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Phonetic and Phonological Aspects of Liquid Devoicing in Thai, Hungarian, and American English Stop-Liquid Sequences*

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It is a well-known coarticulatory phenomenon that liquids preceded by voiceless stops tend to devoice partially, e.g. English *clash* /k^{h}læʃ/ ! [k^{h}l æʃ]. The purpose of this paper was to investigate acoustically whether devoicing of the liquid following a voiceless stop in the three languages Thai, Hungarian, and American English originates at the planning level, e.g. is phonological, or whether it is phonetic, e.g. occurs as artifact of the implementation process. The study reported here investigated VOT and the amount of devoicing in /pl/, /pR/ (R stands for any rhotic), /kl/, /kR/, and /tR/ sequences with respect to: a) the influence of the position of the relevant sequence with respect to a syllable/morpheme boundary, and b) the effect of speaking rate. 12 subjects participated in this study, 4 subjects per language, 2 females and 2 males. The results show that liquid devoicing exhibits a systematic pattern in English but not in Hungarian or Thai, suggesting that it is phonological in English and phonetic in Hungarian and Thai.

1. Introduction

The current paper investigates the well-known coarticulatory phenomenon that liquids preceded by voiceless stops tend to devoice partially, as illustrated in (1) in the English word *clash*:

(1) /k^{h}læʃ/ ! [k^{h}l æʃ]

Many languages exhibit the phenomenon investigated here: a speech sound changes - fully or partially - its phonation type (voiced or voiceless) under the influence of an adjacent sound with an opposite voicing specification. While theoretical phonologists refer to this phenomenon most often as voicing assimilation, phoneticians and experimental phonologists prefer the term laryngeal coarticulation (Ohala, 1993).

Coarticulatory phenomena like the one under investigation here are often called natural processes, since they can be explained in terms of phonetics. If we assume, as for example proposed in Ohala (1993), that the synchronic sound systems of languages often result from cases of fossilized coarticulation, we might expect that in some languages voicing assimilation is a fact of the synchronic sound system and hence part of the phonology, whereas in others it is the result of coarticulation occurring during the phonetic implementation.

To test whether phonetic liquid devoicing is distinguishable from phonological liquid devoicing, the present study investigated the properties of liquid devoicing in three genetically unrelated languages: Thai (Daic), Hungarian (Finno-Ugric), -254(po)-274(calign Indo-Euthe)an 1990())]TJETq18(:)2 [(S)]TJ/F58 4.[(Tf 3.985 -3l15(xhibm15(xhig250(76(15(xhitend)xhiJim15(xhiSa54(iwuschsimi

Based on evidence from the acoustic analysis conducted on stop-liquid sequences in the three languages it will be argued that liquid devoicing is phonetic in Hungarian and Thai, but phonological in English.

In order to determine whether liquid devoicing is phonological or phonetic in the investigated languages it is, of course, necessary to find criteria that can determine the phonological versus phonetic status of liquid devoicing. A common experimental paradigm (Lehiste, 1960; Docherty, 1992) is to study the interaction of coarticulation with prosodic/morphological boundaries. In the case of a significant influence of the boundary on the extent of coarticulation it can be concluded that the presence of a higher order grammatical constituent (e.g. a syllable, morpheme or word) determines the phonetic realization of the sound or sound sequence under investigation, and therefore can be considered a phonological phenomenon. Example (2) illustrates the boundary effect on sonorant devoicing in English according to Lehiste (1960):

(2) night-rate [naIt.ôeIt] vs. nitrate [naI.tôeIt]

Another criterion to determine the phonetic versus phonological status of a given process has been proposed in the work of Keating (1985) who argues that discrete/categorical, contrastive phenomena should be considered phonological, whereas gradient, non-contrastive phenomena should be considered phonetic. While this has been successfully applied to determine the phonetic versus phonological status in studies on nasalization (Cohn, 1993) and on vowel allophony (Choi, 1995), it does not lend itself easily to the investigation of laryngeal coarticulation (for further discussion see below).

A third approach has been used by Solé (1992). She proposes that speaking rate can be used to determine whether a given process should be considered phonetic or phonological. Since speaking rate is under the control of the speaker, it can be seen as a higher-level adjustment. Adjustment of the amount of coarticulation with speaking rate, therefore, indicates systematic control over coarticulation, which suggests that the coarticulatory phenomenon under investigation is phonological rather than phonetic in nature.

