1.29$(Large)) and the retroflex lateral (1650Hz vs. 1302Hz, $p<0.001$, $d=1.38$(Large)). These patterns were observed with respect to all vowel categories. Overall, the patterns observed here are the same as those observed at the midpoint, showing a more posterior articulation than the tap but a more anterior articulation than the trill and the retroflex lateral. Results at offset also show a more pronounced distinction between the formant patterns for vowels preceding taps and alveolar laterals compared with trills and retroflex laterals.

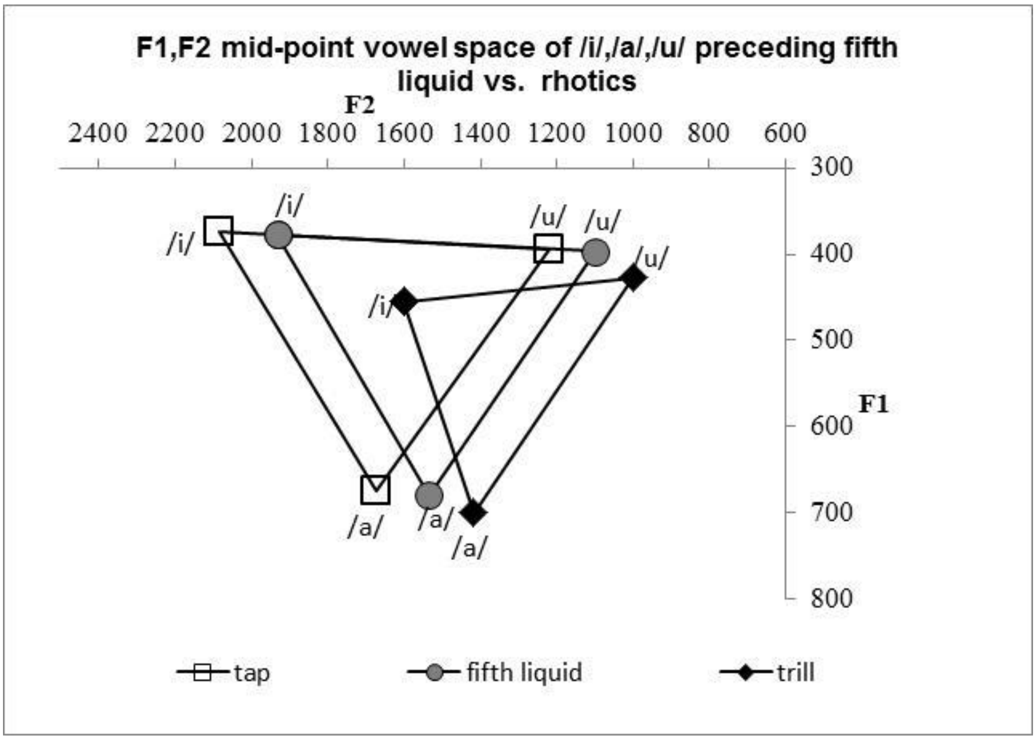

Figure 6: F1-F2 mid-point vowel space of /i/, /a/, /u/ preceding the fifth liquid and the rhotics.

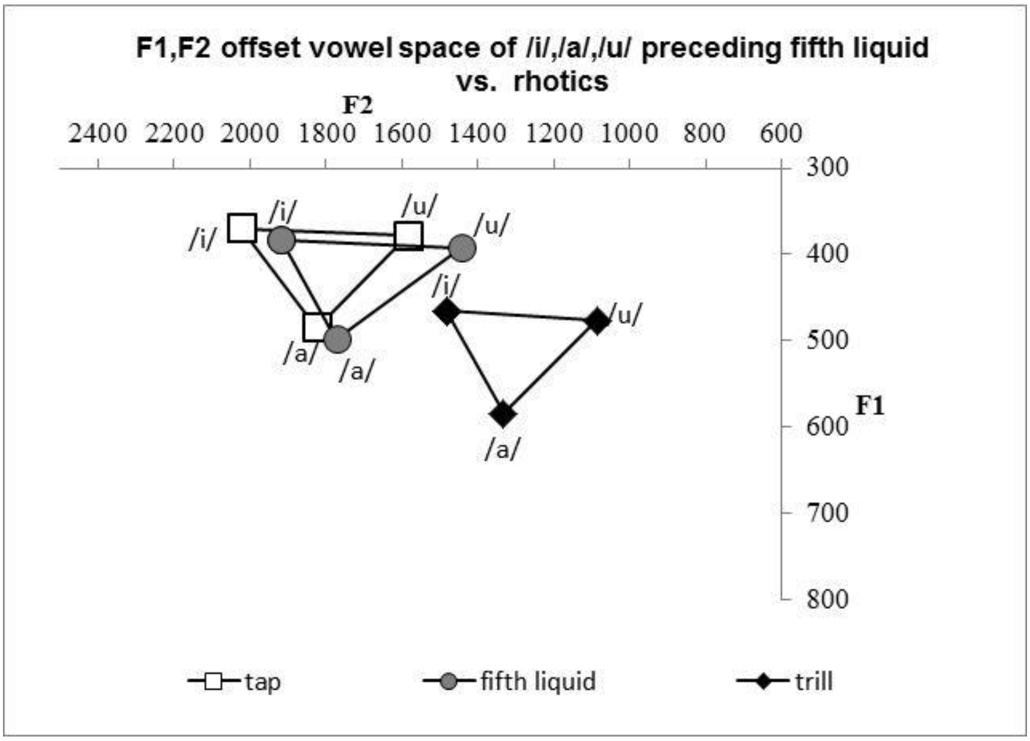

Figure 7: F1-F2 offset vowel space of /i/, /a/, /u/ preceding the fifth liquid and the rhotics.

