Consonantal Changes in the Inventory of English: A Constraint-Based Analysis*

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The aim of this study is to analyze the inventories of phonemic consonants in the three periods of English under the model of dispersion theory (Flemming, 1995) formalized in terms of Optimality Theory (Prince & Smolensky, 1993) and to show how a constraint-based approach can account for inventory structure and its historical change in a more comprehensive and coherent way. In this study, I focus on the inventory of English fricatives and nasals because historical change had occurred only to them. I attempt to explore why the inventories of the three periods were as they were and to find a pattern which dominates historical change. As predicted by Flemming's dispersion theory, the inventory structure of English is also described mainly in terms of three kinds of constraints, "Maintain contrasts," "Mindist" and "LAZY." It is shown in this study that a balance among them, which is different depending on the periods of history, shapes the inventory structure of each period. In this analysis, it is also clearly noted that English consonants had moved toward the inventory structure which prefers multiple contrasts over a large auditory distance and/or effort minimization.

Key words: English consonants, inventory structure, historical changes dispersion theory, optimality theory, constraints

1. Introduction

While the long vowels of English had undergone drastic changes, the consonants of English had been relatively stable throughout the history of English. It is not, however, the case that there had been no change in the inventory of the English consonants at all. It can be noted that throughout history there has been interesting change in the inventory of

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the consonants as well as in their distribution. As in other linguistic changes, we can consider the historical change in the inventory of English consonants from three different perspectives: i) how and why linguistic changes start (the actuation), ii) how they spread (the transmission) and iii) how or whether they can be explained.[1] Depending on the tools adopted, the same sound change has been differently analyzed and sometimes certain phenomena remain unexplained. The actuation or motivation for sound change has also been viewed differently depending on the frameworks in which historical change is analyzed.[2] In this paper, focusing on the first and third problems concerning linguistic change, I would like to show how a constraint-based approach can deal with the two problems in the analysis of the inventory of English consonants and its historical change.

In this study, I would like to elucidate why the inventories of the English consonants in the three periods of history were as they were and to explore why changes had occurred and how they can be accounted for.[3] I will apply Flemming's (1995) dispersion theory formalized in terms of Optimality Theory (OT) (Prince & Smolensky, 1993) to the analysis of the inventory structure of English consonants and its historical change. This paper is organized as follows: the following section will outline the inventories of the English consonants in the three periods of the history. The changes shown in section 2 will be analyzed in section 3. In this section, it will be demonstrated how the functional approach allows us to explicate the problem of the actuation in linguistic change with the help of constraints. This section is devoted to showing how the members of

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1) McMahon (1994, p. 11)

2) Many linguists have tackled with the motivation for sound change. McMahon (1994) overviews the approaches of three schools of linguists: the Neogrammarians who indicate a group of scholars including Brugmann and Ostoff; the Structuralists who mainly include Saussure, Martinet, scholars of the Prague School, including Trubetzkoy and Jakobson, and the American Descriptivists, like Broomfield, and Hockett; and the early Generativists. For example, the Neogrammrians argued that regular sound change occurs due to ease of articulation. According to the Structuralists, sound shift takes place due to the structure of systems and the function of language. The so-called Standard Model of Generative Phonology approaches this problem from a different angle: it is suggested that all changes make the grammar simpler and more economical (King, 1969). For more discussion and comparison of the positions on language change of these three schools, see McMahon (1994, pp. 14-46).

3) In this paper we accept the following delineation of periods: the Old English period is from 449 to 1100, the Middle English period from 1100 to 1500, and the Early Modern English period from 1500 to 1800.

the inventory in each period of English had been effectively arranged to facilitate ease of articulation and distinctiveness of contrasting forms and how the phonological patterning in the three periods of English is unified in terms of interleaved constraints proposed in this study. Section 4 summarizes and concludes this study.

2. Changes in the Phonemic System: System-wide Changes

In this section, we will examine the change in the phonemic inventory of English consonants for the past 1500 years. As mentioned before, the consonant system has remained surprisingly stable. Hence, the inventory of consonants in Old English (OE) given in (1) looks quite modern.

(1) Old English Consonants (Millward, 1989, p. 70)[4)5)6)]

	bilabial	labio-dental	inter-dental	alveolar	alveo-palatal	palatal	velar
stops	p, b			t, d			k, g
fricatives		f	θ	s	ʃ		x
affricates					ʧ, ʤ		
nasals	m			n			
liquids				l, r			
glides	w					j	

The main difference between the consonant phonemes of OE and those

4) This chart includes the consonants of late OE, not those of early OE, due to the presence of affricates. There are two modifications of Millward's chart in (1). First, Millward classifies /j/ as alveo-palatal. Secondly, Millward uses the symbol /h/ to indicate a velar fricative. In other words, she puts the phonetic symbol in the slot of the voiceless velar fricative not in that of the voiceless glottal. She probably intends to use the /h/ in her chart in order to refer to /x/ since many scholars suggest that the OE spelling <h> represent three allophones [h~x~ç] and their phoneme be a velar fricative /x/ as in the stage of the Proto-Germanic language (Görlach, 1974; Hogg, 1992; Lass, 1992, 1994, 1999).

5) Millward's chart of OE consonants looks more modernized than any other charts of OE consonants. It classifies /j/ as alveo-palatal. We can frequently encounter charts which classify /t, d, s, n, l, r/ as dentals, not as alveolar sounds. For more details on the inventory of OE consonants, see Moon (2000).