Finally, cross-linguistic comparison can shed light onto the phonetic versus phonological status of coarticulation. While research over the last decades has shown that gradient coarticulatory variation may very well be language specific and thus has overthrown the long held belief that gradient changes are universal aspects of speech (for a summary see Farentani and Recasens (1999)), it is still interesting to see which gradient variations occur across different languages and which turn out to be language specific. Even though some gradient phenomena are language specific and, therefore, their phonetic status may be disputable, we may still assume that those coarticulatory gradient phenomena that can be observed cross-linguistically are truly phonetic in nature.

Some of the criteria used in the present study to determine the phonetic versus phonological nature of laryngeal coarticulation in stop - liquid sequences have been used previously (Docherty, 1992; Klatt, 1975); however, the current study differs from these studies in several respects:

Previous studies were limited to English; the current study investigates also Thai and Hungarian.

Previous studies included male subjects only; this study includes male and female speakers.

While Dochertys (1992) study like the current study investigates stop liquid sequences within and across boundaries, the current study differs in that it also investigates the effect of speaking rate.

And finally, while previous studies used voice onset time (VOT) alone to study the amount of laryngeal coarticulation in stop-liquid sequences, the current study takes into account the possibility that the amount of devoicing of the liquid is not necessarily equivalent to or correlated with the VOT of the preceding stop. Therefore, the duration of absence of voicing during the liquid was also measured in order to determine the percentage of devoicing of the liquid, since devoicing has to be understood as relative to the total duration of the segment.

2. Distinguishing the Effects of Phonetics from those of Phonology

Coarticulatory / assimilatory phenomena have been the focus of much experimental research over the past 70 years ever since the introduction of experimental techniques into the study of human speech. The results of these studies have informed our understanding of speech production as well as inspired various theories concerning the nature of phonetic and phonological representations (for a comprehensive summary see Hardcaste and Hewlett (1999)). An ever re-occurring issue in the discussion of experimental studies on coarticulation is to what extent coarticulatory phenomena can be regarded as phonetic or phonological, i.e. to what extent is coarticulation a result of the inertia of the articulatory system (Lindblom, 1963, 1990; Öhman, 1966, 1967) as opposed to a feature-spreading process (Daniloff and Hammarberg, 1973; Keating, 1985, 1990) or inherent part of dynamic phonological units (Fowler, 1980; Browman and Goldstein, 1986b).

While phoneticians and experimental phonologists have paid much attention to questions concerning the relationship between phonetics and phonology, theoretical phonologists have only in the last 15 years started to integrate results of experimental phonetic research into phonological modeling (cf. Steriade (1997, 1999); Kirchner (2001); Hayes et al. (2004) and papers therein). One of the reasons why theoretical phonologists might have been rather reluctant to look to experimental studies for clarification of theoretical issues might be that it is not straightforward how detailed

(Chomsky and Halle, 1968), where coarticulation is defined as adjustments in the "vocal tract

Keating's (1985; 1990) window model of coarticulation overcomes this problem by accounting for coarticulation in a language specific phonetic component. Keating, similar to non-linear phonological frameworks like for example Sagey's (1986) model, assumes that phonological units are timeless, abstract, and with no internal temporal structure, whereas phonetic units are continuous in time and space and possess an internal temporal structure. However, while Sagey assumes that the phonetic representation resembles the phonological representation in terms of the feature-geometric architecture, Keating proposes the window as the phonetic unit of representation. A window is formed by the range of values associated with the physical realization of a feature. For each articulatory or acoustic dimension, a window has its own duration and width representing the possible physical values that a target can take. The window width, in turn, depends on the output from the phonological component. If a feature is specified in the phonology, the window associated with this feature will be narrow and allow no or little contextual variation. If, however, a feature is unspecified in the phonology, the corresponding window will be wide and allow large contextual variation.

If we now want to apply the window model to the case of laryngeal coarticulation in stop-liquid sequences, we encounter the following problem. The notion of temporal gradience typically employed in a window model type approach such as for example Cohn (1993) is not applicable in the case of voicing, since at any given point in time voicing is either present, i.e. the vocal folds vibrate, or not present, i.e., the vocal folds dont vibrate. Even though voicing comes in different phonation types, such as modal, creaky, and breathy voicing, we do not find a gradual change over time. Therefore, the current study does not further draw on the window model of coarticulation.