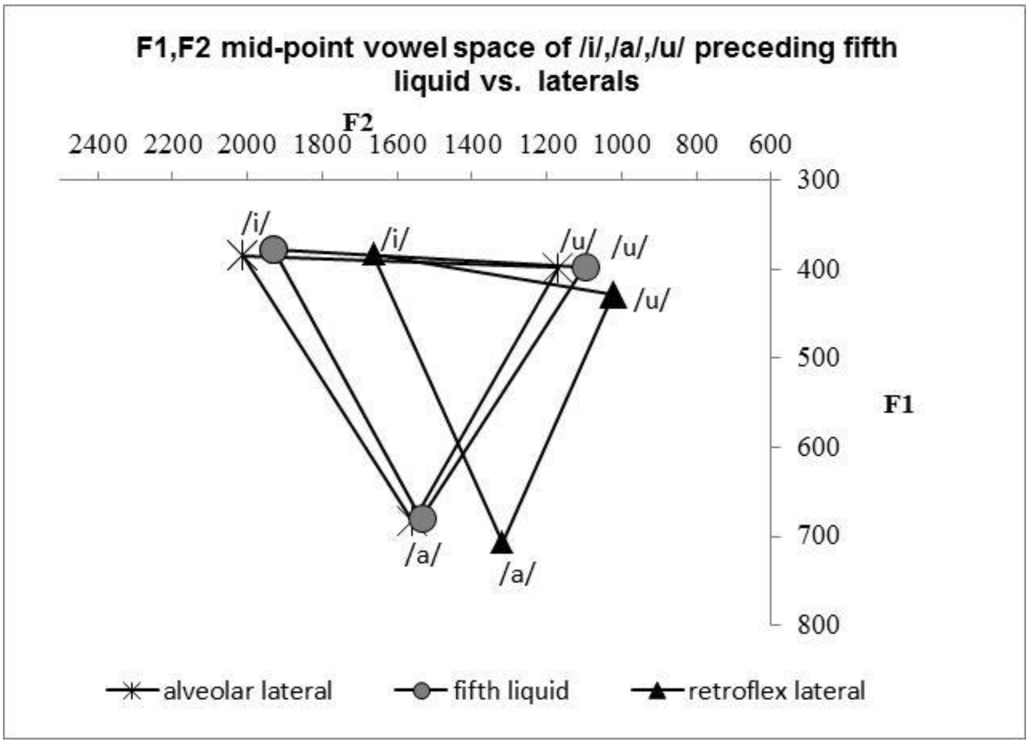

Figure 8: F1-F2 mid-point vowel space of /i/, /a/, /u/ preceding the fifth liquid and the laterals

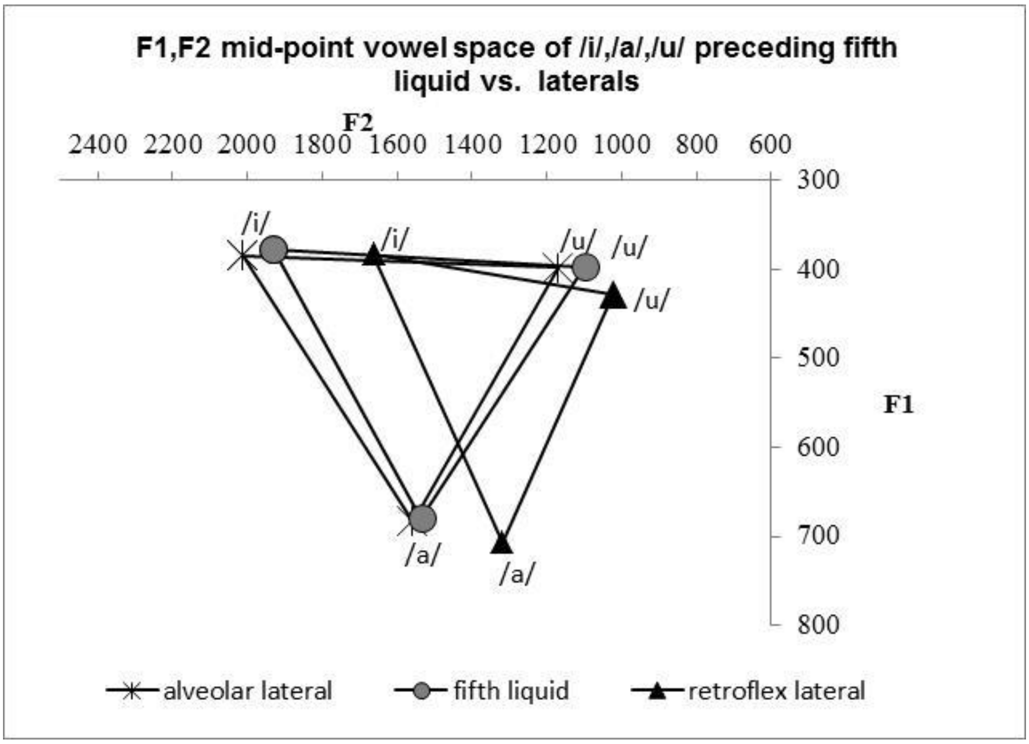

Figure 9: F1-F2 offset vowel space of /i/,/a/,/u/ preceding the fifth liquid and the laterals.

