LINGUOPALATAL CONTACT DIFFERENCES BETWEEN /n/ AND /t/ ACROSS SIX LANGUAGES

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ABSTRACT

This study investigated potential lingual gestural differences between the alveolar/dental nasal /n/ and the voiceless stop /t/ (or /t'/) using electro-palatography data from 28 individuals, native speakers of six languages (English, French, Japanese, Korean, Serbian, and Spanish). An analysis of almost 4,000 tokens of these consonants in initial and medial positions revealed significantly weaker contact for the nasal than the stop with differences varying in magnitude across languages. For some of the languages (English and Spanish), no differences were observed in medial contexts, where the stop was subject to intervocalic lenition. Overall, the results indicate that the seemingly similar lingual gestures involved in the production of nasals and stops differ in their realizations. These differences are argued to reflect the distinct aerodynamic, physiological, and acoustic requirements involved in the production of consonants of different manners.

Keywords: electropalatography, articulation, manner, phonetic typology.

1. INTRODUCTION

The alveolar/dental nasal /n/ and the stop /t/ are produced with the same lingual gesture – a tongue tip closure at the alveolar ridge or the upper teeth. They are thus articulatorily similar, sharing the same lingual gesture. This reflects the general principle of 'gestural economy' [19] or 'articulatory symmetry' [29]: consonants of different manners of articulation tend to exhibit the same or very similar place constrictions. The gestural similarity of nasals and stops is captured in models such as Articulatory Phonology [2] and its more recent task-dynamic implementation TADA [24], in which the tongue tip gesture for /n/ and /t/ is specified for the same constriction degree, constriction location, stiffness, and other parameters (cf. [26]).

Although nasals and stops are produced with the same lingual gesture, their production involves rather different aerodynamic and physiological requirements. Stops are produced with increased intraoral pressure during the occlusion [32, 21] and are released with a salient burst. These events can be facilitated by the lateral tongue bracing against the upper teeth [7] and/or raising of the jaw [23]. These strategies, in turn, can affect the precise positioning of the tongue during the oral constriction. Neither lateral bracing nor jaw raising is necessary for nasals, as these consonants are produced with continuous nasal airflow. The lowering of the velum for nasals, on the other hand, can affect the positioning of the tongue via the palatoglossus muscle [18]. Together, the manner-specific requirements for stops and nasals can lead to differences in their precise phonetic realizations.

Articulatory differences between the English nasal and stop consonants were investigated by Gibbon *et al.* [11]. Using electropalatography (EPG), they compared the degree of linguopalatal contact between word-initial /n/ and /t, d/ as produced by 15 (mainly British) English native speakers. /n/ was often realized with weaker, less complete closure and reduced side contact compared to /t, d/. Using the same method, Liker and Gibbon [17] found similarly weaker closures in /n/ vs. /t, d/ as produced by 6 Croatian speakers. Results of these studies suggest that differences in the realization of the lingual gesture between nasals and stops are rather general, cross-linguistic, and appear to reflect the influence of the aerodynamic and physiological factors reviewed above.

To explore the predicted cross-linguistic nasal/stop articulatory differences, this paper examines data from a cross-language EPG database containing productions of dental/alveolar nasal /n/ and its voiceless stop counterpart /t/ in 6 languages.

2. METHOD

2.1. Speakers

Data for this study were obtained from a set of EPG recordings of 28 participants, native speakers of 6 languages [14, 13]. Table 1 presents a breakdown of the sample by language, gender, and country of origin. All speakers were late English bilinguals who reported using their L1 on a daily basis. Custom-made artificial palates with 62 electrodes were manufactured for each participant; 19 speakers had the traditional *Reading*-style palate, the other 9 a newer *Articulate* model palate [33]. The latter palate can have a somewhat better coverage of dental place. Apart from this, the two models provide similar information about the consonants of interest.

Table 1: Languages and speakers represented in the sample; f = female.

