Some aspects of Japanese consonant articulation: A preliminary EPG study*

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1 Preamble

Osamu Fujimura, a great phonetician who contributed to the foundation of modern phonetic science, passed away on March 13th, 2017 (Erickson & Kawahara, 2017).[1] One of the strong messages that Osamu conveyed to us through personal conversations was in regard to "IPA-based segmentalism"—a hypothesis/belief that our phonetic behavior can be captured or described in terms of a set of discrete symbols; i.e., the IPA (International Phonetic Alphabet). The term "IPA-based segmentalism" implies that, obviously, Osamu was very critical of relying too much on the IPA. While we agree—and probably Osamu would too—that the IPA is a useful and necessary system for phonetic studies, we also think that relying too much on the IPA has a number of drawbacks. In this short paper, we would like to describe some Japanese data concerning consonant articulation that we recently obtained using ElectroPalatoGraphy (EPG) in order to show that there are some articulatory details that cannot be captured by the IPA symbols. We also maintain that the kinds of observations that we report in this paper are very hard, if not impossible, to obtain by impression-based or introspection-based approaches which are very common in theoretical linguistics, and even in some branches of phonetic schools. Instrumental techniques such as EPG allow us to observe what we could not observe otherwise.

Although we have begun this paper with some remarks on Osamu Fujimura and the IPA, the paper can be read more or less independently of the issue of IPA-based segmentalism. Since we were invited to write this article soon after Osamu's death, we opted to relate the data to one of his philosophies about phonetic science. We were actually very interested in hearing what Osamu would think of this dataset, but we did not have a chance to share it with him in person; thus, we would like to present this paper as a tribute to him. However, with this all said, readers are welcome to take this paper as a more descriptively-oriented paper showing some details of consonant articulation in Japanese.[2] There have not been many EPG studies on Japanese consonant articulation (though see Kochetov 2012, 2017; Kochetov & Kang 2017; Sudo et al. 1982, as well as some previous reports written by the second author, in particular, Matsui 2017). Our project, which is admittedly in progress and still preliminary, is intended to provide a step toward filling that gap.

2 Method

2.1 *What is EPG?* ElectroPalatoGraphy (EPG) is a system that detects contact between the tongue and the palate (a.k.a. linguopalatal contact). The first step in conducting an EPG experiment is to create an artificial palate customized for each speaker.[3] The artificial palate we used in this experiment has

* Thanks to Osamu Fujimura and Jason Shaw for their inspiration. Portions of this material were presented at the annual meeting of the Phonetic Society of Japan 2016 at Waseda University (see Matsui et al. 2016) and at the 1st meeting of the Asian Junior Linguistics conference at International Christian University. We are grateful for the comments that we received on these occasions. The author names appear alphabetically; both authors contributed to the conception of this work; the first author mainly wrote up the results; the second author recorded and analyzed the results. As with other working volume papers, this work is in progress. Thanks to Natalie Dresher and Helen Stickney for their skillful proofreading.

[1] See also his memorial website at `http://fujimurainstitute.org/osamu/`.

[2] Students should NOT take this paper as a sample for an experimental report. This paper is written much more informally than it should be for a full experimental report.

[3] Our thanks to Dr. Ichiro Yamamoto for creating these artificial palates.

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62 electronodes (Figure 1, left), each of which detects contact between the tongue and the palate. The electronodes are arranged with 8 columns and 8 rows; the first row has 6 columns, and the rest of the rows have 8 columns. The electronodes are arranged in such a way that the first two rows represent tongue contact at the alveolar region, the next two represent tongue contact at the post-alveolar region, the next three represent tongue contact at the hard-palate, and the last row represents tongue contact at the soft-palate (Figure 1, right). EPG is not suited to study tongue contact any further back in the oral cavity (it would cause the gag reflex to use a longer artificial palate that goes deeper into the soft-palate region), nor is it able to detect labial articulation. Hence, the targets of EPG experiments are necessarily limited to those that are produced with a tongue tip (i.e. coronals and palatals) (though see Kochetov 2017 for an EPG study of non-coronal consonants in Japanese).