6) In this paper, I do not distinguish the alveo-palatal position from the palato-alveolar position. Both are regarded as referring to the front part of the palate immediately behind the alveolar ridge.

of Modern English is the lack of phonemic voiced fricatives [v, ð, z, ʒ] and a phonemic nasal [ŋ] in OE. All the voiced consonants of Modern English except [ʒ] appeared at least allophonically in OE. The voiced fricatives [v, ð, z] were allophones of the voiceless counterparts in OE. When the fricative was flanked by voiced sounds, it was voiced; otherwise, it was voiceless.

(2) a. [f]: fæder 'father', lof 'praise' [v]: cnafa 'boy'
b. [θ]: þorn 'thorn', pæð 'path' [ð]: fæðm 'fathom'
c. [s]: sunu 'son', græs 'grass' [z]: rīsan 'to rise'

The velar nasal was also an allophone of /n/ which appeared before /k/ or /g/.[7]

(3) [n]: naca 'vessel', gān 'to go' [ŋ]: gang 'journey', drincan 'to drink'

The alveo-palatal [ʒ] was neither an allophone nor a phoneme in OE.

Another prominent aspect of the allophonic distribution which made the consonants of OE and ME most different from those of today is that the phoneme represented by the spelling <h> had much wider distribution in OE than in Modern English. The <h> had several allophones not present in Modern English. In OE, [h] appeared initially before a vowel or /l, r, n, w/. Postvocally, <h> had palatal and velar fricatives as allophones depending on the environments. After a front vowel, it became a palatal allophone [ç], while it became a velar fricative [x] after a back vowel or /l, r/.

(4) The allophones of OE <h>
a. [h]: hūs 'house', hlāf 'loaf', hræfn 'raven', hnitu 'nit', hwæl 'whale'
b. [ç]: syhð 'sees', miht 'might', fēhð 'takes'
c. [x]: þurh 'throught', þōhte 'thought'

The allophonic distribution of the phoneme represented by OE <h> in (4) was preserved until the period of ME.

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7) In addition to [ŋ], the palatal nasal sound, [ɲ], is often cited as an allophone of /n/ in OE, which occurs after an alveo-palatal or a palatal sound (Campbell, 1959; Wright & Wright, 1925; among others).

The inventory of the consonants in Middle English (ME) became even more similar to that of Modern English due to the phonemicization of the voiced fricatives /v, ð, z/. A number of factors contributed to the change. The influx of French loanwords, the spread of Southern dialects, and the loss of stress in function words which made the fricatives voicing e.g. *the* [ðə] (< OE þe [θe]) brought about the initial contrast of the voiced and voiceless fricatives. The loss of inflectional ending and that of stress in function words such as *with* [wið] (< OE wiþ [wiθ]) developed the contrast of the voiced and voiceless fricatives in word-final position(Millward, 1989; Pyles & Algeo, 1993; among others). None of the OE consonant phonemes in (1) were lost between OE and ME except that geminates were no longer phonemic in ME.

(5) Middle English Consonants (Görlach, 1974; Lass, 1992)

	bilabial	labio-dental	inter-dental	alveolar	alveo-palatal	palatal	velar
stops	p, b			t, d			k, g
fricatives		f v	θ ð	s z	ʃ		x
affricates					tʃ, dʒ		
nasals	m			n			
liquids				l, r			
glides	w					j	

The inventory of Modern English consonants was established during the Early Modern English (EModE) period. By 1800, the inventory became identical to that of today. The system-wide difference between ME and EModE is the addition of phonemic /ŋ/ and /ʒ/ to the EModE inventory. From a perspective of the Structuralists, both are quite natural since both filled the gaps in the system. The phonemicization of the allophone /ŋ/ provided three nasal contrasts parallel to the three sets of stops. Due to the addition of /ʒ/, there had been the pairs of voiceless and voiced fricatives in all location except for /h/.[8]

8) It is controversial whether /h/ is a fricative or not. Although Bronstein (1959) and Jones (1956) consider it as a glottal fricative, Ladefoged (2001) argues that it is a voiceless counterpart of the vowels that follow it. If we accept Ladefoged's position, the addition of /ʒ/ to the EModE inventory came to fill the last gap in the pairs of voiced and voiceless fricatives.

(6) Early Modern English Consonants (Barber, 1976; Lass, 1999)

	bilabial	labio-dental	inter-dental	alveolar	alveo-palatal	palatal	velar	glottal
stops	p, b			t, d			k, g	
fricatives		f, v	θ, ð	s, z	ʃ ʒ			h
affricates					ʧ, ʤ			
nasals	m			n			ŋ	
liquids				l, r				
glides	w					j		

A comparison of the inventories in (5) and (6) reveals another difference: the disappearance of /x/ and the appearance of /h/ in EModE. Strictly speaking, /h/ was not a new sound. As mentioned above, it had been one of the allophones of the spelling <h>. The postvocalic allophones of the spelling <h>, namely [ç, x], disappeared in the 15th century. We cannot find [ç] in any English word except for a few loanwords. We can sometimes find a trace of [x] in words such as *cough, laugh,* and *tough* in which the [f] is from ME [x].

(7) a. The loss of [ç, x]: si**gh**t, strai**gh**t, cau**gh**t, si**gh**, althou**gh**
b. [x] > [f]: cough, laugh, tough

In accordance with Barber (1976) and Lass (1999), which can be regarded as a dominant view on the change of the sounds represented by the spelling <h>, I assume that after /x/, which had represented a phoneme of <h> until OE and ME, disappeared, its allophone [h] came to take on a phonemic status in EModE.[9)]

Up to now, we have seen the inventories of the three periods of English. The historical change occurred only in the inventory of fricatives and nasals, not in other consonant phonemes. The change until the EModE period can be characterized as the addition of phonemes without the loss of the OE consonant phonemes, given that [x] and [h] had represented the allophones of the same phoneme. The newly-added phonemes except /ʒ/ appeared at least allophonically in OE. The voiced

9) However, there is no obvious reason why /h/ must not be postulated as a phoneme in most grammar books on OE and ME. The clarification of the reason for this seems to require further study.

fricatives /v, ð, z/ were added to the ME inventory, and /ʒ/ and /ŋ/ to the EModE inventory. In the next section, we will explore what the choice of the inventory of each period follows from and what the pattern govening the change in the inventory is.