Language	*Speakers*	*Countries*
EN (English)	3 (1 f)	Canada
FR (French)	4 (4 f)	France, Canada (Quebec)
JP (Japanese)	5 (5 f)	Japan
KR (Korean)	5 (3 f)	South Korea
SP (Spanish)	7 (6 f)	Argentina, Cuba, Spain
SR (Serbian)	4 (3 f)	Serbia

2.2. Materials

All of the languages examined in this study have a manner contrast between /n/ and the corresponding stops. The stops are the voiceless and voiced /t, d/, except for KR, which has the fortis, aspirated, and lenis /t', tʰ, t/ [16, 4]. Both the nasal and stops are described as having the same place: denti-alveolar in FR [5, 9] and JP [25], alveolar in EN [5] and KR [16], or variably dental/alveolar in SR [22, 17]. SP is an exception, with /n/ being described as apical alveolar and /t, d/ being denti-alveolar or dental [27, 20]. The cross-language differences in place are beyond the scope of the paper, as our focus is on the realization of manner differences in each language. Specifically, we compared /n/ to the voiceless stop /t/ (or /t'/ in KR), as both consonants occurred frequently in our materials for all 6 languages.

The data set includes read and semi-spontaneous speech samples that were designed for separate language-specific studies. For the current study, we selected a total of 60 items – real and nonsense words read in carrier sentences and in isolation – 30 each with /n/ and /t/ in prevocalic position. The words were paired with respect to the occurrence of the target consonants by position and general phonetic contexts. As shown in Table 2, there were two general positions, initial and medial. In some of languages, a subset of more specific positions was present: utterance-initial (##_V), word-initial (post-vocalic, V#_V), word-medial pretonic (V_V́), and word-initial posttonic (V́_V). There were on average 7 repetitions per item, exact numbers varying across languages and speakers. Sample items occurring in initial position in the 6 languages are shown in Table 3. Sample items by position for one of the languages, SP, are shown in Table 4. Note that, in most but not all cases, adjacent vowels were the same. The majority of the following vowels were non-front, non-high; none of the words contained /i/, which is known to cause lingual coarticulation [28].

Table 2: Counts of paired /n/-/t/ words and total numbers of tokens per language and position selected for the analysis.

	Pairs of items (/n/ vs. /t/)				*Tokens*
	Initial		*Medial*		
	##_V	V#_V	V_V́	V́_V	
EN	4	6	4	5	*574*
FR	1	2	2	--	*221*
JP	--	1	--	8	*809*
KR	1	--	--	4	*624*
SP	2	4	2	9	*1365*
SR	1	--	--	4	*191*
Tok.	*300*	*899*	*271*	*2314*	*3784*

Table 3: Sample items with /n/ and /t/ in initial position (utterance-initial single words; except for JP: [sore wa __ to itːa]).

	/n/		*/t/*	
EN	[naɪ]	'nigh'	[taɪ]	'tie'
FR	[nɔɛl]	'Christmas'	[tɑ̃dy]	'tense'
JP	[nagai]	'long'	[takai]	'tall'
KR	[nal]	'day'	[t'al]	'long'
SP	[nata]	'cream'	[tasa/taθa]	'cup'
SR	[noːs]	'nose'	[tuːga]	'sadness'

Table 4: Sample Spanish items with /n/ and /t/ in four specific positions.

Position		*/n/*	*/t/*
Initial	##_V	*nata* 'cream'	*taza* 'cup'
	V#_V	*Diga 'nada' otra vez* 'Say 'nothing' again'	*Diga 'tajo' otra vez* 'Say 'cut' again'
Medial	V_V́	*frenó* 's/he pushed the break'	*traté* 'I tried'
	V́_V	*afgano* 'quilt'	*zapato* 'shoe'

2.3. Instrumentation and analysis

The data were collected using a *WinEPG* system [34] at a sampling rate of 100 Hz. The artificial palates used with the system have a 62-electrode grid that can be schematically represented as 8 rows and 8 columns, with the anterior consonants /n, t/ typically showing central closures in the first 4 rows and some side contact (columns 1 and 8) [10].

All /n/ and /t/ closures were annotated based on the waveform and spectrogram using the *Articulate Assistant* program [34]. For /n/, the boundaries were taken to be the onset and offset of the nasal murmur. For /t/, boundaries were the onset and offset of the silent interval (excluding the burst); in utterance-initial position, where onset of /t/ closure cannot be acoustically detected, it was arbitrarily taken to begin 70 ms before the burst. Linguopalatal contact profiles were automatically extracted at the point of maximum contact (PMC). The dependent variable was the *Quotient of activation* (at PMC, *Q_max*) or the amount of contact over the entire palate (the number of 'on' electrodes divided by all electrodes, 62) [10; cf. 11, 17]. Other EPG variables were also measured but are not reported here for space reasons.