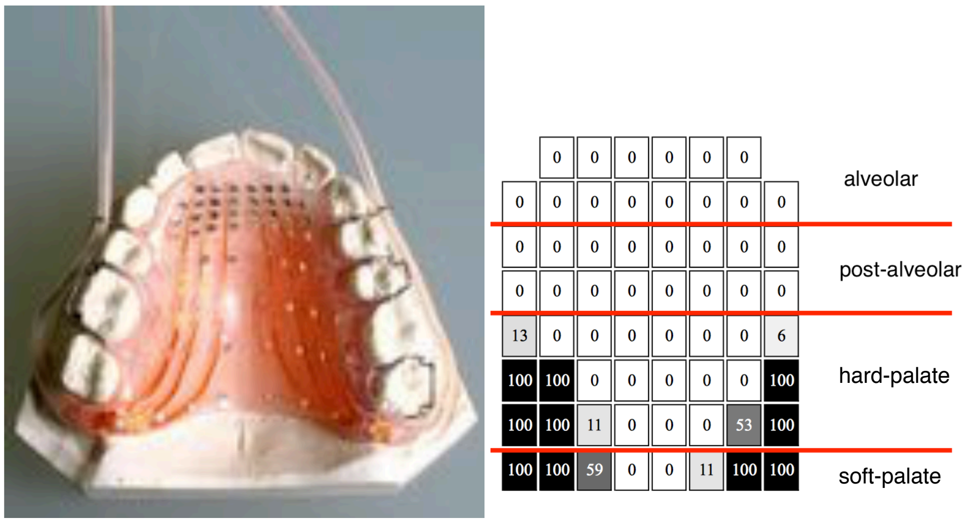

Figure 1: Illustration of the EPG. Left = an actual artificial palate with 62 electronode sensors, right = a schematic result figure.

2.2 *Other methodological details* In the current experiment, the stimuli were existing reduplicated mimetics like /pata-pata/, /pera-pera/, and /ɡutsu-ɡutsu/. These stimuli were chosen for the experiment because Japanese speakers can geminate the second consonant of these words to express emphasis, as in /patta-pata/, /perra-pera/, and /ɡuttsu-ɡutsu/ (Kawahara, 2013), and hence they were suited for exploring the nature of the articulation of geminates, which we report in section 4. There were three items per each consonant type (see Table 1), and each stimulus was repeated five times. While we have so far recorded five speakers, we will limit our discussion to two speakers, referred to as Speakers 1 and 2 in this paper, due to space limitation. Neither of the speakers had a hearing or articulation problem.

Table 1: Stimulus list.

C_2	item 1	item 2	item 3
/t/	/kata-kata/	/ɡata-ɡata/	/peta-peta/
/d/	/ɡuda-ɡuda/	/kudo-kudo /	/odo-odo/
/ɾ/	/paɾa-paɾa/	/peɾa-peɾa/	/doɾo-doɾo/
/z/	/ɡiza-ɡiza/	/ozu-ozu/	/uɟi-uɟi/
/s/	/koso-koso/	/kasa-kasa/	/ɸusa-ɸusa/
/ts/	/katsu-katsu/	/ɸutsu-ɸutsu/	/ɡutsu-ɡutsu/
/tɕ/	/netɕi-netɕi/	/ɡutɕa-ɡutɕa/	/katɕa-katɕa/

The EPG data were recorded using WinEPG (Articulate Instruments Ltd.).[4] The sampling frequency

[4] See `http://bit.ly/2qoYg9a` for a demo video.

of the EPG system was 100 Hz (i.e. linguopalatal contacts were recorded every 10 ms). The analysis was conducted using Articulate Assistant (Articulate Instruments Ltd.). Statistical comparisons, when necessary, were made using a non-parametric Friedman test. Since there were inter-speaker variations, each comparison was made within each speaker.

3 Japanese /t/ and /s/

In order to illustrate how we interpret EPG data, we will start with the discussion of the linguopalatal contact patterns of /t/ and /s/, shown in Figure 2. Numbers in each cell show the percentage of tongue contact across all repetitions. The tongue contact pattern for /t/ (Figure 2, left) shows that for Japanese /t/, the whole alveolar region is sealed. In addition, we observe that the closure is complete in the sense that there is lateral closure as well. The tongue contact pattern for /s/ (Figure 2, right) shows that although the alveolar region is not entirely sealed, which is necessary to create frication, the lateral regions (the leftmost and rightmost columns) are completely sealed. This aspect of /s/—the lateral closure—is something that is not very often discussed in the phonetic literature (or even taught in introductory phonetics classes), and it highlights the importance of examining phonetic behavior through devices such as the EPG.

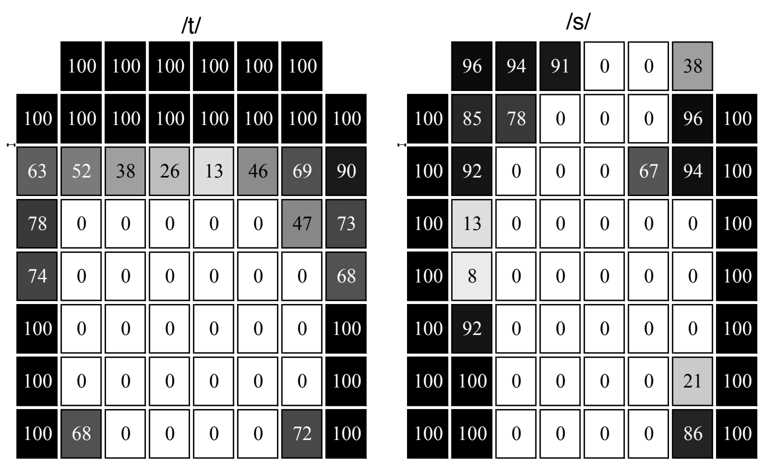

Figure 2: The EPG data of a voiceless stop and a voiceless fricative in Japanese. Left = /t/, right = /s/. Data of Speaker 2.

