The phonetics of obstruent geminates, *sokuon*[*]

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Abstract

This chapter provides an overview of the phonetic aspects of Japanese obstruent geminates, referred to as *sokuon* in the traditional Japanese literature. This chapter starts by reviewing the acoustic correlates of Japanese geminates. The primarily acoustic correlate has been shown to be constriction duration, accompanied by various secondary cues. Then the chapter turns to the effect of manner on geminates, focusing on fricative geminates and voiced stop geminates. The chapter also compares the acoustic features of Japanese geminates with those found in other languages. Then the chapter discusses the perception of geminates, reviewing several perceptual cues for Japanese geminates, again in comparison with other languages. The final topic of the chapter is articulatory studies of geminates. Throughout I raise issues that require future experimentation, and the final section of the chapter lays out more issues that are not covered in the main body of the paper.

Contents

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1 Introduction

Japanese has a phonemic contrast between short and long consonants, as exemplified by minimal pairs like [kata] 'frame' vs. [katta] 'bought' and [hato] 'dove' vs. [hatto] 'hat'. Short consonants are generally referred to as "singletons" and long consonants are referred to as "geminates". In traditional Japanese terms, obstruent geminates (or their coda parts) are called *sokuon*: to represent *sokuon*, their coda part is represented with /Q/ in the traditional literature on Japanese phonology, and is represented with "small tsu" in the Japanese orthographic system. The coda portion of nasal geminates is called *hatsuon* (represented with /N/), but this chapter focuses on obstruent geminates.[1] (In the rest of the paper, I use the term "geminates" to mean "obstruent geminates" or *sokuon*.) This chapter provides an overview of the acoustic characteristics of Japanese geminates and their perceptual cues.[2]

2 The acoustic characteristics of geminates in Japanese

2.1 The primary acoustic correlate: constriction duration

Japanese is often assumed to be a mora-timed language (Warner and Arai 1999 for a review, see also the chapter on mora-timing), and geminates are moraic; for example, disyllabic words containing a geminate like [katta] 'bought' and [hatto] 'hat' have three moras. Reflecting this moraic nature, geminate consonants in Japanese involve long consonantal constriction. Phonetically speaking, the primary acoustic correlate of a singleton-geminate distinction is a difference in constriction duration—closure duration for stops and frication duration for fricatives (In this paper, I use the term "duration" to refer to phonetic measures, and "length" to refer to a phonological contrast; I use the term "constriction" as a cover term for stop closure and narrow aperture for fricatives).[3]

Before proceeding to the discussion of the actual difference, one remark about what is meant by "primary" is in order, because the concept of "being primary" can mean several different notions. A primary acoustic correlate could mean an acoustic parameter that is invariant across speakers,

[1] Approximants (liquids and glides) do not become geminates in Japanese, except in emphatic forms (e.g. [kowwai] 'very scary' from [kowai]). See Aizawa (1985), Kawahara (2001), and section 5.3 for the non-structure preserving nature of this emphatic gemination in Japanese. For phonetic grounding that may underlie the prohibition against approximant geminates, see Kawahara et al. (2011), Podesva (2000) and Solé (2002).

[2] A topic that this paper does not cover, primarily due to limitation of the author's expertise, is L2 learning of Japanese geminates. I would like to direct the readers to the following references: Han (1992); Motohashi-Saigo and Hardison (2009); Oba et al. (2009); Tajima et al. (2008), several papers in a special issue of *Onsei Kenkyuu* 11:1 (Kubozono, 2007), those cited therein, and the chapter on L2 phonology. Another topic that this chapter does not cover is a gemination pattern found in the process of loanword adaptation (e.g. [bakkɯ] 'back'), which arguably has a perceptual basis (e.g. Takagi and Mann 1994). See the chapter on the phonology of geminates and the chapter on loanword phonology on this phenomenon.

[3] For affricates, the primary acoustic correlate seems to lie in the difference in the closure duration, not in the frication duration (Oba et al., 2009).

speech styles, phonological contexts, or even across languages, and/or that it constitutes a primary perceptual cue which dominates other secondary cues (Lahiri and Hankamer, 1988) so that secondary cues are tangible only when the target stimuli are ambiguous, distributing around a range that is not found in natural speech (Hankamer et al., 1989; Pickett et al., 1999). See Abramson and Lisker (1985); Stevens and Blumstein (1981); Stevens and Keyser (1989); Whalen et al. (1993) and others for general discussion on the primacy of cues, and Abramson (1992); Hankamer et al. (1989); Idemaru and Guion (2008); Lahiri and Hankamer (1988); Pickett et al. (1999); Ridouane (2010) for the discussion of primacy in the context of length distinctions. Ridouane (2010) argues that cross-linguistically, differences in constriction duration are the most consistent acoustic correlates of singleton-geminate contrasts.

With this said, the primary acoustic correlate of Japanese geminates is that geminate consonants are characteristically longer than singleton consonants. Figures 1 and 2 show illustrative waveforms and spectrograms of a singleton [t] and a geminate [tt] in Japanese (the time scale is the same, 300ms). As we can see, the geminate [tt] has a longer closure than the singleton [t].

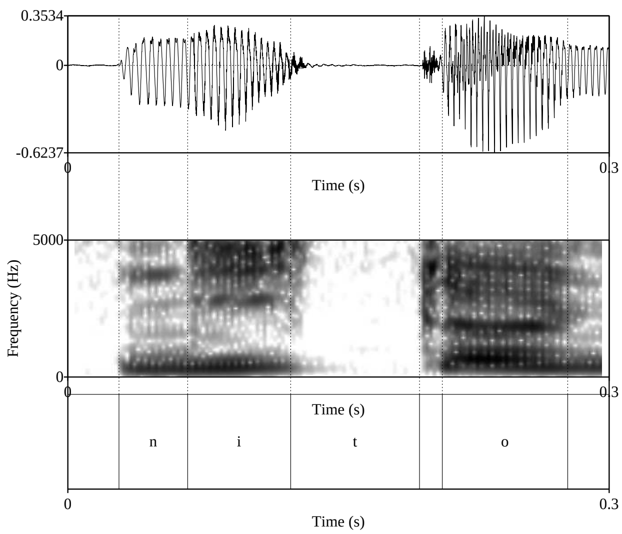

Figure 1: A singleton [t]

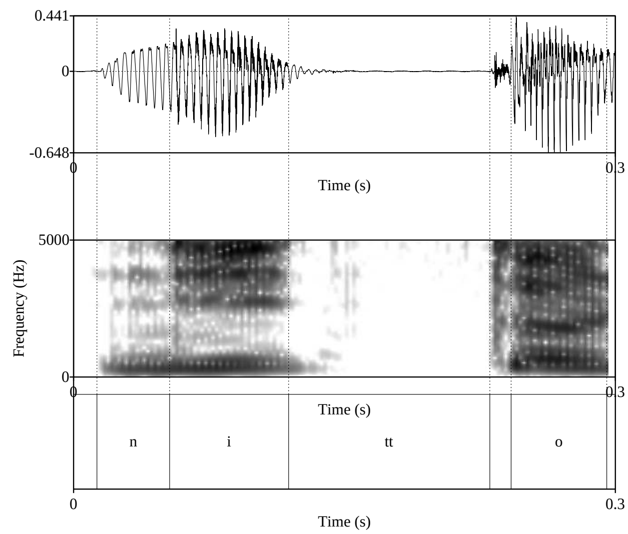

Figure 2: A geminate [tt]

Many acoustic studies have investigated the durational properties of singleton-geminate contrasts in Japanese, and Table 1 summarizes their findings. This summary shows that geminates are generally at least twice as long as corresponding singletons, and can sometimes be as three times as long, regardless of the place of articulation or voicing status of the consonants (though see section 2.3).