2.3. Coarticulation in Co-production Models

The main criticism of feature-based models is that they need a translation process that renders the abstract, static and timeless phonological units into articulatory movements. In this translation process, the speech plan provides the spatial targets, while a 'central clock' specifies the temporal order in which the articulators have to move. Co-production models Fowler (1980); Browman and Goldstein (1986b, 1992); Fowler and Saltzman (1993) overcome this dichotomy by integrating the time program into the speech plan.

According to co-production models, the amount of coarticulation depends on the degree to which the temporally overlapping gestures share articulators. For example, we find a minimal degree of coarticulation in a /VbV/ sequence, where the vocalic and consonantal constriction gestures involve two independent articulators, the tongue body and the lips respectively, and one common articulator, the jaw. However, in the sequence /VgV/, we find a high degree of coarticulation induced by coproduction, since the vocalic and the consonantal gestures share both the tongue body and the jaw. The general idea of coproduction models, then, is that gestures 'blend their impact on the common articulator, which can result in several possible outcomes.

In a sequence of two identical gestures, coproduction models predict that the outcome is a composite movement, e.g. a 'melting together of the two movements into a single one, which, however, is greater in extent than any single movement by itself. In other words; a summation of the two gestures takes place. This prediction is supported by a study of laryngeal abduction/adduction movements in sequences of two voiceless consonants (Munhall and Löfqvist, 1992). Munhall and Lfqvist report that two distinct glottal abduction movements were observed at slow speaking rates, whereas single movements with increased amplitude were found at moderate and fast speaking rates.

In a sequence of two gestures that impose conflicting demands on the same articulator, coproduction models make two controversial proposals. Earlier work by Bell-Berti and Harris (1981) proposed that the gestural conflict can be resolved at the planning level by delaying the onset of the competing gesture so that the ongoing goal can be achieved. Fowler and Saltzman (1993), on the other hand, proposed that no changes at the planning level may be needed. Instead, they proposed that any given gesture has its own characteristic degree of ‘blending strength, where blending strength is a concept introduced to capture the relation between coarticulatory resistance and coarticulatory aggression. If gestural overlap occurs between a stronger and a weaker gesture, the stronger gesture tends to suppress the weaker one and to affect the common articulator more.

3.2. Elicitation Materials

For all three languages a list of ten words was prepared containing each of the stop-liquid sequence /pR/, /pl/, /tR/, /kR/, and /kl/ once in the tautosyllabic and once in the heterosyllabic condition. Since none of the three languages allow tautosyllabic /tl/ sequences, this sequence type could not be investigated causing an asymmetry in the data set. While this general design applies to all three languages, there were some differences between the shape of the words on the three lists due to different prosodic and morphological constraints in each language.

For English, all words were disyllabic and carried primary stress on the first syllable. While all words with the stop-liquid sequence in the tautosyllabic condition were monomorphemic, the words in the heterosyllabic condition were compound words and the syllable boundary for all these words coincides with the morpheme boundary. In English the default syllabification is that the stop-liquid sequence is syllabified as onset. The only way to enforce a different syllabification, such as the stop in coda position and the liquid in the onset of the following syllable, is by imposing a morpheme boundary on the sequence, since contrastive syllabification does not exist in English (nor has it been reported for any other language). The words were designed such that the tautosyllabic sequence occurred in the onset of the second syllable, and for the heterosyllabic sequence, the stop occurred in the coda of the first and the liquid in the onset of the second syllable. This entails that the tautosyllabic sequence has to occur in the unstressed syllable, which has been shown to shorten the VOT of stops in stop-/l/ sequences (Docherty, 1992). This choice seemed, however, unavoidable in order to control for stress. Docherty (1992), for example, designed his word lists so that the tautosyllabic stop-sonorant sequences occurred in a stressed syllable, but couldnt maintain control over stress in the heterosyllabic sequences due to a lack of a large number of unstressed prefixes in English.

not a stress language but has lexical tone. Although it was attempted to control for the tone, this control could not be maintained throughout the word list. While the majority of words had a rising tone, one word had a falling tone and two had a rising-falling contour tone. This asymmetry in the data set was kept in mind, but anticipating the results no effect of the tone on VOT or duration of voicelessness during the liquid could be seen.