Next, Figure 3 illustrates the articulation of /t/ and /s/ by Speaker 1. We observe interesting differences between the two speakers. On the one hand, Speaker 1 has more extensive linguopalatal contact for /t/ than Speaker 2; the clearest difference lies in the post-alveolar constriction and the left lateral constriction. On the other hand, Speaker 1's lateral occlusion for /s/ does not extend to the alveolar region, while Speaker 2's lateral occlusion is much more extensive (see also Kochetov 2017 for a similar observation on the inter-speaker variability of /s/ in Japanese). This observation raises several interesting questions to explore in the future: where does the variation come from?; what kinds of variations are possible?; what are the acoustic and perceptual consequences of these variations? All of these questions should be addressed in future research.

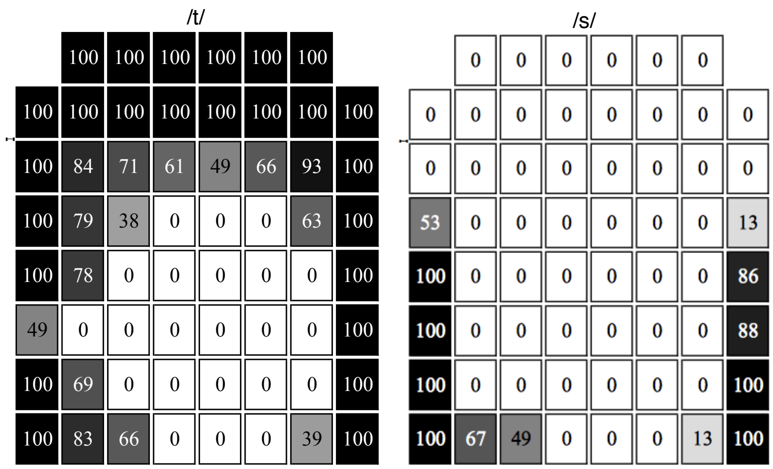

Figure 3: The EPG data of a voiceless stop and a voiceless fricative in Japanese. Left = /t/, right = /s/. Data of Speaker 1.

4 Geminates

One of the main aims of this EPG project is to explore the nature of geminate articulation, and we were inspired to explore this topic for a number of reasons. Although (Japanese) geminates have almost always been characterized as "long consonants" (Kawahara, 2015b), there are a few reasons to think that this is an oversimplified characterization. One is the acoustic observation that F1 is lower next to geminates than next to singletons (Kawahara, 2006), which implies stronger constriction in the oral cavity for geminates (Stevens, 1998). Another reason, which is compatible with this acoustic observation, is the report by Yanagisawa & Arai (2015) who showed via a perception experiment that formant transition in the following vowel is necessary in order for the geminate percept to arise (see also Arai et al. 2017). In general, evidence from speech perception experiments has demonstrated that geminates are not simply "prolonged" versions of corresponding singleton consonants in Japanese, as shortening constriction intervals of geminates does not necessarily result in the singleton percept (Fukui 1978, see Kawahara 2015b for a summary of other similar experiments). All of these results imply that geminates may involve stronger—not just longer—constriction compared to their singleton counterparts. Against this background, we wanted to explore the articulatory nature of geminate consonants in Japanese.

Figure 4 compares the linguopalatal contact patterns of singleton /t/ and geminate /tt/ of the two speakers recorded in the current experiment. Inspection of these patterns reveals that while singleton /t/ has extended contact with the palate already, the geminate /tt/ has even more extended contact, as observed by some previous EPG studies on Japanese geminates (Kochetov, 2012; Kochetov & Kang, 2017). This difference between singletons and geminates was statistically significant (Speaker 1: $\chi^2(1) = 19.17, p < .001$; Speaker 2: $\chi^2(1) = 22.0, p < .001$). We observe that the tongue contact is more extended for geminates not only in the front portion of the palate, but also in the lateral regions. We thus conjecture that the whole tongue is raised more for geminates than for singletons.