2.2 Secondary acoustic correlates

As with many other phonological contrasts, a singleton-geminate contrast is acoustically realized not only in terms of constriction duration, but also manifests itself in multiple acoustic dimensions (multiplicity of acoustic correlates of phonological contrasts has been an important topic in the history of the phonetic theory: e.g. Abramson 1998; Kingston and Diehl 1994; Lisker 1986 and references cited therein).

2.2.1 Other durational correlates

In Japanese, vowels are longer before geminates than before singletons (Campbell, 1999; Fukui, 1978; Han, 1994; Hirata, 2007; Hirose and Ashby, 2007; Idemaru and Guion, 2008; Kawahara, 2006a; Ofuka, 2003; Port et al., 1987; Takeyasu, 2012).[4] Port et al. (1987) found for example that [ɯ] is on average 68ms before singleton [k] and 86ms before geminate [kk]. Kawahara (2006a) similarly found that vowels before voiceless singletons are on average 36.9ms while those before voiceless geminates are 53.4ms. Furthermore, some studies even found that in C_1VC_2V structure, C_1 is longer when C_2 is a geminate than when C_2 is a singleton (Han, 1994; Port et al., 1987) (cf. Takeyasu 2012 who found the opposite pattern; Hindi shows the same lengthening pattern: Ohala 2007).

On the other hand, following vowels are shorter after geminates than after singletons (Campbell, 1999; Han, 1994; Hirata, 2007; Idemaru and Guion, 2008; Ofuka, 2003). Han (1994) found the shortening of following materials (sometimes including word-final moraic nasals) by 9ms after geminates. In Idemaru and Guion (2008), the mean duration of the following vowel is 63ms after geminates and 76ms after singletons. As explicitly noted by Hirata (2007), however, this difference in duration in the following vowels is less substantial and less consistent than the difference in the preceding vowel.

Finally, one may expect that VOT (Voice Onset Time) would be longer for geminate stops than for singleton stops, because longer closure would result in higher pressure build-up behind the stop occlusion. However, it does not seem to be true: VOT is slightly shorter for geminates than for singletons in a study reported by Han (1994), and the relationship is inconsistent in other studies (Hirata and Whiton, 2005; Homma, 1981). See Kokuritsu-Kokugo-Kenkyuujo (1990) for the data on the intraoral air pressure rise in Japanese consonants, which indeed shows that geminates do not involve higher intraoral air pressure rise.

[4] Vowels are also longer in closed syllables before a so-called moraic nasal (or *hatsuon*) than in open syllables (Campbell, 1999), indicating that this lengthening is due to a general, syllable-based phenomenon. The pre-geminate lengthening can also block otherwise productive high vowel devoicing between two voiceless consonants (Han 1994; Takeyasu 2012; see also the chapter on devoicing).

Table 1: Closure duration differences between singleton and geminate stops in Japanese. Duration measures are in mili-seconds. SD=standard deviation; MoE=margin of error for 95% confidence intervals

Sources	Sing duration	Gem duration	Ratio	Note
Han (1962)	–	–	2.6 - 3.0	based on small N
Homma (1981)	[p]: 77	[pp]: 183	2.38	4 speakers
	[b]: 55	[bb]: 159	2.89	
	[t]: 62	[tt]: 170	2.74	
	[d]: 35	[dd]: 144	4.11	
	[k]: 61	[kk]: 175	2.87	
	[g]: 41	[gg]: 134	3.27	
Beckman (1982)				(SD), 5 speakers
	[k]: 89 (17)	[kk]: 195 (32)	2.25	VOT included
	[k]: 64 (15)	[kk]: 171 (32)	2.79	VOT excluded
Port et al. (1987)				(SD), 10 speakers
	[k]: 65 (12)	[kk]: 149 (25)	2.29	ɯ_ ɯ
	[k]: 66 (14)	[kk]: 146 (28)	2.21	a _ ɯ
Han (1994)				(SD), 10 speakers
(see also Han 1992)	[p]: 76.3 (5.6)	[pp]: 195.9 (21.9)	2.57	sɯ_ai
	[p]: 72.9 (9.7)	[pp]: 205.4 (29.9)	2.82	sɯ_ori
	[t]: 71.5 (7.4)	[tt]: 192.3 (27.2)	2.69	i_e
	[t]: 53.5 (8.0)	[tt]: 166.6 (24.1)	3.11	kí_e
	[t]: 57.9 (10.2)	[tt]: 174.5 (21.5)	3.01	ʃi_ei
	[t]: 52.7 (8.0)	[tt]: 170.9 (25.8)	3.24	ki_e
	[t]: 68.2 (9.0)	[tt]: 189.8 (28.5)	2.78	i_a
	[k]: 63.5 (8.5)	[tt]: 178.2 (22.5)	2.81	yo_a
	[k]: 57.5 (8.5)	[tt]: 175.8 (30.9)	3.06	ʃi_e
	[k]: 79.4 (6.6)	[kk]: 198.7 (24.6)	2.50	ha_eN
Kawahara (2006a)	vls: 59.9 (2.1)	vls: 128.6 (3.1)	2.15	(MoE), 3 speakers
	vcd: 42.3 (1.7)	vcd: 113.1 (3.0)	2.67	
Hirose and Ashby (2007)	vls: 60.5	vls: 114.2	1.89	3 speakers
	vcd: 44	vcd: 108	2.45	
Idemaru & Guion (2008)	69 (28)	206 (45)	2.99	(SD), 6 speakers all stop consonants

2.2.2 Other, non-duratinal, acoustic correlates

Several studies, most recently Idemaru and Guion (2008) and Kawahara (2006a), investigated other non-durational, acoustic correlates of a singleton-geminate contrast in Japanese. The findings are summarized in Table 2.

Table 2: A summary of other, non-durational, acoustic correlates of Japanese geminates. F=Fukui (1978), I&G=Idemaru & Guion (2008), O=Ofuka (2003), K=Kawahara (2006a). See the original papers for details of the measurement conditions

	Patterns	References
Intensity	The mean intensity difference is larger across geminates.	I&G, O
F0	Accentual F0 drop is larger across geminates.	I&G, O, K
F0	Pitch falls toward geminates in unaccented disyllabic words.	F
F1	F1 is lower after geminates.	K
Spectral tilt	H1-A1 smaller for geminates after geminates. (i.e. vowels are creakier).	I&G

From what we observe in the previous two subsections, Japanese geminates cannot be characterized as merely "long consonants". A remaining question therefore is how to represent Japanese geminates phonologically—many possibilities exist, such as (i) double consonants (often assumed in phonemic representation), (ii) moraic consonants (Hayes, 1989), (iii) a special Q phoneme—or *sokuon*—as assumed in the traditional literature (e.g. Hattori 1984), or (iv) a special syllable concatenater (Fujimura and Williams, 2008). This topic should continued to be discussed in relation to the phonological behavior of Japanese geminates, as well as to the theory of phonetic implementation of phonological representations.

2.2.3 The search for invariance

One general research program in phonetics is the search for invariance (Stevens and Blumstein, 1981). The issue addressed in this program is whether, for each phonological distinction, there exists any acoustic correlate that is invariant across phonological contexts, individual speakers, and speech styles, etc, and if yes, what they are. This issue is particularly important for a singleton-geminate contrast, because geminates in fast speech styles can be shorter than singletons in slow speech styles (Hirata and Whiton, 2005; Idemaru and Guion-Anderson, 2010).[5] Usually proposals for invariant measures take the form of a relationship between more than one acoustic parameter.