3. A constraint-based Analysis

3.1. Change in the Inventory of Fricatives

It was noted in the previous section that most of the changes had taken place in the inventory of English fricatives: the addition of the phonemes /v, ð, z/ in ME, the addition of a phoneme /ʒ/ in EModE, and the substitution of /h/ for /x/ in EModE. In this subsection, I will show how the inventory of fricatives and its change from OE to EModE can be anaylized in terms of constraints. First, let us consider the inventory of fricatives in OE. As seen in (1), OE had five fricative phonemes, all of which are voiceless: /f, θ, s, ʃ, x/. Looking at this inventory, we can pose the following questions:

(8) a. What forced OE to have only 5 fricatives?
b. Why didn't OE have fricatives of other places of articulation such as bilabial or palatal fricatives?
c. What forbade OE from having voiced fricatives in the inventory?

In order to answer the questions in (8), I adopt Flemming's (1995) dispersion theory initiated and developed in most detail by Martinet (1952) and Lindblom (1986, 1990).

(9) Dispersion Theory (Flemming, 1995, p. 24)
a. Maximize the number of contrasts.
b. Maximize the distinctiveness of contrasts.
c. Minimize articulatory effort.

Flemming claims that the selection of phonological contrasts is subject to the above three functional requirements. The requirements of contrast in (9) conflict: maximization of the number of contrasts and minimization of effort reduces the distinctness of the contrasts. According to the dispersion

theory, the selection of an inventory of contrast is based on a balance between these requirements. Flemming formalizes the dispersion theory in terms of Optimality Theory (OT) (Prince & Smolensky, 1993) since OT is an excellent system which specifies the resolution of conflict between constraints through violability and hierarchy of constraints. In this study, following Flemming's dispersion theory formalized in terms of OT, I will analyze the selection of the inventory of English consonants and the historical change. Most of the constraints proposed here are phonetic, and it is also assumed that the constraints functionally interact with one another and make a choice of an inventory.

Now let us go back to the first question in (8): Why does OE have five fricatives in the inventory? Fricatives are produced by turbulent airflow through a narrow constriction in the oral cavity. The places of articulation in fricatives are characterized by various factors. Among these the most prominent is said to be the spectral peak of noise frequency. The place at which the constriction is made and the shape and size of the front cavity have a frequency-filtering effect on the source sound.[10] One general filtering rule is that the low frequency resonances of the shaping cavity are at frequencies inversely correlated to the size of the cavity (Heinz & Stevens, 1961; Jassem, 1968). The shorter the front cavity, the higher the frequency of the lowest spectral peak, except for a case when there is no front cavity. Pickett (1985) shows that the strongest resonances are around 1kHz for [h], 3kHz for [ʃ], 4kHz for [s], 5kHz for [θ], and a range from about 4.5 to 7kHz for [f]. In labial fricatives, there is no front cavity, so there is no filtering effect. With labial fricatives, there are no spectral peaks and the spectrum is relatively flat and diffuse. A similar spectrum is found in [θ]. Based on these properties of fricative spectra, Flemming (1995) proposes six levels of Noise Frequency (NF) and an auditory feature [diffuse]. Moreover, [strident] and [fricative] are proposed in accordance with the intensity of noise.[11] In this paper, I modify Flemming's levels of Noise Frequency (NF) as in (10a) on the basis of the relationship between the length of the front cavity and the locus of the noise frequency.[12]

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10) The front cavity refers to the cavity in front of the noise source, whereas the back cavity indicates the cavity behind the noise source.

11) I ignore the feature [fricative] in this analysis since fricatives have the same value in the feature.

(10)

	f	θ	s	ʃ	ç	x	h
a. NF							
lowest	-	-	-	-	-	-	+
lower	+	-	-	-	-	+	+
low	+	+	-	-	+	+	+
high	-	+	+	-	-	-	-
highest	-	-	+	-	-	-	-
b. Diffuse	+	+	-	-	-	-	-
c. Strident	-	-	+	+	-	-	-

Considering the dimensions in (10), I propose that the constraint in (11) is visibly active in the account of the OE inventory.

(11) Maintain 5NF contrasts: Maintain 5 contrasts on the Noise Frequency dimension.[13]

Although Maintain 5NF contrasts demands that OE have at least 5 voiceless fricatives in the inventory, there are still many combinatorily possible inventories with five members. To obtain the OE inventory which consists of /f, θ, s, ʃ, x/ ruling out inventories with other combinations, we need to impose restraints on the auditory distance between the members in the inventory. Hence, I propose following constraints in (12).

(12) a. MindistNF=2 & MindistDS=1 (MindistNF=2 & DS=1)
b. MindistNF=2: Sounds that contrast on the Noise Frequency dimension should differ in at least 2 NF features.
c. MindistNF=1: Sounds that contrast on the Noise Frequency dimension should differ in at least 1 NF feature.[14]
d. MindistDS=1: Sounds that contrast on the dimensions of Diffuseness or Noise Intensity should differ in at least 1 feature in [diffuse] or [strident].