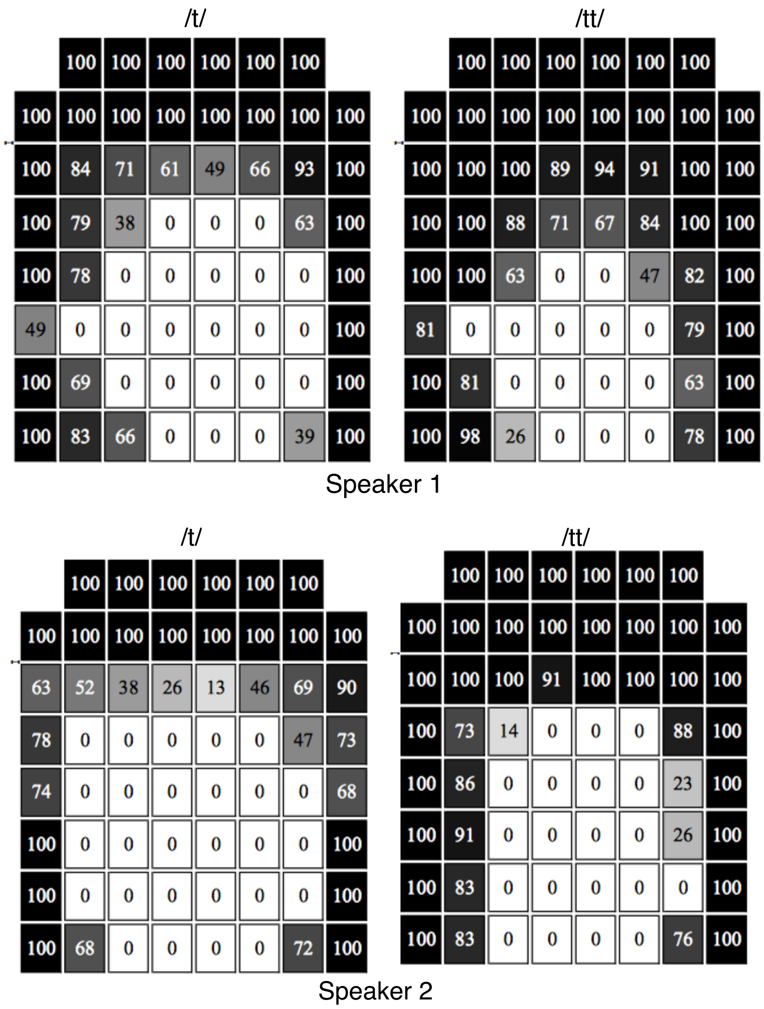

Figure 4: The EPG data of a singleton and geminate pair in Japanese. Left = /t/, right = /tt/. Top panels; Speaker 1; bottom panels: Speaker 2.

In a sense, geminate articulation can thus be considered to be "stronger" than singleton articulation. Note that this stronger articulation of geminate /tt/ in Japanese is not represented in the current IPA system (Okada, 1999); nor has it been, in our opinion, very clearly observed through introspection or impression-based transcription. Indeed, as far as we know, only through EPG studies like the current study or other EPG-based studies (Kochetov, 2012; Kochetov & Kang, 2017), have we been able to reveal this aspect of geminates.[5]

Why do geminates involve stronger closure? It may be that since geminates have a longer time to articulate, they can achieve more extended contact—i.e. they have more time to make closure. In other words, singleton consonants are "undershot" (Lindblom, 1963), because they do not have time to fully reach the "intended target".[6] To explore this possibility, Figure 5 presents the time course of the linguopalatal contact of singleton /t/ and geminate /tt/, in which each frame is 10 ms. The figure shows first of all that

[5] The first author is happy to confess that he did not realize this aspect of geminate /tt/ in Japanese through his introspection, despite having written an overview article on the phonetics of geminates in Japanese (Kawahara, 2015b).

[6] This explanation assumes that the tongue moves with the same speed for singletons and geminates. This assumption, however, does not seem to be true—the tongue moves more quickly for singletons than for geminates (Löfqvist, 2006, 2007), which already undermines the undershoot hypothesis. We will nevertheless examine the possibility of undershoot, because it is a very intuitive explanation.

for both singleton /t/ and geminate /tt/, it takes only 4 frames (= 40 ms) to reach their steady state; i.e. to complete their closure. Second, the singleton /t/ maintains its steady state for 7 frames (= 70 ms). Thus, if the speaker had wanted to make stronger tongue contact for /t/, he indeed had plenty of time to do so, but in reality, he did not. These results therefore deny the possibility that singleton articulation involves articulatory undershoot.