[5]It has been observed in other languages (Italian and Persian) (Hansen, 2004; Pickett et al., 1999) that geminates are more susceptible to change in duration due to speech rate than singletons are. This asymmetry seems to hold in the Japanese data as well (Hirata and Whiton, 2005; Idemaru and Guion-Anderson, 2010).

The general idea behind these studies on phonological contrasts based on durations is rate normalization, in which listeners normalize the duration of incoming acoustic signal according to the speech rate, which can be (unconcsiouly) inferred from the duration of other intervals (Miller and Liberman, 1979; Pickett and Decker, 1960). For example, when a preceding vowel sounds short, a listener may perceive that the speaker is speaking fast, and as a result even a short interval may be interpreted as long.[6]

For a singleton-geminate contrast, several relational correlates have been proposed as an invariant measure that distinguishes between singletons and geminates across different speech rates. Hirata and Whiton (2005) recorded various disyllabic tokens of singletons and geminates in nonce words and real words in three speech styles (slow, normal, fast), and considered three measures: raw closure duration, C/V_1 ratio (the ratio between the target consonant and the preceding vowel), and C/W(ord) ratio. Hirata (2007) and Hirata and Forbes (2007) further considered three more measures: C/V_2 ratio, V-to-V interval (i.e. added durations of preceding vowel, constriction and VOT) and VMora (V-to-V interval divided by mean mora duration). Idemaru and Guion-Anderson (2010) tested yet a few more relational measures: C/V_1, C/C_1V_1, C/V_2, $C/(C+V_2)$ (where C is the target consonant, C_1 and V_1 are the preceding consonant and vowel, and V_2 is the following vowel) in addition to those already tested by Hirata and Whiton (2005) (raw closure duration and C/W ratio). After recording their own various tokens of singletons and geminates in three speaking rates, for each measure, they tested classification accuracy percentages based on raw values as well as z-transformed (normalized) values within each speaker. Discriminant analyses were used, for each proposed measure, to calculate how many percentages of tokens are accurately classified as a member of the intended category. The classification accuracy percentages of all the measures in these studies are summarized in Table 3.[7]

One thing that is clear from Table 3 is that relational measures generally classify singletons from geminates better than raw durational values. Which relational measure best cross-classifies Japanese singletons from geminates is an interesting topic for on-going and future research. We cannot also deny the possibility that there are other measures, relational or not, which better cross-classify singletons and geminates in Japanese, which are yet to be uncovered.

Another important issue is the perceptual relevance—or reality—of the relational, invariant acoustic measures. For example, Idemaru and Guion-Anderson (2010) followed up their acoustic

[6]An alternative theory is auditory durational contrast in which an interval is (more or less automatically) rendered to sound longer next to a shorter interval by a general auditory mechanism (a.k.a. "durational contrast"), which is not specific to speech (Diehl and Walsh, 1989; Kluender et al., 1988). It is beyond the scope of this paper to compare these two theories (see Diehl et al. 1991; Fowler 1990, 1991, 1992; Kingston et al. 2009 for further discussion on this debate).

[7]Other relational invariant measures proposed for length contrasts in other languages include C/V_1 ratio for Italian (Pickett et al., 1999), vowel to rhyme duration ratio for Icelandic (Pind, 1986) (in which long vowels and geminates are (more or less) in complementary distribution), and the ratio of the closure duration to the syllable duration in Persian (with some further complications) (Hansen, 2004).

Table 3: A summary of classification accuracy percentages in the three studies cited in the text. See text for explanations of each measure

Hirata and Whiton (2005)	
raw C duration: C/V_1 ratio: C/W	82.2% (nonce words) and 81.4% (real words) 92.1% (nonce words) and 91.3% (real words) 98% (nonce words) and 95.7% (real words)
Hirata (2007)	
C/V_2 ratio	98.9% (nonce words) and 98.8-9.89% (real words)
Hirata and Forbes (2007)	
V-to-V interval VMora	75.5% 99.6%
Idemaru and Guion-Anderson (2010)	
C/V_1 C/C_1V_1(mora) C/V_2 $C/(C+V_2)$ C/Word raw C duration	83.7% (raw) and 85.5% (normalized) 92.6% (raw) and 94.5% (normalized) 94.1% (raw) and 94.9% (normalized) 92.3% (raw) and 93.0% (normalized) 96.3% (raw) and 96.8% (normalized) 87.2% (raw) and 88.3% (normalized)

study with a perception test, which showed that while preceding mora (CV) duration significantly affects the perception of geminacy, the following materials (C/V_2 ratio) do so only marginally, despite that ratios involving these two factors yielded comparable accuracy percentages in production (see Table 3). See also Amano and Hirata 2010; Otaki 2011 and section 3.2 for further discussion on the relationship between production and perception, especially in terms of contextual effects on the perception of length contrasts.

2.3 Manner effects

One issue that received relatively less attention in the previous literature is the comparisons of different manners of geminates in Japanese. Most previous acoustic studies on Japanese have investigated oral stops (Beckman, 1982; Han, 1992, 1994; Hirata and Whiton, 2005; Hirose and Ashby, 2007; Homma, 1981; Idemaru and Guion, 2008; Kawahara, 2006a), although some studies did measure geminates of various manner types (e.g. Han 1962 who measured oral stops and nasals). Other languages that have been studied in this light include Italian (affricates: Faluschi and Di Benedetto 2001; fricatives: Giovanardi and Di Benedetto 1998; nasals: Mattei and Di Benedetto 2000; see also Payne 2005), Cypriot Greek (Tserdanelis and Arvaniti, 2001), Guinaang Bontok (Aoyama and Reid, 2006), Buginese, Madurese, and Toba Batak Cohn et al. (1999).

2.3.1 Fricative geminates

Japanese allows both (voiceless) stops and fricatives to contrast in geminacy. One complication is that singleton fricatives are generally longer than singleton stops in the first place in Japanese (Beckman, 1982; Campbell, 1999; Port et al., 1987; Sagisaka and Tohkura, 1984) and other languages (Lehiste, 1970). As a result, singleton/geminate duration ratios are smaller for fricatives than for stops. Table 4 reports unpublished data collected by the author based on three female Japanese native speakers. All speakers were in their twenties at the time of recording, and the recording took place in a sound-attenuated room. Each target sound was pronounced in a (nonce) word frame [ni_o], itself being embedded in a frame sentence. All three speakers repeated 10 repetitions of all tokens.[8]

Table 4: The effects of manner of articulation on the duration of singletons and geminates in Japanese (margin of error (MoE) for 95% confidence intervals)

segment	singleton	geminate	ratio
[p]	77.3 (7.8)	129.6 (8.1)	1.68
[t]	55.5 (4.6)	124.4 (7.3)	2.24
[k]	67.3 (7.1)	128.7 (7.1)	1.91
[b]	53.1 (3.8)	131.4 (8.8)	2.47
[d]	36.6 (1.9)	116.0 (10.4)	3.16
[g]	52.1 (3.7)	115.0 (13.2)	2.20
[ɸ]	83.5 (4.8)	144.7 (7.4)	1.73
[s]	83.2 (4.6)	134.5 (7.0)	1.62
[ʃ]	85.9 (5.7)	138.4 (7.3)	1.61
[ç]	63.4 (2.5)	132.0 (6.2)	2.08
[h]	72.2 (4.2)	143.7 (6.4)	1.99

Table 4 shows the results of duration measurements (for stops VOT were not included in the closure duration, as in many studies cited in Table 1). We can first observe that duration ratios are highest for voiced stops than voiceless stops (see also Homma 1981 and Hirose and Ashby 2007 for the same finding), which are also generally higher than for fricatives (except for [ç] and [h]).[9]

One phonological importance of this difference between stop pairs and fricative pairs is that the length contrast may be less perceptible for fricatives than for stops. The lower perceptibility

[8] I am grateful to Kelly Garvey and Mel Pangilinan for their help with this acoustic analysis.