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12) To Flemming's NF dimension, I added the values of [θ], [ç] and [h], on the basis of Pickett's (1985) suggestion and the results of Jassem's (1968) experiments.

13) Maintain 5NF contrasts is from the following hierarchy: Maintain 1NF contrast ≫ Maintain 2NF contrasts . . . ≫ Maintain nNF contrasts.

14) MindistNF=1 and MindistNF=2 are from the hierarchy of the MindistNF constraints, MindistNF=1 ≫ MindistNF=2 . . . ≫ MindistNF=n.

The conjoined constraint (12a), which is ranked above MindistNF=1, is violated only when fricatives which consist of the inventory differ neither in at least two NF features nor in at least one feature of [diffuse] or [strident]. It is expected that the conjoined constraint conflicts with a constraint which restricts the number of contrasts. If an inventory has its constituents under five, it can easily meet MindistF=2. However, as the number of the members in the inventory becomes larger, it is more difficult to satisfy MindistNF=2 & DS=1. Namely MindistNF=2 & DS=1 conflicts with Maintain 5NF contrasts, which is resolved by ranking Maintain 5NF contrasts above MindistNF=2 & DS=1 in OE.

It can be also noted that there are no bilabial and glottal fricatives in the OE inventory. Why are they not allowed? What properties do bilabial and glottal fricatives have in common? Shadle (1991) argues that there is another source sound of turbulent noise for fricatives: the noise generated at an obstacle in addition to turbulent airflow from a narrow channel. According to Johnson (1997), almost all fricative noises involve turbulence produced by airflow hitting an obstacle. In producing [s] and [ʃ] the upper and lower teeth respectively play the role of an obstacle, while the upper lip functions as an obstacle in the production of [f]. Johnson (1997:114) maintains that the only nonobstacle fricatives are bilabial and glottal fricatives. This is the reason why it is very difficult to make bilabial and glottal noises loudly. On the basis of Johnson's claim, I propose the following constraint, which is ranked higher than MindistNF=2 & DS=1 in the hierarchy.

(13) *Nonobstacle fricatives: No nonobstacle fricatives are allowed.
(Nonobstacle fricatives: bilabials [ɸ, β], glottal [h, ɦ], Johnson, 1997)

In summary, we obtain the hierarchy for the inventory of OE fricatives as in (14). Tableau (15) illustrates how the hierarchy in (14) selects the OE inventory.

(14) Hierarchy for fricatives in OE
Maintain 5NF constrasts, *Nonobstacle ≫ MindistNF=2 & DS=1 ≫ MindistNF=1 ≫ MindistNF=2

(15) Fricatives in OE

	Maintain 5NF	*Nonobstacle	Mindist NF=2 & DS=1	Mindist NF=1	Mindist NF=2
a. f-s-ʃ-ç-x			*!	*	***
b. θ-s-ʃ-ç-x			*!		**
c. f-s-ʃ-ç-h		*!			**
d. f-θ-s-ʃ-h		*!			*
☞e. f-θ-s-ʃ-x				*	*
f. f-θ-s-ʃ	*!				

OE includes five fricatives in the inventory. The highly ranked constraint Maintain 5NF contrasts rules out the inventories which have less than 5 members such as (15f), even though (15f) satisfies Mindist constraints. The inventories as in (15c, 15d) are out since they have a nonobstacle fricative /h/. Among the inventories which lack a nonobstacle fricative, only (15e) satisfies MindistNF=2 & DS=1. Even though the pair |f-x|, in which there is no featural difference on the NF dimension, violates MindistNF=1 and MindistNF=2, it satisfies MindistNF=2 & DS=1 since it differs in one [diffuse] feature. On the other hand, the pair |ç-x| in candidates (15a) and (15b) violates MindisNF=2 & DS=1 since it differs in only one NF feature and show no featural difference on the dimensions of Diffuseness and Noise Intensity. The hierarchy of the constraints in (14) also predicts the absence of the three allophones of the spelling <h> in the same phonemic inventory. According to the ranking, only one of them can occur in the inventory as exemplified in (15a, 15b, 15c).

While the voiceless stops in OE have their voiced counterparts, the fricatives in OE are all voiceless in the phonemic inventory. What forbids the voiced fricatives, but not voiced stops, in the inventory of OE? Ohala (1983, 1997) shows us that there is a general bias against voiced obstruents and explains the reason for this from an aerodynamic point of view: blocking airflow required in producing obstruents increases supraglottal pressure, so that transglottal pressure (=the differential of subglottal and supraglottal pressure) does not become high enough to maintain voicing. Furthermore, statistics Ohala (1983) provides indicates that the bias against voicing in obstruents is even stronger in fricatives than in stops. In other words, voicing fricatives is articulatorily more difficult than voicing stops. Ohala (1983, 1997) argues that the more difficulty in voicing fricatives follows from the contradiction of optimal voicing and optimal frication: voicing demands low supraglottal pressure,

whereas frication requires high supraglottal pressure. Optimal voicing requires keeping supraglottal pressure as low as possible and optimal frication requires keeping supraglottal pressure as high as possible. Accordingly, it is not possible to do both simultaneously. In order to have good frication, the voiced fricatives tend to be devoiced, and they tend to have little or no frication in order to maintain their voicing.