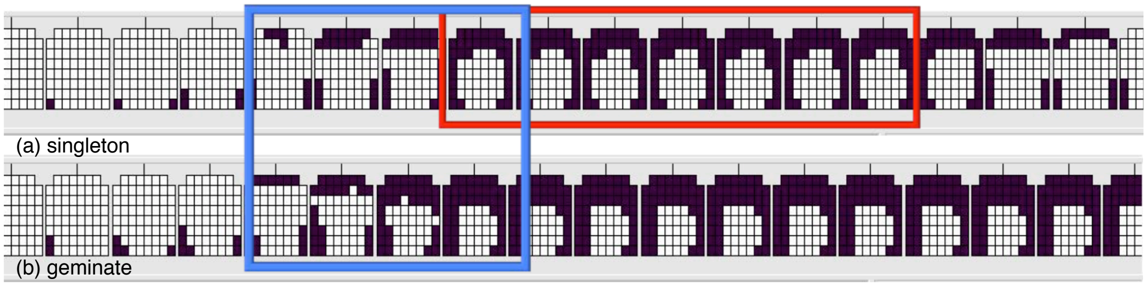

Figure 5: The time course of articulation of singleton /t/ and geminate /tt/. Each frame is 10 ms. Top = singleton /t/; bottom = geminate /tt/. Data of Speaker 1.

Another informative set of examples is given in Figure 6, which shows the articulation of /d/s in various positions: intervocalic /d/, word-initial /d/, and geminate /dd/. The data for word-initial /d/ was obtained from the pronunciation of /doro-doro/ (thus based on 5 repetitions). We observe that both word-initial /d/ and geminate /dd/ show more extended contact than intervocalic singleton /d/ (the difference between intervocalic /d/ and word-initial /d/: $\chi^2(1) = 12.57, p < .001$, and the difference between singleton /d/ and geminate /dd/: $\chi^2(1) = 12.46, p < .001$). The strengthening of articulation of word-initial consonants is well-known (see e.g. Cho & Keating 2001; Cho 2006; Cho & Keating 2009; Fougeron & Keating 1997; see also Maekawa 2010), and it may partly have to do with the fact that speakers have more time to articulate word-initial consonants than intervocalic consonants. However, the comparison between the word-initial /d/ and the geminate /dd/ still shows a difference—geminate /dd/ is even stronger than word-initial singleton /d/ ($\chi^2(1) = 4.48, p < .05$). This observation is another reason for us to think that strengthening of articulation in geminates is an intentional one, rather than mechanical undershoot—the degree of linguopalatal contact is not purely determined by how much time a speaker has to articulate a particular consonant.

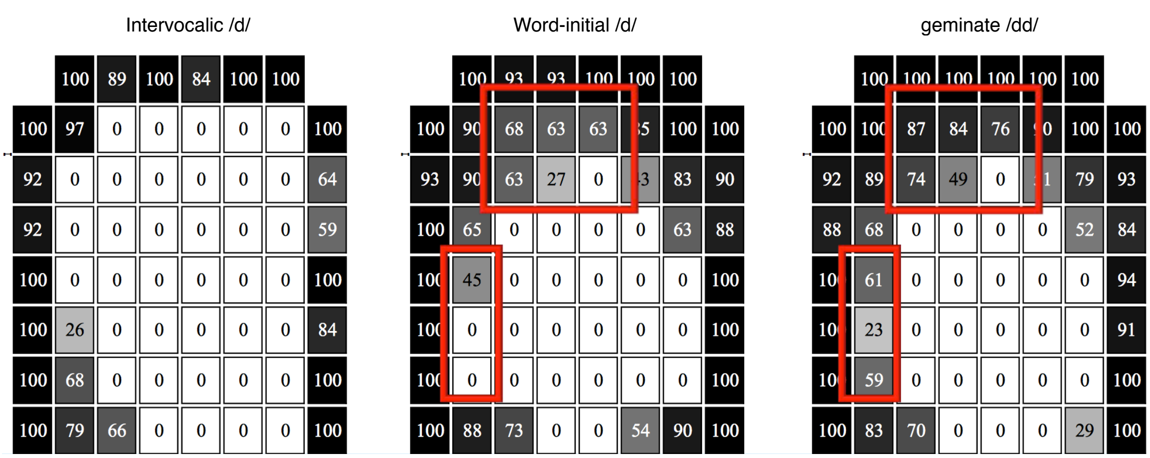

Figure 6: Comparison of /d/s produced in various environments: intervocalic /d/, word-initial /d/, and geminate /dd/. Data of Speaker 1.

Yet another aspect of geminate articulation that we find interesting is the comparison between singleton /s/ and geminate /ss/, shown in Figure 7. For this fricative pair, it seems, there are no substantial differences between singletons and geminates (Speaker 1: $\chi^2(1) = 3.57, n.s.$, Speaker 2: $\chi^2(1) = 1.0, n.s.$). In particular, Speaker 1 could have extended his lateral occlusion toward the front part of the palate to make "stronger" articulation, but no such strengthening is observed. While we have no explanations as to why only /tt/, not /ss/, show articulatory strengthening with respect to their corresponding singletons, the overall observation shows that it is an aspect of Japanese phonetics that is actively controlled (for the general debate concerning "automatic phonetics" vs. "controlled phonetics", see Chomsky & Halle 1968, Keating 1988, and Kingston & Diehl 1994).