3.3. Participants and Data Collection

Overall 12 subjects participated in this experiment; four subjects per language, two male and two female subjects each. All subjects were between 20 and 40 years old. The American English speakers were speakers of the Mid-Western dialect of American English with the exception of one male talker, who grew up in California, but has been living in the Mid-West for several years.

The Thai speakers were all from the Southern part of Thailand and were students in the United States. They all had been here for less than 5 years.

The Hungarian speakers were all from the greater Budapest area. Two of the four speakers were students in the United States who had lived here for less than two years. The other two speakers were visitors from Hungary who spent their summer vacation here.

The participants were instructed to read each of the ten words, which were randomly ordered, at three different speaking rates. The first time, speakers were asked to read the word in isolation and to enunciate very carefully. The second time, speakers were asked to read the word in a carrier sentence at normal speaking rate. The carrier sentences for each language were:

English: I say again.
Hungarian: Azt mondata ugye?
‘He said , didn’t he?’
Thai: Kham níi Páan wâa rWWpláaw?
‘This word is pronounced , isn’t it?’

The third time the participants were asked to read the word again in the carrier sentence, but this time as fast as they could. Overall, 360 utterances were produced by the speakers, 120 per language, 30 per participant, ten at each speaking rate. All utterances were recorded using a Marantz tape recorder.

3.4. Acoustic Analysis

The recorded data were digitized at a sampling rate of 22.05 kHz and analyzed using the speech software PRAAT (Boersma and Weenink, 2008). The analysis procedure involved displaying the speech waveform and a wideband spectrograh268(spec .2ates8cnd)-2id diud72991 (diud7dtd)-268ersa354

4.1.1. English

For English, the VOT in the tautosyllabic condition tended to be longer than in the heterosyllabic condition, but the difference was not significant (F = 3.8; p = .1473) when averaged across all subjects. However, a highly significant interaction between syllable condition and place of articulation of the stop was found (F = 13.3; p = .0002), suggesting that whether or not the VOT differed with the occurrence of the sequence across versus within a syllable boundary depended on the stop consonant in the sequence. While VOT differed significantly for /ô/ versus /t.ô/ (p = .03) and for /kl/ versus /k.l/ (p = .02), it differed marginally for /pl/ versus /p.l/ (p = .09) and not at all for /kô/ versus /k.ô/ (p = .33) and /pô/ versus /p.textturnr/ (p = .11). This result is surprising, since we had expected that all the stop-liquid sequences would pattern together since they form a coherent group phonologically (voiceless stop plus liquid). At this point no explanation for this result can be offered.

If we turn now to the parameter of devoicing, we find that liquids devoice significantly more in the tautosyllabic condition than they do in the heterosyllabic condition (F = 51.14; p = .0056). The percentage of devoicing differed significantly for all stop-liquid sequences in the two conditions: /kl/ versus /k.l/ (p = .03), /pl/ versus /p.l/ (p = .05), /kô/ versus /k.ô/ (p = .05), /ttextturnr/ versus /t.textturnr/ (p = .005), and /pô different was /k.l/ versus /kl/ (p = .06). The pattern of the effect of the syllable / morpheme boundary on the percentage of devoicing in the liquid in Hungarian appear similar to those found in the English data. However, unlike in English, the effect is not statistically significant.

4.1.3. Thai

If we now turn to Thai, we find that the VOT in stop-liquid sequences within a syllable onset does not differ significantly from the VOT in sequences across syllable boundaries (p = .79). If any tendency is discernible, it is the inverse tendency observed for Hungarian and English: the VOT in the heterosyllabic condition tends to be somewhat longer than the VOT in the tautosyllabic condition. This tendency, however, seems to be limited to sequences containing the liquid /r/.

A look at the percentage of devoicing in the liquid shows that the tendency observed in the distribution of VOT is also apparent in the amount of devoicing of the liquid. The liquids in the heterosyllabic condition tended to devoice more than in the tautosyllabic condition, with exception of those liquids following the stop /p/. However, this tendency again was not statistically significant (p = .297). The results for Thai seem to suggest that the presence of a syllable / morlabic condition. Finally, we found that the Thai data did not show any systematic effect of the syllable boundary on the percentage of devoicing in the liquid.

The English results show that the presence of a syllable / morpheme boundary affects the

the duration of the sequence was significantly different for all three speaking rates. The sequence at the fast speaking rate (mean = 71 ms, SD = 18) was significantly shorter (p = .0007) than at medium speaking rate (mean = 86 ms, SD = 18), which, in turn, was significantly shorter (p = .009) than at the slow speaking rate (mean = 97 ms, SD = 21).