[9] This study also found that the duration ratio for [p] is smaller than that of [t] and [k]. This lower ratio may be related to the fact that length is not contrastive for [p] in the native phonology in Japanese (see Itô and Mester 1995, 1999 and the chapter on phonological lexicon and mimetics). One puzzle, however, is why voiced stops have high duration ratios despite the fact that they are not contrastive in native Japanese phonology (Itô and Mester, 1995, 1999). See also Engstrand and Krull (1994) for the relationship between the functional load of length contrasts and their phonetic realizations. A full consideration on this relationship should be explored in future studies.

may lead to a diachronic neutralization (Blevins, 2004) and/or avoidance of fricative geminates in synchronic phonological patterns (Kawahara, 2006b) based on a principle of contrastive dispersion to avoid contrasts that are not very well perceptible (Flemming 2004 and references cited therein).

2.3.2 Voiced obstruent geminates

The effect of voicing on geminates is no less interesting. The native phonology of Japanese does not allow voiced obstruent geminates (Itô and Mester, 1995, 1999; Kuroda, 1965). The lack of voiced obstruent geminates perhaps has its roots in its aerodynamic difficulty (Ohala 1983, and more references cited in Kawahara 2006a). For voiced stops, the intraoral air pressure goes up behind oral stop closure; this rise in the intraoral air pressure makes it difficult to maintain the airflow required for vocal fold vibration. For voiced fricatives, the intraoral airpressue must rise to create frication, which again makes it difficult to maintain the transglottal air pressure drop. Perhaps for these reasons (synchronically or diachronically), Japanese native phonology does not allow voiced obstruent geminates.

However, gemination found in the context of loanword adaptation resulted in voiced obstruent geminates (e.g. Katayama 1998; Kubozono et al. 2008; Shirai 2002); e.g. [heddo] 'head' and [eggɯ] 'egg'. Nevertheless, due to the aerodynamic difficulty, voiced geminate stops are generally "semi-devoiced" in Japanese. All three speakers recorded in Kawahara (2006a) show this semi-devoicing. Figures 3 and 4 illustrate this difference between singletons and geminates: for singleton [g], closure voicing is fully maintained, while for geminate [gg], closure voicing stops in the middle of its whole closure.[10] In Kawahara (2006a), on average, closure voicing is maintained only about 40% of the whole closure. Hirose and Ashby (2007) replicate this finding and showed that voiced Japanese geminates have only 47% of closure voicing.

As far as I know, there is no quantitative study on the phonetic implementation on voiced geminate fricatives in Japanese—this is a topic which is worth pursuing in a future study.[11]

One notable aspect of this semi-devoicing of geminates is that the following, word-final high vowels after "semi-devoiced" geminates (e.g. [egg̊**ɯ**]) do not devoice, even though the vowels are preceded by a voiceless interval (Hirose and Ashby, 2007). The lack of high vowel devoicing shows that the (semi-devoiced) voiced geminates are still phonologically voiced, and that high vowel devoicing is conditioned by phonological, rather than, phonetic factors. See the chapter on vowel devoicing for further discussion on this debate.

The semi-devoicing of geminates is found in other languages (e.g. (Tashlhiyt) Berber: Ridouane 2010), but is not universal despite the fact that it presumably arises from the physical, aero-

[10] These tokens are based on new recordings made in 2010.

[11] Voiced fricatives in Japanese become affricates word-initially, although whether this alternation is free-variation or allophonic alternation is controversial (Maekawa, 2010). Osamu Fujimura (p.c., April 2012) reminded me that this alternation may happen when voiced fricatives become geminates as well, as in [oddzɯ] 'odds'.

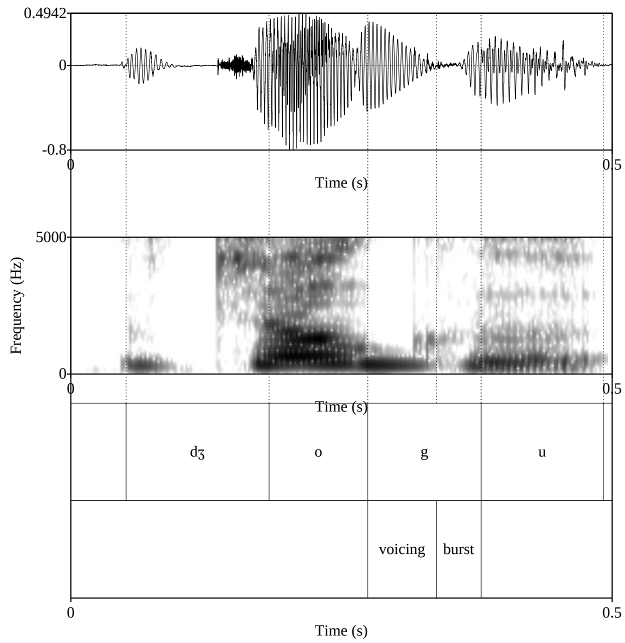

Figure 3: A singleton [g]

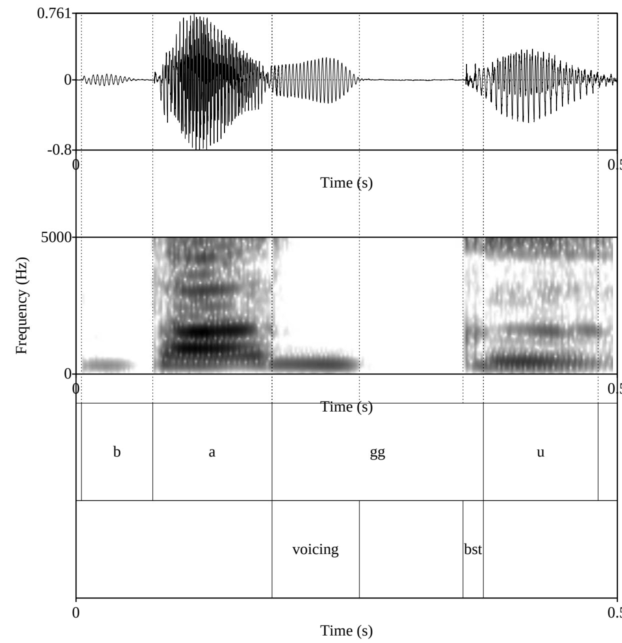

Figure 4: A geminate [gg]

dynamic difficulty (Ohala, 1983). Cohn et al. (1999) show for example that Buginese, Madurese, and Toba Batak all maintain voicing throughout the geminate closure; Egyptian Arabic is another language which has fully voiced geminates (Kawahara, 2006a), and Lebanese Arabic shows high percentages of voicing maintenance in medial, non-final, positions (Ham, 2001). The Nagasaki dialect of Japanese also seems to show fully voiced geminate stops (Matsuura, published data).