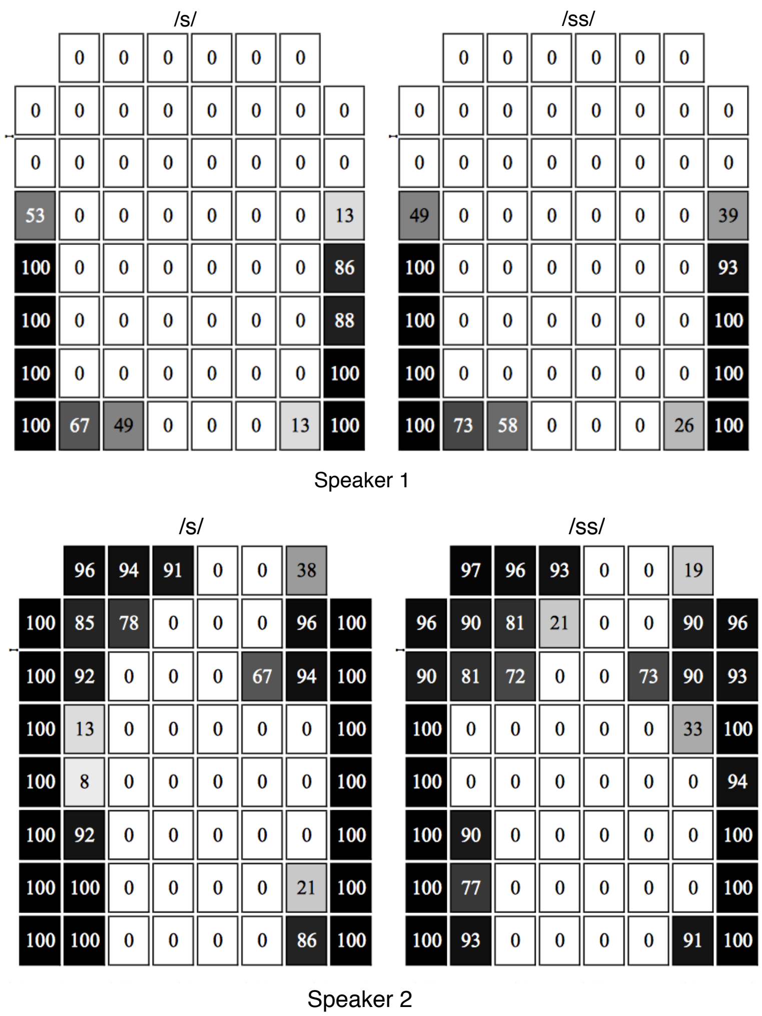

Figure 7: The EPG data of /s/ and /ss/.

The scenario looks slightly different for /z/, however. When geminated, Japanese /z/ is realized as an affricate [ddz] (Maekawa 2010 and references cited therein); as a consequence, the tongue contact is extended for the geminated version, as shown in Figure 8.

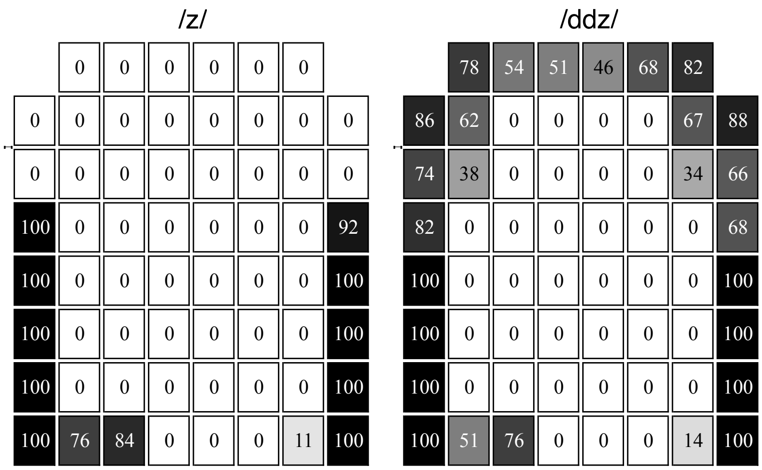

Figure 8: The EPG data of /z/ and /ddz/. Data of Speaker 1

Finally, to explore whether the lack of articulatory strengthening is specific to /ss/ or whether it is observed in other types of fricatives, we re-recorded Speaker 2 pronouncing another mimetic word /içi-içi/, with singleton /ç/ and geminate /çç/ (/ç/ = a palatal voiceless fricative). The results appear in Figure 9, which shows no extended linguopalatal contact for geminate /çç/ compared to singleton /ç/. At this point, it seems safe to conclude that articulatory strengthening does not occur for voiceless fricatives in Japanese geminates.