These results suggest that vowels preceding the fifth liquid were more advanced and raised than those preceding the trill and retroflex lateral but more backed than those preceding the tap, whereas the vowels preceding the fifth liquid were not significantly different in quality from their counterparts preceding the alveolar lateral (see Figs. 6-9). These extrinsic differences in vowel quality appear to be an effect of the resonance characteristics of the adjacent liquid consonant: more advanced and raised when preceding the *clear* fifth liquid, taps and alveolar laterals *versus* more retracted and open when preceding the *dark* trills and retroflex laterals.

5.3.2 Following vowels

Results obtained at both the onset and midpoint of the vowels following the five liquids show the same patterns of variations as the vowels preceding the five liquids (Figs. 10-13). Starting with the results of the 2-way MANOVA at the onset of the following vowel, statistical results suggest that both the manner of articulation of consonants and the vowel type have a significant main effect on the combination of F1 and F2 frequencies (Table 4). The 2-way interaction is also significant if considered at the 0.01 level (Manner: λ=0.452, $F(8,766)=46.7$, $p<0.001$, $\omega^2=0.538$(Large); Vowel: λ=0.324, $F(4, 766)=144.9$, $p<0.001$, $\omega^2=0.672$(Large); Manner*Vowel: λ=0.937, $F(10, 766)=2.5$, $p<0.01$, $\omega^2=0.038$(Small)). The overall vowel spaces in the five consonant categories seem to be different, however the same patterns as the preceding vowels were observed due to the non-highly significant results of the 2-way interaction.

Results of the 2-way follow-up ANOVA are summarised in Table 4 and show that the manner of articulation of the consonants had a significant impact on both F1 and F2 with moderate to large effect sizes. The 2-way interaction was only significant for F1, but with a small effect size.

Table 4: Results of the 2-way ANOVA at the onset and midpoint of the following vowel with degrees of freedom of each factor (*df*1) and the error (*df*2), *F*, *p* and effect size (S = Small, M = Moderate and L = large).

Position	Formant	Factor	*df*1, *df*2	*F*-value	*p*-value	ω^2
Onset	F1	Manner	4, 384	40.4	<0.001	0.15(ML)
		Vowel	2, 384	229.9	<0.001	0.36(L)
		Manner*Vowel	5, 384	4.3	<0.002	0.01(S)

	F2	Manner	4, 384	67.6	<0.001	0.26(L)
		Vowel	2, 384	117.5	<0.001	0.22(L)
		Manner*Vowel	5, 384	0.7	*ns*	0
Midpoint	F1	Manner	4, 384	6.1	<0.001	0.01(S)
		Vowel	2, 384	509.2	<0.001	0.52(L)
		Manner*Vowel	5, 384	0.7	*ns*	0
	F2	Manner	4, 384	14.9	<0.001	0.07(M)
		Vowel	2, 384	159.1	<0.001	0.34(L)
		Manner*Vowel	5, 384	2.6	<0.05	0

Results of the pairwise comparison suggest that vowels following the fifth liquid behave differently from those following both the trill and the retroflex lateral with regards to both F1 and F2 frequencies (Figs. 10-13). Vowels following the fifth liquid had significantly lower F1 frequencies than both the trill (435Hz vs. 488Hz, *p*<0.001, *d*=0.72(Moderate to Large)) and the retroflex lateral (435Hz vs. 512Hz, *p*<0.001, *d*=0.91(Large)). These results again suggest that the vowels following the fifth liquid display a more close/raised articulation. On the F2 axis, pairwise comparison suggests that vowels following the fifth liquid display higher F2 frequencies than following trills (1770Hz vs. 1405Hz, *p*<0.001, *d*=1.54(Large)) and retroflex laterals (1771Hz vs. 1499Hz, *p*<0.001, *d*=1.05(Large)). These results suggest that vowels following the fifth liquid show a more forward articulation at the onset than following trills or retroflex laterals.

Moving on to the midpoint of the following vowel (Figs. 12 and 13), results of the 2-way MANOVA showed that both the manner of articulation of the consonant and vowel type had significant main effects on the combination of F1 and F2, with the 2-way interaction showing no significant differences (Manner: λ=0.844, *F*(8,766)=8.5, *p*<0.001, ω^2 =0.139(Large); Vowel: λ=0.202, *F*(4, 766)=234.5, *p*<0.001, ω^2 =0.795(Large); Manner*Vowel: λ=0.956, *F*(10, 766)=1.7, *p*=0.1(*ns*), ω^2 =0). These results suggest that the F1*F2 vowel space varies as a function of the consonant categories, and the patterns observed are the same across vowels (based on the non-significant 2-way interaction). Results of the follow-up 2-way ANOVAs are summarised in Table 4 (midpoint) and again suggest that manner of articulation had a significant impact on both F1 and F2 with variable effect sizes. No significant differences were observed for the 2-way interaction.