Cohn et al. (1999) speculate that speakers resort to extra articulatory maneuvers like larynx lowering and cheek expansion to deal with the aerodynamic challenges; these articulatory gestures expand the size of oral cavity, thereby lowering the intraoral pressure, providing the transglottal air pressure drop necessary for voicing (see Ohala 1983). The reason that (non-Nagasaki) Japanese speakers do not deploy such articulatory strategies—at least not to the extent that geminates are fully voiced—may be that voiced obstruent geminates are historically relatively new, and therefore the functional load of a voicing contrast in geminates is low, the contrast being contrastive only in loanwords (Itô and Mester, 1995, 1999); i.e. there are not many minimal pairs. It would thus be interesting to observe whether speakers of future generations would start producing fully-voiced geminates, if the voicing contrast in geminate becomes more widespread in the Japanese lexicon in the future. Moreover, a further cross-linguistic comparison is warranted to explore the relationship between how voiced stop geminates are implemented, and how the particular phonetic implementation patterns affect their phonological patterns (if they do at all) (see Kawahara 2006a for discussion).

2.4 Comparison with other languages

2.4.1 Constriction duration

I have already mentioned a few differences and similarities between Japanese geminates and those found in other languages, but we now turn our attention to a more detailed comparison of Japanese with other languages. As reviewed in section 2.1, Japanese geminates are acoustically characterized by long constriction duration, almost always twice as long as the corresponding singletons. Similarly, constriction duration is usually the primary acoustic correlate of a singleton/geminate contrast in other languages; e.g. (Lebanese) Arabic (Ham, 2001), Bengali (Lahiri and Hankamer, 1988), Berber (Ridouane, 2010), Bernese (Ham, 2001), Buginese (Cohn et al., 1999), Estonian (Engstrand and Krull, 1994), Finnish (Engstrand and Krull, 1994), Cypriot Greek (Tserdanelis and Arvaniti, 2001), Guinaang Bontok (Aoyama and Reid, 2006), Hindi (Ohala, 2007; Shrotriya et al., 1995), Hungarian (Ham, 2001), Italian (Esposito and Di Benedetto, 1999; Payne, 2005; Pickett et al., 1999), Madurese (Cohn et al., 1999), Malayalam (Local and Simpson, 1999), Pattani Malay (Abramson, 1987b), Persian (Hansen, 2004), Swedish (Engstrand and Krull, 1994), Swiss German (Kraehenmann and Lahiri, 2008), Toba Batak (Cohn et al., 1999), and Turkish (Lahiri and Hankamer, 1988) (see Ridouane 2010 for more languages and references).

One interesting cross-linguistic difference is the size of duration ratios between singletons and geminates; in Norwegian, for example, the ratio is much smaller than in Japanese (ranging from 1.22-1.38 in medial positions), and more substantial differences manifest themselves in the duration of preceding vowels (Fintoft, 1961) (although one should note that Fintoft measured only non-stop consonants; see section 2.3.1). In Buginese and Madurese, the geminate/singleton duration ratios are generally below 2 (Cohn et al., 1999). Generalizing this observation, Ham (2001) entertains a possibility that geminate/singleton duration ratios are smaller for syllable-timed languages than for mora-timed languages. See also Maekawa (1984) for a comparison between Standard Tokyo dialect and Akita dialect—a dialect that has been believed to be syllable-timed, which points to the same generalization.

2.4.2 Other durational correlates

As discussed in 2.2.1, vowels are longer before geminates in Japanese. This observation may come as a surprise given a cross-linguistic tendency that vowels in closed syllables are often shorter than vowels in open syllables (Maddieson, 1985). Indeed many languages have shorter vowels before geminates than before singletons; e.g. Bengali (Lahiri and Hankamer, 1988), Berber (Ridouane, 2010), Italian (Esposito and Di Benedetto, 1999; Pickett et al., 1999), Hindi (Ohala, 2007; Shrotriya et al., 1995), Malayalam (Local and Simpson, 1999), and the three Polynesian languages studied by Cohn et al. (1999).

However, there are other languages that arguably show lengthening of vowels before geminates: Turkish,[12] Shinhara (although only one of the two speakers showed clear evidence: Letterman 1994) and Persian (Hansen, 2004) (although no direct statistical tests are reported). The existence of such languages shows that Japanese may not simply be a case of typological anomaly, but languages vary in whether geminates shorten or lengthen the preceding vowels. I will come back to this issue of this cross-linguistic difference in section 3.2 in relation to its perceptual relevance.

In some languages, there are no substantial differences in preceding vowel duration between singletons and geminates; e.g. Egyptian Arabic (Norlin, 1987), Lebanese Arabic (at least for short vowels) (Ham, 2001), Estonian (Engstrand and Krull, 1994), and Hungarian (Ham, 2001). In Cypriot Greek, there is slight tendency toward shortening before geminates, but this tendency is not very consistent (Tserdanelis and Arvaniti, 2001).

Finally, the lack of effect of a geminacy contrast on VOT in Japanese is paralleled in many languages including Buginese, Madurese, Toba Batak (Cohn et al., 1999), Bernese, Hungarian, Lebanese Arabic (Ham, 2001), Bengali (Hankamer et al., 1989), and Berber (Ridouane, 2010). Cypriot Greek has consistently longer VOT for geminates (Tserdanelis and Arvaniti, 2001), but Turkish shows shorter VOT for geminates (Lahiri and Hankamer, 1988).

2.4.3 Other, non-durational, acoustic correlates

Different languages seem to show different acoustic correlates to signal singleton-geminate contrasts (in addition to the durational correlates), as summarized in (1)-(6).[13]

(1) Bengali (Hankamer et al., 1989)
  a. Root Mean Square (RMS) amplitude of the following syllable is higher after singletons.

(2) Berber (Ridouane, 2010)
  a. Geminates have higher amplitude during release.
  b. Geminates show burst release more consistently than singletons.

(3) Italian (Payne 2006, based on electropalatographic (EPG) data)
  a. Geminates involve more palatalized constriction than singletons.
  b. Geminate stops involve more complete occlusion.
  c. Geminates are associated with a laminal gesture; singletons are associated with an apical gesture.

(4) Hindi (Shrotriya et al., 1995)

[12] The difference is small and statistically not significant in Lahiri and Hankamer 1988; see also Jannedy (1995) for evidence that this lengthening applies to closed syllables in general, as in Japanese (see footnote 4).

[13] See the original references for stimulus designs and measurement conditions.

a. F0 rises toward geminates in the preceding vowel.

b. Burst intensity is stronger (by about 10dB) for geminates.

(5) Malayalam (Local and Simpson, 1999)

a. Sonorant geminates show palatal resonance with higher F2.

b. The surrounding vowels differ in F1 and F2.

(6) Pattani Malay

a. The peak amplitude of initial vowels (with respect to the following vowel) is higher after word-initial geminates than after singletons (Abramson, 1987b, 1998).

b. Fundamental frequency of word-initial vowels is higher after word-initial geminates (Abramson, 1998).

c. First vowels are longer (with respect to the second vowels) after word-initial geminates (Abramson, 1998).

d. The slope of amplitude rise is steeper after word-initial geminates (Abramson, 1998).

So far Idemaru and Guion (2008) is the most extensive study looking for spectral correlates of geminacy contrasts in Japanese, and it is yet to be investigated whether the correlates listed in (1)-(6) would be found in Japanese. (The Pattani Malay pattern may be special because it involves cases of word-initial geminates.) However, it seems likely at this point that phonetic implementation patterns of singleton-geminate contrasts are language-specific, the only universal rule being that geminates are longer than singletons (Ham, 2001; Ridouane, 2010). A remaining task in the phonetic theory is how to model the universality and language-specificity of phonetic implementation patterns of length contrasts. We should also perhaps bear in mind that "geminates" in different languages may not be the same phonological entity—there remains a possibility that these "geminates" have different phonological representations.