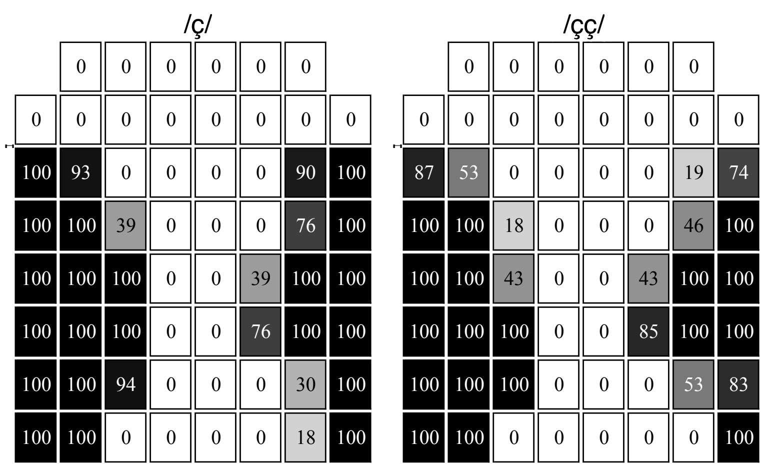

Figure 9: The EPG data /ç/ and /çç/. Data of Speaker 2

In summary, we have found that some types of Japanese geminates—/tt/, /dd/ (and [ddz])—show more extended linguopalatal contact than singletons, while some other types of geminates—voiceless fricatives—do not show such patterns. We maintained that this strengthening effect, when present, is controlled rather than automatic. We are now interested in how robustly the generalization holds across languages. Although the cross-linguistic comparison is at a preliminary stage, Italian seems to show a similar kind of articulatory strengthening in geminates (Farnetani, 1990; Payne, 2006). In Cypriot Greek, geminates show a more extended contact area than singletons utterance-medially, but not utterance-initially (Armosti, 2009). In Berber, we find exactly the same pattern as Japanese: geminate stops show more extended linguopalatal contact than their corresponding singletons, but geminate fricatives do not (Ridouane & Hallé, 2017), a cross-linguistic parallel which we do not believe to be a coincidence. However, in English, such strengthening does not seem to be apparent for "fake geminates"—two sequences of consonants created by morphological concatenation (Byrd, 1995). Further cross-linguistic investigation is warranted to explore in what kinds of environments articulatory strengthening occurs to which kinds geminates in what languages—and why.

5 Japanese "/r/"

While the Japanese liquid is considered to be a "post-alveolar flap" in the standard Japanese IPA transcription system (Okada, 1999), some have argued that its phonetic realization varies rather substantially (Arai, 2013; Kochetov, 2017; Sudo et al., 1982). Our EPG data supports the latter view. Figure 10 compares the articulation of /r/ in three vocalic contexts—between /a/, between /i/, and between /o/—based on 10 repetitions.

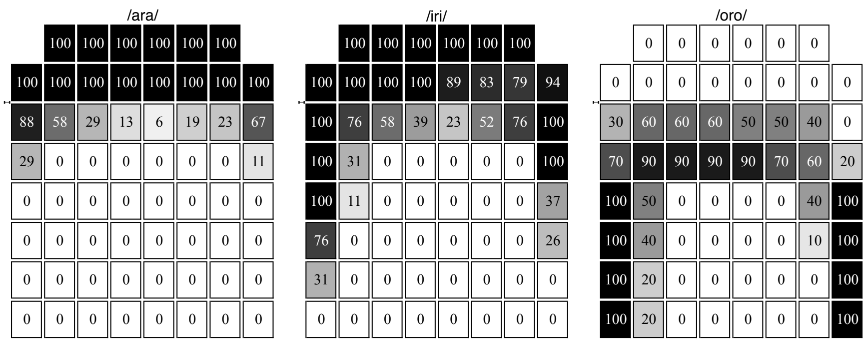

Figure 10: The EPG data of "/r/" in different vocalic environments: /ara/, /iri/, /oro/. Data of Speaker 2.

We observe that the realization of Japanese "/r/" radically differs depending on its vocalic environments. Between /a/, there is no lateral constriction, so this sound is what would be described as "a dentalized lateral" ([l̪]) in the IPA. Between /i/, we observe some lateral constriction in the hard-palate (=palatal) region; thus, one could consider the consonant to be a palatalized tap (i.e. [ɾʲ]). Between /o/, the tongue contact is much further back, mainly distributed around the post-alveolar region, which can be written as [ɹ̠]. Exactly which IPA symbol to assign to each phonetic realization is not that important here; what is important is that the phonetic realizations of /r/ are so variable that it forces us to rethink the convention to call Japanese /r/ simply a "post-alveolar flap".