The data were analysed using linear mixed effects models with the *lme4* package [1] for R. For the cross-language analysis, Language (EN, FR, etc.), Consonant (/n/, /t/), and Position (initial, medial) were fixed effects. For language-specific analyses, the fixed effects were Consonant (/n/, /t/) and Position (utterance-initial, word-initial, word-medial pretonic, word-medial posttonic – depending on the language). Random effects were the same: Speaker, Word Pair, and Vowel Context. Interactions were also included. P-values were obtained using the chi-square test implemented in the *Anova()* function of *lmerTest* package [15].

3. RESULTS

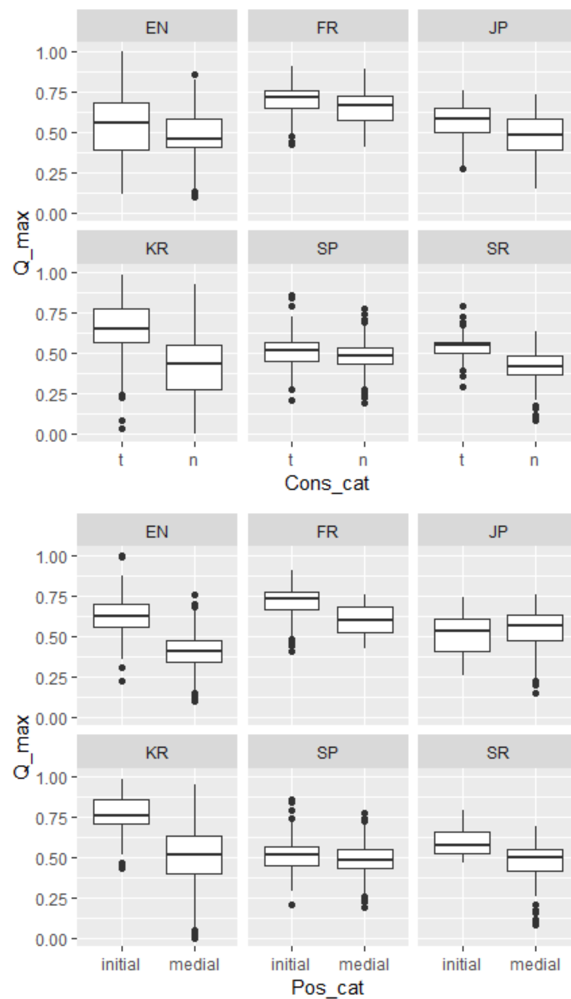
3.1. Manner and position differences across languages

The results of the cross-language model, summarized in Table 5, revealed significant main effects of Language, Consonant, and Position. In addition, there were significant interactions of all three effects. As Figure 1 illustrates, language groups were similar in the direction of the Consonant (a) and Position (b) effects: more contact was observed on average for /t/ than /n/, and for initial than medial position. Language groups differed in the overall amount of contact as well as in the magnitude of the Consonant and Position differences.

Table 5: Results of a linear mixed effects model for the full data set (***<0.001, **<0.01, *<0.05).

Effect	*Chisq*	*Df*	*Pr (>Chisq)*	
Language	20.833	5	0.0009	***
Consonant	65.673	1	<0.0001	***
Position	23.350	1	<0.0001	***
Language * Consonant	14.133	5	0.0148	*
Language * Position	16.503	5	0.0055	**
Consonant * Position	8.5887	1	0.0034	**
Language * Consonant * Position	41.426	5	<0.0001	***

Figure 1: Amount of contact (Q_max) for /t/ and /n/ by language and consonant (top) and language and position (bottom).



3.2. Manner and position differences within languages

Given the observed interactions of Consonant and Position with Language (as well as differences among the datasets described in §2.2), we conducted separate language-specific analyses. As shown in Table 6, the effect of Consonant was significant for all groups except EN; the effect of Position was significant for all groups except JP. These results confirm our observations based on Figure 1.

The results for most groups (EN, JP, KR, SP) also showed significant Consonant * Position interactions (all p<0.01). A closer examination of the EN data revealed that the manner difference was present in word-initial and medial-pretonic positions (e.g. *say nigh* vs. *say tie*, *analogy* vs. *atomic*) but absent in utterance-initial and medial-posttonic positions (e.g. *nigh* vs. *tie*, *analogue* vs. *atom*) as shown in Figure 2. The lack of contact difference in the former position was not expected, but can be reasonably attributed to the ceiling effect from initial strengthening [8, 4]. The lack of difference in the latter position is obviously due to the allophonic process of /t/-flapping in North American English, as a result of which the stop gesture is reduced both in duration and magnitude [6].