3 The perception of geminates

We now turn to the perception of a singleton-geminate contrast.

3.1 The primary cue: constriction duration

Many studies have shown that the longer the constriction, the more likely the target is perceived as a geminate. This effect has been shown to hold in many perception studies using Japanese listeners (Amano and Hirata, 2010; Arai and Kawagoe, 1998; Hirata, 1990; Fujisaki et al., 1975; Fujisaki and Sugito, 1977; Fukui, 1978; Kingston et al., 2009; Oba et al., 2009; Takeyasu, 2012; Watanabe and Hirato, 1985). As an example, Figure 5 reproduces the results of Kingston et al.

(2009) in which closure duration was varied from 45ms to 165ms with 15ms increments (see the next section for the three vocalic contexts). We observe that geminate responses increase as closure duration increases.

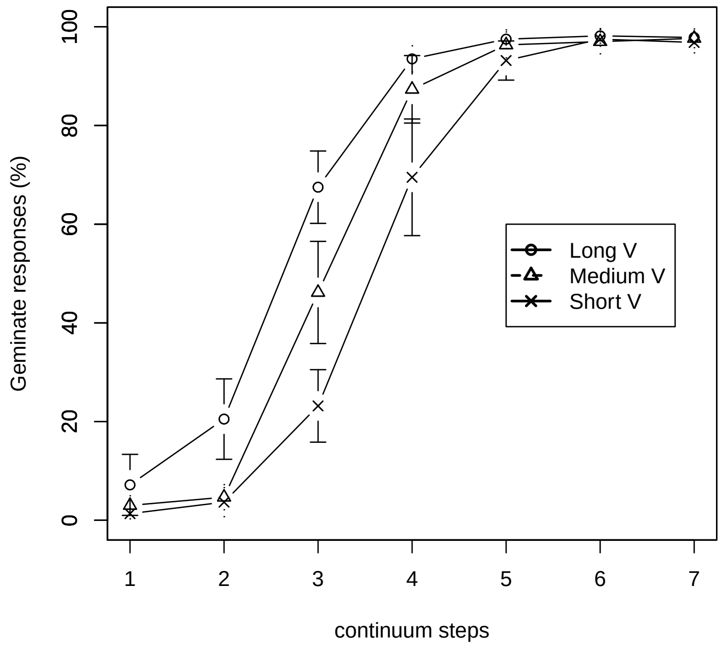

Figure 5: The effect of closure duration and the preceding vowel duration on the perception of geminates by Japanese listeners. Adapted from Kingston et al. (2009).

3.2 Contextual effects

More controversial than the effect of constriction duration is contextual effects. Fukui (1978) found that when the closure duration of an original singleton consonant is lengthened, it is almost always perceived as a geminate when the closure duration is doubled. On the other hand, shortening an original geminate did not result in a comparable shift in perception. The results show that closure duration is not the only cue for a length contrast (see also Abramson 1987a, 1992; Lisker 1958; Hankamer et al. 1989 for similar types of experiments on other languages (Bengali, Pattani Malay, Tamil, and Turkish) which found similar results (albeit to different degrees)).

As reviewed in section 2.2.1, vowels are longer before geminates, and therefore we expect that Japanese speakers would perceive a consonant more likely as a geminate after a longer vowel than after a shorter vowel. Several results indeed found a contextual effect in this direction (Arai and

Kawagoe, 1998; Kingston et al., 2009; Ofuka, 2003; Ofuka et al., 2005; Takeyasu, 2012). This contextual effect is illustrated in Figure 5 in which listeners judged more of the continuum as geminates after longer vowels.

On the other hand, several studies have found opposite results as well. For example, Watanabe and Hirato (1985) found that the perceptual boundaries between singletons and geminates shift toward longer duration after longer vowels, although only two listeners participated in this study. A similar boundary shift was found in Hirata (1990). Idemaru and Guion-Anderson (2010) kept the duration of the consonant at about 140ms and changed the duration of the preceding mora (C_1+V_1), and found that the shorter the mora duration, the more geminate responses were obtained (though see Takeyasu 2012 who argues that it is the duration of C_1/V_1 ratio that matters, and that higher C_1/V_1 ratio would lead to more geminate percepts.). See Fujisaki and Sugito (1977),[14] and Takeyasu (2012) for more references for studies that obtained the results in this direction.

In summary, some studies found an "assimilative" pattern (more geminate responses after longer vowels) while others found a "contrastive" pattern (more geminate responses after shorter vowels). It is an interesting question where the difference between the two types of results come from. There is some evidence that the magnitudes of the duration ratios between the target and context matters in this regard (Nakajima et al., 1992). Takeyasu (2012) also entertains a hypothesis that in experiments that obtained an contrastive effect, listeners may have judged the preceding vowels to be phonological long, in which case they are biased against judging the following consonant as long to avoid a superheavy syllable (see Kubozono 1999 for a phonological constraint against superheavy syllables in Japanese). Further experimentation is necessary to settle this issue.

Unlike preceding vowels, vowels are shorter after geminates than after singletons (Campbell, 1999; Han, 1994; Idemaru and Guion, 2008; Ofuka, 2003) (see section 2.2.1). While Hirato and Watanabe (1987) found no effects of the duration of the following vowel on the perception of geminates, Ofuka et al. (2005) did indeed find that listeners are more likely to judge the stimuli as a geminate before a shorter vowel; Idemaru and Guion-Anderson (2010) found a similar effect, although they found the effect of preceding CV mora to be more substantial. See also Nakajima et al. (1992) for a relevant discussion.

Furthermore, Hirata (1990) tested the effect of sentence level speech rate on perception of length contrasts, and found that the durations of the whole sentential materials following the target word can impact the perception of geminates. The study found that those tokens that are unambiguously identified as either a singleton or a geminate can be perceived as a member of a different category if the following materials provide enough cues for speech rate.

One remaining question in this regard is, when listeners normalize the perceived duration for speech rate, to what extent they rely on local cues (like immediately preceding/following vowels

[14] They found a contextual effect for the /s/-/ss/ contrast, but is not explicit about the other two geminate pairs (/t/-/tt/ and /m/-/mm/).

or (CV) moras), and to what extent they rely on more global cues (like entire speech). On the one hand, in terms of psycholinguistic computational simplicity, local cues are presumably easier to track (Idemaru and Guion-Anderson, 2010); on the other hand, some studies (Amano and Hirata, 2010; Hirata, 1990; Pickett and Decker, 1960) show the effect of global cues; for example, by comparing several relational measures, Amano and Hirata (2010) demonstrates that the relationship between consonant duration and word duration[15] provides a good perceptual cue to a length distinction in Japanese.

However, taking into account a whole word or sentence to determine a length property of a single contrast may impose a psycholinguistic burden: in order to identify what the word is, it is necessary to determine whether the consonant in question is a singleton or a geminate. I do not wish to imply that this challenge is insurmountable, and more phonetic and psycholinguistic research is necessary to address this issue. Hirata (2007) suggests that gating experiments (Grosjean, 1980) may address the issue of the (non)locality of the perception of length contrasts. In this way, the relationship between production and perception of geminates in Japanese (and other languages) provides an interesting forum of research, which may bear on the general theory of speech perception (see Amano and Hirata 2010; Idemaru and Guion-Anderson 2010; Otaki 2011; Pind 1986 and others for discussion).