Results of the pairwise comparison showed that vowels following the fifth liquid have significantly higher F1 frequencies than following taps at the midpoint of the vowel (537Hz vs. 490Hz, $p<0.002$, $d=0.35$(Small to Moderate)). This suggests that these vowels are more open when following the fifth liquid. On the F2 axis, pairwise comparison showed that the vowels following the fifth liquid have higher F2 frequencies than those following trills (1823Hz vs. 1659Hz, $p<0.001$, $d=0.49$(Moderate)) and retroflex laterals (1823Hz vs. 1661Hz, $p<0.002$, $d=0.49$(Moderate)). These higher F2 frequencies suggest that the effects of the fifth liquid are still observed at the midpoint of the following vowels, which show a more anterior articulation of these vowels compared with vowels following the trill and the retroflex lateral.

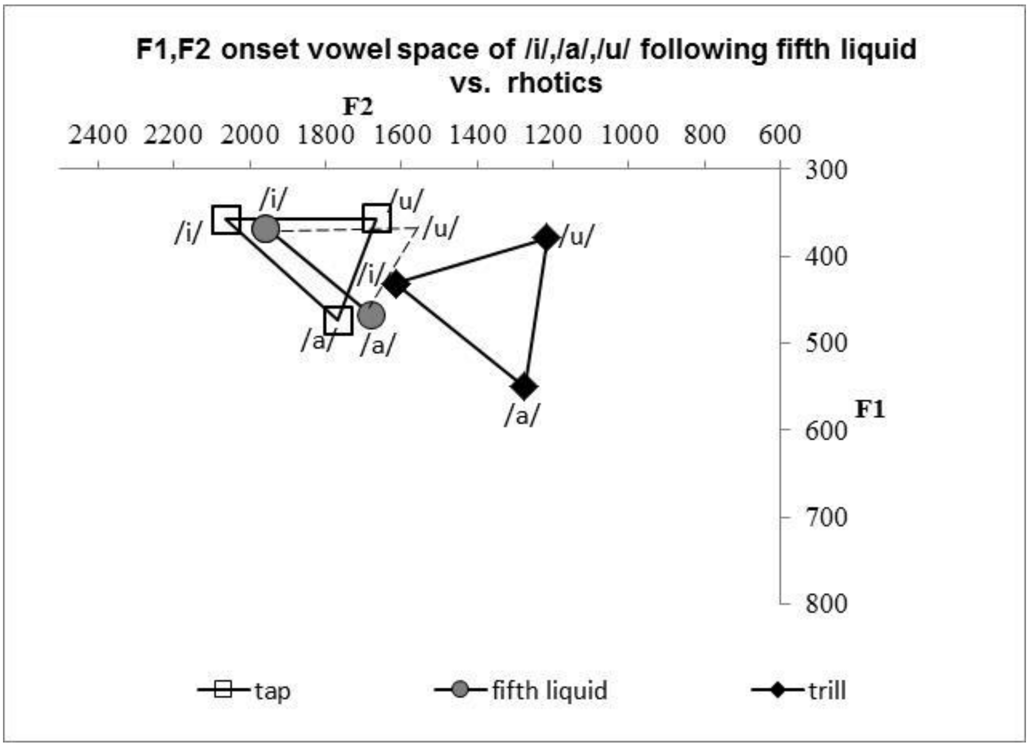

Figure 10: F1-F2 onset vowel space of /i/, /a/, /u/ following the fifth liquid and the rhotics. Here and in Figs. 14-16 the dotted lines are hypothetical projections of /u/ following the fifth liquid for comparative purposes only, as words with /u/ following the fifth liquid are extremely rare in the lexicon.