Given the Ohala's argument, it is most likely that the absence of voiced fricatives in OE is also forced by the articulatory difficulty which results from the contradictory requirements of voicing and frication. In fact, front fricatives /f, θ, s/ had their voiced counterparts as their allophones in OE, although there were no phonemic voiced fricatives. Moon (1997) analyzes the alternation of the voiced and voiceless fricatives in OE as the interaction of the constraints LAZY and IDENT(voiced). The voicing and unvoicing of the OE fricatives are responsible for the minimization of articulatory effort. In other words, the voicing of a fricative between voiced sounds and the unvoicing of a fricative in other positions are required due to effort minimization. I would like to attribute the absence of voiced fricatives in the OE inventory to minimization of articulatory effort. According to Kirchner (1998), voicing of obstruents in word-initial and word-final position demands more articulatory effort due to passive devoicing, whereas devoicing of obstruents in voiced environments requires more articulatory effort due to passive voicing. The status of voiced fricatives as a phoneme means that voiced fricatives and voiceless counterparts contrast in initial and final position as well as in voiced environments. If so, producing voiced fricatives in word-initial and word-final position as well as next to voiceless sounds demands greater articulatory effort than producing the voiceless counterparts in the same environments. In the same way, producing voiceless fricatives in the voiced environment requires more articulatory effort than producing voiced counterparts in the same environments. The phonemic distinction between voiced and voiceless fricatives would have lead to more articulatory effort in total. Accordingly, it can be proposed that the absence of the voiced fricatives /v, ð, z/ in the OE inventory be forced under the pressure of LAZY which overrides the constraint which requires that voice onset time (VOT) contrast in the inventory.

(16) a. LAZY: Minimize articulatory effort.
b. Maintain VOT contrast: Maintain a contrast on the VOT dimension.

(17) LAZY ≫ Maintain VOT contrast (OE)

LAZY ranked higher than Maintain VOT contrast in OE prohibits the presence of the voiced fricatives in the position contrasting with their voiceless counterparts. In other words, the voiced fricatives did not contrast with their voiceless fricatives in OE under the pressure of effort minimization.

Tableau (18) is provided to illustrate how the inventory of OE fricatives is determined, excluding voiced fricatives. The constraints in (14) which determine the places of articulation of the OE fricatives are not crucially ranked with respect to the constraints in (17) which are relevant to the presence and absence of voiced fricatives in OE. Because of this, sometimes it is not clear which constraint is fatally violated, hence ! is added to the constraints which belong to each group of the constraints, as seen in (18b) and (18d).[15]

(18) Fricatives in OE

	Maintain 5NF	*Nonobstacle	Mindist NF=2 & DS=1	LAZY	Maintain VOT
a. f-s-ʃ-ç-x			*!		
b. θ-s-z-ʃ-ʒ-ç-x			*!	*!*	***
c. f-s-ʃ-ç-h		*!			*****
d. f-v-s-z-ʃ-ç-h		*!		*!*	***
e. f-v-θ-ð-s-z-ʃ-ʒ-x-ɣ				*!****	
f. f-v-θ-ð-s-z-ʃ-x				*!**	**
☞g. f-θ-s-ʃ-x					*****
h. f-θ-s-ʃ-ʒ-x-ɣ				*!*	***
i. f-v-θ-ð-s-z-ʃ	*!			***	*
j. f-θ-s-ʃ	*!				

Now let us move to the next period. In ME, the voiced fricatives /v, ð, z/, which were allophones of the voiceless counterparts in OE, became an independent phoneme. Other than this, there was no change in the

15) In the same vein, shading in the tableau is also difficult to mark due to lack of the ranking relationship of the constraints in (14) and the constraints in (17).

consonant inventory in ME. The emergence of the voiced fricatives as phonemes in the inventory indicates that minimization of articulatory effort was sacrificed in favor of Maintain VOT contrast in ME. However, it is not adequate to reverse the ranking in (17) in order to account for the distribution of the inventory in ME since the reversed ranking, Maintain VOT contrast ≫ LAZY, would predict the presence of the five voiced fricatives–v, ð, z, ʒ, ɣ– instead of three. The voiced alveo-palatal and velar fricatives were not phonemic in ME. In other words, the phonemic system of the voiced fricatives in ME was partially symmetrical.

Why then don't the voiceless alveo-palatal and velar fricatives have their voiced counterparts in the inventory of ME? I assume that partial symmetry seems to be related to the relative difficulty of articulation among the voiced fricatives. As mentioned above, across and within languages, voiced fricatives tend to be disfavored relative to voiceless ones, and are difficult to produce (Johnson 1997; Pickett 1985; Ladefoged & Maddieson, 1996; Ohala, 1983, 1997). In addition, voicing in fricatives can be influenced by another factor: the place of articulation.[16] The difficulty in pronouncing voiced fricatives increases as the back cavity becomes smaller. The smaller back cavity increases the supraglottal pressure, whereas voicing is possible whenever air pressure in the mouth drops sufficiently. Therefore, the further back in the mouth a place of articulation is, the harder it is to maintain voicing.

The interrelationship between the maintenance of voicing and the place of articulation is also discussed in Kirchner (1998). According to the table given in (19) showing when passive devoicing occurs in medial geminate fricatives, passive devoicing occurs earlier as the place of articulation of the voiced fricatives moves backward in the mouth: passive devoicing takes place earlier in a voiced velar than in a voiced alveolar, and passive devoicing occurs earlier in a voiced alveolar than in a voiced labial. The occurrence of the earlier passive devoicing represents the difficulty in maintenance of voicing. Namely, the results in the table (19) also

16) This suggestion is derived from aerodynamics studied by Ohala (1983, 1997) and Westbury and Keating (1986). They observe that in a stop, maintaining the voiced state is relatively easier for fronter places. In order to maintain voicing in stops, the supraglottal pressure becomes lower by enlarging the oral cavity. According to Ohala's (1997) claim, however, this option is less effective the further back the supraglottal closure is made because there is lesser surface area and because there are few options for cavity enlargement. For more details, see Ohala (1997). Hayes's (1996) chart of "difficulty for voiced stops" also confirms this argument.

demonstrate that the maintenance of voicing is more difficult as the place of articulation of the voiced fricatives moves backward in the mouth.