Another remaining question is how non-durational cues—F0 values and movement, spectral envelope, burst intensity, etc (see also Table 2)—interact with durational cues in the perception of Japanese geminates. For example, Ofuka (2003) observes that geminates are shorter in accented disyllabic words than in corresponding unaccented words, and also that in perception shorter closure duration can yield geminate perception when the word is accented (see also Hirata 1990 who obtained similar results). Likewise, Kubozono et al. (2011) show that English monosyllabic utterances with a falling pitch contour is more likely to be perceived as geminates by Japanese listeners. More extensive studies are warranted to investigate the intricacy of perception of geminates in Japanese.

3.3 Comparison with other languages

Like Japanese, the effect of constriction duration on the perception of duration has been found in many languages; e.g. Arabic (Obrecht, 1965), Bengali (Hankamer et al., 1989), English[16] (Pickett and Decker, 1960), Hindi (Shrotriya et al., 1995), Italian (Esposito and Di Benedetto, 1999; Kingston et al., 2009), Norwegian (Kingston et al., 2009), Pattani Malay (Abramson, 1987a, 1992),

[15]They demonstrate that it is not a simple ratio between these two measures, but a regression function with an intercept that most accurately predicts the perceptual behavior of Japanese listeners. This function is equivalent to the ratio between closure duration plus some constant and word duration; i.e. $(C + k)/W$ (where k is a constant).

[16]English does not have a lexical geminate contrast; this experiment tested a pair like *topic* vs. *top pick* where one member of the pair contains multiple morphemes.

and Turkish (Hankamer et al., 1989).

Across languages, the effect of language particular implementation pattern—shortening or lengthening of preceding vowel—is often reflected in the perception pattern as well. For example, both in Norwegian and Italian, vowels are shorter before geminates, unlike Japanese (Esposito and Di Benedetto, 1999; Fintoft, 1961). This shortening affects the perception of geminates—listeners of these languages perceive a consonant more likely as a geminate before a shorter vowel than a longer vowel (Esposito and Di Benedetto, 1999; Kingston et al., 2009; van Dommelen, 1999). In Icelandic in which long vowels and geminates are in a complementary distribution, Pind (1986) shows that vowel duration with respect to the entire rhyme duration is a good predictor of geminate perception—given fixed rhyme durations, shorter vowel durations yielded more geminate responses.

One interesting puzzle that arises from a cross-linguistic comparison regarding shortening vs. lengthening in pre-geminate position is as follows: some researchers proposed that C/V duration ratios provides mutually enhancing perceptual cues for duration when a shorter consonant is preceded by a longer vowel, as is the case for voicing contrasts in many languages (Kingston and Diehl, 1994; Kohler, 1979; Pickett et al., 1999; Port and Dalby, 1982). A combination of a short vowel and a long consonant yields enhanced, high C/V_1 duration ratios, whereas a combination of a long vowel and a short consonant yields low ratios. Languages like Italian and Norwegian, in which preceding vowels are shorter before geminates, can be assumed to deploy this perceptual enhancement pattern. In this light, a question arises why Japanese lengthens a vowel before a geminate. A tentative answer that I can offer is that V_1C unit (or V-to-V interval) may constitute a perceptual unit, a unit that has been hypothesized to play a role in the perception of Japanese and other languages (Hirata and Forbes, 2007; Kato et al., 2003; Kingston et al., 2009; Ofuka et al., 2005; Sato, 1978; van Dommelen, 1999).[17] If V_1C is an important perceptual unit—whether it is universal or specific to Japanese—then a longer vowel before a geminate can be considered as perceptually enhancing the long duration of geminates.

4 Articulatory studies of Japanese geminates

Compared to acoustic and perception studies of Japanese geminates, there are a relatively fewer studies on articulations of Japanese geminates, although there are some notable studies. Ishii (1999), for example, obtained articulatory data of Japanese geminates and long vowels using X-

[17] An alternative idea is that although Japanese is a mora-timed language (where a mora usually constitutes a CV unit), geminates, whose coda part should constitute its own mora, are not by themselves as long as a CV unit; pre-geminate vowel lengthening may occur to compensate for this shortage of duration, as hypothesized and discussed by Warner and Arai (1999). See also the chapter on mora-timing. One puzzle for this explanation is why, then, Japanese speakers shorten the following vowels after geminates.

ray microbeam, as shown in Figure 6. The three types of the stimuli were tested in this study, which were [papa] (ϕ), [paapa] (H), and [pappa] (Q).

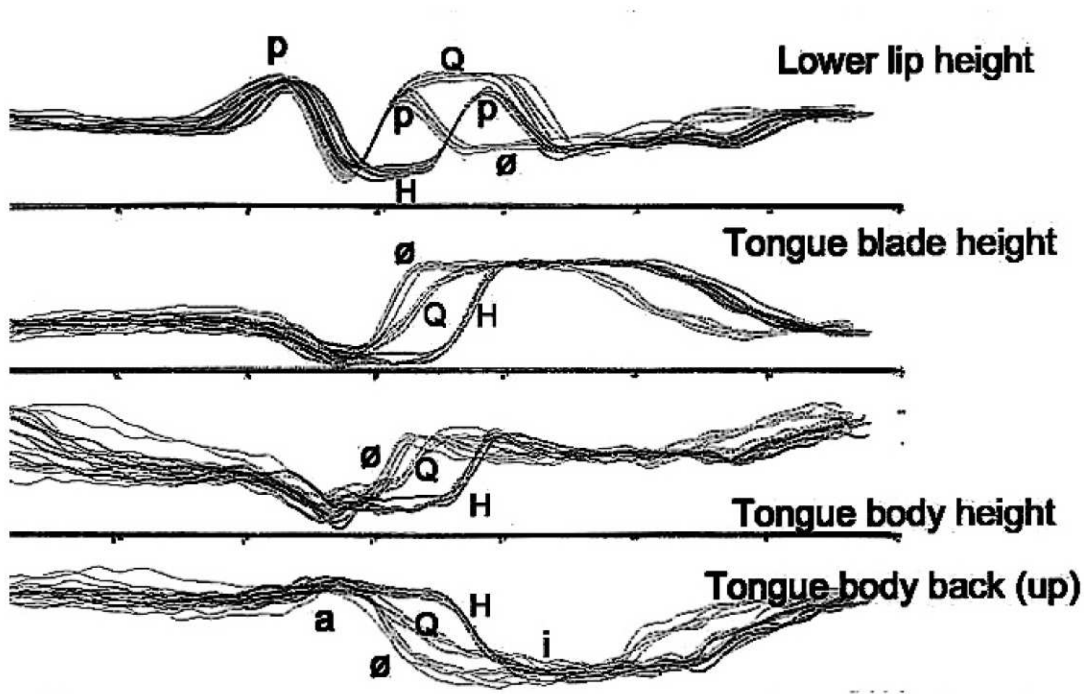

Figure 6: The articulatory movement of Japanese geminates, as compared to singletons and long vowels. Based on Ishii (1999), cited and discussed in Fujimura & Williams (2008). Three conditions are [papa] (ϕ), [paapa] (H), and [pappa] (Q)

Based on Figure 6, Fujimura and Williams (2008) make three observations. First, as we observe in the top panel, a geminate [pp] in Japanese shows a prolonged lip closure compared to a singleton [p]. Second, while the lip movement matches between singletons and geminates (the top panel) (though cf. Smith 1995), the lingual (tongue) movements are slower for geminates than for singletons (the second and the third panel). Finally, the V-to-V movement is slower across geminates than across singletons (the bottom panel).