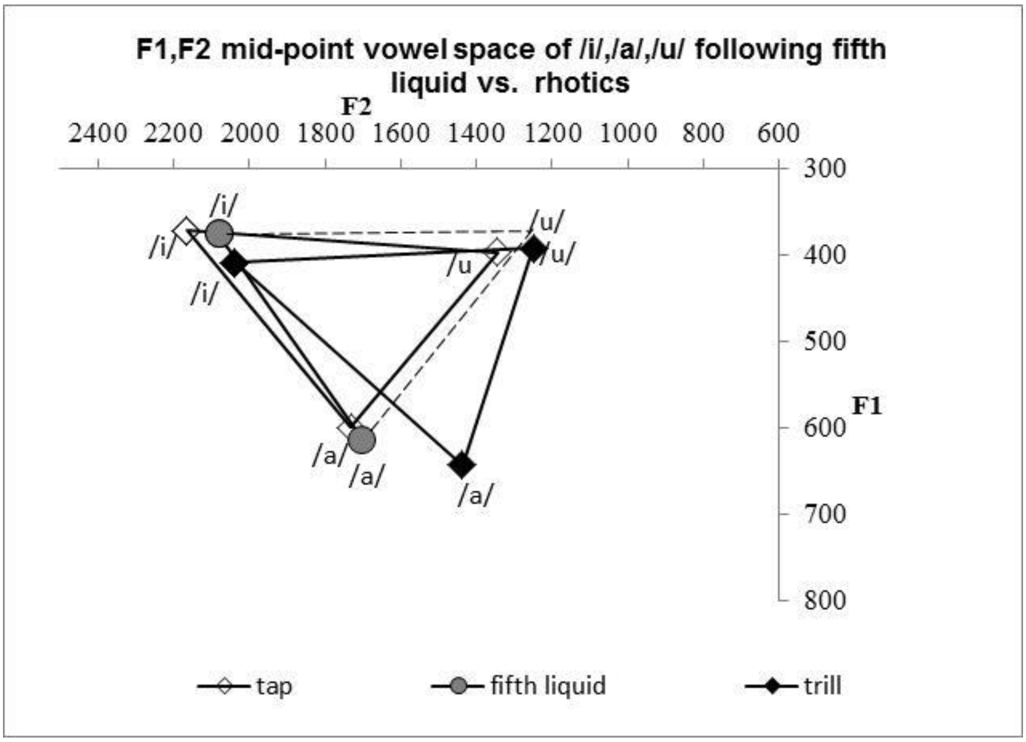

Figure 11: F1-F2 mid-point vowel space of /i/, /a/, /u/ following the fifth liquid and the rhotics

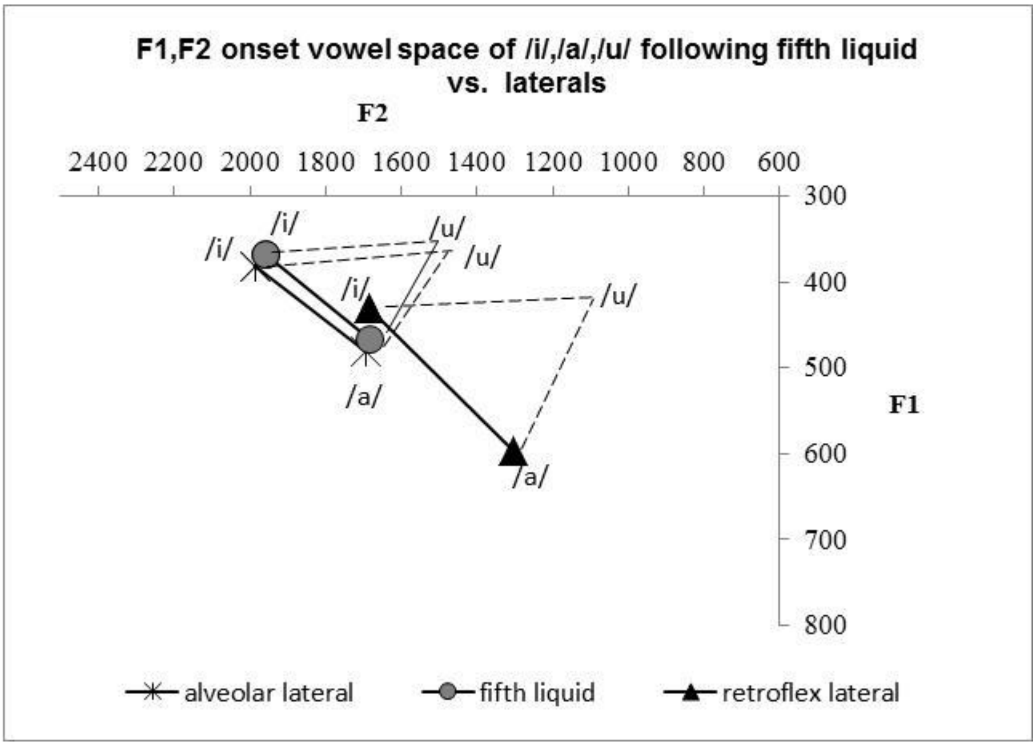

Figure 12: F1-F2 onset vowel space of /i/, /a/, /u/ following the fifth liquid and the laterals.