(19) Point of passive devoicing, medial geminate fricative, in msec (Kirchner, 1998, p. 164)[17]

	Oral aperture=20mm^2	Oral aperture=30mm^2
Glottal aperture =4mm^2	125(lab) 95(alv) 85(vel)	___(lab) 166(alv) 127(vel)
Glottal aperture =5.5mm^2	95(lab) 89(alv) 80(vel)	117(lab) 99(alv) 85(vel)

Considering what has been addressed up to now, it can be assumed that maintenance of voicing in fricatives involves more precise control of airflow which leads to greater articulatory effort, as the place of articulation moves backward in the mouth. On the basis of this consideration, I propose a series of the LAZY constraints in line with Kirchner's (1998) proposal. In the exploded LAZY hierarchy, the values of the constraints are in abstract units and are deduced from the general consideration addressed above.

(20) $LAZY_a \gg LAZY_b \gg LAZY_c \gg LAZY_d \gg LAZY_e \gg LAZY_f$[18]

i) a, b, c, d, e, and f represent effort required for the voiced fricatives, [ɦ], [ʋ], [ʒ], [z], [ð] and [v], respectively.

ii) $LAZY_a$ = Do not expend effort $\geq$ a

17) There are two points to be explained about this table. First is on the relationship of passive devoicing and the size of glottal aperture. From an aerodynamic perspective, glottal aperture must be big enough to create oral pressure which is demanded to produce fricative noise. With an increase in glottal aperture, it is easier to produce fricative noise. However, this makes it more difficult maintain voicing and hence passive devoicing occurs much earlier. Secondly, the blank in the labial when oral aperture is 30mm^2 requires an account. Kirchner suggests that with a more open fricative (namely when oral aperture is 30mm^2), labials are not to reach the point of passive devoicing. This may be due to the fact that supraglottal pressure drops enough to maintain voicing.

18) Since no supraglottal articulators are involved in the glottal fricatives [h, ɦ], it may be inappropriate to assume that the voiced glottal fricative is also subject to the generalization of the relationship of the maintenance of voicing and place of articulation. However, since we have regarded the glottal [h] as fricative in this analysis, I added [ɦ] to this hierarchy under the assumption that the difficulty in maintaining noise friction in the glottal fricative would involve more articulatory effort than in any of the other voiced fricatives.

The historical change shown in the inventory of English fricatives is consistent with the generalization that the further back in the mouth a place of articulation is, the more difficult it is to maintain voicing. Therefore, I assume that the gaps in the fricative inventories in the history of English occurred in a region where the size of the oral cavity makes voicing difficult. We can interleave Maintain VOT contrast within the series of the LAZY constraints in (20), to obtain period-specific effort thresholds. ME allows the voiced fricatives /v, ð, z/, but not /ʒ, ɣ/ in the inventory. This means that in ME Maintain VOT contrast intervenes between $LAZY_c$ and $LAZY_d$ as in (21).

(21) ME: $LAZY_a \gg LAZY_b \gg LAZY_c \gg$ Maintain VOT contrast $\gg LAZY_d \gg LAZY_e \gg LAZY_f$ (a=[ɦ], b=[ɣ], c=[ʒ], d=[z], e=[ð], f=[v])

As seen in tableau (22), the hierarchy of the constraints given in (21) accounts for the presence of the voiced fricatives /v, ð, z/ and the absence of /ʒ, ɣ/ in the ME inventory. The effort expended to produce /ʒ/, which is represented as an abstract value c in the hierarchy of the LAZY constraints, was the threshold that ME speakers could not cross. For ease of comparison and explanation, I posit only the voiced sounds in the following tableau. However, we have to take it into account that there are voiceless fricatives—f, θ, s, ʃ, x—in the inventory since we can evaluate the observation and violation of Maintain VOT contrast on the condition that there are voiceless counterparts in the tableau or in the inventory.

(22) Voiced fricatives in ME (c=[ʒ], d=[z])

	$LAZY_c$	MaintainVOT	$LAZY_d$
a. v-ð-z-ʒ-ɣ	*!*		***
b. v-ð-z-ʒ	*!	*	**
☞c. v-ð-z		**	*
d. v-ð-ʒ	*!	**	*
e. z-ʒ-ɣ	*!*	**	***

Two kinds of change are left to be explained about the inventory of fricatives in EModE. First is the loss of /x/ and the phonemicization of its allophone [h]. The phonemicization of [h] in EModE indicates that

*Nonobstacle became less important than the distinctiveness of contrast in the inventory. Substitution of /h/ for /x/ makes the distance from /f/ greater: the pair |f-x| has no difference in NF features, whereas the newly formed pair |f-h| differs in one NF feature.[19] The distinctiveness of contrast became improved at the expense of *Nonobstacle.

(23) Hierarchy for voiceless frictives in EModE
Maintain 5NF constrasts ≫ MindistNF=2 & DS=1 ≫ MindistNF=1 ≫ MindistNF=2 ≫ *Nonobstacle

(24) Voiceless fricatives in EModE

	Maintain5NF	Mindist NF=2 & DS=1	Mindist NF=1	Mindist NF=2	*Nonobstacle
a. f-s-ʃ-ç-x		*!	*	***	
b. θ-s-ʃ-ç-x		*!		***	
c. f-s-ʃ-ç-h				*!*	*
☞d. f-θ-s-ʃ-h				*	*
e. f-θ-s-ʃ-x			*!	*	
f. f-θ-s-ʃ	*!				