Table 6: Results of language-specific models, the effects of (a) Consonant and (b) Position (***<0.001, **<0.01, *<0.05).

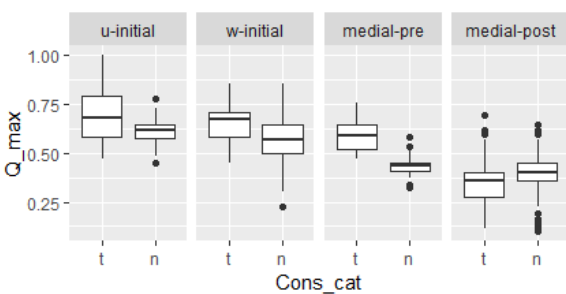
a.

	Chisq	*Df*	*Pr(>Chisq)*	
EN	2.305	1	0.129	
FR	4.3931	1	0.0361	*
JP	10.621	1	0.0011	**
KR	33.529	1	<0.0001	***
SP	4.295	1	0.0382	*
SR	12.911	1	0.0003	***

b.

	Chisq	*Df*	*Pr(>Chisq)*	
EN	35.378	3	<0.0001	***
FR	66.566	2	<0.0001	***
JP	0.001	1	0.9742	
KR	22.136	1	<0.0001	**
SP	10.964	3	<0.0001	***
SR	6.046	1	0.0139	*

Figure 2: Amount of contact (Q_max) by position for the English group.



The interaction in SP appears to be related to lenition as well. Here, the contact difference was present in both initial positions but absent in both medial positions. Note that medial position (regardless of stress) is the site of the allophonic process of /d/-spirantization [27, 20]. Although /t/ is not usually reported to participate in this lenition process (but see [15]), our results suggest that it is affected gradiently and to a similar extent as /n/ (cf. [30]). The relatively small magnitude of the manner difference in SP can be due to different places for /n/ (alveolar) and /t/ (dental), with the contact for the latter being partly beyond the scope of the artificial palate. In contrast to the SP positional differences, the interactions observed for JP and KR were opposite: a greater nasal vs. stop difference medially than (word- or utterance-) initially. This indicates that /n/ in these two languages patterns with voiced/lenis stops (which are subject to lenition [25, 16, 31]). The lack of a positional difference in JP can be attributed to phonetic context differences: in the JP dataset, the word-initial consonants occurred exclusively next to low /a/, while word-medial consonants occurred next to the mid/high vowels /e, o, u/. A greater proportion of high and front vowel contexts in the FR dataset (62% compared to 33% on average) may have also been responsible for the relatively small manner difference for this group and the overall highest Q_max values (see Figure 1).

4. DISCUSSION AND CONCLUSION

Overall, our examination of EPG data from 6 languages revealed that the nasal /n/ tends to be produced with less contact than the voiceless stop /t/. These differences were found to be subtle yet significant both across and within languages. The results thus confirm previous findings for British English and Croatian [11, 17] and suggest that the differences are not language-particular, reflecting manner-specific aerodynamic and physiological constraints [7, 18, 21, 23, 32]. However, the overall magnitude of the differences observed in this work is lesser than reported in previous studies. Specifically, the average amount of contact (Q_max) in our study was 0.48 for /n/ vs. 0.56 for /t/, compared to 0.55 vs. 0.87 in [13]. At least in part, this is clearly due to differences in the materials used: a small number of minimal pairs (as in [13]: *a tab – a nab*, *a tip – a nip*) compared to a larger set of words and sentences from the inherently more variable data studied here. Although not perfectly controlled for, our focus on various positions and stress conditions was important, as it revealed much more complex patterns characterized by interactions between manner-specific constraints on the one hand and language-specific allophonic processes and general phonetic effects (initial strengthening and coarticulation) on the other.

Finally, the results also revealed very robust positional effects. In particular, both consonants exhibited considerably more contact at the edges of prosodically strong domains (utterance-initially, word-initially, and pretonically), further confirming previous articulatory work on prosodic effects [8, 4]. Future research should seek to model interactions among various phonetic effects, including manner differences, teasing apart the underlying general (aerodynamic and physiological) and language-particular factors.

ACKNOWLEDGEMENTS

This research was supported by grants from the *Social Sciences and Humanities Research Council of Canada* and the University of Toronto.

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