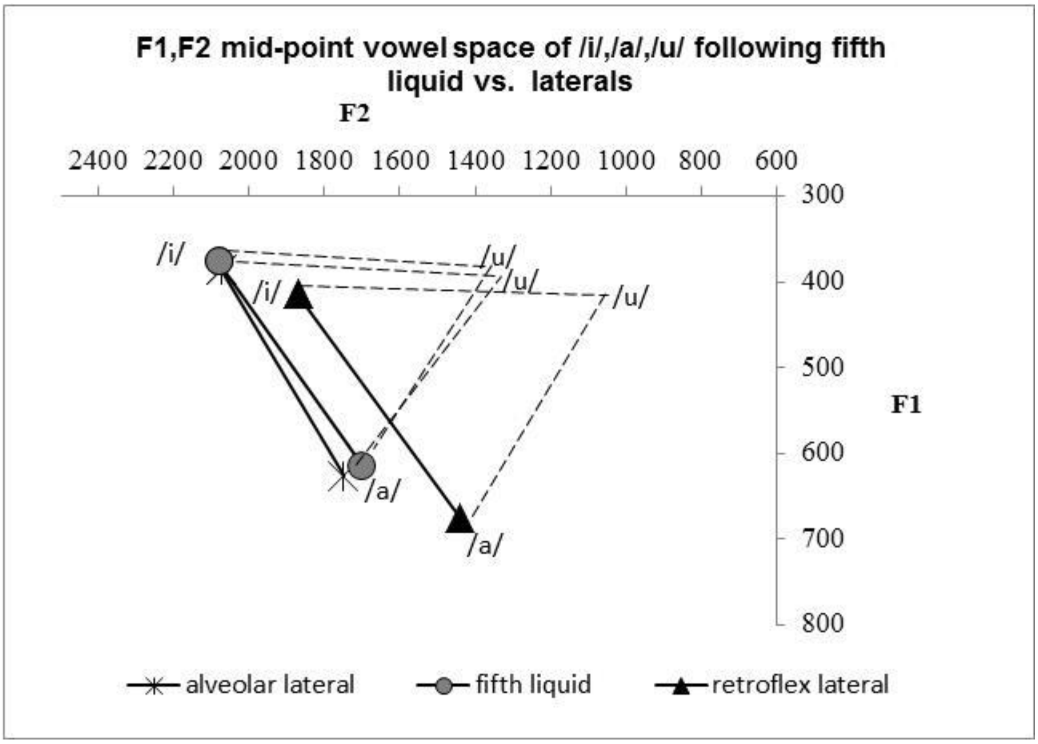

Figure 13: F1-F2 mid-point vowel space of /i/,/a/,/u/ following the fifth liquid and the laterals.

The vowel space preceding and following all liquid types is smaller at offset and onset respectively and larger at mid-points, reflecting vowel centralisation due to the constriction required for the laterals, tap, trill and 5th liquid. The smaller vowel spaces at the offset of preceding vowels and onset of following vowels leads to a clear demarcation between the vowel spaces for the clear *versus* dark liquids, with little overlap in the case of the laterals and no overlap in the case of the tap and trill (compare Figs. 6-13 above). The vowel space surrounding the fifth liquid is most similar to that surrounding the alveolar lateral followed by that surrounding the tap. This corresponds with the auditory and acoustic characterisation of the fifth liquid, tap and alveolar lateral as having a clear resonance.

5.3.3 Implications of the effect of liquids on vowel quality

Given the expected correlation between acoustic patterns of vowels and articulatory characteristics such as vowel height and frontness, results from the first four formants in the fifth liquid and F1 and F2 of surrounding vowels suggest a clear/palatalised resonance with fronting effect on vowels. The vowel categories overlapped more at the mid-point of the surrounding vowels than at the offset for the preceding vowel and the onset for the following vowel, suggesting a general effect of liquids on vowels. The acoustic characteristics of vowels surrounding the fifth liquid patterned most closely together with those surrounding target taps and alveolar laterals, and appeared to be maximally different from those surrounding target trills and retroflex laterals. Therefore the similarities or differences between vowels surrounding the fifth liquid and those surrounding the other four liquids do not appear to be based on a rhotic *versus* lateral distinction, but rather on whether they were fronted or backed, and the resulting clear or dark resonance. The vowels surrounding the fifth liquid patterned most closely with those surrounding clear and front cavity liquids, i.e., taps and alveolar laterals.

6. Summary and discussion

6.1 Auditory and acoustic properties of the fifth liquid in Malayalam

The fifth liquid in Malayalam as produced by the speakers in this study sounds like a post-alveolar approximant, and its spectrographic characteristics exhibit supporting evidence in the form of vowel-like continuous formant structure. While Malayalam has other retroflex consonants which involve sublaminal contact, the type of weak retroflexion that was heard in the fifth liquid may be due to both its approximant nature and its clear resonance. While retroflexion is normally associated with retraction (Hamann, 2003) results for /r/ and /ʐ/ remind us that tongue tip/blade retraction is independent from the curved movement typical of a retroflexed articulation. We do not believe /ʐ/ involves a retroflexed sublaminal articulation, but further articulation work is required to examine this and the puzzling dynamic movement upon the release of the constriction which we witnessed in the ultrasound study (Scobbie et al, 2013). EPG work would also shed further light on the approximant nature of this sound. While in this study we used auditory and acoustic profiling evidence for this, the patterns of palatal contact for this sound would provide more robust evidence, as would an acoustic measure of amplitude or noise in the spectrum. In this study we refrained from measuring amplitude due its low mileage in distinguishing between /ʐ/ and the other liquids; some of the taps and trills were occasionally realised as approximants while the laterals varied in amplitude depending on the effect of the anti-formants. Occasional friction occurred in tokens from all five liquids during our articulatory study (Scobbie et al, 2013), potentially due to slight restriction from the probe.