4.2.1. English

In the English data, we find a significant interaction between VOT and speaking rate in both the tautosyllabic (F = 17.5; p = .0031) and the heterosyllabic condition (F = 10.2; p = .0117). The VOT in both conditions was proportionally shorter at the fast speaking rate compared to medium and slow speaking rate, indicating that the VOT adjusts to speaking rate. As mentioned in the previous section, the medium and slow speaking rate were not significantly different from each other in the mean duration of the stopliquid sequence. However, in the tautosyllabic condition, where stop and liquid form a complex onset, we find a stronger linear correlation of the VOT with the length of the

the heterosyllabic condition, the duration of devoicing during the liquid adjusts to speaking rate only in the tautosyllabic condition.

4.2.2. Hungarian

For Hungarian, the VOT at the three different speaking rates is not significantly different in the tautosyllabic condition (p = .3554). However, we do find a significant difference between the VOT at fast and slow speaking rate (F = 9.009; p = .0102) in the stop-liquid sequences across syllable boundary suggesting that the VOT adjusts to speaking rate in the heterosyllabic condition. The VOT for the three speaking rates in the tautosyllabic and heterosyllabic condition are shown in Figure 4:

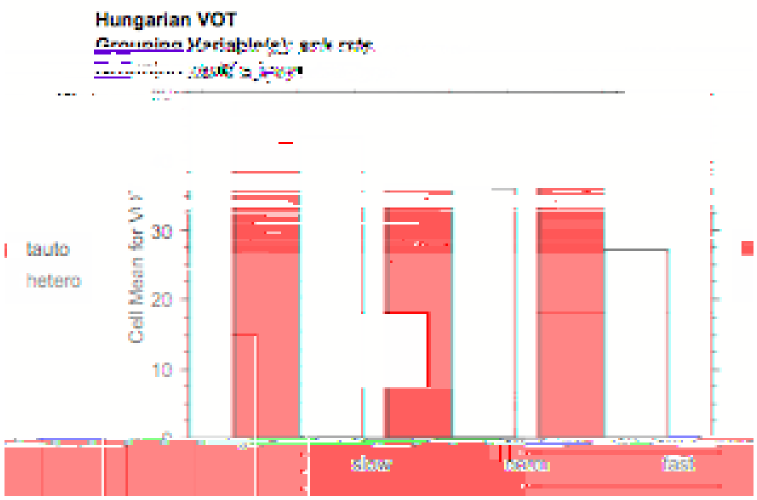

Figure 4: Effect of speaking rate on VOT in Hungarian.

If we now turn to the duration of voicelessness during the liquid, we find that the amount of devoicing does not adjust to speaking rate in either the tautosyllabic (p = .1314) or in the heterosyllabic condition (p = .2198).

4.2.3. Thai

For the Thai stopliquid sequences in the tautosyllabic condition, the VOT does not differ significantly across the three speaking rates (p = .2015). Similar to Hungarian, we do find a tendency for the VOT in the heterosyllabic condition to adjust with speaking rate (F = 12.732; p = .0184). These results are illustrated in Figure 5:

The duration of devoicing during the liquid again like Hungarian - does not adjust to speaking rate in Thai, as it does not differ significantly across the three speaking rates in either the tautosyllabic (p = .5867) or the heterosyllabic condition (p = .2349).

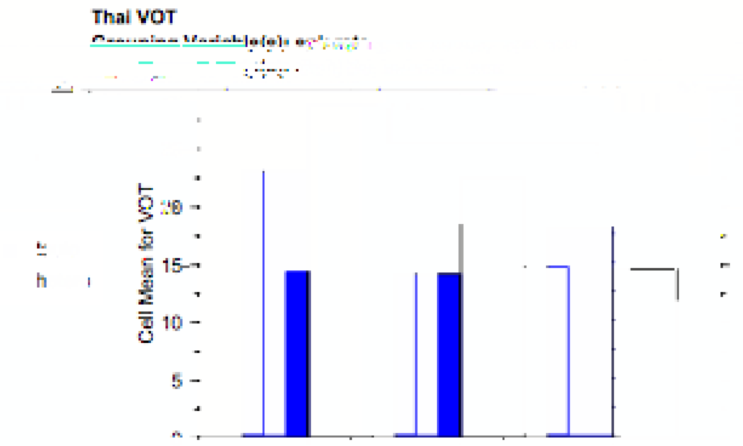

Figure 5: Effect of speaking rate on VOT in Thai.