Takada (1985) also investigated x-ray data of Japanese consonants, and found a slower movement for geminates in terms of lingual contact, in addition to jaw movement, in that maximal constriction is formed at the later phase of constriction. Smith (1995) shows, again based on X-ray microbeam data, that in Japanese a singleton/geminate distinction affects the gestural timing of the following vowel, whereas in Italian it does not. Sawashima (1968), using a fiberscope, shows that glottal abduction is larger for geminate fricatives than singleton fricatives. Finally, Kokuritsu-Kokugo-Kenkyuujo (1990) offers detailed articulatory data of Japanese sounds in general, including those of geminates.

5 Remaining issues

Although I have raised a number of remaining questions already, I would like to close this chapter with discussion of several more remaining issues that require further experimentation.

5.1 Non-intervocalic geminates

Although for lexical contrasts, Japanese allows geminates only intervocalically, some word-initial geminates are found due to an elision process in casual speech; e.g. [ttaku] from /mattaku/ (a phrase that often accompanies a sigh) and [sseena] from /usseena/ 'shut up'. Cues to word-initial geminates have been studied in some other languages (Abramson, 1992, 1999; Kraehenmann and Lahiri, 2008; Muller, 2001; Ridouane, 2010), but the Japanese case has not been extensively investigated. A specific question is whether such word-initial geminates involve longer constriction just like intervocalic geminates. Articulatory studies, using devices like EPG (Kraehenmann and Lahiri, 2008; Payne, 2006; Ridouane, 2010), would address this question of whether word-initial geminates do indeed involve longer constriction (Kraehenmann and Lahiri 2008 and Ridouane 2010 found a positive answer to this question in Swiss German and Beber).

Similarly, an orthographic marker for Japanese geminates—"small tsp" —can also appear word-finally, especially in mimetic words (see the chapter on mimetics), although one should note that this word-final gemination mark does not carry a lexical contrast. The exact nature of its phonetic realization is also yet to be explored—it is likely that it is realized as a glottal stop, but as far as I know, it has not been fully explored in instrumental work. See the chapter on mimetics.

5.2 Derived geminates vs. underlying geminates

Some phonetic studies in other languages have compared lexical geminates and geminates derived by some phonological processes, most often by assimilation.[18] They have generally shown that lexical geminates and geminates derived via a phonological processes are phonetically identical, as in Berber (Ridouane, 2010), Bengali (Lahiri and Hankamer, 1988), Sardinian (Ladd and Scobbie, 2003), and Turkish (Lahiri and Hankamer, 1988). However, Ridouane (2010) found a difference between lexical geminates and geminates created via morpheme concatenation in terms of preceding vowel duration and burst amplitude. Similarly, Payne (2005) argues that in Italian lexical geminates tend to be longer than post-lexical geminates created by RADDOPPIAMENTO SINTATTICO (RS) (although there are some complicating factors; see Payne 2006 for further

[18] In some languages, geminates can arise via simple morpheme concatenation without a further phonological change (known as "fake geminates"); e.g. /pat̪+t̪e/ → [pat̪t̪e] 'spread out (infinitive)' in Bengali (Lahiri and Hankamer, 1988)). In Japanese, fake geminates rarely if ever arise because root-final consonants always assimilate to the following consonant anyway.

discussion.)

As far as I know no studies have compared underlying and derived geminates in Japanese. For example, the final consonant of a prefix /maQ-/ 'truly' assimilates to the root-initial consonant, resulting in a geminate (e.g. [mak-ka] 'truly red' and [mas-sakasama] 'truly reversed'). It would be interesting to investigate whether there remains a difference between such derived geminates and underlying geminates. One reason why we may expect a difference is as follows. Monomoraic roots in Japanese can be lengthened when pronounced in isolation without a particle (Mori, 2002); however, duration ratios between these lengthened vowels and short vowels are smaller than the ratios between underlying long vowels and short vowels found in the previous research (Mori 2002 compares her results with the data from Beckman 1982; Braver and Kawahara 2012 confirmed this pattern in one experiment). It would be particularly interesting if we find such an incomplete neutralization pattern (Port and O'Dell 1985 *et seq.*) in the context of gemination.

5.3 Phonetics of emphatic geminates

Japanese deploys gemination for emphasis (e.g. [sɯggoi] 'awesome' from [sɯgoi]). In terms of orthography, this gemination can be written with multiple signs of gemination ("small tsu") (Aizawa, 1985). It would be interesting to investigate to what extent such repetition of geminate diacritics is reflected in actual production (and for that matter, can be tracked in perception). This issue is addressed in a project by the author in progress.

Furthermore, this emphatic gemination pattern can create otherwise unacceptable types of geminates, such as voiced obstruent geminates in native words and approximant geminates (Aizawa, 1985; Kawahara, 2001). Together with the general phonetic properties of emphatic geminates, the phonetic realization of approximant geminates, in particular, has been understudied and is yet to be investigated.

5.4 Laryngeal "tension" of geminates

Despite the studies mentioned in section 4, the exact articulatory nature of Japanese geminacy contrasts is yet to be explored. One particular issue concerns whether Japanese geminates involve laryngeal constriction or not. Impressionistically, sometimes Japanese geminates are conceived of as accompanying glottal constriction. Hattori (1984) suggests that the first half of geminates involves glottal tension (p. 139). Aizawa (1985) uses a term "chocked consonant" to refer to (emphatic) geminates. Idemaru and Guion (2008) also found shallower spectral tilt (H1-A1) in the vowels following geminates, indicating some creakiness, which implies some glottal constriction (although we should also note that two other measures of creakiness did not show differences in their study). Fujimura and Williams (2008) argue that laryngealization is a distinctive characteristics of Japanese geminates, which may even contribute to the perception of geminates.

On the other hand, a study by Fujimoto et al. (2010) using a high-speed digital video recording system did not find evidence for laryngeal or glottal tension in Japanese geminates. They also found that glottal opening is slightly larger during (voiceless) geminates than during singletons. Therefore, whether Japanese geminates involve glottal tension, and if so how that glottalization is coordinated/synchronized with super-laryngeal (oral) gestures, is to be explored.

5.5 Dialectal differences

There are few cross-dialectal studies on Japanese geminates, especially those written in English, which would be available to those scholars who do not read the Japanese literature. Due to the limitation of my expertise, I cannot discuss this issue extensively, but it would be particularly interesting to compare the properties of geminates in mora-timed dialects and syllable-timed dialects, such as Aomori dialect (Takada, 1985), Akita dialect (Maekawa, 1984), and Kagoshima dialect (Kubozono and Matsui, 2003).

5.6 Manner differences and the perception of geminates

Finally, as discussed in section 2.3, manner effects on the production of geminates in Japanese have been understudied. Relatedly, many perception experiments on Japanese geminates are based on voiceless stops (Amano and Hirata, 2010; Arai and Kawagoe, 1998; Hirata, 1990; Hirato and Watanabe, 1987; Fukui, 1978; Idemaru and Guion-Anderson, 2010; Kingston et al., 2009; Ofuka, 2003; Takeyasu, 2012; Watanabe and Hirato, 1985). Fujisaki et al. (1975) studied all the manners, but nevertheless only report the results of fricatives (though see also Fujisaki and Sugito 1977 where they report the data of all manners). There are a few recent studies (Matusi, 2012; Takeyasu, 2009; Tews, 2008) which investigated factors affecting the perception of geminates in fricatives. Oba et al. (2009) showed that the primary cue for affricate geminates lies in the closure phase, not in the frication phase. Further experimentation comparing the production and the perception of different manners of geminates, including nasal geminates, would warrant further studies.

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