Acoustic results for the liquids further show a unique profile for /ʐ/: on the one hand, its F2 patterns more closely with that of the alveolar lateral and tap, with a large magnitude for the F2 differences between the fifth liquid on the one hand and the retroflex lateral and the trill on the other. By contrast, its F3 and F4 pattern most closely with those of the retroflex lateral and the trill, and are significantly lower than those of the alveolar tap and lateral. Its F1 falls in between that of the alveolar and the retroflex liquids, but is only significantly higher than the F1 for the alveolar lateral and significantly lower than the F1 for the trill. When all formants are looked at together, the fifth liquid patterns most closely with the alveolar tap in terms of its F1, F2, and F3 patterns. F2 generally plays a big role in distinguishing the more advanced (/l/, /ɾ/, and /ʐ/) from the more retracted (/ɭ/ and /r/) liquids and their surrounding vowels. Vowels preceding and following the fifth liquid, taps and alveolar laterals are advanced and raised while those preceding and following the trills and retroflex laterals are retracted and more open. The slight centralisation of the vowels preceding the fifth liquid compared with the tap, especially in the /a/ context, highlights the relative effect of the clear/dark distinction; despite the advanced tongue root position of the fifth liquid and its anterior articulation in comparison with the trill and the retroflex lateral, the clear effect may be slightly masked by the behaviour of adjacent vowels (c.f. Carter and Local, 2007, who show that vowels sometimes show the predicted F2 difference between /l/ and /r/ in English even if the liquids themselves do not).

This raises the question of why /ɻ/ would be described or perceived as a retroflex lateral in some of the literature, since the central/lateral airflow of these two sounds and their different resonance characteristics should be perceptually distinguishable. One reason may lie in the similarity of their F3 patterns. While low F3 is normally taken to be an indicator of rhoticity (Espy-Wilson et al, 2000), results from this study show that F3 of the fifth liquid was only significantly different from that of the alveolar lateral, but not the retroflex lateral (Fig. 5). In other words, in a crowded liquid space where there are already two laterals and two rhotics, F3 in Malayalam serves as a cue for place (to distinguish front and back liquids in terms of primary constriction) but not manner of articulation. Another reason may lie in the close proximity of F2, F3, and F4 in the realisation of /ɻ/. In recent research on the perception of rhoticity, Heselwood (2009) suggests that low F3 may in fact have an inhibiting effect on rhotic perception. Heselwood conducted a perception experiment which involved forty phonetically trained listeners listening to rhotic realisations of the words *fort*, *stars* and *hurt* in two conditions, filtered (where F3 and all higher formants were removed) and unfiltered (where F3 and formants up to 5.5kHz were present). Results revealed that stronger rhoticity was perceived in the filtered condition, which Heselwood explains as due to the F1-F2 distance becoming more auditorily prominent in the absence of F3 and "the presence in the auditory space of a distinct and relatively sharp peak in the region of 9.0-11.5 Bark" (p. 62). While perception work on Malayalam is required to investigate the role of F3 in lateral/rhotic perception, if F3 is occasionally low enough to merge with F2 they may be perceived as one formant, leading to a sharper contrast between a merged F2/F3 formant and F4 (perceived as F3), resulting in a more similar profile to that of /ɭ/.

Our articulatory work using Ultrasound Tongue Imaging provides further support for our auditory and acoustic results, confirming the intermediate place of articulation for the main constriction of the fifth liquid in comparison with the trill and retroflex lateral on the one hand, and the alveolar liquids on the other. Moreover, the release of the constriction in /ɻ/ was puzzling, as it showed a zig-zag motion that was difficult to convey graphically (Scobbie et al, 2013: 23) but that the authors attributed to a potential transition from grooved central to a more lateral airstream. Tongue root position, on the other hand, placed /ɻ/ firmly with the alveolar liquids, showing that its main post-alveolar constriction is not enough to draw similarities with the other post-alveolar liquids in the language and that both resonance and primary liquid manner may be equally relevant in understanding the system and placing the 5th liquid in it.

6.2 The Fifth Liquid: Phonetically clear but phonologically dark?

In terms of its phonotactic behaviour the fifth liquid aligns with the 'dark' liquids in Malayalam (/r/ and /ɭ/); yet its articulation exhibits advanced tongue root and its secondary acoustic resonance exhibits a high F2 that is closer to the second formant of the alveolar /ɾ/ and /l/, giving an auditory impression of a clear resonance. This, together with the debate around its lateral/rhotic identity, suggests that /ɻ/ has a mixed phonological identity which may be due to it being part of a crowded liquid system, and which has led to the loss of this sound in many Dravidian languages. While further articulatory work is needed to examine the fifth liquid's behaviour along the central/lateral plane, it could be that its realisation varies along that dimension and that it is not specified for lateral or medial tongue bracing (Derrick, personal communication). This, however, would suggest that co-articulation with surrounding vowels is what provides /ɻ/ with medial or side bracing of the tongue, but our impressionistic analysis did not reveal any differences in the centrality/laterality of the fifth liquid depending on surrounding vowel.

Resonance quality was found to be more than just a secondary feature in the articulation of the liquid. Rather, it was found to play a primary role in the contrast maintenance between the two rhotics in Malayalam and between the two laterals (for further details, see Punnoose 2011), i.e. to differentiate between the lexically contrastive advanced and retracted rhotic on the one hand and the alveolar and retroflex lateral on the other. Interestingly, resonance differences have also been argued to underlie the maintenance of several other contrasts in the language, namely the dental-alveolar distinction (Dart & Nihilani 1991) and the singleton-geminate distinction (Local & Simpson, 1999). As Carter (2003: 238) points out that "what is secondary in a degree of stricture sense may in fact be an important part of the phonetics of any given stretch of speech".