4.2.4. Discussion

In this section we have examined whether or not the VOT and/or the amount of devoicing of the liquid adjusts to speaking rate in the three languages under investigation. The results are summarized in Table 2:

	VOT		Devoicing of liquid	
	tautosyllabic	heterosyllabic	tautosyllabic	heterosyllabic
English	yes	yes	yes	no
Hungarian	no	yes	no	no
Thai	no	yes	no	no

Table 2: Adjustment of VOT and devoicing of liquid to speaking rate.

The fact that the VOT in English adjusts with speaking rate is not surprising, since it has ticulation is concerned, it seems that the observed VOT pattern are solely a property of the stop consonant and do not seem to contribute to the devoicing of the liquid since they have also been observed in stop-vowel sequences as mentioned above and they occur independent of liquid devoicing as seen in the data discussed here. Therefore, the observed VOT pattern cannot contribute much to the answer of the research question of whether laryngeal coarticulation adjusts to speaking rate. The results presented above show that devoicing of the liquid adjusts proportionally to speaking rate only in the English tautosyllabic condition, indicating that devoicing in that condition originates at the level of gestural planning, and, therefore, should be considered phonological in English, but not in Hungarian or Thai.

4.3. Language Specific Differences and Similarities

One respect in which the three languages differ is the phonetic category of the stop consonants. While English voiceless stops are classified as aspirated stops, the Hungarian voiceless stops have been claimed to be unaspirated (Gósy, 2001). The Thai stops used in the current study were also voiceless unaspirated. This classification corresponds to some degree with the VOT values obtained from the three languages in the current study. Averaging across all subjects and utterances for each language, we find that the VOT in English is significantly longer than in Thai (p ¡ .0001). However, although the VOT in Hungarian tended to be somewhat shorter than in English, the difference between the English and Hungarian VOTs was only marginally statistically significant ($p = .07$). The difference between Hungarian and Thai on the other hand was statistically significant ($p < .0001$). This suggests that Hungarian stops should be categorized phonemically as aspirated rather than unaspirated stops.

The expectation stated earlier was that the VOT would be correlated with the amount of liquid devoicing. However, once again, we find that VOT does not predict very well how much devoicing to expect. While the VOT in Hungarian stops was only marginally shorter than the VOT in English stops, the amount of devoicing in Hungarian liquids following a voiceless stop is significantly greater ($p = .03$) than in English. The overall percentage of devoicing in Thai is significantly less than either English ($p = .001$) or Hungarian ($p = .0001$).

The other difference in phoneme identity lay in the difference between the rhotics: trilled /r/ for Hungarian and Thai, and the alveolar approximant /ô/ in English. However, the overall difference in VOT and percentage of devoicing in the liquids for the three languages, as well as the languages specific differences with respect to the influence of the presence of a boundary and speaking rate observed above are confounding factors that render a general comparison of the difference between the two types of rhotics impossible.

5. Discussion and Conclusion

The study reported in this paper investigated the devoicing of liquids in voiceless stop-liquid sequences in Thai, Hungarian, and English. More specifically, the study investigated whether liquid devoicing is influenced by the presence of a syllable or morpheme boundary between the voiceless stop and the liquid, and whether it adjusts to speaking rate. The results showed that the VOT was marginally influenced by a boundary in English, but not at all in Hungarian and Thai. The amount of devoicing, on the other hand, was significantly influenced by the presence of a boundary in English, marginally influenced in Hungarian, and not at all in Thai. Furthermore, the results indicated that for sequences in the onset of a syllable the VOT adjusted to speaking rate only in English; however, across syllable boundaries the VOT adjusted in all three languages. The effect that speaking rate had on the amount of devoicing was very similar for the tautosyllabic condition in that only in English the amount of devoicing adjusted to speaking rate. In the heterosyllabic condition, however, the amount of devoicing in the liquid did not adjust to speaking rate for any of the three languages. This mismatch in the patterning of VOT and devoicing shows that the devoicing of liquids in voiceless stop-liquid sequences does not correlate with the VOT of the voiceless stop. While the VOT seems to be the the Vogebp6-28 guage9:-28

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