Finally, Figure 11 compares the EPG data of singleton /r/ and geminate /rr/. Just like the stop geminates in Figure 4 (=/tt/) and Figure 6 (=/dd/), we observe strengthening of the articulation in the sense that geminate /rr/ shows more extended contact with the palate than a singleton /r/ does. Most notably, the alveolar region is almost completely sealed, while the lateral constriction is weak; these patterns remind us of the articulation of [l]. It may be the case that Japanese /r/, when geminated, is realized as [ll].[7]

[7] Michael Becker, a graduate colleague of the first author, insisted that the first author's Japanese /rr/ sounds like [ll]. This data seems to show that he was right.

An interesting implication of this observation is that Japanese speakers *are* able to produce [l] and (some sort of) [r], as different realizations of /r/, despite the fact that (untrained) Japanese speakers are famously unable to perceive the difference between /l/ and /r/ in English (see e.g. Bradlow et al. 1997). There may be a pedagogical application of our current finding—knowing that they are producing both a rhotic liquid and a lateral liquid in their native language may help Japanese speakers to overcome the perceptual challenge that they face when listening to, and speaking in, English. Since we are not experts in this area, we will not go into further detail on this topic, but we hope that this is an interesting line of research to pursue.

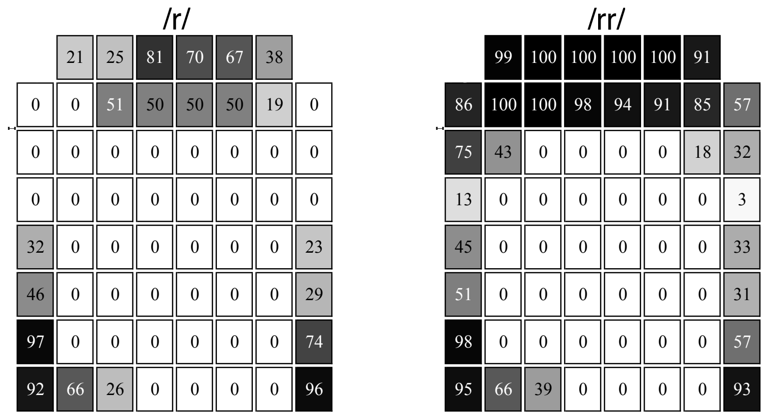

Figure 11: The EPG data of singleton and geminate /r/.

6 Conclusion

The main aim of this paper was a modest one. We reported a set of preliminary results from our EPG experiment that is still in progress. Despite its preliminary nature, the dataset has already revealed some aspects of Japanese consonant articulation which have hitherto not been discussed in depth in the literature: the lateral closure of /s/, articulatory strengthening of geminate stops and lack thereof for geminate fricatives (modulo /z/), and various realizations of Japanese /r/. We also discussed how these results may bear on the issue of the IPA-based transcription of Japanese phonetics. Of course, none of the problems are insurmountable within “IPA-based segmentalism”. One can always refine and include coarticulatory and other phonetic details in IPA-based transcriptions. However, as Ladefoged (2006) puts it, “In practice, it is difficult to make a transcription so narrow that it shows every detail of the sounds involved” (p.47). Some abstraction is always necessary. Our overall message is that it is important to always bear in mind that IPA transcriptions do not perfectly represent phonetic reality. Maybe this is an obvious message to most researchers in the field, but we feel that it is sometimes forgotten.

We reiterate that we are not at all proposing to purge the IPA from phonetic studies. Our message is a bit more subtle: relying too much on the IPA may cause one to miss some important phonetic details, such as those that we identified in this paper. To end this paper, we would like to briefly come back to Fujimura’s C/D model (Fujimura, 2000), which is designed to handle both qualitative and quantitative aspects of speech sounds. It is a model that takes as its input a set of qualitative features, converts them to quantitative articulatory commands, and distributes them to different articulators appropriately. Both of us agree with Osamu that it is absolutely essential that we recognize the qualitative aspects of sound representation—which may as well consist of something like the IPA, or as in the C/D model, a set of unary distinctive features—and quantitative aspects of sounds, which include those aspects of consonantal articulation revealed in this paper (Kawahara, 2015a; Matsui, 2017).[8]

[8] Another undesirable consequence of the dominance of the IPA system may occur in the pedagogical context. Some students, apparently, are given the wrong impression that describing sounds in unknown languages using the IPA is all there is to it in phonetics, and it is necessary for them to memorize all the IPA symbols, plus their place of articulation and manner of articulation. The first author was once interested in how Japanese university students think of phonetics (“Onseigaku”) and searched on Twitter. Alas, Twitter was filled with tweets complaining how tedious it is to have to remember IPA symbols for their phonetics exams. We believe that there is something that is more fun and attractive in phonetics research than that, and we need to try our best to convey that message to our students. Of course, if students like transcribing languages with IPA, we do not mean to claim at all that it is not a fun thing to do.

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