The palatalised resonance was not restricted to the consonant itself, but manifested itself in the surrounding vowels too, which were fronted and raised. The spread of influence over surrounding vowels is likely to raise the salience of secondary resonance as a prosodic feature in the realisation of liquids and may play a more important role in the phonology than the structural units that define laterals, rhotics, and the sub-category members within them. For instance, backing/fronting effects on the vowels surrounding the liquids may actually be used by listeners to distinguish between the different liquids; perception work is needed to investigate whether Malayalam listeners rely on differences in primary constriction place/manner or in clear-dark resonance to distinguish between the liquids in Malayalam.

Our results are compatible with those of Carter's (1999) study of British English liquids, which focussed on rhotic-lateral interaction in rhotic and non-rhotic dialects and found that resonance characteristics of the liquids played an important role in their phonetic and phonological patterning. Resonance patterns in British English are syllable- and dialect-specific. For instance, initial laterals tend to be clearer than final laterals (as evidenced by F2 patterns), while initial rhotics tend to be darker than final rhotics (Carter, 2003). While these patterns are motivated by the gestures involved in onsets and rhymes, learned dialect-specific differences are present too, e.g. some varieties may have clear (e.g. Newcastle) or dark (e.g. Leeds) laterals throughout. In terms of the interaction between rhotics and laterals within a syllable position, the general tendency is for one to be clearer/darker than the other for contrastive purposes (Kelly and Local, 1986). This creates a conundrum: in a rhotic variety where laterals are dark throughout (e.g. Fife), a syllable-initial lateral may count as phonologically 'clear' because it contrasts with a dark rhotic in the same system and yet its phonetic realisation is 'dark'. This enables the rhotic and lateral categories to still be maximally differentiated at the phonological and phonotactic level while showing overlapping acoustic patterns at the phonetic level. The phonological patterns that are evident in the Malayalam lexicon suggest that resonance also plays an important role in the patterning of the liquids in the language, but is more important for distinguishing within- rather than across category members of rhotics and laterals.

So why should resonance characteristics of the fifth liquid in Malayalam manifest themselves differently at the phonetic and phonological level? Based on our phonetic study, the fifth liquid is a retroflex central approximant, which would imply that there are two retroflex liquids in the inventory– the fifth liquid and the lateral. While the rhotic status of the fifth liquid should be enough to distinguish between it and the retroflex lateral, our study has shown that the rhotic-lateral divide in Malayalam is less important than the retracted/advanced divide. This necessitates a phonetic implementation of the fifth liquid that maintains maximal perceptual distinctiveness with the retroflex lateral using low cost but salient language-specific resources (e.g. Lindblom & Maddieson, 1988). We think that the weak retroflexion and phonetically clear resonance of the fifth liquid serve that purpose. A clear-dark long domain resonance contrast may contribute to an increased perceptual salience of the distinction between two or more members of a crowded liquid space (Carter, 1999).

For instance, the tap and the trill may overlap in their manner of articulation, but the clear/dark resonance they have serves to maintain the contrast between them. Similarly, the fifth liquid may overlap with the retroflex lateral in terms of its F1, F3, and F4 patterns, but the significantly higher F2 in the former may serve as a strong distinguishing cue at the acoustic and auditory levels. This is very important for the survival of a sound that, in other Dravidian languages, has now merged with other sounds, including /ɭ/. Moreover, clear/dark resonance differences have also been shown to play a significant role in determining other sound contrasts in Malayalam, namely the dental-alveolar contrast (Dart and Nihalani, 1991) and the singleton-geminate lateral and nasal contrasts, where the geminate lateral and nasal are clearer than their singleton counterparts (Local and Simpson, 1999). Recent work on Tamil dialects that also retain a fifth liquid shows that it exhibits similar F1, F2 and F3 values as the retroflex lateral in its inventory, differing only in having a higher F4 (Narayanan et al, 1999). The tendency of speakers of other Tamil dialects (where the fifth liquid is lost) to perceptually identify the surviving fifth liquid in the Brahmin dialect as /ɭ/ (McDonough & Johnson, 1997) may be due to the similar resonance characteristics of the two sounds in Tamil and the retroflex articulation of /ʐ/. In contrast, resonance quality as a differentiation strategy seems to be responsible for contributing to the long lasting presence and survival of the fifth liquid in all dialects of Malayalam.

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Appendix A

Word list

ɾ	r	ʐ	l	ɭ
/kaɾi/ *soot*	/kari/ *curry*	/kaʐi/ *eat*	/kali/ *anger*	/kaɭi/ *game or play*
/kaɾa/ *shore*	/kara/ *stain*	/maʐa/ *rain*	/vala/ *net*	/vaɭa/ *bangle*

/viɾa/ *tapeworm*	/vira/ *shivering*	/pɪẓa/ *penalty/ fine*	/vila/ *price*	/kɪḷi/ *bird*
/ʧiɾi/ *smile*	/ʧiri/ *lip*	/kuẓi/ *pit/hole*	/puli/ *tiger*	/puḷi/ *bitter/tamarind*
/puɾa/ *house*	/pʊram/ *the outer/reverse side*	/puẓa/ *river*	/mula/ *breast*	/muḷa/ *sprout/seedling*
/kuɾu/ *pimple*	/kuri/ *note*	/muẓa/ *swelling*	/kula/ *bunch of flowers*	/t̠uḷa/ *hole*

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