Another change in EModE is found in the voiced fricatives. The voiced alveo-palatal fricative /ʒ/ became a phoneme in the seventeenth century. Palatalization of /z/ before /j/ and French borrowing were the source of the new phoneme. /ʒ/ derived from palatalization occurs only in medial position as in (25a), whereas /ʒ/ in word-final position is found in loanwords borrowed from French in EModE as in (25b).

(25) a. vision [vizjon > viʒən], derision, occasion, measure, pleasure
b. beige, garage, rouge.

It seems that the new phoneme /ʒ/ was easily accepted since it provided a voiced counterpart of the phoneme /ʃ/, whereby it filled a gap in the

19) In addition to the improvement of the distance from /f/, there could be another reason for the choice of [h] over [x] as a phoneme in the inventory of EModE. Moon (2001) discusses that the substitution of /h/ for /x/ is partly attributed to the fact that /h/ was in the more salient position, i.e. word-initial onset. Between the improvement of distinctiveness of contrast and positional faithfulness, it is not certain which is more crucial in the change. I think both elements were active in the change.

consonant system (Barber 1976, McMahon 1994). This change in EModE leads to the promotion of Maintain VOT contrast above $LAZY_c$.

(26) EModE: $LAZY_a \gg LAZY_b \gg$ Maintain VOT contrast $\gg LAZY_c \gg LAZY_d \gg LAZY_e \gg LAZY_f$ (a=[ɦ], b=[ɣ], c=[ʒ], d=[z], e=[ð], f=[v])

How the voiced fricative inventory of EModE is selected by the hierarchy in (26) is illustrated in tableau (27). The same reasoning mentioned in the account of tableau (22) applies to the evaluation of the candidates in tableau (27). Namely, it is assumed that there are voiceless fricatives in EModE – f, θ, s, ʃ, h – in the inventory of the following tableau, which satisfies the constraints which determine the places of articulation of the fricatives in EModE. The voiceless fricatives are not given in the tableau due to lack of space and for ease of explanation.

(27) Voiced fricatives in EModE (b=[ɣ], c=[ʒ], d=[z])

	$LAZY_a$	$LAZY_b$	MaintainVOT	$LAZY_c$	$LAZY_d$
a. v-ð-z-ʒ-ɦ	*!			**	***
☞b. v-ð-z-ʒ			*	*	**
c. v-ð-z			**!		*
d. v-ð-ʒ			**!	*	*
e. z-ʒ-ɣ		*!	**	**	***

The hierarchies of constraints which have been proposed for the phonemic inventory of fricatives are summarized as follows:

(28) a. OE, ME: Maintain 5NF contrasts, *Nonobstacle ≫ MindistNF=2 & DS=1 ≫ MindistNF=1 ≫ MindistNF=2
b. EModE: Maintain 5NF contrasts ≫ MindistNF=2 & DS=1 ≫ MindistNF=1 ≫ MindistNF=2 ≫ *Nonobstacle

(29) a. OE: LAZY ≫ Maintain VOT contrast
b. ME: $LAZY_a \gg LAZY_b \gg LAZY_c \gg$ Maintain VOT contrast $\gg LAZY_d \gg LAZY_e \gg LAZY_f$
c. EModE: $LAZY_a \gg LAZY_b \gg$ Maintain VOT contrast $\gg LAZY_c \gg LAZY_d \gg LAZY_e \gg LAZY_f$

The hierarchies of constraints in (28) select the phonemic inventory of voiceless fricatives in OE, ME, and EModE. Those in (29) account for the distribution of voiced fricatives in the three periods of English. It can be viewed that the hierarchies in (28) share a property of language which values multiple contrasts at the expense of a large auditory distance. By comparing the hierarchies in (29), it can be observed that the English fricatives had moved toward the inventory structure which prefers multiple contrasts over effort minimization.

3.2. Change in the Inventory of Nasals[20]

In this subsection, we will discuss the historical change which took place in the inventory of English nasals. The change that occurred in the nasal inventory is relatively simple compared with that in the inventory of English fricatives. [ŋ], which was an allophone of /n/ in OE and ME, became a phoneme in EModE even though its distribution is restricted even today. Although the velar nasal /ŋ/ is more marked than other nasals, the addition of phonemic /ŋ/ could be easily accommodated since it filled the gap in the system. That is, the emergence of phonemic /ŋ/ may be due to the paradigmatic pressure in the inventory: the velar stops have the homorganic nasal /ŋ/, in parallel with the labial and alveolar stops. The nasal inventories of the three periods are summarized in (30).

(30) a. nasals in OE, ME: /m, n/
b. nasals in EModE: /m, n, ŋ/

I propose the change in the nasal inventories given in (30) results from the conflict between the markedness constraint *Velar, which is from the hierarchy in (31), and one of the constraints which represents the paradigmatic pressure from the oral stops, and ultimately requires the maximization of the number of nasal contrasts.

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20) The analysis which will be presented in this section would be unnecessary. At the systematic phonemic level, the velar nasal is still analyzed as an allophone of /n/ in Modern English, because its restricted distribution and predictability. I present an analysis on the premise that there was a change in the inventory of nasals, because the phonemic consonant chart in EModE which most handbooks on the history of English provide contains the phonemic /ŋ/. Given the chart as such, the analysis proposed here could be considered.

(31) *Velar ≫ *Labial ≫ *Alveolar[21]

In order to formulate a constraint which limits the number of nasal contrasts, we need to know what properties distinguish the three places of articulation. The places of nasal consonants are acoustically characterized by the spectral peaks in the nasal murmur as well as by the formant transitions in adjacent vowels. Although the latter is considered to be more distinctive than the former (Fant, 1960; Fujimura, 1962)[22], I would like to represent the nasal dimension on the basis of the spectral peaks in the murmur since here we are concerned with the inventory of nasals independent of the contexts, not with the influence of adjacent segments. The spectral peaks in the nasal murmur are affected by an antiresonance (zero) in the transmission of the pharyngeal nasal tract. The frequency of the zero tends to be inversely related to the length of the oral side branch which is greatest for a labial, shorter for an alveolar, the shortest for a velar. The frequency of the zero is at about 800 Hz for [m], 1500-2000Hz for [n] and about 5000Hz or above for a [ŋ] (Pickett, 1985). Accordingly, for the analysis of the nasal contrast, we can represent the nasal dimension as in (32) and formulate the hierarchy of constraints which limit the number of nasal contrasts as in (33).

(32) Nasal murmur

murmur	m	n	ŋ
high	-	-	+
low	+	-	-

(33)[23] a. Maintain 1 Nmurmur contrast ≫ Maintain 2 Nmurmur contrasts ≫ . . . ≫ Maintain n Nmurmur contrasts

b. Maintain n Nmurmur contrasts: Maintain n contrasts on the Nasal Murmur dimension. (N represents a nasal)

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21) Relying on the markedness hierarchy, *Pharyngeal ≫ *Velar ≫ *Labial ≫ *Alveolar, Zubritskaya (1995) analyzes variations shown in Russian.

22) The differences in murmur spectra are less prominent as a cue to places of nasals because the murmur spectrum is strong in amplitude below about 500Hz and relatively weak above 500 Hz.

23) If we accept the view that the emergence of phonemic /ŋ/ is a response to the paradigmatic pressure from the oral stops, it is more appropriate that the constraints proposed here have to be revised as other kind of constraints which apply to both nasal and oral stops, not restricted to the account of nasals. I would like to leave this revision for future study.

Given the markedness hierarchy in (31) and the hierarchy governing the number of nasal contrasts in (33a), the selection of an inventory of nasal contrasts in each period of English depends on where the two hierarchies intersect. In OE and ME, *Velar, ranked higher than Maintain 2 Nmurmur contrasts, yields the two-membered inventory which is devoid of /ŋ/. This is illustrated in the following tableau:

(34) OE, ME: *Velar ≫ Maintain 2 Nmurmur contrasts

	*Velar	Maintain 1 m contrast	Maintain 2 m contrasts	*Labial
a. m-n-ŋ	*!			*
☞b. m-n			*	*
c. n-ŋ	*!		*	
d. m-ŋ	*!		*	*
e. m		*!		*
f. n		*!		

(In the constraints, in represents Nmurmur.)

On the other hand, the addition of phonemic /ŋ/ in EModE demands the reverse of the relative ranking between *Velar and Maintain 2 Nmurmur contrasts. The nasal inventory in EModE is chosen by the ranking Maintain 2 Nmurmur contrasts ≫ *Velar, as shown in tableau (35).

(35) EModE: Maintain 2 Nmurmur contrasts ≫ *Velar

	Maintain 1 m contrast	Maintain 2 m contrasts	*Velar	*Labial
☞a. m-n-ŋ			*	*
b. m-n		*!		*
c. n-ŋ		*!	*	
d. m-ŋ		*!	*	*
e. m	*!			*
f. n	*!			

Compared with the previous stages, EModE prefers multiple nasal contrasts over prevention of a velar nasal which is marked. This change is represented by the promotion of Maintain 2 Nmurmur contrasts in the

hierarchy. The nasal inventories of the three periods of English are provided in (36), all of which are formalized in terms of the hierarchies of constraints.

(36) a. OE, ME: *Velar ≫ Maintain 2 Nmurmur contrasts
b. EModE: Maintain 2 Nmurmur contrasts ≫ *Velar

4. Summary and Conclusion

In this study, we have analyzed the inventory structure of the three periods of English within the model of dispersion theory formalized in terms of OT. One of the basic assumptions of the dispersion theory is that the selection of an inventory of contrast is shaped by the interaction of three functional requirements: maximization of the number of contrasts, maximization of distinctiveness, and minimization of articulatory effort. This claim has allowed us to characterize the inventories of the three periods of English and to compare them in a comprehensive and coherent way.

The inventory structure of each period of English is the result of a compromise among the three functional requirements which are formalized into "Maintain nNF contrasts", "Mindist" and "LAZY" constraints. How these constraints are balanced to yield the consonant inventories of the three periods is summarized in (28), (29) and (36). The hierarchies in (28) select the phonemic inventory of fricatives in OE, ME, and EModE. The presence of five places of articulation of the fricatives in the inventory is mainly determined by the dominance of Maintain 5NF contrasts over other constraints favoring a large auditory distance. What places of articulation are chosen follows from the interaction of the constraints of auditory distinctiveness and *Nonobstacle. In addition to the characteristics provided in (28), the hierarchy provided in (29a) accounts for why OE did not have voiced fricatives in the phonemic inventory. Another hierarchy in (29b) explains why only the front voiced fricatives became phonemes in ME.

The preference of multiple contrasts has been shown in the change of the nasal inventory, too. As shown in (36), the historical change in the nasal inventory is represented by the promotion of Maintain 2 Nmurmur contrasts in the hierarchy which can be considered as the formulation of

the paradigmatic pressure in the inventory of consonants.

In the analysis of the inventory structure, we have also noted a pattern which continued throughout the history of English: English imposed more value on the number of contrasts, resulting in a number of fine contrasts on the dimensions of the acoustic features for fricatives and nasals and in the expenditure of more articulatory effort.

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